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Trends Analysis of Hydrometeorological data for Buner Basin, Khyber Pakhtunkhwa, Pakistan

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Abstract

Assessing trends of hydrometeorological variables is necessary for climate change modeling, accurate water resources management and improved regional planning. This study investigated the seasonal, annual, maximum (max.) and mean rainfall trend using data from 1986 to 2013 collected from three selected gauge stations including Tarbela, Daggar and Saidu sharif. Similarly, the historic data (1986 to 2013) of flow of Brandu river and max. and minimum (min.) temperature of Tarbela and Saidu Sharif gauge station were analysed. To identify trends for the hydrometeorological parameters, both non-parametric and parametric (MK) tests were applied at 10% significant level. The study concludes, a mixture of increasing and decreasing trends. Annual max. rainfall exhibited an increasing trend in the study area. Similarly, total annual and mean annual rainfall for Daggar and Saidu Sharif gauge stations showed decreasing trend while Tarbela gauge station exhibited an increasing trend. Statistically significant trends were found for annual total rainfall (

Keywords: Hydrometeorological varaibles; Seasons; Climate change; Parametric and non-parametric tests; Trend analysis; Significant change.

1. Introduction

Change in hydrometeorological events can have significant cultural, economic and environmental impacts (Manton et al., 2001). It drew attention of the scientific community because of the devastating effects of these events on the socio-economic development (Tabari et al., 2014). Investigating the change in hydrometeorological variables is vital to understand the disastrous behaviour of extreme events (Nyeko-Ogiramoi et al., 2013). It is observed that the emission of greenhouse gases is increased in the atmosphere and believed to be the main source of the global warming and change in hydrometeorological events. This increase has been observed since 1950s (IPCC, 2013). Increase in the emission of CO2 has significantly increased the global average temperature (0.74 oC) (UNFCCC, 2007). The increase in temperature has significant effects on the rainfall, stream flow, snowfall, glacier melting and consequently on agriculture and socio-economic life.

The developing countries are facing threats of climate change where water resources assessment is very essential for planning infrastructure, project designing and operation (Akhtar et al., 2008). Small scale farmers are among the most affected by climate variability because of their agriculture is mainly dependent on rainfall (Easterling, 2011). It may lead to their food insecurity and even unavailability of drinking water. Seasonal as well as annual flow forecasting would be a useful tool for management of natural resources. Rainfall and temperature are the two most important variables to investigate the climate variability (IPCC, 2007) and can severely affect stream flow. Cheung et al. (2008) pointed out that the rainfall variability and its trends are the two important factors to understand the socio-economic status of the countries primarily dependent on rainfed agriculture. Several studies reported that seasonal reliability is more important for agricultural activities than annual reliability (Simane et al., 2016).

Wide variation in meteorological parameters and diverse trends have been detected in various climatic regions (Chaudhry and Sheikh, 2002; Afzaal et al., 2009; Ullah et al., 2018). Climate change and trend analysis is of great concern for scientists in the recent

(Tabari and Talaee, 2011). Similarly, various studies are carried out in Pakistan for rainfall, runoff, and temperature trend analysis. Rio et al. (2013) used non-parametric technique for mean temperature data of Pakistan and found an increasing trend in temperature. Ullah et al. (2019) investigated temperature of 48 stations using Mann Kendal method and found an increasing trend in maximum and minimum temperature during 1980-2016. Hussain et al. (2005) studied the variability in temperature and rainfall in mountainous region of Pakistan using parametric test. They concluded that winter and monsoon temperature showed an increasing trend while precipitation has decreasing trend in all seasons except winter in sub mountainous region and an increasing trend in all seasons in high mountainous region. Afzaal et al. (2009) used linear trend analysis for temperature across Pakistan. T-test and F-test were used for comparison of the mean and variant of the data set at 95% confidence level. It was inferred that the temperature raised at the rate of 0.2 °C/decade during 1907–1945. It was decreased afterward at the rate of 0.03 °C/decade until 1993. An abrupt rise in temperature was observed in 1993. Since then, the temperature raised by 0.53 °C/decade up to 2007. An overall increase in temperature was found 0.06 °C/decade. In a recent study, it was found that the average temperature of Pakistan has been increased by 1.04 °C at the rate of 0.09 °C from 1960 to 2014 (Ali et al., 2018). Similarly, Ma et al. (2021) investigated temperature and precipitation data of 68 climatic stations for Fujian Province (China) from 1971 to 2018 using different tests including MK test and found an increasing trend for these two parameters during summer and autumn seasons. Keggenhoff et al. (2014) also used the non-parametric technique for extreme values of precipitation and temperature of 88-gauge stations across the Georgia from 1971 to 2010. Increasing trend in precipitation, minimum and maximum Temperature was found in majority of the gauge stations. Various other studies investigated the hydrometeorological parameters using the MK technique (e.g., Khattak et al., 2011; Marofi et al., 2012; Huang et al., 2013; Guo and Xia, 2014; Amirataee et al., 2016; Liuzzo et al., 2016, Nyeko-Ogiramoi et al., 2013; Ullah et al., 2018).

