HYDROLOGICAL TRENDS AND VARIABILITY IN THE MANGLA WATERSHED, PAKISTAN

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ABSTRACT: *Pakistan's economy is based on agriculture that is highly dependent on water resources originating in the mountain sources of the Upper Indus. The aims of this study are to detect trends, variability analysis and assessment of changes in minimum (low), mean and maximum (high) flows in Mangla Basin, Pakistan. Trend analyses are performed by applying Mann-Kendall, non-parametric test. Sen's method was applied to estimate slope time series that indicates changes in river flows. The influence of serial correlation was eliminated from time series by applying the trend-free pre-whitening (TFPW) method prior to the trend analysis. Results of this study revealed that trends were more common in mean and low flows compared to high flows. Statistically significant increasing and decreasing trends are noticed in different parts of Mangla watershed. The annual minimum flow at the outlet of Mangla watershed has decreased whereas mean and maximum flow has increased.*

Keyword: Upper Indus Basin; climate change; trends; stream flows.

1. INTRODUCTION

Pakistan's economy is largely based on agriculture that is highly dependent on the Indus Basin Irrigation system (IBIS). The IBIS covers an area of 22.2 million hectares (ha) and irrigated land accounts for 85% of all crop/food production [16]. Pakistan has three major reservoirs (Tarbela, Mangla and Chasma), which have storage capacites of 19.43 BM^3 Mangla Dam was constructed as part of Indus Basin Project, to mitigate the impact of ceding three eastern rivers (Ravi, Sultej and Beas) to India under 1960 Water Treaty. Though provided as part of the package for the replacement works, it was intended to: provide a live storage of 6.6 BM3 (34% of total storage) [33] with a command area of about 6 million (ha) including an element of development; generate cheap hydropower through a staged development of 1000 MW capacity; increase agricultural production and provide a base for further development of agriculture through structural integration/regulation of IBIS. Therefore, quantitative estimates of hydrologic effects are essential for understanding and analyzing the potential water resources issues associated with water supply, power generation, and agriculture as well as for future water resource planning, reservoir design and management, and protection of the natural environment. The population of Pakistan is increasing annually at 2 % and has reached up to 180 million [24]. Being an agricultural country with heavy population growth, there is a great stress on water resources to meet the food and fiber requirement for the people. The per capita water availability is declining with the passage of time due to combined impact of rising population, falling water flow and reduction in the storage reservoir capacities. 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 [9].

According to Intergovernmental Panel on Climate Change [13], the global average surface temperature has increased by 0.074°C (± 0.018°C) and 0.13°C (± 0.03°C) per decade over the past 100 years (1906–2005) and 50 (1956-2005) years respectively. Since 1981, the rate of warming is faster, with a value of approximately 0.177 °C (±0.052°C) per decade. The global average precipitation has increased over the 20th century between 30°N and 85°N during 1901–2005. From 10°N to 30°N, precipitation has increased markedly from 1900 to the 1950s, and declined after 1970. Various scientists [23,14,15] have indicated large-scale warming of the Earth's surface over the last hundred years. Such warming affects global circulation patterns as often simulated and predicted by use of general circulation models (GCM) but also directly affects local climatic settings with changes in the distribution and characteristics of precipitation and temperature. Decreasing trends in rainfall patterns along Pakistan's coastal areas and arid plains have also been observed [13]. Stations located in different zones of the country, mainly from North, North West, West and Coastal areas respectively show an overall significant decreasing trend, whereas plain areas and South West of the country have been observed with no significant trend [26]. Hydrological impacts by climate change may significant affect water resources and may cause changes in the hydrological cycle [4]. The frequency and severity of drought events could increase as a result of changes in both precipitation and evapotranspiration. Changes in hydrologic regime that occurs are not expected to be equally distributed throughout the year. For example, increased temperatures in the winter are expected to lead to earlier snowmelt events and a shift in runoff from the spring to late winter with a corresponding decrease in runoff in the summer period. Changes in climate and related hydrological impacts vary in space and time domains as affected by local climatological and topographic settings.

