DISASTER MANAGEMENT AND SUSTAINABILITY: HYDROLOGICAL ASSESSMENT OF MOUNTAINOUS CATCHMENTS USING REMOTE SENSING AND GIS TECHNIQUES: A CASE STUDY OF UPPER INTERSPECIAL

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ABSTRACT: *Agriculture is very important for Pakistan's economy, and the whole agriculture industry in the country depends on three big reservoirs called Tarbela, Mangla, and Chashma. Climate change and its rapid growth can greatly affect how fast snow and glaciers melt, which in turn affects the water flow at dams. The main sources of water flow are snowmelt and rainfall, and these can change depending on the time and place. That is why it is very important to understand how the distribution of climate and water conditions changes in the Upper Indus Basin. The purpose of this study is to look at and examine the changes in climate and water conditions in the Upper Indus Basin. We collected daily data on temperature (minimum and maximum), rainfall, and water flow from the Surface Water Hydrology Project (SWHP), WAPDA, and the Pakistan Meteorological Department (PMD) from 1961 to 2012. We analyzed the data for annual and seasonal maximum and minimum temperatures, rainfall, and stream flows. The three-month seasons were winter (December, January, and February), spring (March, April, and May, before the monsoon), summer (June, July, and August, during the monsoon), and autumn (September, October, and November, after the monsoon). The annual average is the average of the monthly averages from January to December. To check for climate change, we looked at 52-year data (from 1961 to 2012) on temperature, rainfall, and stream flows from 27 meteorological stations and 35 streamflow monitoring stations. We divided this data into two parts of 26 years each (1961 to 1986 and 1987 to 2012) to find if there have been changes in the speed of climate change. We found significant changes in temperature, rainfall, and stream flows between these two periods using the student-t test, F-test, and Mann Whitney U test. We also calculated the relative changes in the second period compared to the first. We used the Mann-Kendall test and Sen's method to study trends. The results showed that there were changes in the second period compared to the first, and we found different trends in annual and seasonal temperature (minimum and maximum), rainfall, and streamflow data during the two 26-year periods (1961-1986 and 1987-2012). A detailed study of how climate factors interact with stream flow patterns is not part of this study. It is necessary to clearly understand the results and to check them against real causes, like changes in land use or human activities affecting river stations. Changes in stream flows, droughts, and their frequency could result from changes in climate (mainly rainfall and temperature) and human activities like groundwater use, irrigation, and urbanization. Some hydrological models should be used to see the current impact of these changes.*

Key words: precipitation, stream flows, hydro-climatic variability, climatic change

INTRODUCTION

According to IPCC report 2013, the global temperature has increased up to 0.89 °C between the period of 1901-2012. Large scale warming of the earth surface over last 100 years or so is reported by IPCC in 2001 and 2008. Such very high scale global warming affects the circulation patterns worldwide but also directly affects the local climatic conditions by changing the distribution and characteristics of precipitation & temperature. Hydrological impacts by climate change can seriously affect the water resources and may cause changes in the hydrological cycle. Changes vary according to space and time domains as affected by local climatic and topographic settings. IPCC report (2012) indicates that the climate changes are increased and that impacts may become more intense [1]. This aspect of climate change has motivated this study were we aim to assess possible solutions for climate changes and hydrological impacts for Upper Indus Basin in Pakistan. This system plays a vital role in providing sustainable water supply to large populations living in the lower Indus region in Pakistan. In Pakistan, The effect of climate change shows differences between regions. There is a sustainable difference of temperature in day and night. The difference in temperature between day and night is extremely substantial. The temperature in the southern part increases up to 45°C or even more in the summers. Insufficient rainfall makes the place more dry and barren. The climate in Pakistan is characterized by hot summers and cold winters. The northern part of Pakistan is generally cold because the mountains and peaks are covered with snow while the southern part is dry with deserts all around. Pakistan Climate is divided into four seasons the hot dry spring, from March to May, summer rainy season from June to September, retreating monsoon in october and november and the cold dry winter from December to February. Temperature of the capital city of Pakistan Islamabad varies from 2°C in the winter in January to 40°C in June. So the climate of Pakistan can be called to be extreme [2]. The average rainfall during monsoon is about 255 millimeters. The total population of Pakistan is about 255 million having a growth rate 2 % annually (PCO) [3]. As an

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agricultural country with heavy population growth, there is a great pressure on water resources to fulfill the food and fiber requirement for the people. The per capita water availability is decreasing with time due to integrated impact of rising population, falling water flow and reduction in the storage reservoirs capacities in Pakistan (Pakistan Gateway 2003). The per capita water availability is declining from 5650 m^3 in 1951, 1700 m^3 in 1992, 1400 m^3 in 2000 and 1000 m^3 in 2012 (GOP, 2007). Being one of the very sensitive factors, climate change can cause major impacts on water resources by resulting changes in the hydrological cycle [4]. The change on temperature and precipitation components of the cycle can have a direct impact on the quantity of evaporation & transpiration component, and effects both quality and quantity of the runoff water. As a result, the spatial and temporal water resource availability, or in general the water balance, can be significantly affected, which clearly increases its impact on different sectors like agriculture, industry and urban development. Changing climate will also have serious impacts on the availability of water, along the quality and quantity of water which is available and accessible. It is expected that the global climate change may have great impacts on the regime of hydrologic events such as floods and droughts. As a result, the sustainable planning and management of water resources systems must adapt to the changing hydrologic extremes [5].

PROBLEM STATEMENT

Climate change greatly affects the sources of water such as glaciers and streams. Glaciers are melting rapidly because of the increasing temperature. Stream flows are also affecting as well as pattern of rain fall has also changed because of the climate change [6]. Analysis of past depicts that our climate is changing. The changing rate and the nature of the resulting impacts will vary over time and across the country, affecting all aspects of our life. In addition to reduce greenhouse gas emissions, it will also be necessary to adjust the impacts of a changing climate. Understanding what climate change means for Pakistan is the very first step in that process. Further climate changes of the scale projected by most global climate models have a major impact on our water resources, and consequently affect food supply, health, industry, transportation and ecosystem sustainability. Problems are most likely occurring to southern parts of country where the resources are already under pressure, because that stress would be increased by changes in supply or demand associated with climate change. Climate changes seem to accelerate the hydrological cycle and are expected to increase the frequency and impact of extreme events like droughts and floods. Climate change also can cause significant impacts on water resources by changes in hydrological cycle processes [7, 4]. Any change on temperature and precipitation can have a direct impact on the quantity of evaporation & transpiration and on stream flow. As a result, the spatial and temporal water resource availability, or in general the water balance can be affected, which may turn into serious impact on agriculture, industry and urban development. It's well known that hydrological processes are influenced by climate change and human activities both in spatial and temporal distributions. At the same time, the regional available of water is directly affected by human activities such as irrigation, afforestation, deforestation and water construction [8]. At the Indus basin scale, changes in flow magnitudes are likely to raise tensions among the provinces, in particular with the downstream areas (Sindh province), with regard to reduced water flows in the dry season and higher flows and resulting flood problems during the wet season [6]. It's important to understand the effects of climate change on stream flows over different time scales. Therefore, in Pakistan future water resources estimation considering these factors is important for planning and operation of hydrological installations. Assessments and quantitative estimations of hydrologic impacts of climate change are essential for understanding and analyzing the potential water resources issues associated with water supply for domestic and industrial water use, power generation, and agriculture as well as for future water resource planning, reservoir design and management, and protection of the natural environment [9].

OBJECTIVES OF THE STUDY

The overall objective of this study is to examine the aspects of climate change and related hydrological impacts on the UIB.

The specific objectives of this study are as follows:

1. To study and examine the climate change and hydro-climatic variability in Upper Indus Basin (UIB) at spatial-temporal scale
2. To assess aspects of acceleration of climate change and its impact on stream flows of Upper Indus Basin (UIB).
3. To Estimate the probable changes in annual and seasonal temperature and precipitation in the historic climatic records.
4. To Estimate the stream flows of UIB in the historic stream gauging records.
5. To Estimate the impacts of climate change on stream flows of UIB.
6. To Estimate the climate change in maximum and minimum temperature.
7. To Estimate the change in precipitation and the rates of change vary in seasons at spatial-temporal scale.

UTILIZATION OF STUDY

The study has unlimited scope of the hydrological assessment of mountainous catchments as latest research must be done in this regard so future steps and studies can be planned according to the new conditions. It is estimated that if the recent change in temperature increase for two or three decades then the whole glaciers in the Indus basin will melt down in 2035, so new parameters should be introduced to control the current condition. This study contributes new aspect in the field of hydrology [10]. This research will focus to determine if climate change acceleration is/has happening in the study area. This study will analyze the impacts to examine the climate change acceleration on the trend of river flows in Pakistan. This study's results will helpful for decision makers to develop the strategies for planning and management of water resources under different climatic conditions to reduce the harmful impact.

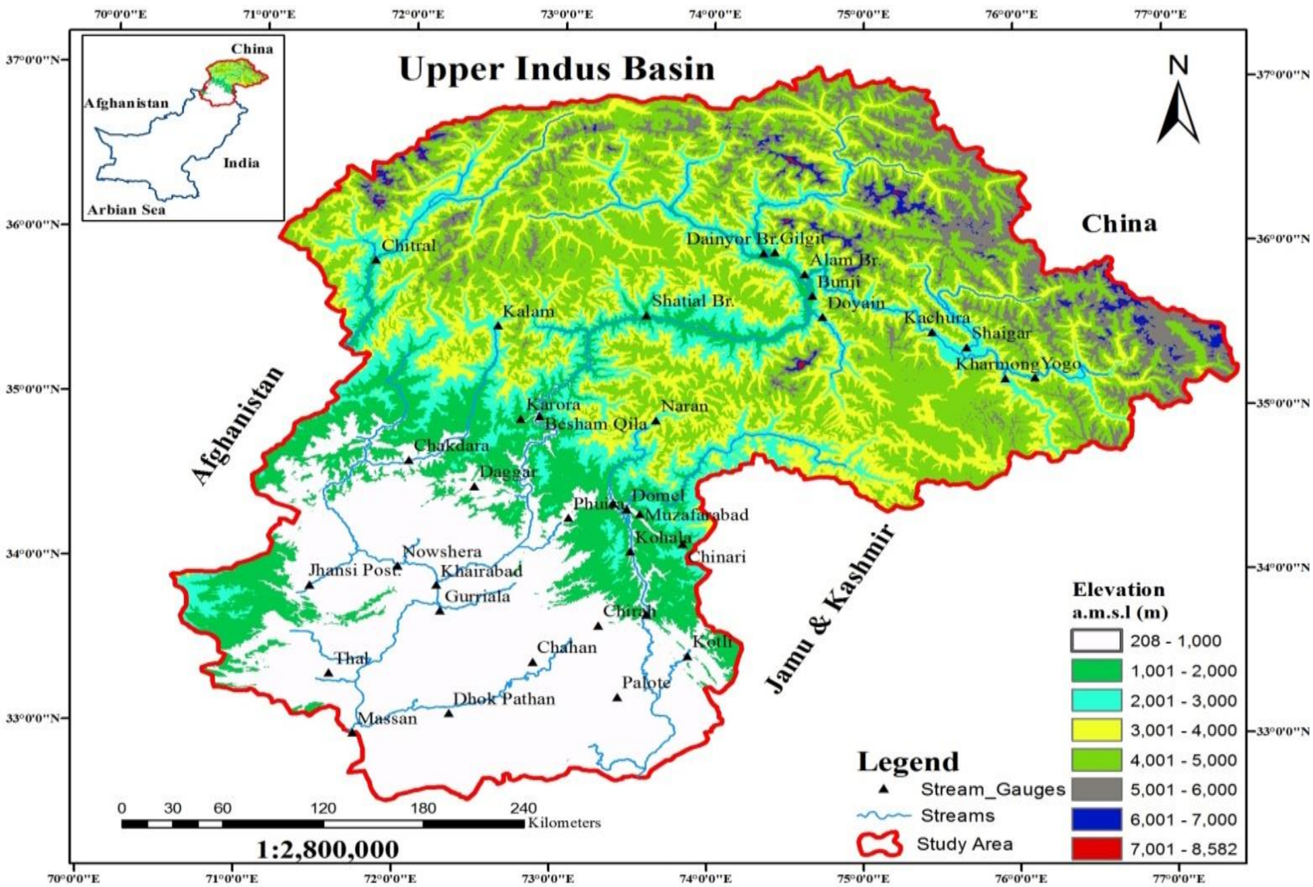


Fig 1: The (UIB) boundary in Pakistan showing rivers, stream gauges and elevation

MATERIALS AND METHODS

STUDY AREA

The Upper Indus Basin (UIB), a critical watershed in South Asia, is the focus of this study. Geographically, the catchment area spans 33º, 40′ to 37º, 12′ North latitude and 70º, 30′ to 77º, 30′ East longitude. Defined by the area upstream of Massan as shown in Fig 1, the UIB's substantial portion lies within China and India. However, due to data limitations, this research concentrates on the portion of the catchment within Pakistan. Elevations within the study area range dramatically, from 254 m to 8570 m above mean sea level [11]. The Indus River, originating in Tibet, is fed by numerous tributaries, including the Chitral, Swat, Kabul, Hunza, and Gilgit rivers. These tributaries significantly contribute to the Indus's flow as it traverses diverse terrains before entering the Punjab plains. The Jhelum River, another vital Eastern tributary, originates in Pir Panjal and ultimately drains into the Mangla Dam reservoir, contributing to hydropower generation and flow regulation. The Jhelum's sub-catchments, including the Neelum, Kunhar, Poonch and Kanshi rivers,are the sub-catchments of Jhelum river so that they all are essential components of the overall Indus River system. The Indus River, a vital waterway, receives contributions from several tributaries along its course. The Kabul River merges with the Indus near Attock, while the Kunar, also known as the Chitral River, joins downstream from Warsak. The Haro River adds to the Indus's flow a few miles below Attock, and the Soan River converges upstream of the Jinnah Barrage [11]. The Jhelum River, an important eastern tributary, originates in Pir Panjal and runs parallel to the Indus. Its basin, situated on the southern slopes of the Himalayas, spans an elevation range of 300 to 6282 meters above sea level, encompassing approximately 33425 km2 at the Mangla Dam. This dam serves the dual purpose of hydropower generation and flow regulation from the Mangla reservoir Fig 1. The Jhelum's sub-catchments, including Jhelum, Poonch, Kanshi, Neelum/Kishan Ganga, and Kunhar, drain into the Mangla reservoir. The Neelum River, the largest tributary, joins the Jhelum at Domel Muzaffarabad, followed by the Kunhar River at Kohala Bridge. The Jhelum's flow ultimately enters the Mangla Dam reservoir, along with the flows of the Poonch and Kanshi Rivers.