Being an agricultural country, Pakistan is very sensitive to climate change. Therefore, studying the hydrometeorological variables and identifying their trends are very important for policy makers and designers to make informed decisions. Characterization of temporal trend of hydrometeorological variables like precipitation, temperature, and stream flow in the perspective of climate change is vital to evaluate climate-provoked changes and propose feasible adaptation policies and agricultural practices. The situation demands a deep consideration for future planning of economy and development. Although trend analysis and climate change study are not new in Pakistan, no prior comprehensive study was conducted in the study area (Fig.1). The main objective of this study was to investigate the hydrometeorological parameters variability and trend analysis based on historical data for annual and seasonal rainfall, temperature and stream flow using non-parametric and parametric tests.

2. Materials and Methods

2.1 Study Area

The study area is sub mountainous rural area where 95% of the population depends on agriculture and livestock for their earning. The rest 5% of the population relies on daily labour and other earning sources (Pakistan Bureau of Statistics, 2010). Three stations with installed gauges (Daggar, Saidu Sharif, Tarbela) and Brandu river were selected to investigate the hydrometeorological parameters variability and trend analysis. The Brandu river is flowing through district Buner, located at 153 km towards the Northeast of Peshawar in Khyber Pakhtunkhwa province. This river ultimately joins Indus River about 44 km upstream of Tarbela dam. The study area and details of three meteorological gauge stations are given in Fig. 1 and Table 1 respectively. Being an agricultural dependent basin and a hydroelectric power generation (Brandu weir) with capacity about 84 MW is proposed. These facts make it important to study this area.

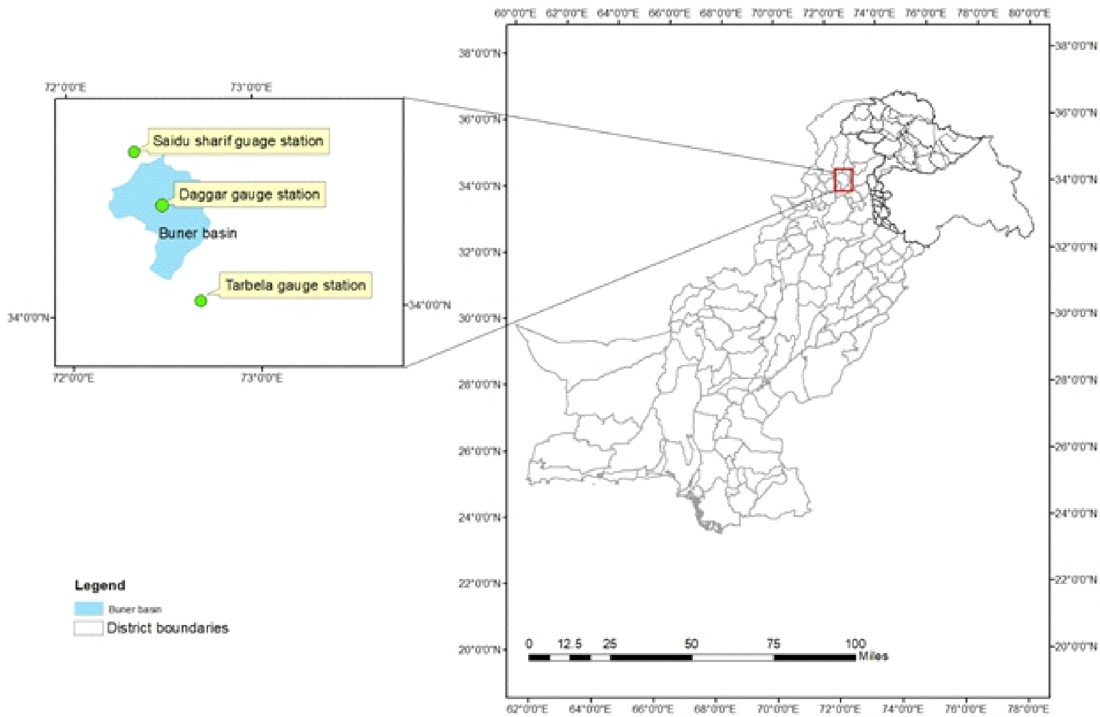

Fig. 1 Showing the location of the stations in the study area.