Stream flow (also called river flow) varies over space and time. The temporal scale ranges from minutes (e.g. in the case of flash floods) to decades (e.g. in the case of water resource assessments). River flow regimes describe the temporal patterns of flow variability. Knowledge about changing river flow regimes is vital for assessing climate change risks related to freshwater. Estimation of changes in seasonality, inter-annual variability, statistical low, mean and high flows, and floods and droughts is required to understand the impact of climate change on humans and freshwater ecosystems. River flow regime alterations affect humans with respect to water supply, navigation, hydropower generation and flooding, and they affect ecosystems with respect to habitat suitability for freshwater-dependent biota. Trend existence in the maximum (flood) and minimum (drought) flows in rivers carries significance for different types of water resources problems. Floods and mean flows are considered in the design of flood mitigation structures and water storage reservoirs. Low flows are especially significant for the water quantity released to the downstream of a dam in order to protect the ecological sustainability. The low flow indicators are important for water resources planning and management since severe reductions in these indicators can adversely affect riparian ecology, water quality and water availability. Individual values of these indicators represent severity of hydrological droughts experienced in a year (or season) and are generally used for designing safe water abstractions and waste load allocations in order to protect river water quality and aquatic ecosystems. Glacial melt waters from the Karakoram glaciers dominate the flows of the main Indus [11,12] and thus changes in precipitation and temperature directly affect streamflow discharges. [7,8] show declining river flows from the highest central Karakoram watersheds over the past two decades and suggests that much winter precipitation is going into long-term storage by glacier surges. Recent work has [17] indicated that maximum and mean temperature has warming trends and increased with increased in elevation while the minimum has the reverse situation. Annual precipitation has more decreasing rate in higher mountainous catchments. The impact of altitudinal variability under changing climate yields that Annual stream flows in River Indus (at Kharmong, Alam Br. and Khairabad), Sawat (at Kalam) and Kabul (at Nowshera) have decreased, whereas in River Gilgit, Hunza, Chitral, Shoyk, Shigar and Astore have increased. Some effect of timing and magnitude of flows by climate change in the high elevated areas of the Upper Indus Basin (UIB) has been suggested [29]. The flows are affected due to seasonally varied trends in temperature and initial snowpack conditions by winter precipitation at the beginning of the spring snow melt derived stream flow. Most studies in the UIB (i.e. the Northern part of Indus basin) are focused on high elevated catchments such as in the Chitral, Hunza and Shyok with special emphasis on aspects of glacier melt [1]. In the lower areas, a warm monsoon climate exists with much precipitation in the form of rainfall in the summer season [2]. Therefore the hydrological regime differs from the higher elevated areas but also changes in the climate are dissimilar to changes at high elevated areas [17]. Assessments of the hydrological impacts in the southern slopes of the Himalayas are not frequent although these slope areas cover a major part of the Indus River runoff source area. This aspect is one of the main reasons why we selected Mangla basin with elevation range between 300 m and 6500 m.a.s.l. In this study, we explore hydrological trends and variability in minimum, mean and maximum streamflow for the Mangla watershed resulting from climate variability. The results of this study will also be helpful for decision makers to develop the strategies for planning and development of water resources under different climatic scenarios to overcome their adverse impact. In Sections 2 and 3 we describe the study area and all data available for this study, respectively. Section 4 describes the methodology and statistical analysis performed. Results of this study are presented and discussed in Section 5. In Section 6 conclusions are drawn.

2. STUDY AREA

Mangla basin is located on the southern slope of the Himalayas ranges and situated between latitudes of 33°00′ N - 35°12′ N and longitudes of 73° 07′ E - 75°40′ E. It covers an area of 33,425 km^2 (at Mangla dam) with elevation ranges from 300 m - 6,260 m above mean sea level (a.m.s.l.). The dam serves hydropower generation and regulates the flow from Mangla reservoir. About 55% of the catchment area lies in Indian held Kashmir and remaining 45% lies in Pakistan including Azad Kashmir. Five subbasins: Jhelum, Poonch, Kanshi, Neelum/Kishan Ganga and Kunhar drain water to Mangla reservoir (Fig 1.). The river Jhelum originates from Verinag Spring that is situated in located between Himalaya mountain ranges and Pir Panjal ranges in Jammu and Kashmir. Large tributaries to Jhelum River are Neelum River and Kunhar River that join the main stream at Muzaffarabad and Kohala Bridge, respectively (Fig. 1). The flow of Jhelum River enters Mangla reservoir in the Mirpur district. Flows from Poonch and Kanshi Rivers also enter into Mangla reservoir. The catchment area lies in the active monsoon belt; summers bring heavy rainfall and light showers and snowfall in winters. In winters, precipitation is mostly deposited in the Mangla catchment as snow which is a source of runoff during summer months. The runoff from this precipitation is more than runoff due to rainfall. The major source of rainfall is the monsoon weather system with August/September being the most active months. Mangla catchment has two peak flow conditions; one occurs in June and the other in July-September. The higher June inflow is attributed to the increased-quantity of snow-melt (due to rising temperatures) while the July-September increase is a combination of rainfall and snow-melt.

3. DATA AVAILABILITY

Daily stream flow records (Q_{st}) for 9 gauging stations were collected from Water and Power Development Authority Surface Water Hydrology Project (WAPDA-SWHP) with earliest records dating back to 1960. we selected nine gauges that are Naran and Garhi-Habibullah (now Talhata Bridge) in Kunhar River, Chinari (Now Hattian Bala), Domel, Kohala and Azad Pattan in Jhelum River that cover largest areas in Mangla watershed (Fig 1) in Pakistan, but also in India Streamflow discharges of the relatively small subbasins Neelum, Kanshi and Poonch are measured at Muzaffarabad, Palote and Kotli respectively repetition: already described in study area section. Characteristics of selected gauging sites are given in Table 1. The mean annual runoff at the Azad Pattan station located upstream of Mangla reservoir is 1239 m^3s^{-1}.

