Research Article

Comparative Study of Temperature Change Effects on Precipitation for Upper Indus Basin Pakistan

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Abstract: Global warming and abrupt seasonal changes are the current challenging issues across the globe. Precipitation and temperature are two most important climatic factors. Both these climatic parameters seriously affect the water demand and strategies to assure its availability. Pakistan is an agricultural country and its economy, food security and prosperity lies in the best water management of water resources. These facts prompt us to study the changing temperature and precipitation relationship in Upper Indus Basin, UIB (hub of Pakistan water supply). Five substations of UIB (Drosh, Gilgit, Astore, Gupiz and Skardu) were selected for study, mean monthly precipitation and temperature data were collected for a period of (1980 to 2014) from Pakistan Meteorological Department (PMD). A non-parametric Mann-Kendall test with a 5% significance level was used for trend analysis. Study revealed the fact that except substation Astore all other substations' precipitation trend is reciprocating temperature trend. Strangely for substation Astore the precipitation trend imitates the temperature trend. It was also found that temperature is changing in three of the four seasons on an annual basis during the study period and there is a variation in the precipitation and Temperature trend patterns among the five selected sub-basins of the UIB depending upon the location of these basins. From the results, longer summer and shorter winter are expected in the future due to rising temperatures.

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Introduction

The climatic parameters are in a transition period after they got disturbed through a series of anthropogenic activities like deforestation, industrialization, urbanization, war, pollution etc. How can the world sustain its balance if rapid deforestation keeps depleting rainforest which is 7% (Prasad, 2016) of the world's total area and its importance can be imagined from the fact that only the rainforest of amazon pumps 7 trillion tons (Prasad, 2016) of water in a year into the atmosphere. Unfortunately, these activities that are still in full swing have accumulated Green House Gases (GHGs) in general but CO_2 in particular resulting in augmentation in temperature at a global level. Over one century i.e. from 1901 to 2012, the overall earth temperature has been increased up to 0.89°C (Khan et al., 2015).

The increase in global warming/temperature is going to affect the hydrological cycle of the earth and disturb the average availability of water of hydrological systems by increasing the frequency and intensity of precipitation causing heavy rain (Mahmood et al., 2016). Temperature change has badly affected the spatial, temporal and seasonal distribution of precipitation, research in Malaysia under the name “Recent trends in Malaysia” concluded, that the rate of increase in the seasonal precipitation is lower as compared to the annual precipitation (Amirabadizadeh et al., 2015).

Among the world’s most important hydrological systems Indus basin is on the top of the list (Shrestha et al., 2015; Prasad, 2016; Lutz et al., 2016; Abbasi et al., 2017) due to the following reasons:

1. Serving largest population as compared to other hydrological systems
2. Home to the world’s largest glaciers
3. Home to highest peaks of the world

The Catchment area of the Indus basin is almost 1.1 million square kilometres (Prasad, 2016) and is shared by many countries such as India, Afghanistan, China and Pakistan. UIB is spread over Hindukush, Himalayas and Karakoram ranges comprising an area of 289,000 km^2 (Prasad, 2016). Through several large dams, the Indus basin serves as the largest irrigation system in the world (Lutz et al., 2016). At the downstream of the Indus Basin, the weather is dry which increases the load over the upper part of the basin which is well rich in water resources (Lutz et al., 2016). It is evident form the various studies performed on the Indus Basin in Pakistan that the temperature has significantly increased while there is a decrease in precipitation in the region (Mahmood and Jia, 2017; Shahid and Rahman, 2020).

In UIB the spring is warming, causing early glacier melt thus increasing discharge in the region. Contrastingly the cooling is observed during early autumn on the long term basis and demonstrates the characteristics of the area that overall summer is getting longer, proceeding towards spring while the winter is getting shorter but starting a bit earlier (Hasson et al., 2017).