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

S. No.	Station	Latitude	Longitude	Mean Monthly Rainfall	Mean Temperature	Mean Flow
1	Daggar	34^{o} 29 '	72^{o} 29 '	34.80 mm	-	72.90 m^3/sec
2	Saidu Sharif	34^{o} 44 '	72^{o} 02 '	36.60 mm	19.1 ^{o}C	-
3	Tarbela	34^{o} 04 '	72^{o} 43 '	31.60 mm	28.8 ^{o}C	-

2.2 Hydrometeorological Data Set

Daily data was collected from Pakistan Meteorological Department (PMD), Surface Water Hydrology Project (SWHP) Water and Power Development Authority (WAPDA) from 1986 to 2013. The monthly total, maximum, minimum, and mean rainfall, temperature, and flow were computed from the daily data. Maximum and minimum was the max. and min. value of the daily data for whole month, while mean monthly was the average of the daily values. Mean monthly temperatures are based on the arithmetic average of daily mean max. and mean min. temperatures. The four seasons were, pre-monsoon (March, April and May), monsoon (June, July, August and September), post-monsoon (October and November) and winter (December, January, and February). The missing data were calculated by averaging the data of the previous and the following year or previous day and the following day.

2.3 Trend Analysis

For trend analysis, rainfall, temperature and river flow data were grouped into total, max., min. and mean. Then trend analysis was carried out on annual and seasonal basis. To identify statistically significant trends detection, both non-parametric and parametric techniques were applied. The parametric trend detection was carried out using the excel built-in functions in four steps, (i) monthly total, max., min. and average climatic variable calculated from daily data, (ii) annual and seasonal: total, max., min. and average climatic variables were calculated from monthly data, (iii) trends for different variables were found, (iv) the parametric test (regression analysis) was carried out at 10% significance level (α). The p-value was compared with . The p-value > shows statistically non-significant, while p-value exhibit that the trend is statistically significant. Non-parametric Mann Kendall (MK) test was applied using the XLSTAT extension in the Microsoft Excel.

3. Results and Discussions

Before trend analysis, data was checked for descriptive statistics such as total, mean, max. and min. values. Annual rainfall of Daggar, Saidu Sharif and Tarbela varied from 1589.9 mm to 786.8 mm, 1650.9 mm to 727.7 mm and 1458 mm to 624 mm respectively with annual mean of 1065.1 mm, 1116.3 mm, and 971 mm respectively. Mean annual total flow was 2219 m3/sec and varied annually from 1235 m3/sec to 3664 m3/sec. Mean max. and mean min. temperature varied from 36.2 oC to 14.4 oC and 22.2 oC to 1.7 oC for Saidu sharif, while 46.4 oC to 21.6 oC and 33 oC to 10.8 oC for Tarbela station, respectively. One day max. rainfall at Daggar, Saidu Sharif and Tarbela was recorded on 24 September 2003, 29 July 2010 and 25 July 1985 with peak values of 147.3 mm, 187 mm, 181.6 mm respectively. Recorded max. and min. flow (226.1, 0.94 m3/sec) was observed on 29 July 2010 and 8 September 2010 respectively.

3.1 Results of Trend Analysis for Annual (total, max. and mean) Rainfall

Both non-parametric and parametric tests exhibited decreasing trend for observed annual total and annual mean of Daggar and Saidu Sharif gauge station while increasing trend was observed for annual total, annual max. and annual mean rainfall of Tarbela gauge station and annual max. rainfall of Daggar station. Parametric test showed that annual total, annual mean, mean of the post-monsoon and mean of the winter rainfall of Saidu Sharif, mean pre-monsoon rainfall of Daggar and Tarbela and mean monsoon rainfall of Tarbela rainfall has statistically significant trends. Other trends were statistically non-significant. Table 2 summarises the results of non-parametric and parametric trends. Fig. 2 shows the seasonal and annual rainfall trend in three stations. The findings of this study agree with the study of Salma et al. (2012), who concluded that precipitation has a decreasing trend of 1.18 mm/yr in Pakistan.