The annual runoff for Neelum and Kunhar varies from 47 m^3s^{-1} to 1394 m^3s^{-1} and 19 m^3s^{-1} to 445 m^3s^{-1} respectively before joining the River Jhelum. The annual contribution of Jhelum, Neelum and Kunhar e tributaries to total flow is 45%, 43% and 13% respectively before their confluence at Kohala station. The total mean annual runoff of all four tributaries (Kunhar, Neelum, Pooch and Kanshi) and main River Jhelum drain into Mangla reservoir is 1371 m^3s^{-1} The percentage of flows at dam site is 10%, 34%, 13%, 1% and 41% for River Kunhar, Neelum, Poonch, Kanshi and Jhelum respectively. The monthly distribution of flows (see Fig.2) indicates that the river Kunhar, Neelum and Jhelum (at Azad Pattan) has the peak flows in June whereas other Rivers Kanshi and Poonch record highest flows in August.

The variability in the magnitude of peak discharges and time to generate peak flows (figure 2) suggests differences in climatic and topographic settings. Most prominent are the differences in the hydrographs between the low elevated stations (Palote and Kotli) and high elevated station (Naran) (Figure 2). The low elevated stations have highest mean flow in August whereas the high elevated stations have highest mean flow in June. These differences reflect on the differences between the local climates with the low elevated station affected by monsoon rainfall in summer month June, July, August (JJA) and high elevated stations affected by winter snow and glacier melt in spring months March, April, May (MAM) (Figure 2).

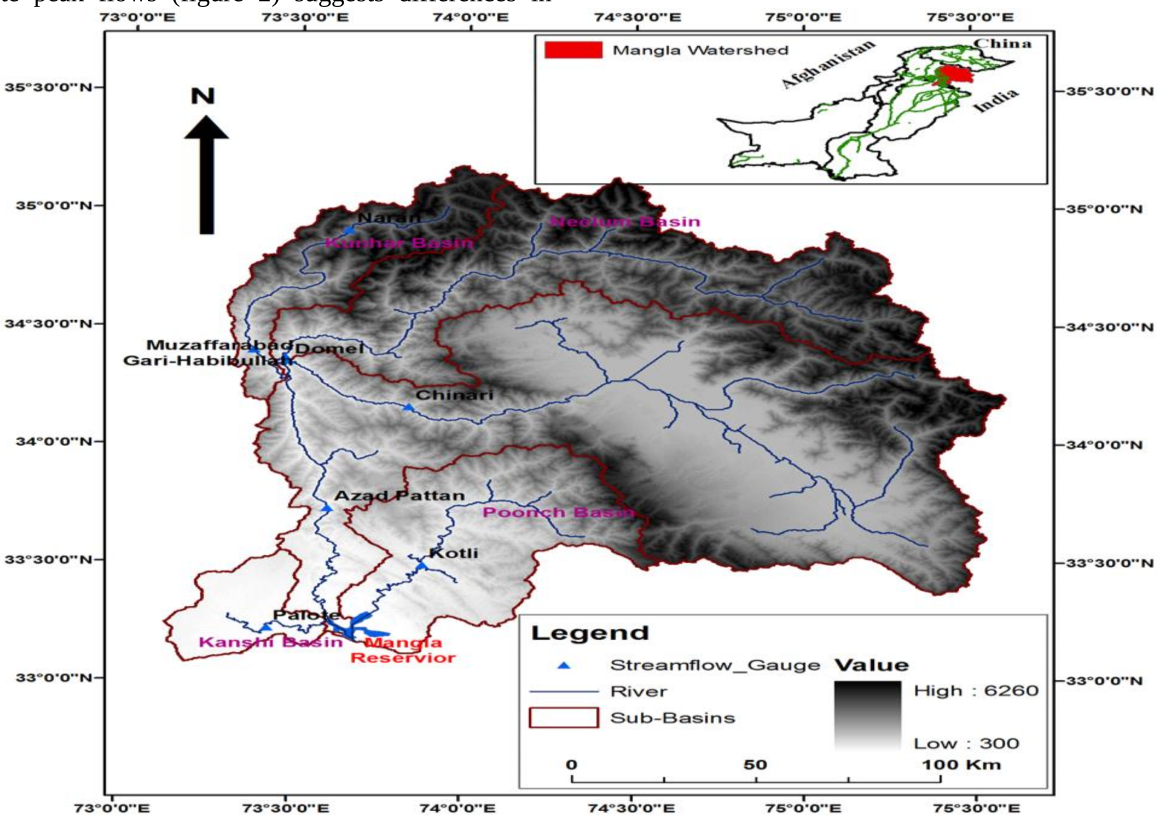

Figure 1: Digital elevation model of Mangla basin showing major subbasins, and streamflow gauges (Table 1).

Table 1. List of stream gauges used in the present study and their characteristics.