In a study published in 2013, it is reported that the trends in precipitation and temperature for 4 substations of the Upper Indus Basin were analysed using the data from 1980-2010 and it was found that overall both the summer and winter seasons are getting extreme. Further, the Gilgit and Bunji stations are demonstrating that both the seasons are less prevalent and clearly accessed. Precipitation increases over the Chitral-Hindukush and Northwest Karakoram while it decreases over the Himalayas as reported by the above-mentioned study (Winston et al., 2013).

Pakistan agriculture is dependent on the melting of snow and glaciers of the Himalaya-Karakoram-Hindukush (HKH) ranges. Since Pakistan’s population is mainly dependent on agriculture, therefore, almost 76 % of its population live in rural areas of the country and any changes in the pattern of melting of glaciers/snow due to global warming may adversely affect the food security as well as the economy of Pakistan.

Because climate change is observed in the UIB region, therefore, Mann Kendall test (a non-parametric approach) is applied to the temporal data to analyse the current trend in temperature and precipitation and to compare their results.

Study area

The catchment area of the UIB is almost 289000 sq.km and it spreads over the Hindu-Kush-Himalaya (HKH) and Karakoram ranges (Figure 1) Indus basin is among the highly ranked in human dependency either directly or indirectly. Various departments like Agriculture, Industries, Domestic and energy production for people living in the region are dependent on the UIB which makes it a prevalent basin. The main sources of flow in the Indus River are seasonal precipitation and the Glaciers/Snow. These watersheds have unique hydrological regimes and these are linked with the main source i.e. glaciers/snow of the meltwater generation.

Hydro-meteorological networks established by Pakistan Water and Power Development Authority (WAPDA) in the 1960s for monitoring the Upper Indus Basin Cryosphere, through its Surface Water Hydrology Project are demonstrated in Figure 2.

Mean monthly and annual records of temperatures (T) and precipitation (P) are collected from the Pakistan Meteorological Department (PMD). Details of the selected meteorological stations in the relevant sub-basin are given in Table 1. The time series of T and P, from 1985 to 2014 have been used in this study.