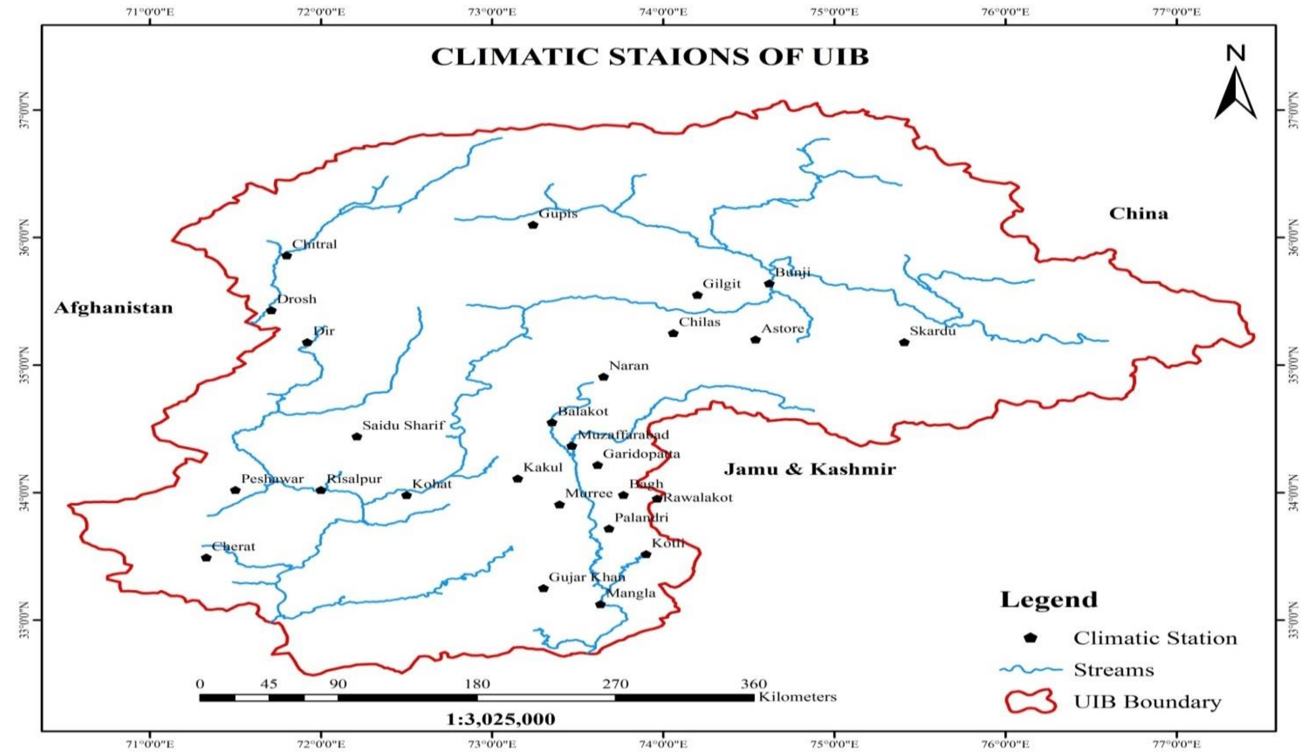


Fig 2: The (UIB) showing climatic stations, rivers and catchment area laying in Pakistan [11].

. Table 1: Type of Data used in the present study ant their source

Sr. No	Data type	Source
1	Temperature (Max. and Min.)	PMD, WAPDA-SWHP, FAO
2	Precipitation data	PMD, WAPDA-SWHP, FAO
3	Stream flow data	WAPDA-SWHP
4	Topography data (DEM)	WEB (http://srtm.csi.cgiar.org)

DATA REQUIREMENTS, SOURCE & AVAILABILITY

The Upper Indus Basin (UIB) is a critical region for studying the impacts of climate change on water resources. Streamflow data, essential for understanding these impacts, has been collected in the UIB by the Water and Power Development Authority—Surface Water Hydrology Project (WAPDA-SWHP) since 1960. These stream gauges monitor a diverse range of drainage areas, spanning from 262 km2 to 286,000 km2, providing a comprehensive dataset for analyzing the effects of climate change on stream flows within the UIB. This long-term collection effort offers a valuable foundation for research and informed water resource management in the face of a changing climate.[5]. The hydrological characteristics of the Upper Indus Basin, encompassing the Jhelum, Indus, and Kabul basins, are monitored through a network of stream flow gauges. These gauges are strategically positioned within the 21 sub-basins that comprise the three major basins. This arrangement facilitates comprehensive data collection crucial for understanding water resource dynamics in the region as shown in Fig.1.. The Surface Water Hydrology Project (SWHP), WAPDA, will serve as the source for flow data spanning the period from 1961 to 2012. This dataset, encompassing twenty-seven carefully selected stations, will be utilized for subsequent analysis. The temporal scope and spatial distribution afforded by this data collection effort provide a robust foundation for hydrological investigation. The geographical distribution of these stations is shown in Fig. 2. The data of daily precipitation and temperature (max & min) will be collected from Surface Water Hydrology Project (SWHP), WAPDA and Pakistan Meteorological Department (PMD) for the period 1961-2012.

METHODOLOGY

An analysis of temperature trends in the Upper Indus Basin (UIB) from 1961 to 2012 reveals significant climatic shifts. Data from 27 climatic stations were examined, focusing on annual maximum and minimum temperatures. The study period was divided into two 26-year intervals (1961-1986 and 1987-2012) to evaluate the acceleration of climate change. Mean monthly values for maximum temperature (T-max) and minimum temperature (T-min), along with precipitation (P) and stream flow (Qst), were calculated from daily time series for each year. Seasonal and annual totals for P and Qst were derived by aggregating monthly records. This research provides a quantitative assessment of temperature fluctuations within the UIB, offering valuable insights into the region's evolving climate.[12]. Seasonal variations are a fundamental aspect of climate and environmental studies. To effectively analyze these variations, a standardized approach to defining seasons is necessary. One common method involves delineating the year into four distinct seasons: winter, spring, summer, and autumn. For the purposes of assessment, winter is defined as the months of December, January, and February (DJF). Spring encompasses March, April, and May (MAM). Summer includes June, July, and August (JJA), while autumn is represented by September, October, and November (SON). This temporal framework provides a consistent and readily applicable structure for investigating seasonal patterns in various datasets and geographical locations. By adhering to this standardized seasonal classification, researchers can facilitate comparative analyses and gain a more comprehensive understanding of the multifaceted influences of seasonality.

Assessing the impacts of environmental changes often necessitates a rigorous analytical approach. In the study outlined, two primary analyses are employed to investigate shifts in key hydrological variables. First, relative changes in temperature, precipitation, and stream flows are assessed to discern potential patterns in their interconnected behavior. This comparative approach allows for the identification of proportional variations across these elements, as detailed in reference [13]. Second, trend analysis is conducted to determine the statistical significance of observed trends and to identify spatial patterns across the basin area, as supported by reference [14]. The combination of these two analytical methods provides a comprehensive framework for understanding the complex interplay of environmental factors and their impact on regional hydrology.

Table 2: characteristics of stream gauges used in the present study (Period # 1: 1961-1986; Period # 2: 1987-2012)

Sr.No.	Station	Lat (dd)	Lon (dd)	Area(Km2)	Period	Annual Mean Streamflows(cumec)
1	**Naran**	34.9	73.7	1036	1	47.7
					2	45.6
2	**G. Habibullah**	34.4	73.4	2355	1	100.0
					2	105.5
3	**Muzaffarabad**	34.4	73.5	7275	1	342.3
					2	321.9
4	**Chinari**	34.2	73.8	13598	1	298.7
					2	289.0
5	**Domel**	34.4	73.5	14504	1	327.3
					2	322.3
6	**Kohala**	34.1	73.5	24890	1	776.0
					2	780.5
7	**Azad Pattan**	33.7	73.6	26485	1	1150.7
					2	1241.8
8	**Kotli**	33.5	73.9	3238	1	123.9
					2	127.3
9	**Palote**	33.2	73.4	1111	1	6.0
					2	5.3
10	**Kharmong**	35.2	75.9	67858	1	462.7
					2	465.0
11	**Yogo**	35.2	76.1	33670	1	341.2
					2	368.8
12	**Shigar**	35.4	75.7	6610	1	194.6
					2	220.5
13	**Kachura**	35.5	75.4	112665	1	962.0
					2	1159.6
14	**Gilgit**	35.9	74.3	12095	1	277.2
					2	333.7
15	**Dainyor Br.**	35.9	74.4	13157	1	365.4
					2	295.0
16	**Alam Br.**	35.8	74.6	26159	1	661.8
					2	619.3
17	**Bunji**	35.7	74.6	142709	1	1706.0
					2	1875.3
18	**Doyain**	35.5	74.7	4040	1	118.3

					2	149.2
19	**Shatial Br.**	35.5	73.6	150220	1	1938.9
					2	2110.6
20	**Karora**	34.9	72.8	635	1	20.4
					2	17.5
21	**Besham Qila**	34.9	72.9	162393	1	2350.2
					2	2436.8
22	**Daggar**	34.5	72.5	598	1	5.4
					2	5.9
23	**Phulra**	34.3	73.1	1057	1	18.6
					2	20.5
24	**Kalam**	35.5	72.6	2020	1	85.7
					2	86.2
25	**Chakdara**	34.6	72.0	5776	1	169.1
					2	207.1
26	**Chitral**	35.9	71.8	11396	1	264.4
					2	285.4
27	**Jhansi Post**	33.9	71.4	1847	1	6.7
					2	5.2
28	**Nowshera**	34.0	72.0	88578	1	849.0
					2	824.2
29	**Gurriala**	33.7	72.3	3056	1	26.9
					2	24.8
30	**Khairabad**	33.9	72.2	252525	1	3222.7
					2	2834.4
31	**Thal**	33.4	71.5	5543	1	27.7
					2	22.6
32	**Chirah**	33.7	73.3	326	1	5.7
					2	4.0
33	**Chahan**	33.4	72.9	241	1	1.7
					2	1.3
34	**Dhok Pathan**	33.1	72.3	6475	1	44.0
					2	38.4
35	**Massan**	33.0	71.7	286000	1	3527.2
					2	3809.5

Table 3: Climatic stations in (UIB) (Period # 1: 1961-1986; Period # 2: 1987-2012)

Sr. No.	Station	Lat	Lon	Elevation	Period	Max. Temp	Min. Temp	Precipitation
		(dd)	(dd)	(m)		(oC)	(oC)	(mm)
1	Astore	35.2	74.5	2168	1	15.4	4.0	38.8
					2	15.8	4.1	41.5
2	Bagh	34.0	73.8	1067	1	25.4	4.0	12.8
					2	19.9	4.6	13.3
3	Balakot	34.6	73.4	995.5	1	15.4	14.5	50.4
					2	15.9	14.2	50.1
4	Bunji	35.6	74.6	1372	1	24.0	14.0	15.1
					2	23.7	14.3	16.7
5	Cherat	33.5	71.3	1372	1	21.9	8.9	32.8
					2	21.1	8.3	38.2
6	Chilas	35.3	74.1	1250	1	26.6	8.3	129.7
					2	26.2	7.8	122.7
7	Chitral	35.9	71.8	1497.8	1	22.8	11.1	44.4
					2	23.8	11.4	48.7
8	Dir	35.2	71.9	1375	1	22.5	7.9	11.0
					2	23.3	7.4	11.3
9	Drosh	35.4	71.7	1463.9	1	23.8	7.1	7.3
					2	24.3	6.1	13.9
10	Garidopatta	34.2	73.6	813.5	1	15.4	9.3	117.4
					2	15.9	10.2	116.2