Sr. No	Stream Gauges	Lat (dd)	Lon (dd)	River	Area (Km^2)	Mean Annual stream flow (m^3s^{-1})		
						Min.	Mean	Max.
1	Naran	34.9	73.7	Kunhar	1085	6.1	47	233
2	G-Habibullah	34.4	73.4	Kunhar	2379	19	103	445
3	Muzaffarabad	34.4	73.5	Neelum	7412	47	333	1394
4	Chinari	34.2	73.8	Jhelum	13652	51	297	942
5	Domel	34.4	73.5	Jhelum	14396	58	328	1172
6	Kohala	34.1	73.5	Jhelum	24464	145	785	2737
7	Azad Pattan	33.7	73.6	Jhelum	25967	155	1239	3041
8	Kotli	33.5	73.9	Poonch	3210	19	126	1760
9	Palote	33.2	73.4	Kanshi	1078	0.2	5.8	318

The monthly averages of minimum Q_{min}, mean Q_m and maximum Q_{max} streamflows were derived from the daily mean streamflows. The seasonal mean streamflows were calculated by averaging the monthly values. We considered the three month seasons for our analysis: winter (December, January, and February), spring (March, April and May, pre-monsoon), summer (June, July and August, monsoon) and autumn (September, October and November, post-monsoon). Annual mean is the average of January - December monthly means.

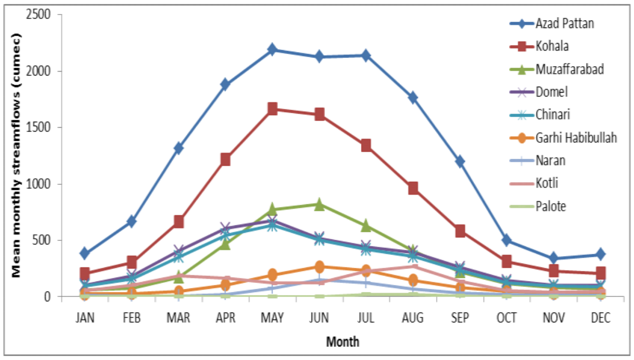

Figure 2: Mean monthly stream flow distribution at different gauges installed in Mangla watershed.

4. METHODOLOGY

4.1 Trend Detection

Trend detection statistically determines if the values of a random variable generally increases or decreases over time [10]. Parametric or Non-parametric statistical tests are used to assess significance of trends.

The trend analysis was carried out for the time series of the regional annual and seasonal temperature, precipitation and streamflow. These steps essentially involve: (i) testing the serial correlation effect; (ii) Trend detection by Mann–Kendall test (iii) Estimate the trend value (changes in time series variables) by Sen's estimator.

4.1.1 Serial correlation effect

For time series analysis, it is essential to consider serial correlation, defined as the correlation of a variable with itself over successive time intervals, prior to testing for trends [32,35]. The existence of positive serial correlation will increase the possibility of rejecting the null hypothesis of no trend, while the null hypothesis is true [18]. Von Storch and Navarra [32] advocated that the time series should be 'pre-whitened' to eliminate the effect of serial correlation before applying the Mann–Kendall test or any trend detection test. In [35] authors showed that removal of serial correlation by pre-whitening can effectively remove the serial correlation and eliminate the influence of the serial correlation on the MK test test. [34] modified the pre-whitening method as the trend-free pre-whitening (TFPW) to the series in which there was a significant serial correlation. Studies (e.g.,[,3, ,19,21,22,34,35] showed successful application of TFPW method to detect trends in hydrological and meteorological parameters. This study incorporates these suggestions, and thus possible statistically significant trends in variables observation (x_1, x_2. . . x_n) are examined using the following procedures:

1. For a given T, P and Q time series of interest it is better to use actual word like temperature rather than of interest, the slope of the trend (β) is estimated by using the Sen's method. Then the time series is de-trended by assuming a linear trend as:

$$Y_i = x_i - (\beta \times i) \qquad (1)$$

2. Where Y_i is the de-trended time series value at time interval i, x is the original time series value at time interval I and β is the estimated slope of time series. Compute the lag-1 serial correlation coefficient (r_1).
3. If r_1 is not significant at the 5% level, then the statistical tests are applied to original values of the time series. If the calculated r_1 is significant, prior to application tests, then the fine pre-whitened) $\overline{Y_i}$ time series for time interval I are obtained as:

$$\overline{Y_i} = Y_i - rY_{1-i} + (\beta \times i) \qquad (2)$$

4.1.2 Mann Kendall test

Mann Kendall statistical test is widely used to detect time series trends in climatological [31], [20], [5], [25], and in hydrological parameters [37]. It is a non-parametric test and does not require data to be normally distributed. Also, the test has low sensitivity to abrupt breaks due to inhomogeneous time series [30]. This test has found to be an excellent tool for trend detection.

The number of annual values of the data series is denoted by *n*. The differences of annual values *x* were determined to compute the Mann-Kendall statistics. The Mann-Kendall statistic(S)is computed using equation3:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \qquad (3)$$

Where *sgn* $(x_j - x_k)$ is an indicator function that takes on the values 1, 0 or -1 according to sign of difference (x_j - x_k), where $j > k$:

$$sgn(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \qquad (4)$$

The values x_j and x_k are the annual values in the year j and k respectively.

The variance *S* is computed by the following equation:

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

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

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

$$Z = \begin{cases} \frac{S-1}{[VAR(S)]^{1/2}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{[VAR(S)]^{1/2}} & if\ S < 0 \end{cases} \qquad (6)$$

The trend is evaluated using *Z* values. A positive value of *Z* indicates an upward (warming) trend while negative value shows downward trend (cooling trend). The statistics *Z* has a normal distribution. For this study, the significance of trends are evaluated with $\alpha \leq 0.1$.