3.2 Results of Trend Analysis for Seasonal Rainfall

For pre-monsoon season, both parametric and non-parametric tests showed decreasing trend of rainfall of all three stations. Trends were statistically significant at 10% significance level except seasonal max. rainfall of Saidu sharif whereas Tarbela station showed non-significant trend. For monsoon season, all trends were increasing while total rainfall of Tarbela station was statistically significant using parametric test. Non-parametric test results showed that max. rainfall trend of Saidu Sharif was significantly decreasing. In post-monsoon season, all rainfall data showed decreasing trend confirmed by both parametric and non-parametric tests. The above results are almost in agreement with the finding of Ullah et al. (2018). In winter season, both increasing and decreasing trends were found. In winter season, Daggar and Saidu Sharif rainfall has decreasing trend while Tarbela rainfall has increasing trend (Parametric test). Similarly, from the non-parametric test it was concluded that no trend exists in mean rainfall of the three stations whereas the total rainfall of Tarbela and Daggar showed an increasing trend and Saidu Sharif as decreasing trend. The maximum rainfall in winter season of Saidu Sharif and Tarbela showed an increasing trend and for Daggar a decreasing trend was identified. All trends were statistically non-significant (Table 2). Our findings are almost in agreement with Hussain et al. (2005) where they concluded that in mountainous region of Pakistan the rainfall has decreasing trend in all seasons except winter in sub mountainous region and increasing trend in all seasons in high mountainous region. In this study, the rainfall of Daggar and Saidu Sharif has decreasing trend except monsoon season. Rainfall of Tarbela showed an increasing trend except pre-monsoon and post-monsoon season.

3.3 Results of Trend Analysis for Annual Stream Flow

The trend analyses tests showed that total, max., min. and mean annual stream flow were increasing. The min. stream flow was statistically significant with an increasing trend at 10% significance level. All the results of trends analysis are summarised in Figure 3 and Table 3. Possible reason for increasing in the stream flow values might be the increasing snow melting in mountainous regions or increase stream flow rate of springs from the watershed.

3.4 Results of Trend Analysis for Seasonal Flow

Like annual data, seasonal stream flow data was also categorised as total, max., min. and mean. The pre-monsoon season flow showed a decreasing trend for total and max. stream flow and slightly increasing trend for min. and mean flow. Maximum stream flow was statistically significant at 10% significance level. Other stream flows were statistically non-significant. Increasing trend was observed in the monsoon season stream flow. This increase in stream flow is possibly due to an increase in the rainfall. Total and mean stream flows were significantly increased for monsoon season as shown in Figure 3 and Table 3. Non-parametric test showed an increasing trend but non-significant. In post-monsoon season, both parametric and non-parametric tests revealed that trends of min. stream flow were significantly increasing at 0.04 m3/sec/yr. Other stream flows were also increasing but not significant. In winter season, all stream flow trends were increasing. The winter increase in flow for eight hydrometric stations at upper Indus basin during 1970-2005 was also observed by Khattak et al. (2011). The Daggar rainfall gauge has 74% stream flow contribution, while at Saidu Sharif it was 26%. The increasing stream flow might be due to increase in precipitation at upper region. Also, an increase in temperature might cause increasing rate of snow melt.

It was inferred from the study of Khattak et al. (2015) that annual and winter stream flow of Tarbela, Warsak, Mangla and Marala has increasing trend while summer flow has decreasing trend. The results of this study agree with those found by Khattak et al. (2015). However, here the monsoon stream flow was not decreasing possibly due to increase in monsoon rainfall.

Table 2. Summary of annual and seasonal rainfall (total, maximum and mean rainfall) trend analysis using non-parametric and parametric test during 1986–2013.