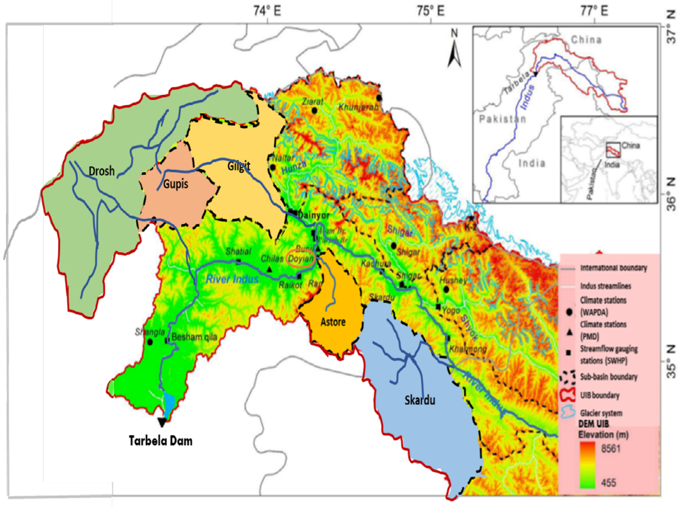

Figure 1: *Study sub basins is study area.*

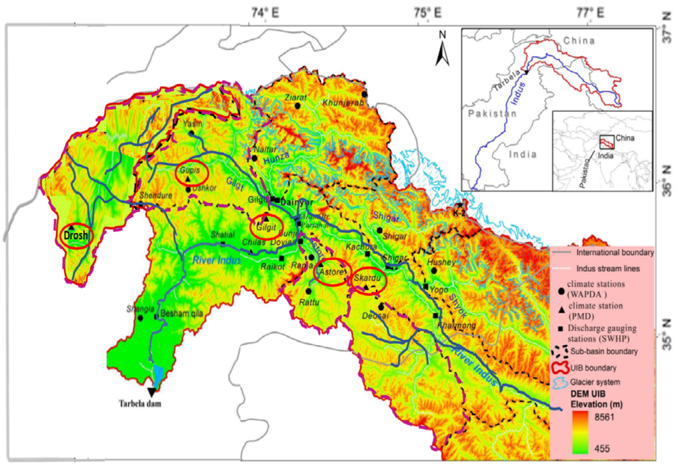

Figure 2: *Climatic stations in Upper Indus Basin.*

Literature review

The Fifth Assessment Report of the Intergovernmental Panel (IPCC-AR5) on climate change suggested an increase of 0.85°C in the global average temperature for a period from 1800 to 2012 as compared to the period from 1961 to 1990 (Mahmood et al., 2016). In a case study conducted at meteorological stations in Kentucky State USA, long-term precipitation and temperature trend analysis showed fewer significant trends (Chattopadhyay and Edwards, 2016) while the studies on the Greater Himalaya showed a warming trend (Chand et al., 2019; Dahal et al., 2019; Zaz et al., 2019). A study (Amirabadizadeh et al., 2015) reveals that the rate of increase in the annual precipitation is higher than the seasonal precipitation (Lutz et al., 2016).

Table 1: *Data of the climate stations in the Upper Indus Basin.*

ID	Station name	Lat (°N)	Long (°E)	Elevation (m a.s.l.)
1.	Astore	35.33	74.90	2394
2.	Gupis	36.01	73.40	2156
3.	Drosh	35.56	71.78	1465
4.	Skardu	35.30	75.68	2210
5.	Gilgit	35.91	74.33	1460

It was assessed in a study conducted by Bocchiola and Diolaiuti in 2012 that winter is warming and summer is cooling for Bunji and Gilgit stations and are no more prevalent from 1980 to 2009 (Khan et al., 2015). Sixteen stations of the Upper Indus Basin (UIB) were investigated by using the Mann-Kendall test and the Sen's Slope method. The results showed a sudden increase of mean and annual maximum temperature for a period from 1961 to 2011 (Mahmood et al., 2016).

The research of (Mahmood et al., 2016), concluded that an increase in the floods and droughts season in the future is possible in Kunhar River catchment because of the forecast increase and decrease in high and low flows, respectively (Nam et al., 2016). The study of (Nam et al., 2015, 2017) showed whether under the climate change and at different time scales, the spatial and temporal trends in maximum and minimum temperature and precipitation observed statistically insignificant changes or not. It was assumed in this study that global warming/climate change has significantly affected the meteorological elements, particular locations and urban areas.

A study was performed in northern India, to assess the impact of El Niño Southern Oscillation (ENSO) on temperature, precipitation, and potential evapotranspiration (PET) pattern change during the monsoon season through the last century. The results showed that in the number of the districts a considerable negative trends/change in temperature and PET have been observed while both positive and negative trends/change were observed in precipitation based on the location of the districts (Tamaddun et al., 2019).

Materials and Methods

A trend is a pattern in data that shows movement of a series or the rate at which the values of a parameter changes over a time period. In statistics, a change i.e.

increase, decrease in the values of the parameters is known as a trend.

Trend analysis methods

The two non-parametric trend tests that are extensively used for trend detection are the Mann Kendall test and Sen's Slope test. The test used for this study is described here.

Mann kendall test

A non-parametric test for which the data required is not normally distributed is known as the Mann-Kendall test. Because of the inhomogeneous time series, this test has a very low sensitivity to abrupt breaks. This test is used in situations when various stations are required to be studied at once.

Computational procedure: This test assumes a null hypothesis H_0 which indicates no trend and this is tested against an alternative hypothesis H_1 which indicates a trend.

Mann kendall test statistics(S): The Mann–Kendall Statistic S is given as (Kendall, 1975; Mann, 1945).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(x_j - x_i) \quad \ldots(1)$$

Where x_i represents the time series; i is the rank of time series from *1, 2,………, n,* and x_j is the data points ranked from *j= i+1, i+2, i+3,…., n*. Each of the data points x_i is taken as a reference point which is compared to the rest of the data points, x_j so that:

$$Sgn(x_j - x_i) = \begin{Bmatrix} +1,)(x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, ((x_j - x_i) \end{Bmatrix} \begin{matrix} \text{trend increasing} \\ \text{no trend} \\ \text{trend decreasing} \end{matrix}$$

Where x_i and x_j are the annual values in years.