4.1.3 Sen's estimator of slope

We followed non-parametric procedure developed by [28] to evaluate linear trend in time series. If xj and xk represents observations at time instants *j* and *k respectively,* then the slope (change per unit time) (Q) can be estimated by using equation (7) as follows:

$$Q_i = \frac{x_j - x_k}{j-k} \qquad \text{If } j > k \qquad (7)$$

Sen's estimator is the median of the N pairs of Q_i. In the procedure N values of Q_i were ranked from smallest to largest and the Sen's estimator reads:

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

Q_{med} is further evaluated by a two-sided test at the 100(1-α) % confidence interval and the true slope is obtained by the non-parametric test. Data is processed using an Excel macro named MAKESENS created by [27].

5 RESULTS AND DISCUSSION

The variability analysis and changes in streamflow for stream gauges installed in Mangla basin, Pakistan were evaluated for the period 1971-2010. The analysis was performed on annual and seasonal (three months) time series. The numbers of stations with increasing and decreasing trends as well as significant trends for annual and seasonal time series are shown in Figures (3f, 4f & 5f). To examine the spatial consistency of the observed trends, maps were created displaying the locations of stream gauges in all four subbasins (Kunhar, Neelum, Kanshi and Poonch) with decreasing and increasing trends. The spatial distribution of trends and changes in annual and seasonal minimum, mean and maximum streamflow are shown in Figures 3, 4 and 5 respectively. The coefficient of variation (CV) is also estimated for these variables at the outlet of all basins and is given in Table 3.

5.1 Variability in Minimum (Low) Flows

The range of the statistics for the annual minimum flows of the selected stations is presented in Table 2. The mean annual minimum flow varies from 0.3 to 155 cumecs. The CV varies from 1.1 - 20whereas the skewness has a minimum and maximum values of –2.1 and2.6 respectively. The annual minimum flows have decreasing trends at 67% of stations. MK and Sen's slope estimator depicts that minimum flow has decreased significantly ($p<0.01$) in Neelum basin at Muzaffarabad upto 9% of mean annual low (46 cumec) for period 1971-2010 and has also decreased 4% in Jhelum basin at Azad Pattan but non-significant. The Kanshi basin has significant increasing flow with the rate of 39%, whereas the Poonch and Kunhar basin at Gari-Habibullah have also non-significant increasing trend with 3% and 13% respectively. The highest decreasing trend was found at Naran in Kunhar basin with 67% per decade of mean annual minimum flow.

Winter season has the lowest minimum flow as compared to other seasons. Minimum flow in this season has increased at 5 stations (out of 9) in Jhelum basin. Streamflow in Poonch and Kunhar at Gari-Habibullah, and Neelum and Jhelum at Azad Pattan Rivers have significantly ($p<0.05$) increased upto 15%, 11%, 1% and 2% of mean winter minimum flow respectively. Chinari has significant ($p=0.1$) decreasing trend. Similar trend was observed for flows in spring and winter season. Neelum and Kunhar basin have significant decreasing trends whereas Jhelum and Kanshi Rivers have non-significant decreasing trends. Poonch basin has the increasing trend (non-significant). The minimum flow in summer has significant ($p<0.05$) decreasing trend at outlets of Poonch basins and also in Jhelum and Neelum basins have non-significant decreasing trends. Kanshi and Kunhar at Naran have significant increasing trends. In autumn season only two stations have significant decreasing trends. (8)

5.2 Variability in Mean Flows

Trend analysis with the MK test showed trend existence in mean annual flow at 4 stations (see Fig. 4). The mean flow have more decreasing trends. The decreasing trends in annual mean flows were found at 78 % (33% significant) of stations. The annual mean flow in Jhelum basin at Azad Pattan has increasing trend with rate of 0.2 mm/year (1% of data period mean). Jhelum River at Kohala has significant ($p=0.1$) decreasing trend with the rate of 7%. The other three tributaries (Neelum, Kanshi and Poonch) of this basin have negative trends (changes in flow are given in Fig.4) whereas forth tributary Kunhar has the only significant positive trend at Gari-Habibullah.

Winter mean flow at all rivers has increasing trends. The significant increasing trends were found in River Neelum, Kanshi and Jhelum at Kohala with the rate of 11%, 1% and 22% per decade of mean winter flow. Kunhar River at Naran has significant trend with the rate of 27% and Jhelum River at Chinari and Domel has also increasing non-significant trend. The mean flow for spring months has only significant increasing trends were found in Jhelum River at Azad Pattan and Kohala whereas significant decreasing trend was found in Kunhar River at Naran. Neelum, Kanshi and Poonch rivers have the non-significant decreasing trends. All stream gauges have the decreasing trends in summer season and 56% of stations have the significant trends. The significant trends were found in Rivers Neelum, Poonch, Kanshi and Jhelum (at Azad Pattan and Domel). The changes in flows are shown in Fig.4. 72% of stations have the decreasing trends whereas only 22% (2 stations) have the significant trends. The decreasing trends were found in rivers Jhelum (at Azad Pattan) and Neelum with the rate of 22% and 14% per decade. Only the Kunhar River has the significant increasing trend at both stream gauges (Gari-Habibullah and Naran) with the rate of 8% and 9% per decade.