Trend analysis using non– parametric test												
Total Rainfall												
Period	**Daggar**				**Saidu Sharif**				**Tarbela**			
	Kendall's tau	*S*	*p*	Sen's slope	Kendall's tau	*S*	*p*	Sen's slope	Kendall's tau	*S*	*p*	Sen's slope
Annual	– 0.23	– 86	**0.09**	–	– 0.2	– 74	0.15	– 11.1	0.04	14	0.80	2.34
Pre–	– 0.40	–	**0.00**	–	– 0.4	–	**0.00**	– 11	– 0.3	– 118	**0.00**	– 3.3
Monsoon	0.05	20	0.71	1.08	– 0.19	– 70	0.17	– 1.52	0.2	74	0.15	4.67
Post–	– 0.07	– 26	0.62	–	– 0.2	– 71	0.15	– 2	– 0.22	–	**0.10**	–
Winter	0.01	2.0	0.98	0.18	– 0.02	– 8.0	0.89	– 0.21	0.08	30	0.57	0.91
Max. Rainfall												
Annual	0.07	26	0.62	0.32	– 0.12	– 47	0.36	– 0.65	0.11	40	0.44	0.42
Pre–	– 0.21	– 79	0.12	–	– 0.33	–	**0.01**	– 1.33	– 0.19	– 70	0.17	–
Monsoon	0.16	60	0.25	0.93	– 0.24	– 90	0.08	– 0.73	0.05	19	0.72	0.18
Post–	– 0.06	– 22	0.68	–	– 0.25	– 89	**0.07**	– 0.84	– 0.28	– 107	**0.04**	–
Winter	0	– 1.0	1.0	–	0.01	2.0	0.98	0.02	0.20	76	0.14	0.82
Mean Rainfall												
Annual	– 0.20	– 78	0.13	–	– 0.40	–	**0.002***	–	0.16	62	0.23	0.06
Pre–	– 0.28	–	**0.03**	–	– 0.50	–	**0.0001***	–	–	– 54	**0.30**	–
Monsoon	0.00	0	0.98	0.00	– 0.16	– 62	0.231	–	0.31	118	**0.01**	0.23
Post–	0.01	4.0	0.95	0.01	– 0.33	–	**0.0142***	–	–	– 42	0.42	–
Winter	– 0.22	– 86	**0.09**	–	– 0.34	–	**0.011***	–	0.15	58	0.26	0.09
Note: "*S*" in the parametric test should be read as Mann-Kandall test *S*-statistics.												

Trend analysis using parametric test						
Period	**Daggar**		**Saidu Sharif**		**Tarbela**	
	Sen's Slope	*p*	*Sen's Slope*	*p*	*Sen's Slope*	*p*
Total Rainfall						
Annual	– 7.06	0.15	– 11.97	**0.04***	1.55	0.76
Pre– monsoon	– 7.84	**0.0004***	– 11.21	**0.00***	– 3.42	**0.02***
Monsoon	1.73	0.65	0.95	0.79	5.79	**0.10***
Post– monsoon	– 0.59	0.55	– 1.67	0.16	– 2.21	**0.02***
Winter	– 0.36	0.88	– 0.04	0.99	1.40	0.46
Max. Rainfall						
Annual	0.25	0.69	0.38	0.58	0.77	0.30
Pre– monsoon	– 0.78	0.14	– 1.16	**0.02***	– 0.21	0.61
Monsoon	0.88	0.24	0.76	0.33	0.53	0.51
Post– monsoon	– 0.78	0.83	– 0.81	**0.07***	– 1.12	**0.01***
Winter	– 0.26	0.71	– 0.03	0.96	0.87	0.21
Mean Rainfall						
Annual	– 0.59	0.15	– 0.25	**0.0001***	0.050	0.29
Pre– monsoon	– 2.61	**0.0004***	– 3.74	**0.001***	– 1.14	**0.02***
Monsoon	0.27	0.81	– 0.14	0.13	0.22	**0.01***
Post– monsoon	– 0.30	0.55	– 0.30	**0.01***	– 0.17	0.22
Winter	– 0.12	0.88	– 0.24	**0.01***	0.09	0.29