11	Gilgit	35.6	74.2	1460	1	23.5	17.1	44.8
					2	24.3	17.0	45.1
12	Gujar Khan	33.3	73.3	457	1	28.1	9.4	65.3
					2	29.0	6.9	67.4
13	Gupis	36.1	73.2	2156	1	18.7	15.8	35.9
					2	18.9	16.4	37.3
14	Kakul	34.1	73.2	1308	1	22.7	9.3	117.4
					2	23.3	10.2	116.2
15	Kohat	34.0	72.5	1440	1	28.9	17.1	44.8
					2	30.3	17.0	45.1
16	Kotli	33.5	73.9	610	1	28.4	16.6	1271.9
					2	28.4	14.9	1183.4
17	Mangla	33.1	73.6	282	1	30.4	17.6	34.6
					2	30.9	17.0	38.8
18	Murree	33.9	73.4	2206	1	16.3	8.9	1765.4
					2	18.0	8.4	1733.7
19	Muzaffarabad	34.4	73.5	702	1	15.4	17.6	34.6
					2	15.9	17.0	38.8
20	Naran	34.9	73.7	2363	1	14.1	8.7	41.5
					2	10.5	9.6	44.0
21	Palandri	33.7	73.7	1402	1	15.4	17.6	34.6
					2	15.9	17.0	38.8
22	Parachinar	33.5	70.1	1725	1	21.1	9.4	65.3
					2	21.3	6.9	67.4
23	Peshawar	34.0	71.5	320	1	29.3	15.8	35.9
					2	29.7	16.4	37.3
24	Rawalakot	34.0	74.0	1677	1	20.0	8.7	43.7
					2	21.1	9.6	45.8
25	Risalpur	34.0	72.0	575	1	29.5	14.6	55.1
					2	29.9	14.2	53.9
26	Saidu Sharif	34.4	72.2	961	1	25.6	12.3	90.1
					2	26.3	11.9	89.6
27	Skardu	35.2	75.4	2317	1	18.0	5.1	16.6
					2	19.2	4.7	19.6

Change Detection

To detect climatic change and any possible climatic change Acceleration the following three tests are selected [14, 15].

1- Student T-test, to assess sample mean
2- F-test, to assess aspects of variability of time series.
3- Mann-Whitney test (U-test), to assess aspects of the distribution of observations.

Student-t and F tests

Statistical analysis often involves comparing datasets to identify significant differences. When examining two distinct 26-year periods, the student's t-test serves as a valuable tool for determining whether a shift in mean values is statistically significant. This test is particularly relevant when assessing changes in central tendency across the two periods. Complementing this, the Fisher test (F-test) is employed to detect alterations in the variability of the time series data. By focusing on variance, the F-test reveals whether the dispersion of data points has significantly changed between the two periods. Both the t-test and the F-test, when conducted at a 90% confidence level, provide a robust framework for evaluating the statistical significance of changes in both the mean and variability of the time series data across the two defined periods. The t-statistic calculation, guided by equation (1) when variances are similar, ensures accurate assessment of mean differences.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_p\sqrt{\frac{1}{n1}+\frac{1}{n2}}} \qquad (1)$$

$\bar{X}_1$ and $\bar{X}_2$ are mean values; n_1 and n_2 indicate number of observations; s_1 and s_2 are the standard deviations; subscript 1 and 2 indicate the periods (1961-1986) and (1987-2012); and s_p is the pooled standard deviation which reads:

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

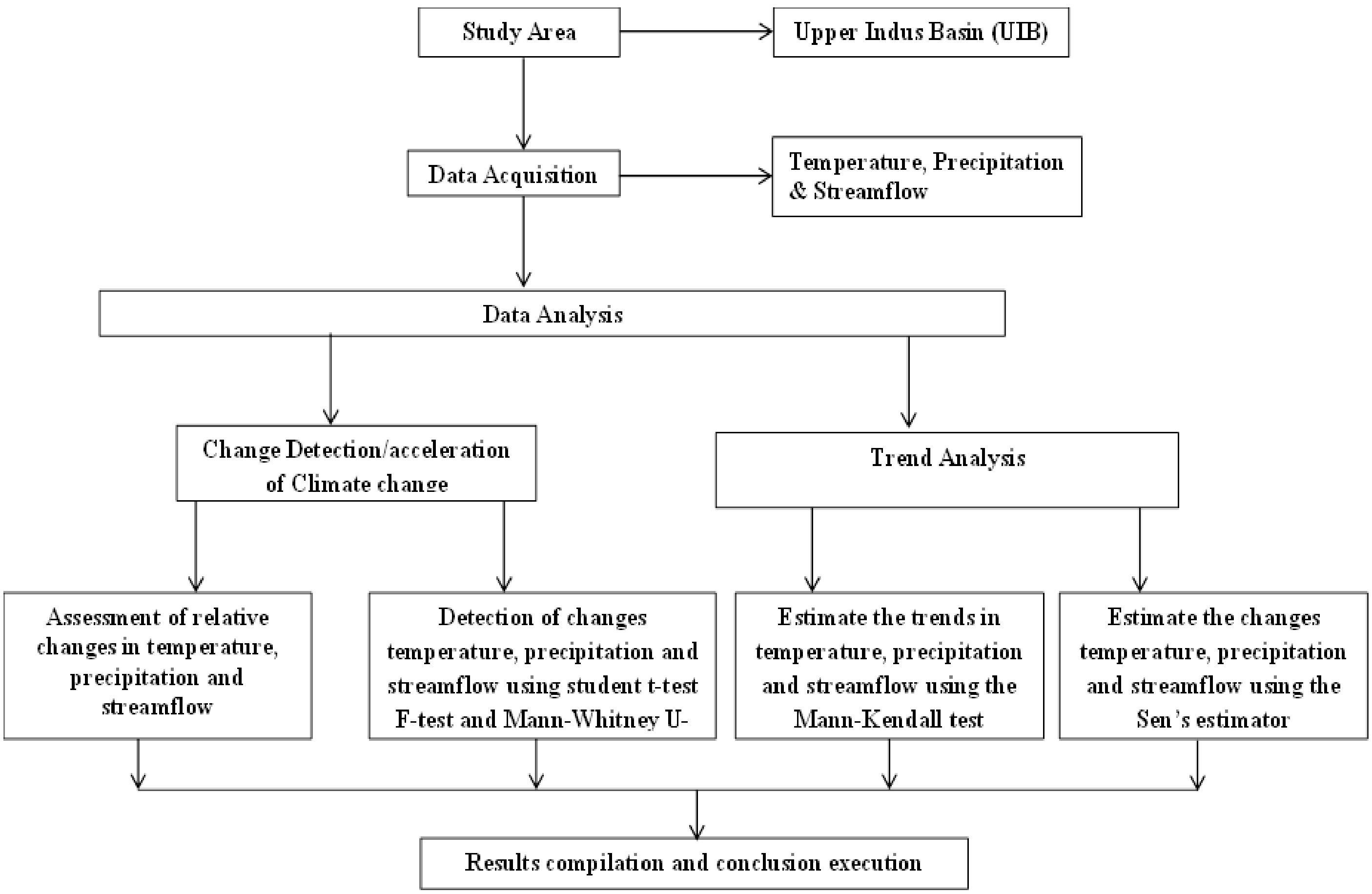
If the variance of the two periods is dissimilar then the t-statistic is calculated by Eq. (3)

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{1}{n1}+\frac{1}{n2}}} \qquad (3)$$

Mann Whitney U-test

The Mann-Whitney U-test, also known as the Wilcoxon rank-sum test, offers a non-parametric approach to detecting shifts in the distribution of two independent samples. As articulated by Wilcoxon (1945), this test is particularly useful for analyzing time series data, such as temperature, precipitation, and stream flow, where the assumption of normality may not hold. The core of the test lies in the Mann-Whitney statistic U, as detailed by Yue and Wang (2002), which quantifies the degree of separation between the two samples, effectively indicating the presence of a step change or shift in the data. This characteristic makes the Mann-Whitney U-test a valuable tool for identifying and analyzing trends and discontinuities in environmental time series.

Figure 3: Flow chart of methodology



$$U = min[U_1, U_2] \quad (4)$$

In which

$$U_1 = n_1n_2 + \frac{n_1(n_1+1)}{2} - R_1 \quad (5)$$

$$U_2 = n_1n_2 + \frac{n_2(n_2+1)}{2} - R_2 \quad (6)$$

Where U_1 and U_2 are the total count of sample I and sample II; and R_1 and R_2 are the rank sums of Sample I and sample II, respectively. When the null hypothesis, H_0, is true and when n_1 and n_2 are both larger than 8, U is approximately normally distributed with mean of E(U) and variance of V(U) as:

$$E(U) = \frac{n_1n_2}{2} \quad (7)$$

$$V(U) = \frac{n_1n_2(n_1+n_2+1)}{12} \quad (8)$$

Relative Changes

The relative change (%) in annual and seasonal temperature, precipitation and stream flow was assessed following Eq. (9)

$$\text{Relative Change} = \frac{\text{Mean of 2nd period} - \text{Mean of 1st period}}{\text{Mean of 1st period}} \quad (9)$$

TREND ANALYSIS

For detection of trend we (i) pre-whitened time series to eliminate effect of serial correlation of observations (ii) we applied Mann-Kendall trend analysis to identify if trends are significant and (iii) we assessed the trend slope line by means of sen's estimator [16, 17].

Mann-Kendall test

The Mann-Kendall (MK) test, also known as Kendall's tau statistic, is a non-parametric method frequently employed in time series analysis to assess the presence of statistically significant trends. This rank-based approach evaluates randomness against trend, making it suitable for hydro-metrological data that may be irregularly spaced and not normally distributed. A key advantage of the MK test lies in its independence from assumptions regarding the underlying statistical distribution of the data. Furthermore, its rank-based nature minimizes the influence of extreme data points, ensuring a more robust analysis. Prior to applying the MK test, pre-whitening the time series is crucial to mitigate the effects of serial correlation and ensure the reliability of the trend assessment.

The Mann –Kendall statistic Z_{mk} reads:

$$Z_{mk} \begin{Bmatrix} \frac{S-1}{Q_S} & if & S > 0 \\ 0 & if & S = 0 \\ \frac{S+1}{Q_S} & if & S < 0 \end{Bmatrix} \quad (10)$$

The MK test statistic S reads:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (11)$$

Where n is the number of years, X_j and X_k are the sample values (here annual and seasonal) for two consecutive time instants j and k respectively. The function $sgn(x_j-x_k)$ is an indicator function that takes the value 1,0 or -1 according to sign difference (x_j-x_k),where j>k:

$$sgn(x_j - x_k) = \begin{Bmatrix} 1 & if\, x_{j-}x_k > 0 \\ 0 & if\, x_{j-}x_k = 0 \\ -1 & if\, x_{j-}x_k < 0 \end{Bmatrix} \qquad (12)$$

A positive value of Z_{mk} indicate an upward trend (i.e., increasing) whereas a negative value indicate a downward trend(i.e., decreasing) The statistic (S) follows the standard normal distribution where probability of observing a value higher than the test statistic Z_{mk} is tested under the null hypothesis, H_0 that there is no trend for chosen a –level of significance. H_0 is rejected if the absolute value of $Z_{mk}>Z_{1-a/2}$ at the a-level is significant.

Sen's estimator of slope

If a linear trend is present in a time series, then the trend slope can be estimate by using a simple non-parametric procedure developed be Sen (1968). The slope of two observations over time instants j and k is estimated as follows:

$$Q_i = \frac{x_{j-}x_k}{j-k} \qquad If\, j > k \qquad (13)$$

Sen's estimator is the median Q_{med}, of the N pairs of Q_i. In the procedure N values of Q_i are ranked from smallest to largest and the Sen's estimator read:

$$Sen'sestimator = \begin{Bmatrix} Q_{\left[\frac{(N+1)}{2}\right]} & if\ N\ was\ odd \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\left[\left(\frac{N+2}{2}\right)\right]}\right) & if\ N\ was\ even \end{Bmatrix} \qquad (14)$$

Finally, Q_{med} is tested by a tow–sided test at the 100(1-a) % confidence interval and the true slope may be obtained by the non–parametric test. Data were processed using an Excel macro named XLSTAT and MAKESENS created by Slmi et al [16].