5.3 Variability in Maximum Flows

The variation intervals of the statistics for the annual maximum flows of these stations are presented in Table 3. The mean annual maximum varies from 233 to 3041 m/s^3. The coefficient of variation, CV, changes between 0.33 and 0.87 whereas the skewness has a minimum 0.7 and a maximum 4. The decreasing trends in annual maximum flows were found at 56 % (11% significant). The annual maximum flows in main Jhelum River have increasing (non-significant) trends at all stream gauges whereas the flows in all subbasins have the decreasing trends.

Table 2: The range of statistical parameters for annual time series.

Variables	Mean (cumec)	Standard Deviation (SD)	Coefficient of variation (CV) %	Kurtosis	Skewness
Minimum Flow	0.0.155	0.3.35	20…89	-1.0…8.9	-0.5…2.5
Mean Flow	6.1231	3.341	19…49	-0.9…1.9	-0.5…0.9
Maximum Flow	233….3041	75…1776	0.33…0.87	0.1….19	0.7…4.0

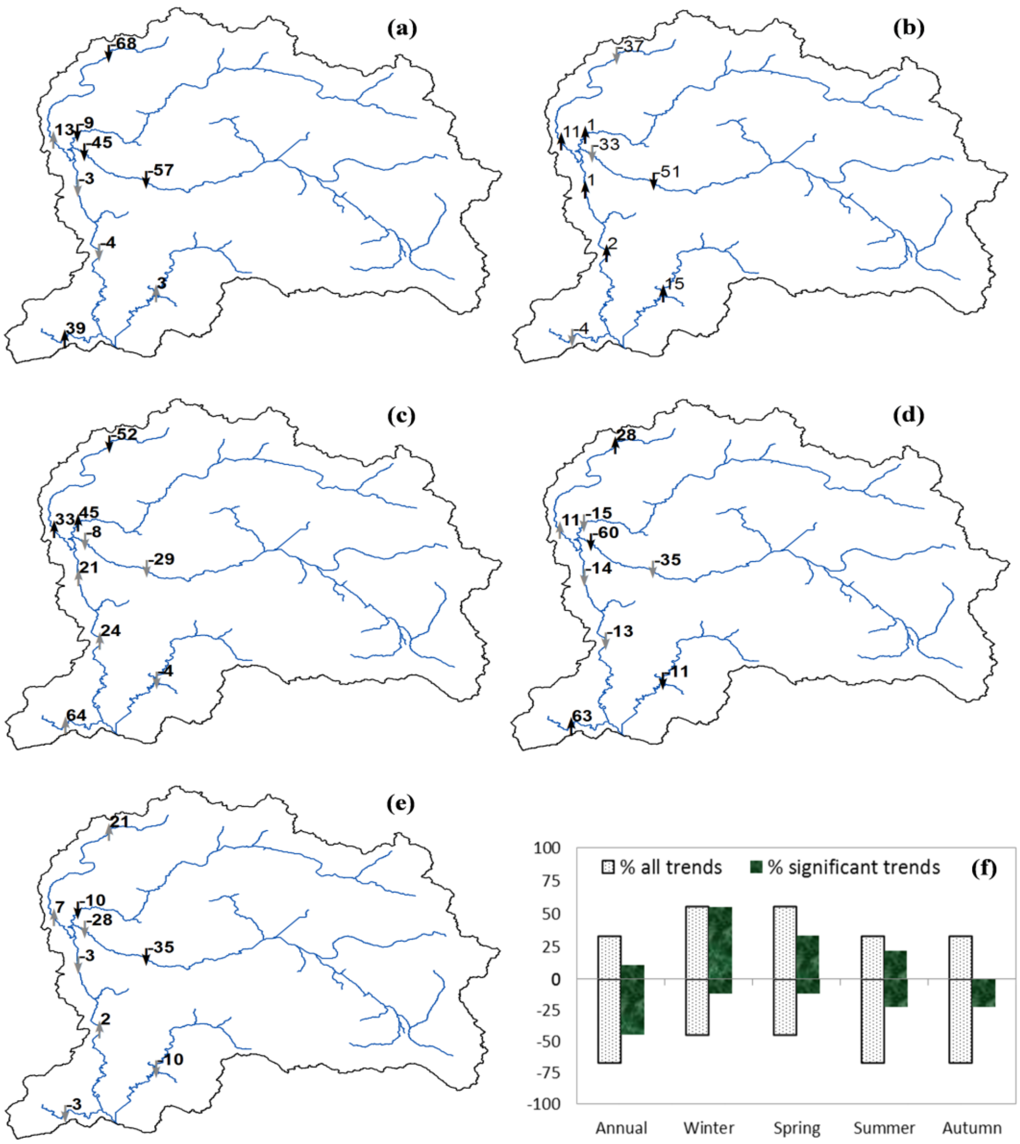

Figure 3: Spatial distribution of trends detected by Mann-Kendal and trend values estimated by Sen's method showing change in % decade^{-1} of minimum streamflows in: (a) annual, (b) winter, (c) spring, (d)