Tied group (t_i): The data measurement values that are repeated in a single data set are called as a tied group (t_i). The summation term in the numerator is used only if the data series contain tied values.

The variance is given as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2_i+5)}{18} \quad \ldots(2)$$

Where t_i denotes the number of ties to an extent *i*.

Mann kendall test statistic (Z_c): The test statistics Z_c is computed as follows;

$$Z_c = \begin{Bmatrix} \frac{S-1}{\sqrt{Var(S)}} \\ 0, S=0 \\ \frac{S+1}{\sqrt{Var(S)}}, S\langle 0 \end{Bmatrix} \quad \ldots(3)$$

The significance of the trend is best explained by the Mann-Kendall test statistics (Z_c). For a certain significance level, it only takes the values having significant trend. Indeed, this test statistic is used to test the null hypothesis, H_0. If Z_c is greater than $Z_{\alpha/2}$ where α (alpha) represents the chosen significance level (e.g. 5% (0.05) with $Z_{0.025}$ = ±1.96) then the null hypothesis is invalid implying that the trend is significant.

Significance level: The rigidity of our results is shown by the Significance level (α). A value of α= 5% (0.05) shows that there is a 5% probability of a trend existence or there exists a 5% probability of making mistake while rejecting H_0.

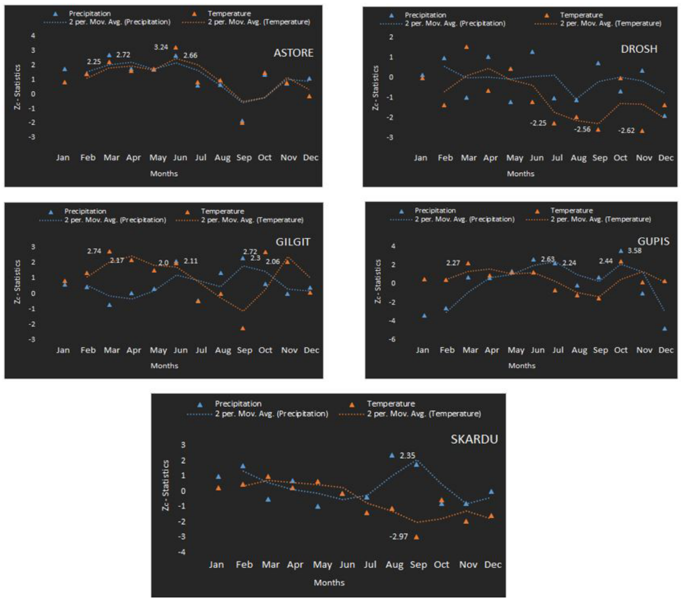

Figure 3: *Overall moving average trend of the five selected sub-basins of UIB, Pakistan.*

Results and Discussion

The trends analysis were performed using Mann-Kendall Test and the results obtained are shown in Table 2 and are graphically presented too in Figure 3 by plotting overall moving average trend line along with the significant trends. The summary statistics for temperature and precipitation time series data (1985-2014) are given in Tables 3 and 4, respectively. Overall, mostly positive significant trends have been observed in precipitation for all the five selected sub-basins of UIB except Gupis in January and February while the temperature significant increasing trends are observed in Astore, Gilgit and Gupis and decreasing significant decreasing trends in Drosh and Skardu. The Astore and Gilgit also showed negative significant trend in September.

For comparative analysis of Temperature versus Precipitation, in Astore sub-basin, the Precipitation trend paths are almost imitating the trend lines of temperature except in December, it means both parameters are changing but in the same pattern, an upsurge of temperature will increase precipitation and vice versa.