RESULTS AND DISCUSSIONS

CHANGE DETECTION

Change Detection in Maximum Temperature

Statistical analyses, employing the Student t-test, F-test, and Mann-Whitney U-test, were conducted on maximum temperature (Tmax) data across two consecutive 26-year periods to identify statistically significant differences indicative of climate change acceleration. Results, summarized in Table 4, reveal varying trends across individual stations on seasonal and annual bases, coupled with relative percentage changes between the two periods. Bagh and Naran stations exhibited decreases in annual Tmax (-22% and -27%, respectively), while Muree and Peshawar showed increases (10% and 20%, respectively). Seasonal analysis indicates pronounced changes during winter and spring. Naran station experienced the most significant decreases in Tmax during winter and spring (-165% and -58%, respectively). Bagh station displayed decreases across all seasons (-25%, -24%, -15% and -24% for winter, spring, summer and autumn, respectively). Muree station showed increases in winter and spring (14% and 49%, respectively). Peshawar station exhibited substantial increases in Tmax during winter and autumn (48% and 110%, respectively). These findings suggest heterogeneous climate change impacts across the studied stations, with seasonal variations playing a crucial role.

Table 4 : Annual and seasonal maximum temperature Relative change (%) in 2nd period (1987-2012) w.r.t 1st period (1961-1986) (Bold, underline and * showed significant trend with Student t-test, F- test and Mann Whitney U test respectively at 90% confidence level.

Sr. No	Station Name	Maximum Temperature				
		Annual	Winter	Spring	Summer	Autumn
1	**Astore**	3*	**14***	4	-2	**5***
2	**Bagh**	**-22***	**-25**	**-24***	**-15***	**-24***
3	**Balakot**	-1*	0	0*	-1*	-2*
4	**Bunji**	-1	**6***	1	**-5***	-1
5	**Cherat**	**-4***	**-7***	0	**-3***	**-6***
6	**Chilas**	-1	0	0	**-2***	-1
7	**Chitral**	**4***	**16***	**7***	0	**4***
8	**Dir**	**3***	**3***	**5***	**1***	**2***
9	**Drosh**	**2***	**7***	**4**	0	1
10	**Garidopatta**	**4***	**10***	**5***	**2***	**4***
11	**Gilgit**	**3***	**12***	**5***	-1	**4***
12	**Gujar Khan**	3*	**8***	2	1	3*
13	**Gupis**	1	**14**	4	**-2***	0
14	**Kakul**	**3***	**6***	3	1	**2***
15	**Kohat**	**5***	**6***	**7***	**4***	**3***
16	**Kotli**	0	1	2	-1	-2
17	**Mangla**	**2***	3*	**3***	1	-36
18	**Murree**	**10***	**14***	**49***	**4***	**9***
19	**Muzaffarabad**	**3***	**5***	**4**	1	**2***
20	**Naran**	**-27***	**-165***	**-58***	**-7***	-4

21	Palandri	3*	15*	4	-1	5*
22	Parachinar	1	2	4	0	0
23	Peshawar	20*	48*	2	1	110*
24	Rawalakot	6*	20*	4*	2*	6*
25	Risalpur	1*	4*	3*	0	-1*
26	Saidu Sharif	3*	9*	5*	1*	0*
27	Skardu	7*	37*	8*	1	7*

Change Detection in Minimum Temperature

Analysis of minimum temperature (Tmin) time series across two consecutive 26-year periods reveals a complex pattern of climate change acceleration [19]. Applying the Student t-test, F-test, and Mann-Whitney U-test to data from 27 climatic stations, statistically significant differences were detected, though varying across stations and seasons. While a few stations, such as Bunji, Peshawar, and Rawalakot, exhibited positive changes in Tmin, the majority demonstrated negative trends. The most substantial positive change was observed at the Bunji station (128% increase), while Drosh and Parachinar experienced the largest negative changes (-47% and -27%, respectively). Discrepancies identified by the Student t-test were prevalent in Tmin across all four seasons. Furthermore, the F-test and U-test results support the conclusion that the climate in the second period differs significantly from the first, with changes generally statistically significant at a 90% confidence level. Variance changes were also notable for most stations, particularly for Tmin. Results are shown in table 5.

Change Detection in Precipitation

Statistical analyses, specifically the Student t-test, F-test, and Mann-Whitney U-test, were applied to annual and seasonal precipitation data from two consecutive 26-year periods [20]. The results indicate significant differences in precipitation patterns at Naran and Gupis stations across all seasons. The Gupis station exhibited particularly pronounced differences during the summer, suggesting alterations in monsoon rainfall. A different pattern emerged for total precipitation, with the most significant changes occurring during winter and summer. Statistically significant percentage changes were generally substantial as shown in Table 6, with only a few stations exhibiting changes within the +25% to -25% range. Gupis and Naran stations displayed the highest percentage changes, characterized by notable increases in precipitation across all seasons. Conversely, lower elevation stations generally showed a decrease in precipitation.

.Table 5: Relative change (%) in annual and seasonal minimum temperature in 2nd period (1987-2012) w.r.t 1st period (1961-1986) (Bold, underline and * showed significant trend with Student t-test, F- test and Mann Whitney U test respectively at 90% confidence level.

Sr.	Stations	Minimum Temperature				
		Annual	Winter	Spring	Summer	Autumn
1	Astore	1	-6	15*	-6*	1
2	Bagh	-8*	7	-13*	-6*	-8
3	Balakot	-1	-15	6*	7	-16
4	Bunji	128*	-128*	168*	46*	95*
5	Cherat	-3	0	-1	-6*	0
6	Chilas	2	55*	2	-1*	1
7	Chitral	-6*	-36*	-4*	-7*	-7*
8	Dir	-8*	-8	-8*	-6*	-7*
9	Drosh	-47*	-92*	-48*	-33*	-48*
10	Garidopatta	1	-2	0	-3	11
11	Gilgit	-6*	-20*	-2	-8*	-10*
12	Gujar Khan	-6*	-16*	-8*	-5*	-2
13	Gupis	-14*	16	-3	-12*	-12*
14	Kakul	-11*	-36*	-10*	-6*	-15*
15	Kohat	-1	-2	-1	0	-1
16	Kotli	-10*	-3	-21*	-13*	-2*
17	Mangla	-3*	-10*	-3*	-1	260*
18	Murree	-5	13*	64	-1	5
19	Muzaffarabad	0	7*	2	-1	-1
20	Naran	9*	378*	10*	1	10*
21	Palandri	-8*	7	-13*	-6*	-8
22	Parachinar	-27*	368*	-23*	-14*	-25*
23	Peshawar	4*	20*	5*	0	3*
24	Rawalakot	9*	378*	10*	1	10*
25	Risalpur	-1	22*	-3*	-2*	-2
26	Saidu Sharif	-3*	3	0	-3*	-6*
27	Skardu	-8*	-11	-2	-7*	-19*

Table 6: Relative change (%) in annual and seasonal precipitation in 2nd period (1987-2012) w.r.t 1st period (1961-1986) (Bold, underline and * showed significant trend with Student t-test, F- test and Mann Whitney U test respectively at 90% confidence level).

Station Name	Precipitation				
	Annual	Winter	Spring	Summer	Autumn
Astore	4	23	-12	**36***	7
Bagh	2	**30***	8	-9	-3
Balakot	-6	-1	**-15***	-6	8
Bunji	**31**	**66**	-17	**101***	23
Cherat	-13	-3	**-24**	-10	-13
Chilas	**37***	**86***	5	**91***	90
Chitral	**14***	**24**	-5	**74**	**66***
Dir	-3	-3	-5	**-3**	**6**
Drosh	-2	14	-12	9	11
Garidopatta	**-13***	13	**-23***	-14	**-25***
Gilgit	16	35	-2	30	42
Gujar Khan	-3	3	-11	-4	6
Gupis	**119***	**109***	**106***	**135***	**136**
Kakul	4	13	1	1	8
Kohat	**40***	**75***	-2	**73***	18
Kotli	-7	4	-8	-7	-16*
Mangla	-5	-8	-22	1	4513
Murree	-2	6	-9	0	-5
Muzaffarabad	7*	**25***	3	6	2
Naran	**80***	**80***	**90***	**72***	**55***
Palandri	**-17***	1	-20	**-22***	-10
Parachinar	-3	8	-8	-5	2
Peshawar	**20***	**48***	2	1	**110***
Rawalakot	-7	7	-10	-11	-16*
Risalpur	**-11**	**-9**	-13	**-18**	**22***
Saidu Sharif	19	27*	7	26	25
Skardu	**30***	**60***	12	30	20

Change Detection in Stream flow

Observed streamflow trends in the Kurram, Soan, and Indus River basins reveal a complex hydrological response. Annual streamflow has decreased in all three rivers, with the Indus experiencing a statistically significant reduction of 12%. The Kurram and Soan rivers show decreases of 18% and 13%, respectively, although these changes are not statistically significant. Winter streamflow exhibits the most substantial seasonal changes, with the exception of the Kurram River, which displays a negative trend. High-elevation Rivers demonstrate positive changes in spring and autumn, contrasting with negative changes observed in low-elevation rivers. Summer streamflow has decreased across all rivers, with many of these reductions being statistically significant. Analysis of the timing of streamflow (Qst) reveals small, mostly insignificant changes annually, suggesting overall temporal stability. However, high-elevation stations display the largest relative changes in Qst. The Sawat River shows a significant increase of 22%. Seasonally, winter exhibits positive changes as shown in table 7, while summer shows negative changes. The Chakdara station in the Kabul basin displays a notable 69% increase in winter streamflow. Overall, these findings suggest an acceleration of climate change impacts on streamflow patterns within these river basins.

Table 7: Relative change (%) in annual and seasonal streamflow in 2nd period (1987-2012) w.r.t 1st period (1961-1986) (Bold, underline and * showed significant trend with Student t-test, F- test and Mann Whitney U test respectively at 90% confidence level).

	Streamflow				
Series	Annual	Winter	Spring	Summer	Autumn
Naran	-4	-6	-3	-10	**24**
Garhi Habibullah	5	17	**19***	-5	21
Muzaffarabad	-6	13	3	**-16***	6
Chinari	-3	6	0	-7	-5
Domel	-2	13	2	-8	0
Kohala	1	**21***	6	-8	8
Azad Pattan	8	**37***	12	0	13
Kotli	3	**36***	6	-10	10
Palote	-12	27	-27	-14	-17
Kharmong	1	**7***	7	-7	1
Yogo	**8***	4	**19**	6*	**19***
Shigar	**13***	2*	5*	**12***	3

Kachura	**21***	**18***	**24***	**19***	**26***
Gilgit	20	**14***	**43***	16	26*
Dainyor Br.	**-19***	**8**	5	**-25***	-6
Alam Br.	**-6**	**12***	**21***	**-13***	3
Bunji	**10**	**12***	**35***	5*	**15***
Doyain	**26***	**34***	**28***	**18***	**39***
Shatial Br.	**9***	**11***	**19***	**7**	**7***
Karora	**-14**	**19***	**-20***	**-28***	14
Besham Qila	4	**18***	**14***	-1	**13***
Daggar	9	**39***	**21**	-6	2
Phulra	10	**38***	13	0	5
Kalam	1	**9***	**20***	-5	1
Chakdara	**22***	**69***	**36***	8	**37***
Chitral	**8***	**5***	**15***	6*	**12***
Jhansi Post	-23	-21*	**-35***	-1	-30*
Nowshera	-3	8	5	-9	1
Gurriala	-8	24	5	-18*	-11
Khairabad	**-12***	**-17**	**-18***	**-15**	**-19**
Thal	**-18***	**-24***	**-31***	-1	**-17***
Chirah	**-29***	-11	-29*	**-35***	-16*
Chahan	-21	0	-18	**-30**	6*
Dhok Pathan	-13	18	-3	**-25***	15
Massan	**8***	**28***	7*	2	**18***

TREND ANALYSIS

Results of MK-trend analysis for the two time series are Analyses are for Tmax, Tmin, P and Qst at annual and at seasonal base.

Trends in Maximum Temperature

Temperature trends in the Upper Indus Basin (UIB) were analyzed across 27 climatic stations, examining annual maximum and minimum temperatures over two 26-year periods: 1961-1986 and 1987-2012. The Mann-Kendall test and Sen's method were employed to investigate trends in annual mean maximum temperature. Statistical significance was assessed at the 99.99%, 99%, 95%, and 90% levels, providing a rigorous evaluation of temperature fluctuations within the UIB.

Trends in Annual Maximum Temperature

Trend analyses of maximum temperature across two 26-year periods (1961-1986 and 1987-2012) reveal notable spatial and temporal variations; Table, 8. The Mann-Kendall (MK) test identified trends in annual maximum temperature, indicating a predominance of increasing trends during both periods. In the first period, 21 stations exhibited trend existence, with 56% showing increasing trends (4% significant) and 44% decreasing trends (19% significant). Cherat, Gujar Khan, and Kakul demonstrated the most significant decreasing rates. The second period displayed a greater prevalence of increasing trends (85%, 44% significant). Four stations showed decreasing trends, with Bagh and Parachinar exhibiting significant decreases. These findings underscore a shift towards warmer temperatures over time, although localized cooling trends persist.