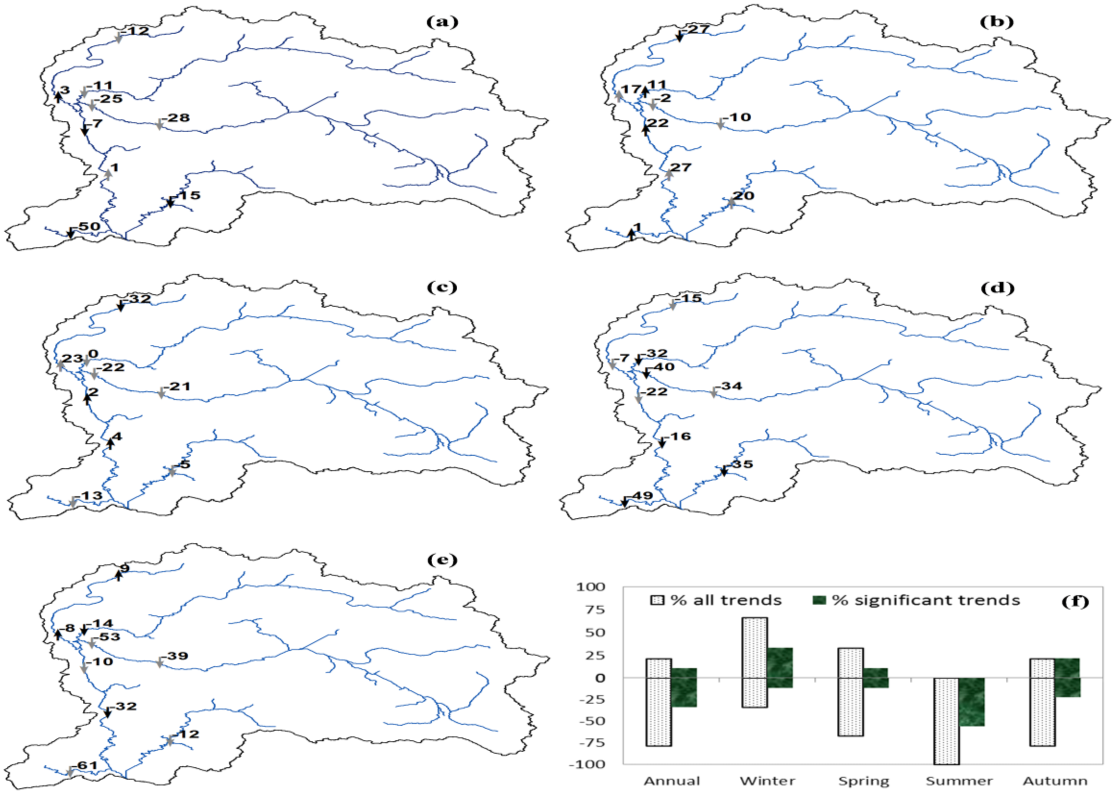

Figure 4: As Figure 3 but for mean stream flow.

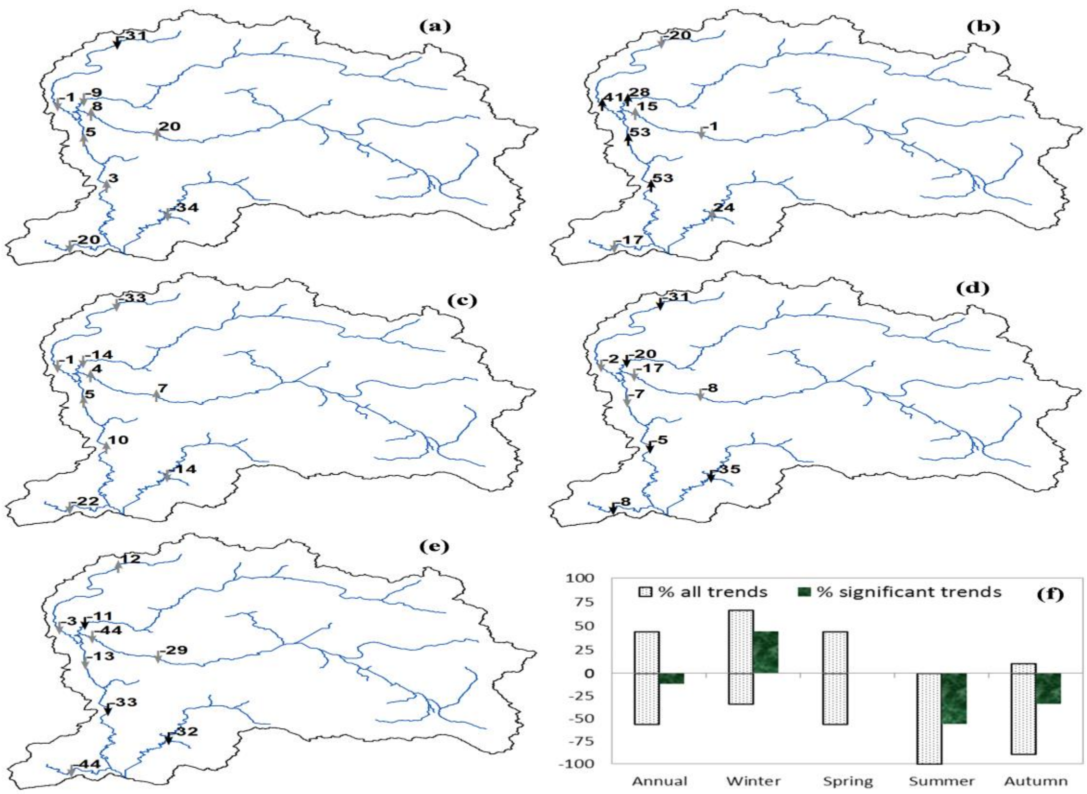

Figure 5: As Figure 3 but for maximum stream flow.