Unlike the Astore substation, Drosh substation, exhibits a different scenario. The precipitation trend lines are almost reciprocating the temperature trend pattern expect July, August and December, where the precipitation is decreasing with a decrease in temperature. As a whole, the results reveal the fact that precipitation will increase with a decrease in temperature and similarly any increase in temperature will decrease the precipitation and cause dry weather conditions in Drosh. The sub-basin Gilgit not only shares its boundaries with Drosh but also the same impacts of changing climate prevails here, where the trend patterns of the two parameters are not identical except in Jun

Table 2: *Mean monthly precipitation (P) and temperature (T) trend analysis (Zc- Statistic) results.*

Stations months	Astore		Drosh		Gilgit		Gupis		Skardu	
	P	T	P	T	P	T	P	T	P	T
Jan	1.75	0.85	0.14	0.00	0.60	0.82	-3.39*	0.54	0.98	0.25
Feb	1.38	1.42	0.98	-1.36	0.43	1.34	-2.59*	0.47	1.69	0.49
Mar	2.72*	2.25*	-0.98	1.55	-0.71	2.74*	0.73	2.27	-0.49	0.99
Apr	1.73	1.63	1.04	-0.64	0.02	2.17*	0.63	0.89	0.72	0.23
May	1.71	1.73	-1.19	0.45	0.32	1.49	1.38	1.22	-0.98	0.64
Jun	2.66*	3.24*	1.30	-1.20	2.11*	2.00*	2.63*	1.22	-0.11	-0.12
Jul	0.62	0.82	-1.02	-2.25*	-0.44	-0.49	2.24*	-0.64	-0.35	-1.4
Aug	0.64	0.97	-1.10	-1.96	1.33	0.00	-0.17	-1.2	2.35*	-1.09
Sep	-1.85	-1.98*	0.75	-2.56*	2.30*	-2.23*	0.70	-1.53	1.76	-2.97*
Oct	1.36	1.48	-0.66	0.00	0.63	2.72*	3.58*	2.44*	-0.8	-0.56
Nov	0.74	0.81	0.37	-2.62*	0.00	2.06*	-0.97	0.21	-0.79	-1.96
Dec	1.09	-0.14	-1.89	-1.36	0.39	0.08	-4.80*	0.29	0.03	-1.57

** Significant trends are bolted (with critical value at α = 0.05, ±1.96).*

Table 3: *Summary statistics for temperature time series data (1985-2014).*

Station	Statistics/ Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Astore	Mean	-2.34	-0.24	4.33	9.57	13.99	17.68	20.62	20.40	16.76	11.12	5.89	0.79
	Median	-2.28	-0.38	4.20	9.18	14.30	17.73	20.70	20.58	16.80	10.98	5.90	1.00
	Standard deviation	1.81	1.69	1.62	1.50	1.91	1.41	1.36	0.99	0.99	1.17	1.08	1.52
Drosh	Mean	4.68	6.19	10.91	16.84	22.88	27.63	29.77	28.75	25.31	18.95	12.70	7.27
	Median	4.77	6.03	11.20	16.58	22.42	27.85	29.68	28.94	25.25	19.13	12.83	7.41
	Standard deviation	1.97	2.05	2.11	1.60	2.91	1.46	1.24	1.42	1.63	1.83	1.69	1.90
Gilgit	Mean	3.72	6.97	12.24	16.81	20.63	24.27	26.82	25.96	21.99	16.03	9.74	5.14
	Median	3.53	6.90	12.00	16.85	20.88	24.05	27.10	25.98	22.03	15.88	9.60	5.20
	Standard deviation	1.13	1.19	1.36	1.09	1.92	1.21	1.43	1.10	0.96	0.94	0.82	0.99
Gupis	Mean	-0.76	1.68	7.13	10.97	17.23	21.31	24.28	23.12	19.37	13.17	7.51	1.59
	Median	-1.00	1.75	6.55	12.90	17.10	20.90	24.18	23.00	19.13	13.15	7.38	1.68
	Standard deviation	1.38	1.70	1.92	9.87	2.37	1.69	1.58	1.37	1.28	1.36	0.89	1.06
Skardu	Mean	-2.46	1.49	7.42	12.93	16.86	20.83	23.89	23.28	19.31	12.29	6.06	1.07
	Median	-2.70	1.63	7.30	12.98	17.10	20.65	23.75	22.98	19.18	12.25	5.93	0.65
	Standard deviation	2.59	1.80	1.29	1.24	1.68	1.37	1.49	1.16	1.28	0.97	1.03	1.44