Trends in Seasonal Maximum Temperature

As seen in the results of annual, almost stations have the warming trends. But, there is more need to see the clear picture of climate change acceleration in the study. So, to get more detail about the trend of climate change, three month seasonal analysis was investigated. More warming trends were found in winter, spring and autumn seasons of 1st period (1961-1986). MK detected 25, 24 and 22 significant trends (at 90%-99.9% significant level) in winter, spring and autumn temperature series as shown in Table 8 and Fig.4. In summer non-consistent trends were found. The maximum temperature has decreased at 70% of stations (33% significant) in summer. Significant increased temperature was found at 59%, 67% and 44% stations. The spring season has higher rate of warming as compared to other seasons. As compare to 1st period (1961-1986) more positive trends found in 2nd period (1987-2012). MK detected positive tends at 81%, 89%, 67% and 84% (15%, 70%, 19% and 11% significant) in four seasons winter, spring, summer and autumn respectively. Negative trends were found at 19%, 11%, 33% and 26% (11%, 4%, 15% and 15% significant). It indicates that climate change acceleration incrases in 2nd period.

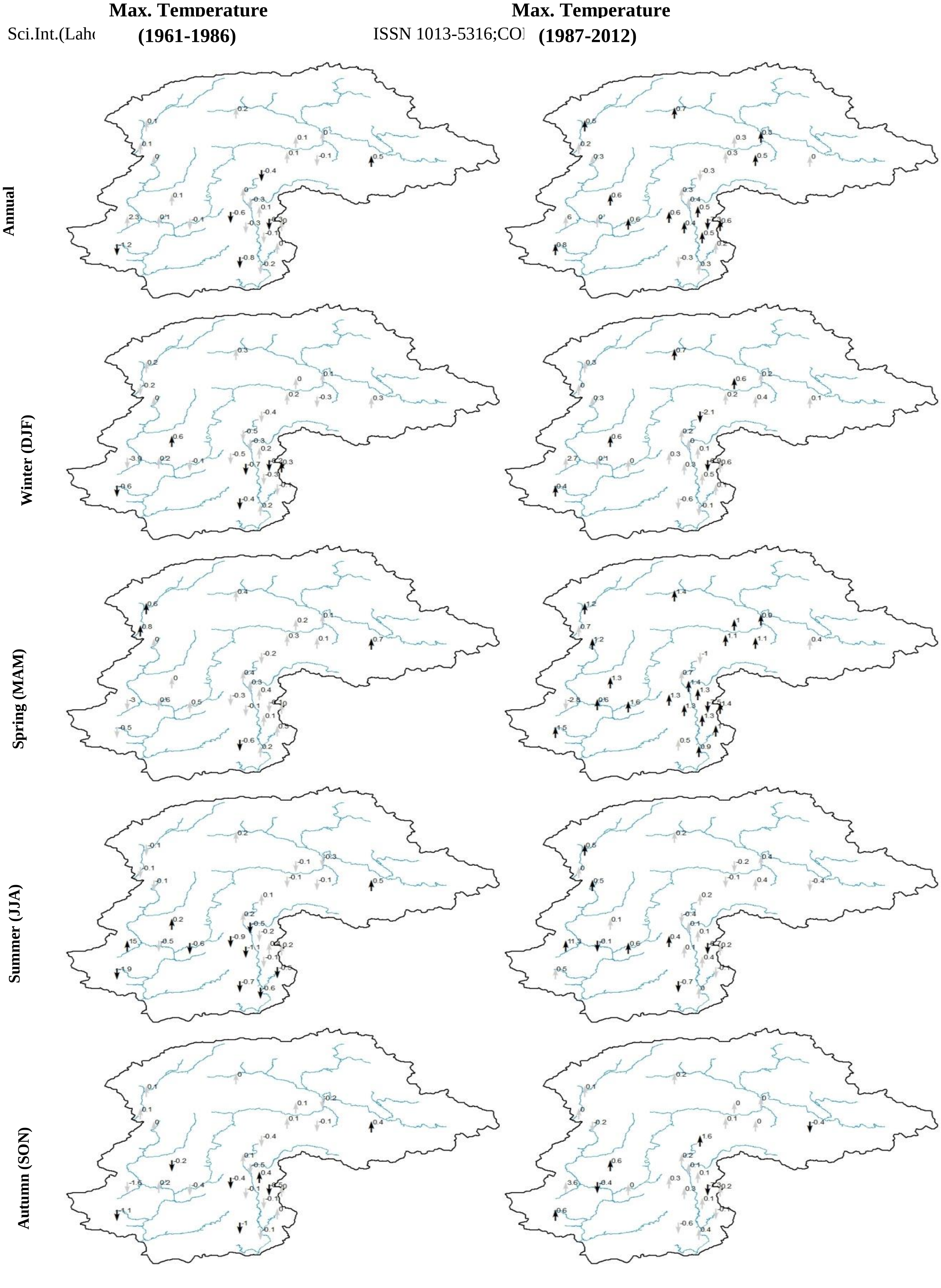


Figure 4: Spatial distribution of trends detected by Mann-Kendal and estimated by Sen's method in annual and seasonal maximum temperature showing change in °C decade -1. (Upward and downward arrow shows positive and negative trends respectively, bold arrow shows significant at α=0.1

TRENDS IN MINIMUM TEMPERATURE

Trends in Annual Minimum Temperature

Table 9 showed the results of trends analysis in annual and seasonal minimum temperature time series for the two consecutive 26-year period (1961-1986) and (1987-2012). In 1st period trend analysis with the MK test displayed trend existence in annual minimum temperature at 22 stations. More decreasing trends were observed. The decreasing trends in annual minimum temperature were found at 59% (41% significant). Only three significant increasing trends were found at Bunji, Chilas and Peshawar. Bunji has highest warming rate (1.5°C per decade). In 2nd period trend analysis with the MK test displayed trend existence at 25 stations. More increasing trends were observed. The increasing trends were found at 56% (19% significant). And the decreasing trends were found at 44% (7% significant).

Trends in seasonal minimum temperature

Trend analysis in seasonal minimum temperature at 1st period (1961-1986) revealed that winter and spring seasons have the more increasing trend at 63% and 67% (30% and 22% significant) respectively. While in summer and autumn there is a decreasing trend at 74% and 67% (41% and 41% significant) were found respectively. As compared to 1st period winter and summer season showed decreasing minimum temperature while spring and autumn seasons showed increasing minimum temperature in 2nd period (1987-2012). Figure 5 demonstrated that at 67% (26% significant) and 52% (11%) warming trend were found for the winter and autumn season. For summer season 74% (67% significant) has the cooling trends. The cooling rate varies from 0.1 °C decade^{-1} to 1.9 °C decade^{-1}. The rates of change in minimum temperature of all seasons are given in Table 6.

Negative Trend

TRENDS IN PRECIPITATION

Trends in Annual Precipitation

The results of analysis by applying Mann-Kendall test and Sen‘s slope estimator method in annual rainfall were summarized for two consecutive 26-year periods (1961-1986) and (1987-2012). As showed in Table 10. In 1st period at five stations, the annual rainfall has increased significant and at four stations has decreased significant. Amongst all stations only Gupis has the highest decreasing trend 32% per year with 99% level of confidence. In 2nd period at two stations the annual rainfall has increased significant and at ten stations has decreased significant. The highest increasing trend were observed 47% per year with 99.9% level of significant at Kohat station and the highest decreasing trend were observed 26% with 95% level of significance at Risalpur station. All trends are shown in Figure 6.

Table 8: Trends detected by Mann-Kendal and trend values estimated by Sen's method in annual and seasonal maximum temperature (^oC decade-1) for the period 1961-1986 and 1987-2012 in Upper Indus Basin (UIB).

Sr.No.	Stations	Max Temperature change per decade (%) 1st Period and 2nd Period									
		Annual		Winter (DJF)		Spring (MAM)		Summer (JJA)		Autumn (SON)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Astore	**-0.1**	0.5*	**-0.3**	0.4	0.1	1.1*	**-0.1**	0.4	**-0.1**	0.0
2	Bagh	**-0.3****	**-7.3******	**-0.2**+	**-6.9******	**-0.1**	**-7.5******	0.4	**-6.7******	**-0.5*****	**-7.3******
3	Balakot	0.0	0.3	**-0.5**	0.2	0.4	0.7	0.2	**-0.4**	0.1	0.2
4	Bunji	0.0	0.3+	0.1	0.2	0.1	0.9+	**-0.3**	0.4	**-0.2**	0.0*
5	Cherat	**-1.2******	0.8**	**-0.6**+	0.4+	**-0.5**	1.5**	**-1.9******	0.5	**-1.1******	0.6*
6	Chilas	0.1	0.3	0.2	0.2	0.3	1.1+	**-0.1**	**-0.1**	0.1	0.1
7	Chitral	0.1	0.5+	0.2	0.3	0.6+	1.2*	**-0.1**	0.5**	0.1	0.1
8	Dir	0.0	0.3	0.0	0.3	0.0	1.2*	**-0.1**	0.5*	0.0	**-0.2**
9	Drosh	0.1	0.2	**-0.2**	0.0	0.8+	0.7	**-0.1**	0.0	0.1	0.0
10	Garidopatt a	0.1	0.5*	0.2	0.1	0.4	1.3*	**-0.2**	0.1	0.4*	0.1
11	Gilgit	0.1	0.3	0.0	0.6*	0.2	1.0+	**-0.1**	**-0.2**	0.1	0.0
12	Gujar Khan	**-0.8*****	**-0.3**	**-0.4**+	**-0.6**	**-0.6**+	0.5	**-0.7*****	**-0.7****	**-1.0*****	**-0.6**
13	Gupis	0.2	0.7*	0.3	0.7*	0.4	1.4*	0.2	0.2	0.0	0.2
14	Kakul	**-0.6*****	0.6*	**-0.5**	0.3	**-0.3**	1.3**	**-0.9*****	0.4*	**-0.4**+	0.3
15	Kohat	**-0.1**	0.6***	**-0.1**	0.0	0.5	1.6***	**-0.6****	0.6***	**-0.4**	0.0
16	Kotli	0.0	0.2	**-0.1**	0.1	0.3	1.0*	**-0.5****	**-0.1**	0.0	**-0.1**
17	Mangla	**-0.2**	0.3	0.2	**-0.1**	0.2	0.9+	**-0.6****	0.0	**-0.1**	0.4
18	Murree	**-0.3**	0.4*	**-0.7*****	0.3	**-0.1**	1.3*	**-1.1******	0.1	**-0.1**	0.3
19	Muzaffarab ad	**-0.3**	0.4	**-0.3**	0.0	0.3	1.4+	**-0.5****	0.1	**-0.5**	0.1
20	Naran	**-0.4****	**-0.3**	**-0.4**	**-2.1*****	**-0.2**	**-1.0**	0.1	0.2	**-0.4**	1.6*
21	Palandri	**-0.1**	0.5**	**-0.3**	0.5	0.1	1.3**	**-0.1**	0.4	**-0.1**	0.1
22	Parachinar	**-0.3**	**-0.7****	**-0.6**	**-1.4**+	0.1	0.3	**-0.5*****	**-0.2**	**-0.2**	**-1.5******
23	Peshawar	2.3	6.0	**-3.9**	2.7	**-3.0**	**-2.8**	15.0*	11.3*	**-1.6**	3.6
24	Rawalakot	0.0	0.6+	0.3*	0.6	0.0	1.4**	0.2	0.2	0.0	0.2
25	Risalpur	0.1	0.0	0.2	0.1	0.6	0.6***	**-0.5**	**-0.1****	0.2	**-0.4******
26	Saidu Sharif	0.1	0.6+	0.6***	0.6*	0.0	1.3+	0.2**	0.1	**-0.2****	0.6+
27	Skardu	0.5*	0.0	0.3	0.1	0.7+	0.4	0.5+	**-0.4**	0.4+	**-0.4****

***Significance level <= 99.9%, **Significance level <= 99%. *Significance level <= 95%. +Significance level <= 90%.Bold = Negative Table 9: Trends detected by Mann-Kendal and trend values estimated by Sen's method in annual and seasonal minimum temperature (oC decade-1) for the period 1961-1986 and 1987-2012 in Upper Indus Basin (UIB).