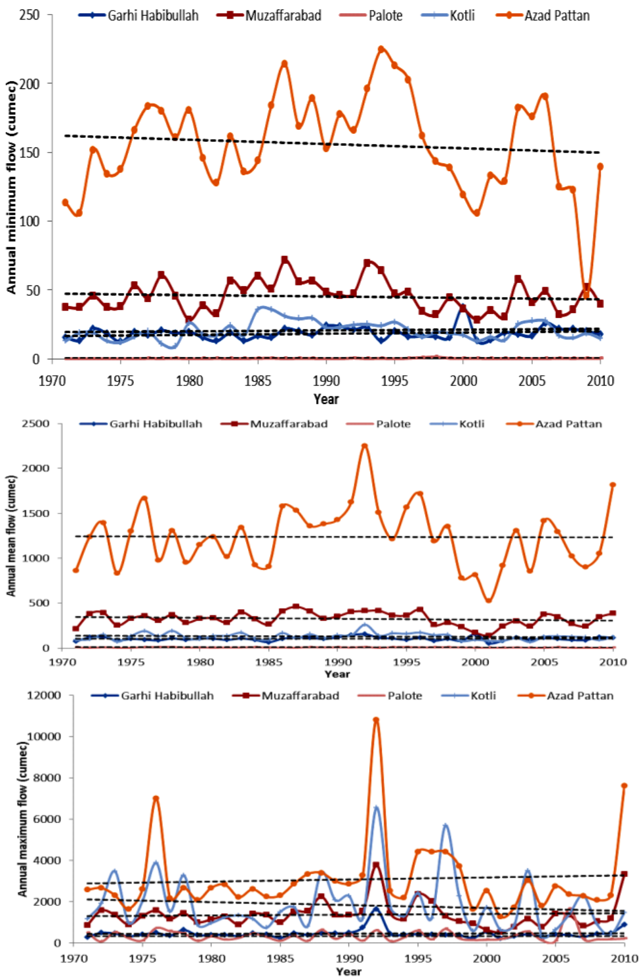

Figure 6: Time series of annual minimum, mean and maximum flows (in cumec) at outlet of basins (, Kunhar, Neelum, Kanshi, Poonch and Jhelum).

Winter season showed statistically significant changes at 4 stations (4 increases and 0 decreases). Fig. 5b presents the stations where and how much significant change (at the level of 10%) have been observed. Summer and autumn maximum flow has decreased (increased) significantly at 9 (5) and 8(3) stations. The summer season has the maximum discharge values as compared to other seasons. The mean maximum flow in summer season (JJA) varies from 228 to 2666 cumec whereas maximum of summer maximum flow varies from 448 to 7622 cumec. All stream gauges have the decreasing trends and 56% of stations have the significant (see Fig.5d). The flow in Hunza river a predominated glaciated catchment has also significant trend ($p<0.001$) and has decreased upto 31% of mean maximum flow (228 cumec). A significant decrease was observed in Kunhar, Neelum, Poonch and Jhelum (at Azad Pattan) rivers. In autumn season the mean maximum flow varies from 54 to 1220 cumec. This season has also more decreasing trend as summer season. The decreasing trend were observed at 89% of station but 33% have the significant trends for the period 1971-2010. The significant trend was found in Poonch, Neelum and Jhelum (at Azad Pattan) rivers. The changes in flows detected from Sen'method over the different period are shown in Fig.5e.

6. CONCLUSIONS

The present study analyses the investigation of annual and seasonal maximum, minimum and mean streamflow in Mangla basin and its sub-basins (Kanshi, Poonch, Kunhar and Neelum) for period (1971-2010) by Mann Kendall tests in time series of temperature for Mangla catchment and its sub-basins (Kanshi, Poonch, Kunhar and Neelum). The following specific conclusions from this study are:

- The annual minimum flow in main Jhelum River (at Azad Pattan) has decreased where mean and maximum flow has increased but non-significantly.
- The annual mean and maximum flows in all subbasins have decreasing trends (except only in Kunhar for mean flow) whereas minimum flow has increasing trend except in Kunhar basin.
- The winter minimum, mean and maximum streamflows in main basin and subbasins have increased (except only in Kanshi for mean and maximum flow) whereas have decreased for the summer season.
- In spring, minimum and mean flows have increasing and decreasing trends for high elevated basins and low elevated basins respectively.
- The maximum flow for the spring, summer and autumn seasons has decreasing trend in all basins.

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