Table 4: *Summary statistics for precipitation time series data (1985-2014).*

Station	Statistics/ Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Astore	Mean	43.56	50.29	69.10	79.49	63.13	27.11	26.98	25.51	26.98	19.55	18.38	34.04
	Median	32.95	50.45	60.40	67.35	45.00	21.90	22.55	23.10	13.15	13.30	8.90	16.50
	Standard deviation	41.08	31.85	45.62	49.82	53.84	20.43	18.31	19.69	36.54	31.07	26.84	43.96
Drosh	Mean	47.57	78.78	108.84	99.57	58.14	23.71	19.62	20.09	19.92	36.19	30.58	36.20
	Median	37.45	70.35	107.02	105.85	59.05	18.35	13.85	15.05	18.40	21.80	24.80	21.85
	Standard deviation	43.96	46.66	55.47	53.24	34.37	21.40	20.29	18.52	17.78	47.81	26.13	39.45
Gilgit	Mean	4.15	7.76	11.25	22.30	25.13	12.20	15.32	17.34	11.58	6.99	3.37	0.00
	Median	1.20	5.10	8.60	14.25	15.95	9.55	12.60	11.20	7.70	1.85	0.25	1.20
	Standard deviation	7.17	9.95	10.03	21.23	25.81	9.99	12.59	19.75	14.16	18.96	6.39	0.00
Gupis	Mean	9.70	17.36	20.97	50.04	32.30	23.54	20.17	31.84	16.50	11.31	2.65	2.59
	Median	4.25	7.60	17.00	17.80	17.85	14.00	15.90	25.25	6.35	4.65	0.00	1.80
	Standard deviation	12.73	30.73	19.02	85.58	33.98	31.68	19.70	31.94	25.27	19.65	5.91	22.34
Skardu	Mean	34.93	33.68	36.94	34.22	25.50	9.39	10.60	14.29	15.64	6.63	6.08	19.99
	Median	29.25	29.40	26.05	21.80	8.15	5.80	7.95	12.45	5.60	1.90	0.80	11.10
	Standard deviation	32.27	24.67	28.03	37.51	30.54	9.22	10.40	12.66	26.98	20.74	14.13	24.10

when the precipitation and temperature have the positive significant trends. Overall the precipitation trend pattern is opposite of the temperature trend pattern, the precipitation is decreasing with increase in temperature except August, September and October, where it is increasing with the decrease in temperature and this relationship between the key climatic factors will seriously affect the dependents of this region.

The Gupis substation shows somewhat conservative results for temperature although exhibiting some +ve trends, while precipitation has been badly affected by the world's changing climate. Studies reveal the delicate dependence of precipitation on temperature, a minor temperature change is causing a huge change in precipitation. The overall average trend pattern for precipitation is decreasing while for temperature, increasing. The study also revealed that climate is in a transition period at Skardu substation, a +ive significant trend is detected for precipitation in August and a -ive significant trend for temperature in the month of September. The trend patterns for temperature and precipitation are changing throughout the year but almost reciprocating each other, depicting extreme weather conditions.

The variation in the results among the five selected sub-basins can be due to difference in the elevation (m.a.s.l) of these basins given in table 1, like Astore, Gupis and Skardu are at much higher elevations than Gilgit and Drosh. These results are alarming for Pakistan because it is certain that climate is changing and can accelerating the extreme events. Pakistan being an agricultural and underdeveloped country will face hard problems to cope with.