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		Minimum Temperature change per decade (%) 1st Period and 2nd Period									
		Annual		Winter (DJF)		Spring (MAM)		Summer (JJA)		Autumn (SON)	
Sr.No.	**Stations**	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Astore	0.1	0.4*	0.0	0.3	0.4+	0.8**	**-0.1**	0.6*	0.0	0.4
2	Bagh	**-1.0*****	0.1	**-0.5**+	0.2	**-1.5*****	0.0	0.4	0.2	**-1.2*****	0.4
3	Balakot	**-0.1**	**-0.3***	**-0.1**	**-0.6*****	0.4	0.0	0.2	**-0.1**	**-0.4***	**-0.4**+
4	Bunji	0.2	**-1.1*****	0.2	**-0.8*****	0.5+	**-0.6***	**-0.3**	**-1.3*****	0.2	**-1.9*****
5	Cherat	0.2	**-0.2**	0.3	**-0.6**+	0.6+	0.2	**-1.9*****	**-0.5***	0.5*	**-0.3**+
6	Chilas	0.3+	**-0.1**	0.5*	**-0.4**	0.4	0.4	**-0.1**	**-0.2**	0.3	**-0.3**
7	Chitral	0.0	0.1	0.2	**-0.1**	0.1	0.4*	**-0.1**	0.1	**-0.2***	0.1
8	Dir	**-0.3**+	0.4**	**-0.3**+	0.4**	0.1	1.1***	**-0.1**	0.3	**-0.3**	0.1
9	Drosh	**-1.7***	**-0.1**	**-3.3****	0.0	**-3.2**+	**-0.2**	**-0.1**	**-0.5**+	**-1.8**+	0.0
10	Garidopatta	**-0.1**	0.2	**-0.4**	**-0.3**	0.1	0.6*	**-0.2**	0.0	**-0.1**	0.4
11	Gilgit	0.0	0.3*	0.3	**-0.2**	0.1	0.5**	**-0.1**	0.4	**-0.1**	0.3
12	Gujar Khan	**-0.2****	0.2	0.1	**-0.2**	**-0.6***	0.5+	**-0.7****	**-0.1**	0.0	0.3+
13	Gupis	**-0.1**	**-0.3**	0.2	**-0.7**+	**-0.2**	**-0.1**	0.2	**-0.1**	**-0.2**	**-0.4**
14	Kakul	**-1.3*****	0.0	**-1.3*****	**-0.2**	**-1.2*****	0.2	**-0.9****	0.1	**-1.2*****	**-0.2**
15	Kohat	0.0	0.9***	0.1	**-0.1**	0.3	1.4***	**-0.6***	1.1***	0.0	0.8**
16	Kotli	**-0.4****	0.1	0.0	**-0.2**	**-0.2**	0.6*	**-0.5***	**-0.2**	**-0.5*****	**-0.1**
17	Mangla	**-0.8*****	0.1	**-0.7***	**-0.6***	**-0.6***	0.4	**-0.6***	0.1	**-0.8****	0.2
18	Murree	0.7**	**-0.5**	0.5***	**-0.2**	0.9+	0.4	**-1.1*****	**-0.1**	0.9***	**-0.6**
19	Muzaffarabad	**-0.2**+	0.2	0.0	**-0.4***	**-0.1**	0.5	**-0.5***	0.3	**-0.2**	0.2
20	Naran	**-0.5*****	**-0.1**	**-0.6*****	0.3	0.0	0.1	0.1	**-0.2**	**-1.1*****	0.3
21	Palandri	**-1.0*****	0.1	**-0.5**+	0.2	**-1.5*****	0.0	**-0.1**	0.2	**-1.2*****	0.4
22	Parachinar	0.0	**-0.3**	0.0	**-1.9***	0.0	0.7	**-0.5****	**-0.5**	0.0	0.3
23	Peshawar	**-0.1**	0.8***	0.0	0.5**	0.2	1.2**	15.0*	0.4**	-0.3	0.6**
24	Rawalakot	**-0.5*****	**-0.1**	**-0.6*****	0.3	0.0	0.1	0.2	**-0.2**	**-1.1*****	0.3
25	Risalpur	**-0.1**	0.0	0.1	0.0	0.2	0.0	**-0.5**	0.0	**-0.2**	**-0.1***
26	Saidu Sharif	0.2*	**-0.1**	0.1	**-0.3**	0.1	0.5+	0.2**	**-0.2**	0.1	**-0.4**
27	Skardu	0.0	**-0.3**	0.0	**-0.6**	0.1	**-0.1**	0.5+	**-0.1**	**-0.4**+	**-0.5***

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

Table 10: Trends detected by Mann-Kendal and trend values estimated by Sen's method in annual and seasonal precipitation (% of data period average) for the period (1961-1986) and (1987-2012) in Upper Indus Basin (UIB).

		Precipitation change per Year (%) 1st Period and 2nd Period									
		Annual		Winter (DJF)		Spring (MAM)		Summer (JJA)		Autumn (SON)	
Sr.No.	**Stations**	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Astore	0	-11	-6	0	1	-17+	13	-11	2	-7
2	Bagh	11+	-7	3	2	8	-15	13*	-16+	4	-9
3	Balakot	13**	-5	12	6	-13	-21**	14*	-3	10	-1
4	Bunji	21+	13+	6	41*	0	-4	23	17	16	12
5	Cherat	0	1	-12	-6	2	-31*	19*	14	-10	16
6	Chilas	-3	-15+	-33	0	15*	-14	36+	-21	-4	-3
7	Chitral	-12	-4	-13+	7	0	-23*	-13	-36*	-5	-2
8	Dir	9*	-16**	9*	-16**	-6	-37***	12**	-19	8	-2
9	Drosh	-12	-6	3	0	-6	-23+	-6	-10	-5	-3
10	Garidopatta	-12**	-6	-25*	9	11	-16	-5	-9	-7	-1
11	Gilgit	3	10	-26	23	0	8	2	-4	-12	11
12	Gujar Khan	6	-11+	-1	-3	3	-10	6	-12+	-11	-6
13	Gupis	-32**	12	-47**	39*	5	-2	-34+	-7	-34+	10
14	Kakul	9	-8+	8	-2	0	-14	24	-4	0	-9
15	Kohat	-1	47***	-19	54**	-7	9	15	56***	-27+	48***
16	Kotli	1	-7	-9	2	0	-17	5	-4	-3	1
17	Mangla	8	-5	1	-12	-6	-19+	6	-3	627	12
18	Murree	3	-15**	15	-16	-4	-23*	8	-10+	-10	-7
19	Muzaffarabad	-5	-7*	-8	-4	13	-27*	1	-4	-10	1
20	Naran	-19*	-6	-18+	0	34+	-11	-4	-9	-10	-4
21	Palandri	5	-15*	0	-6	2	-24*	9	-4	8	-5
22	Parachinar	-15*	10	-10	13	-3	-24+	-12	18	-16+	16
23	Peshawar	7	15	-14	6	1	-5	36*	27*	-13	14
24	Rawalakot	1	-14*	-5	2	1	-23**	4*	-12+	-2	-10
25	Risalpur	12+	-26*	-8	-33*	15	-24	30	-14*	6	-1
26	Saidu Sharif	1	-12+	0	-3	7**	-33**	-10*	-4	9*	-16
27	Skardu	10	-1	10	0	3	-4	22	1	20	-19

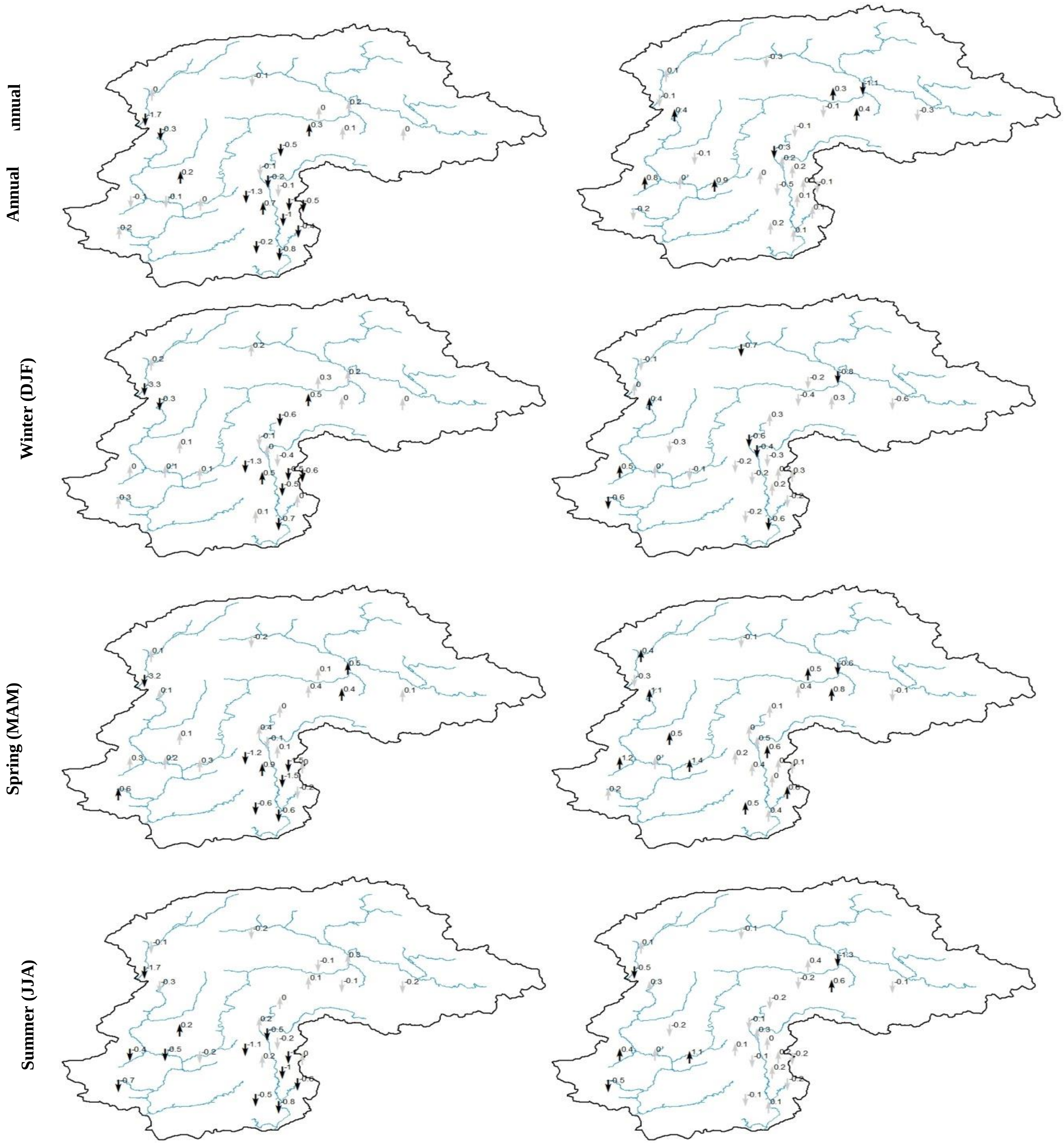
***Significance level <= 99.9%, **Significance level <= 99%. *Significance level <= 95%. +Significance level

Table 11: Trends detected by Mann-Kendal and trend values estimated by Sen's method in annual and seasonal streamflows (% of data period average)) for the period 1961-1986 and 1987-2012 in Upper Indus Basin (UIB).

Sr.No.	Stations	Streamflows change per Year (%) 1st Period and 2nd Period									
		Annual		Winter (DJF)		Spring (MAM)		Summer (JJA)		Autumn (SON)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	Naran	-5	-7*	0	3	7	-10	-9	-13*	-11*	7
2	Garhi Habibullah	-5	-8+	-7*	-2	5	0	-11	-15*	-12**	-8
3	Muzaffarabad	-5	-14*	1	-9	0	-8	-11+	-23*	-3	-13+
4	Chinari	4	-22**	0	-23+	4	-23*	1	-23*	-5+	-19
5	Domel	0	-24**	-3	-14	0	-25**	0	-28**	-9**	-18+
6	Kohala	-3	-18*	2	-15	1	-16*	-9	-23*	-5	-13+
7	Azad Pattan	0	-22**	-5	-9	7	-19*	-1	-26*	-5+	-18**
8	Kotli	6	-12+	5	-5	23	-14	5	-18	9	-3
9	Palote	1	-43***	-6	-22*	15	-30*	5	-46**	-13	-21*
10	Kharmong	0	-7	2**	2	0	-8	0	-11+	0	2
11	Yogo	1	5	-2	-2	-3	6	-1	4	2	3
12	Shigar	3+	1	1+	1	1**	1*	3+	1	0	-2
13	Kachura	-1	-3	-3*	1	-7*	-2	0	-2	2	-5
14	Gilgit	1	4	-5	3	4**	22*	2	3	-5*	5
15	Dainyor Br.	-6	6	-4+	3	0	12	-8	5	-4*	2
16	Alam Br.	-6*	1	-3	3	-3	10*	-7+	-1	-9+	3
17	Bunji	-3	-2	-5**	0	5	8	-4	-2	-3	-6+
18	Doyain	2+	-5	-3	-6	-13+	13	3*	-6	0	-11
19	Shatial Br.	1	5	0	9*	3*	14*	1+	4	0	4
20	Karora	-1	-28**	-4	-12	1	-33***	-7**	-32***	-3	-28**
21	Besham Qila	0	-2	-1+	4*	-5+	4	-2	-4	-1	0
22	Daggar	11*	5	10+	9	18**	-10	11+	10	-2	6
23	Phulra	0	-7	-6	1	10+	-14	-8	-8	-12	-12
24	Kalam	-6	-10**	3	-4	4	6	-7	-14*	-12*	-18**
25	Chakdara	-6	11	3	32*	1	11	-11+	1	-8+	16+
26	Chitral	1	-3	1	1	-3	7	1	-1	5	-6*
27	Jhansi Post	-43***	-2	-38***	-48***	-39**	-23	-45**	2	-63***	7
28	Nowshera	-10*	-6	-5	-5	-7	-12	-13+	-5	-3	-3
29	Gurriala	6	-28*	12+	10*	15	-25*	-7	-22+	7	-31*
30	Khairabad	-3*	-32***	-4+	-4+	-1+	-35***	-1	-27**	0	-38***
31	Thal	-1	-7	1	2	-5	-36*	0	5	-2	2
32	Chirah	22+	-19	-9	-10	9	-23	26	-21	7	-3
33	Chahan	18	-32**	20	20	27	-44*	18	-30*	23	-20***
34	Dhok Pathan	2	-25	11	9	9	-39*	-8	-21	22	-23+
35	Massan	0	-7*	15***	12***	-2	-9+	-8**	-8	6***	-4

Min. Temperature (1961-1986)

Min. Temperature (1987-2012)



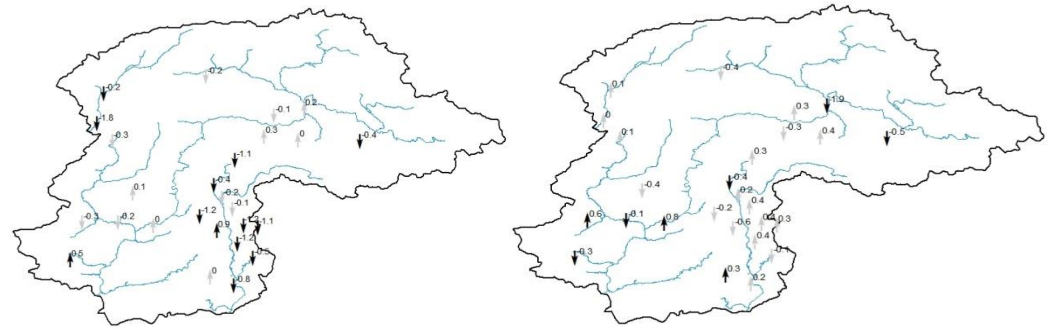
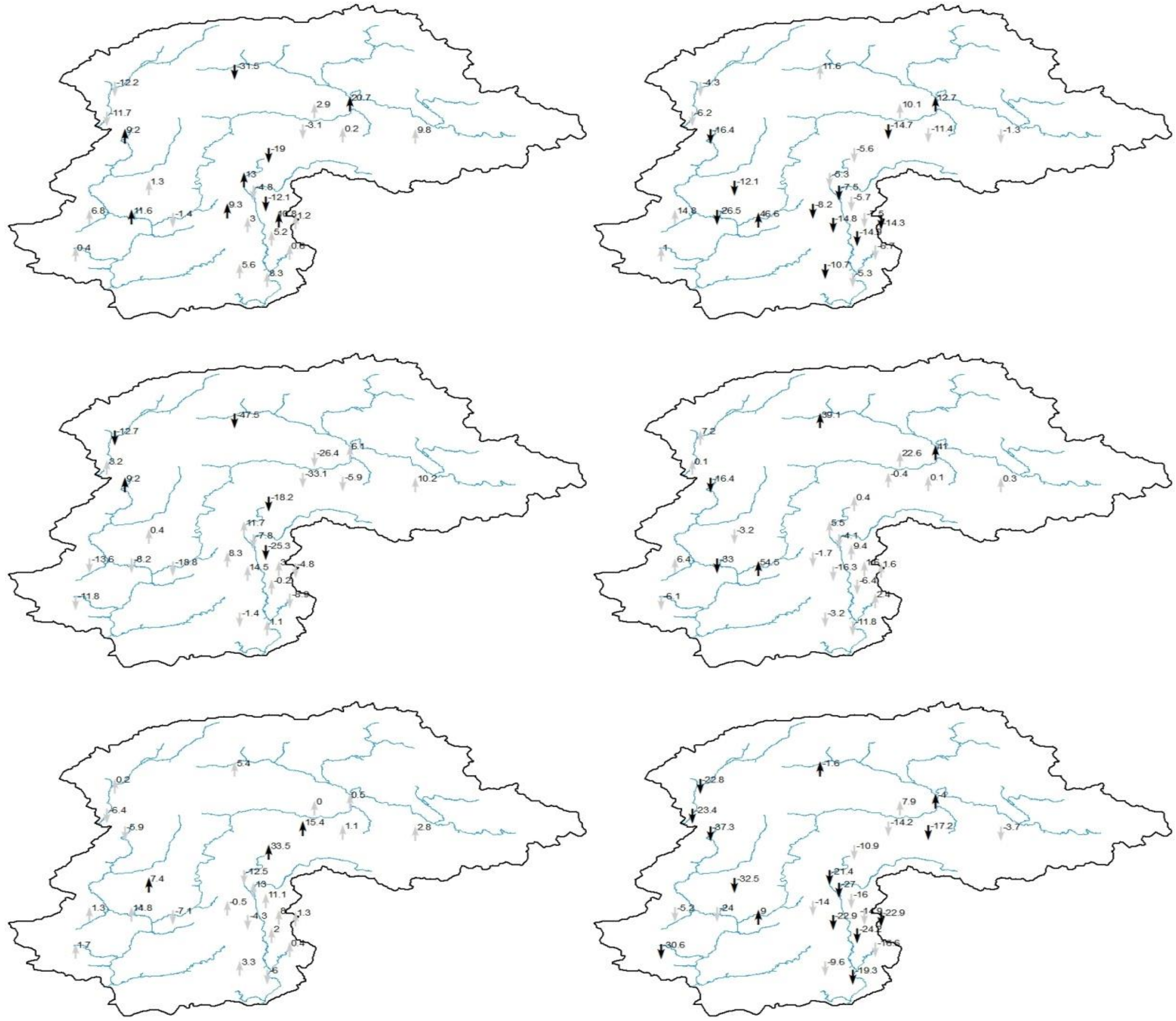


Figure 5: Spatial distribution of trends detected by Mann-Kendal and estimated by Sen's method in annual and seasonal minimum temperature showing change in °C decade -1. (Upward and downward arrow shows positive and negative trends respectively, bold arrow shows significant at α=0.1

figure 6.

<= 90%. Bold = Negative Trend



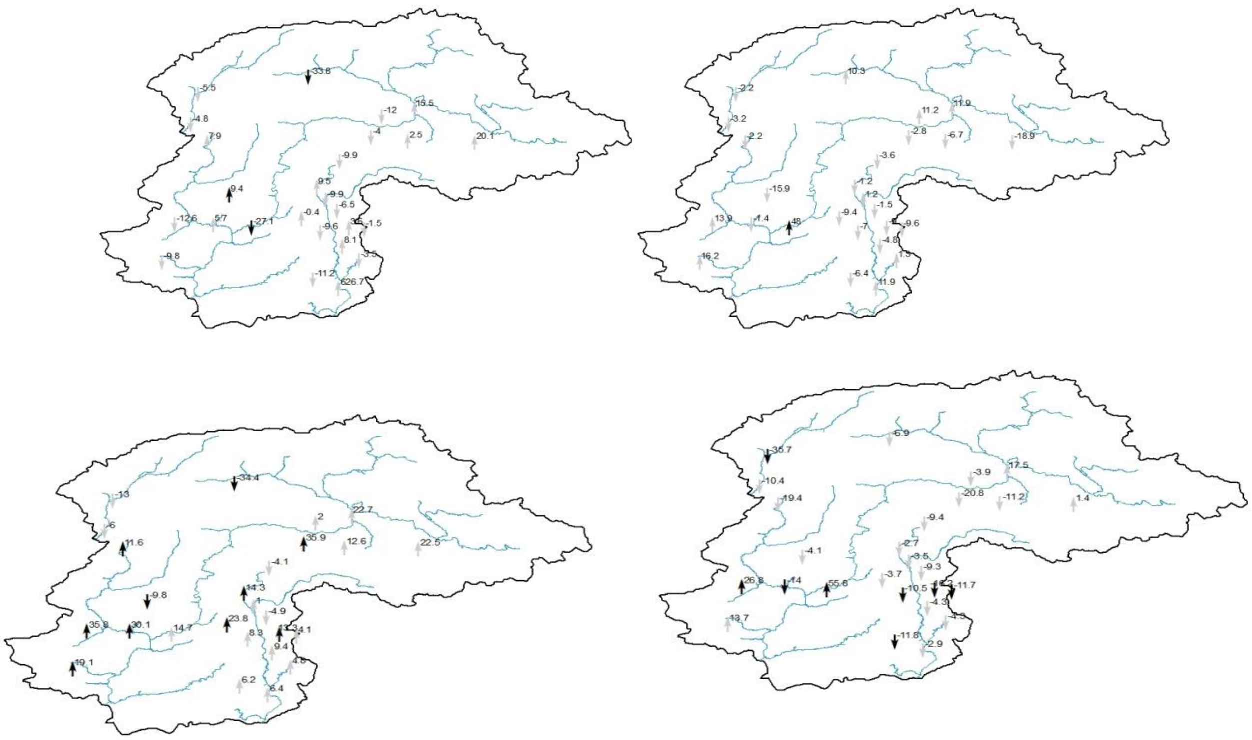


Figure 6: Spatial distribution of trends detected by Mann-Kendal and estimated by Sen's method in annual and seasonal precipitation showing change in °C decade -1. (Upward and downward arrow shows positive and negative trends respectively, bold arrow shows significant at α=0.1

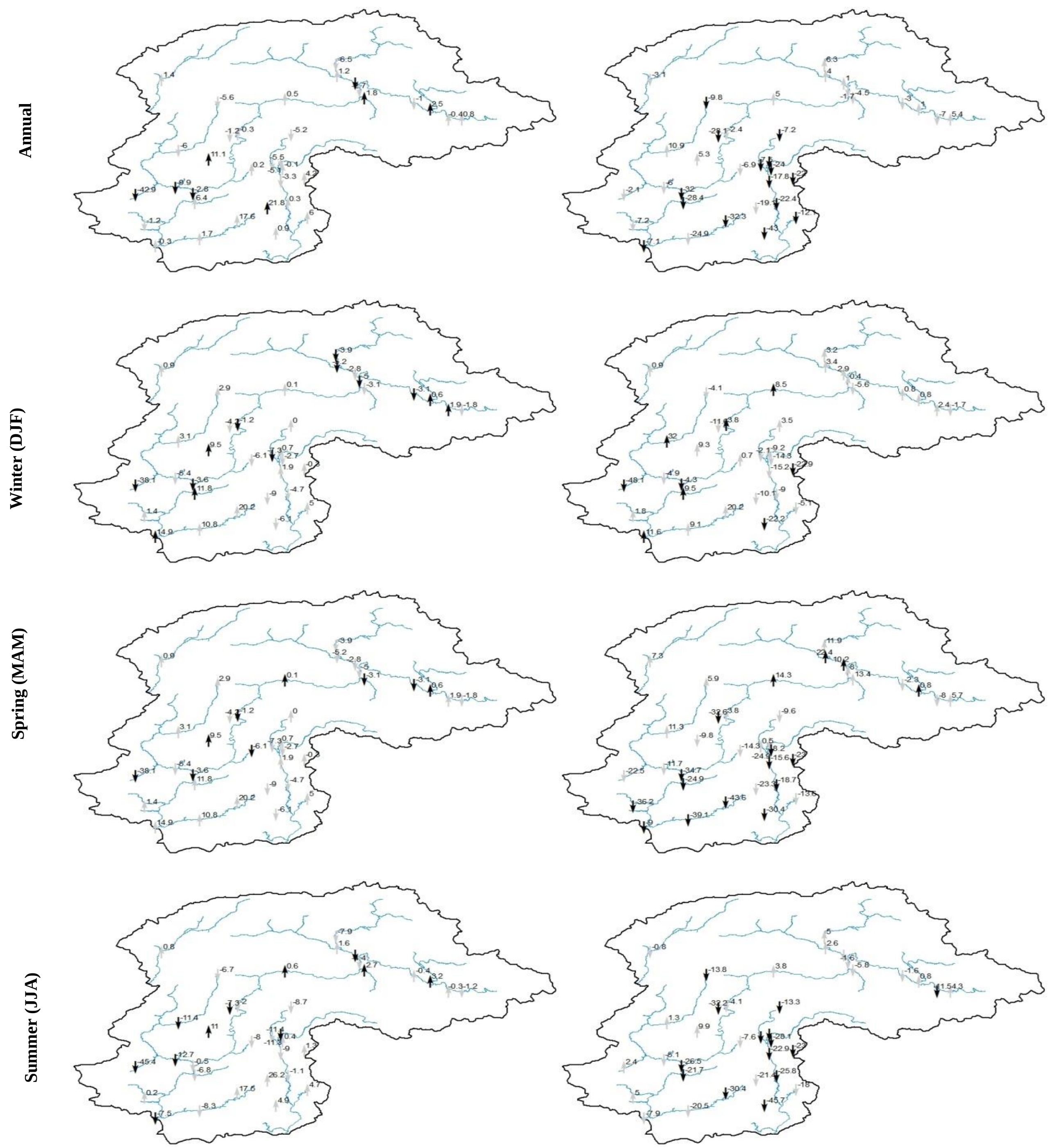
Trends in Seasonal Precipitation

In 1st period the MK nonparametric test shows negative trends (Figure 6) in precipitation for winter and autumn seasons with 59% (15% significant) and 59% (11% significant) while positive trends with 74% (11% significant) and 74% (30% significant) for spring and summer respectively. For winter the highest negative trends were observed 47%, 13%, 25% and 18% at Gupis, Chitral, Garidopatta and Naran stations respectively. In 2nd period more decreasing trends were found 93% (48% significant) and 78% (22% significant) for spring and summer season. For winter 63% (11% significant) increasing trends were found. In autumn season 63% non-significant decreasing trends were found by MK test. All trends are shown in