Number of studies had been carried out to investigate the meteorological trend patterns in Indus Basin spread throughout India, Pakistan and China. There is significant variation among the results of the different studies conducted in the said region that is evident from the findings of the earlier studies mentioned in this study. According to two studies (Mahmood and Jia, 2017; Shahid and Rahman, 2020) temperature has significantly increased while there is a decrease in precipitation in the Indus Basin, of Pakistan and almost similar results have be obtained in this study, a reverse relationship between temperature and precipitation, except substation Astore where monthly precipitation is increasing and decreasing with the increase and decrease in temperature. In another study, a sudden increase of mean and annual maximum temperature has been found for a period from 1961 to 2011 in the UIB, Pakistan (Mahmood et al., 2016) showing gradual temperature rise in the region since the middle of the last the century.

It is found in a study (Hasson et al., 2017) that overall summer is getting longer while the winter is getting shorter, which is almost identical to observations of this study that the temperature starts increasing in March and stays raised till the month of June and starts increasing again in October thus resulting in expansion of summer season.

Contrary to these findings, in a study performed in northern India, a considerable negative trends in temperature and potential evapotranspiration (PET) have been observed while both positive and negative trends were observed in precipitation based on the location of the selected districts during the last century (Tamaddun et al., 2019). Similarly, in a study it has been found that overall both the summer and winter seasons are getting extreme in Karakorum-Himalayan Mountains (Winston et al., 2013). The similar results are determined in this study that there is a variation in the climatic trends among the selected sub-basins of UIB, Pakistan and this variation seems to be due to difference in their elevation (m.a.s.l). So, it is important for the country like Pakistan to take serious steps to overcome the impact of the climate change in the region and make such policies that future generation must not be at risk. This study will help in the impact assessment as well as will pave the way for policymakers and water resource managers in the region.

Conclusion and Recommendations

Except for substation Astore, all other stations show almost a reverse relationship between temperature and precipitation among the different months of the year. The overall moving average trend lines demonstrate increasing and decreasing pattern for temperature and precipitation in the five selected sub basins respectively except in few months where the trend lines diverts from this pattern. Also the temperature is changing in three of the four seasons on an annual basis during the study period. The variation in the trend results among the five selected sub-basins can be due to difference in their elevation (m.a.s.l).

The findings of this study and its comparison with the previous studies reveal that climatic trend patterns for both temperature and precipitation are too much varying and there is a difference between the results of the studies performed in the study region which demands for the further study in the relevant field using more advanced computer aided tools, like, GIS and Remote Sensing to reveal the precise climatic trends in the UIB. Also the installation of new and sophisticated climate stations in the study region is recommended to measure the various climatic variables regularly and precisely in order to get best data for the study of climatic variation in the region.

A disaster can happen as a result of the interaction of extreme climate/weather events with the exposed and vulnerable natural systems. So management of risks for meteorological deserters can be made at any scale as mentioned below:

- Greenhouse gases emission can be reduced by introducing climate-friendly technology in industries.
- A large scale plantation is obvious to reduce the rate of rise in temperature.
- Tropical deforestation may be reduced and hence it's associated with global warming emissions.
- The use of renewable energy and the transformation of our energy system can reduce the risks.
- Urbanization can be controlled by imposing strict laws which may reduce the human effects on the earth as global warming is also caused by urbanization.

The government needs to introduce and implement such laws that can reduce the misuse of water. New irrigation/ agriculture technologies such as drip, trickle irrigation need to introduce for more water-conserving and the public should be educated regarding the importance of conservation of water.

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Novelty Statement

The variation in climate parameters in UIRB and their impact on its stream flows has been done by only a few researchers. The research work for prediction of variation in climatic variables and variations in peak flows under environment changes are needed to fill the gap in data base of water resources of UIRB.

Author's Contribution

Ateeq-ur-Rauf: Performed the research and wrote the paper.
Wisal Khan: Did the rephrasing and corrections in the English.
Muhammad Salman Rafi and Nauman Khan: Compiled the results, plotted the graphs and drawn tables.

Conflict of interest
The authors have declared no conflict of interest.

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