Trnds in Seasonal Streamflow

Results of trends in seasonal streamflow series for two consecutive 26-year periods (1961-1986) and (1987-2012) are given in Table 7 and spatial distribution of these trends are shown in Figure 7. Winter mean flows have significantly increased at 4 stations and decreased at 7 stations. The highest significantly increasing trend was found at (Massan) Indus basin and decreasing was found at (Jhansi Post) Kabul basin with rate of 15% and 38% data period mean for the record length and period (1961-1986) respectively. All three major rivers have the increasing trends at Azad Pattan in Jhelum, Besham in Indus and Nowshera in Kabul but only the Indus River has the significant trend. For spring season flows have 10 significant (5 increasing and 5 decreasing). The Brandu River at Daggar has significant increasing with the rate of 18% whereas the Bara River has decreasing trend at Jhansi Post significant decreasing the rate of 39%. Most of decreasing trends were observed in summer and autumn flows as given in Table 11 and shown in Figure 7. 57% (9% significant) and 60% (31% significant) of total stations have the decreasing trends were found in summer and autumn season respectively. In 2nd period for winter season mean flows have increased with 54% (14% significant) and decreased with 46% (11% significant) of the data period average for the period (1987-2012). The highest significantly increasing trend was found at (Chakdar) Swat river in Kabul basin and decreasing was found at (Jhansi Post) Kabul basin with rate of 32% and 48% data period mean for the record length and period (1987-2012) respectively. All three major rivers have the increasing trends at Azad Pattan in Jhelum, Besham in Indus and Nowshera in Kabul but only the Indus River has the significant trend. For spring season flows have 16 significant (4 increasing and 12 decreasing). The Gilgit River at Gilgit and Alam Br. have significant increasing trends with the rate of 22% and 10%. The Indus River at Shatail Br. has increased 14% of data period average whereas the lower parts of Indus basin and Jhelum basin have decreasing significant trends. Most of decreasing trends were observed in summer and autumn flows as given in Table 11 and shown in Figure 7. 74% (40% significant) and 66% (37% significant) of total stations have the decreasing trends were found in summer and autumn season respectively. All three basins have the significant decreasing trends at outlets (Azad Pattan, Besham and Nowshera). All sub basins of Jhelum basins have the decreasing trends. Rim stations of Kunhar, Neelum and Kanshi basins have the significant deceasing trends with the rate of 15%, 23% and 46% respectively where Poonch has non-significant with the rate of 18% .

level <= **Streamflows (1961-1986)** ***Significance 99%. +Significance level **Streamflows (1987-2012)** level <= 99.9%, **Significance *Significance level <= 95%. <= 90%. Bold = Negative Trend



July-August

ON)

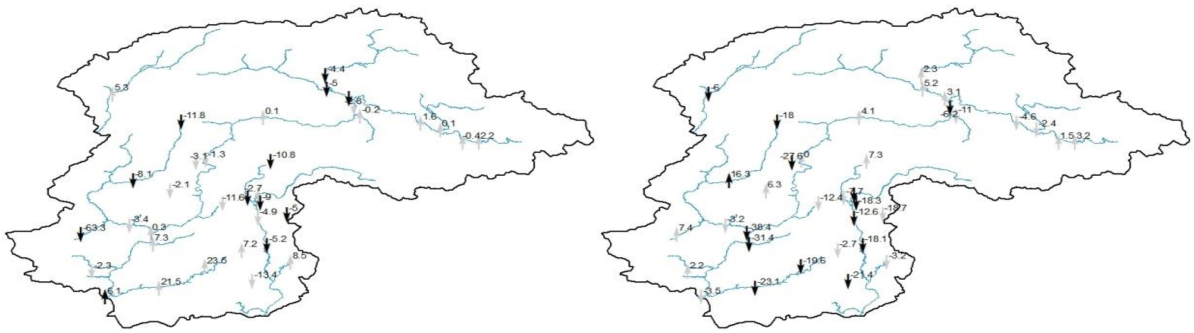
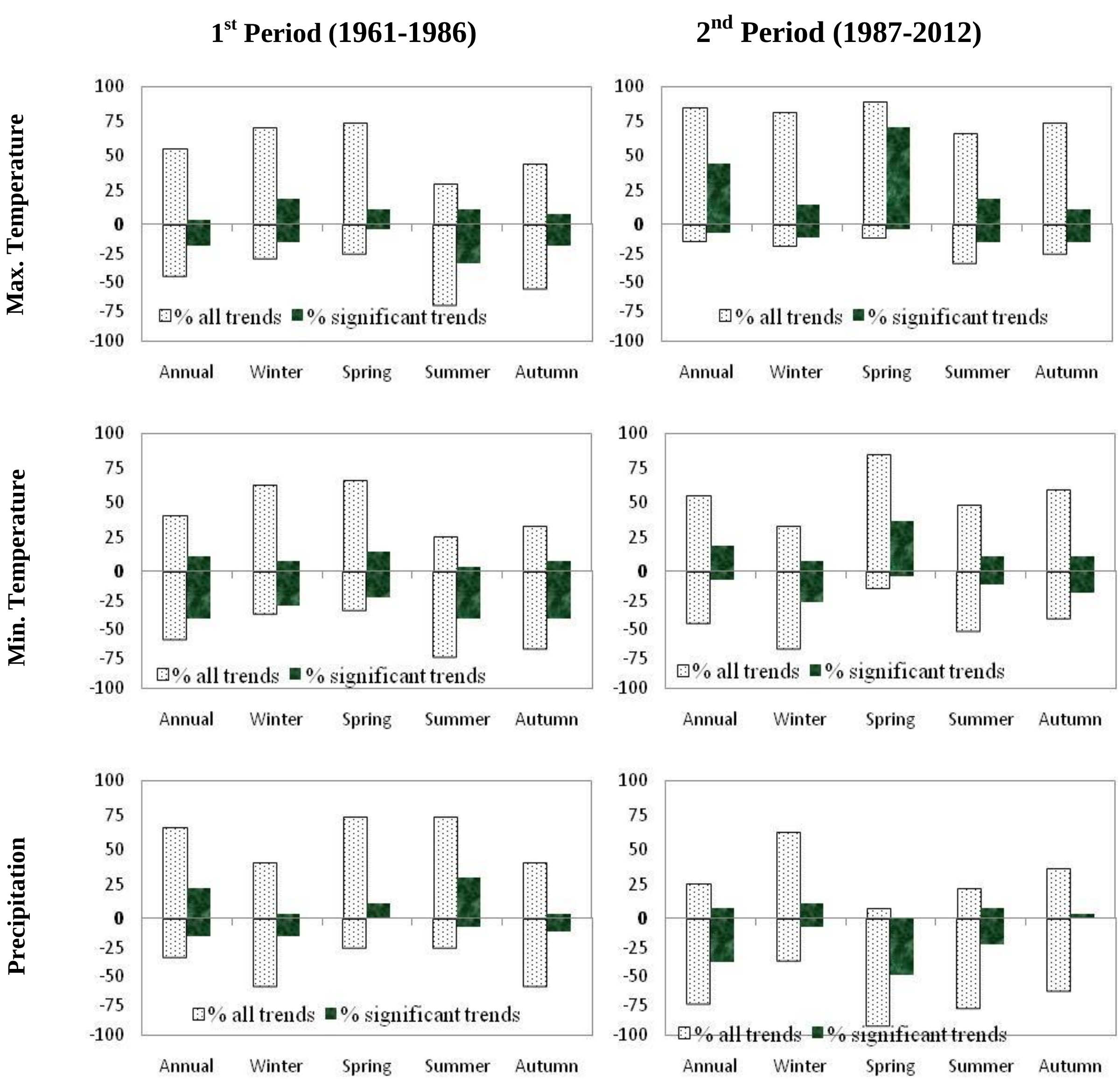


Figure 7: Spatial distribution of trends detected by Mann-Kendal and estimated by Sen's method in annual and seasonal streamflows showing change in °C decade -1. (Upward and downward arrow shows positive and negative trends respectively, bold arrow shows significant at α=0.1



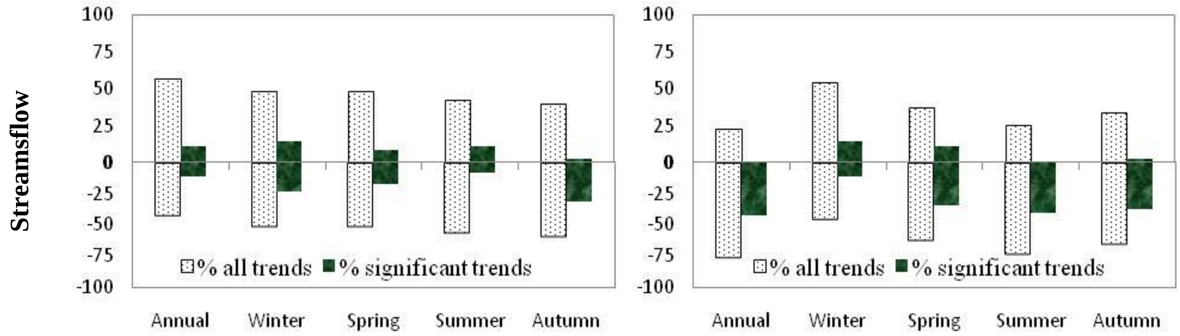


Figure 8: Percent number of stations with positive (upward) and negative (downward) trends in annual and seasonal time series for different periods and number of stations with significant trends by Mann-Kendall test at α=0.1.

CONCLUSIONS AND RECOMENDATIONS

CONCLUSIONS

According to this research climate change and acceleration of climate change in UIB may seriously affect stream flow in Indus River. The main source of stream flow for the UIB is snowmelt and rainfall across the basin. This study investigates the existence of trends and relative changes in the annual and seasonal maximum and minimum temperature, precipitation and streamflows for two consecutive 26-year periods. The study is adopted for UIB and aimed to access possible acceleration of climate change since 1960s.

The result of this study shows that climate change occurs more severe with warming and cooling trends in UIB. The existing trends causes by climate change have great effect on water flows that should be more helpful for better water management and to minimize scarcity of water in Pakistan.

The specific conclusions of this study are as under:

1 Change in maximum temperature in the 2nd period are higher than in the 1st period across the UIB that indicated acceleration of climate change. Changes also are more significant for the 2nd period.

2 In Annual and seasonal minimum temperature large variability was observed for both periods but change in min temperature are largest for 2nd period.

3 Annual and seasonal precipitation in high mountainous catchment (Kunhar and Neelum) showed increasing trends whereas low elevated catchment (Kanshi and Poonch) have decreasing trends.

4 Results indicate that in 2nd period Annual and seasonal precipitation has decrease with decreasing trend across the UIB.

5 The annual streamflow in high elevated stations of UIB show decreasing trends for 1st period while the low elevated stations show increasing trends. In 2nd period the annual streamflow at most stations showed rapidly decreasing trend.

6 For seasonal streamflow the results of this study shows that trends are quite equal with the decreasing and increasing ratio in all seasons for 1st period while in the 2nd period trend is increasing in winter season and decreasing in rest of spring, summer and autumn seasons.

7 Climate change mostly occurring in lower part of UIB with warming trend while cooling trends were observed in high elevated part of UIB and have effect on stream flows.

RECOMENDATIONS

1. Adaptation of this study for whole Indus basin is very essential for better result.
2. Statistical tests can only indicate the significance of the observed test statistics and do not provide unequivocal findings. It is therefore important to clearly understand the interpretation of the results and to corroborate findings with physical evidence of the causes, such as land use changes or river stations influenced by human activities. Changes in streamflow, drought severity and frequency might occur as a result of changes in climate (mainly precipitation and temperature) and artificial influences in the catchment such as groundwater abstraction, irrigation and urbanization.
3. Some hydrologic simulation models should be used to see contemporary impact.

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