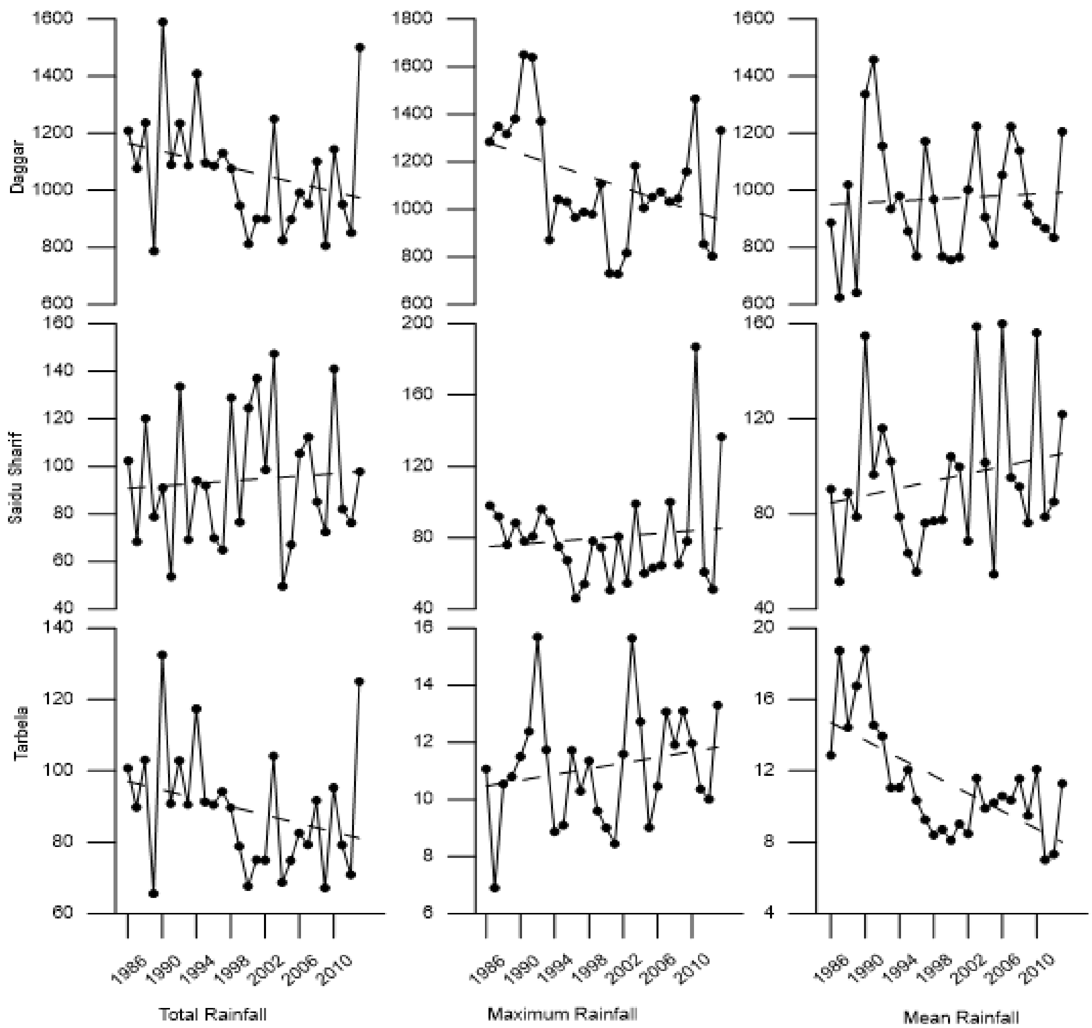

Fig. 2. Trend of annual total, annual maximum and annual mean rainfall (mm) for Daggar, Saidu Sharif and Tarbela during 1986–2013.

Table 3. Summary of stream flow trend analysis using non-parametric and parametric test for Brandu river during 1986–2013.

Trend analysis using non-parametric test								
Period	Total Flow				Max. Flow			
	Kendall's tau	*S*	*p*	Sen's slope	Kendall's tau	*S*	*p*	Sen's slope
Annual	0.07	26	0.62	14.95	0.05	18	0.74	0.54
Pre– monsoon	– 0.12	– 44	0.40	– 5.26	– 0.22	– 82	0.11	– 1.42
Monsoon	0.14	54	0.30	10.17	0.15	58	0.26	1.06
Post– monsoon	0.17	66	0.20	2.25	0.12	46	0.38	0.05
Winter	0.28	104	**0.04***	5.17	0.10	38	0.47	0.14
	Mean Flow				Min. Flow			
Annual	0.07	28	0.60	0.05	0.29	108	**0.03***	0.03
Pre– monsoon	0.08	30	0.57	0.01	0.05	18	0.74	0.01
Monsoon	0.14	52	0.32	0.09	0.18	68	0.19	0.02
Post– monsoon	0.18	68	0.19	0.04	0.27	102	**0.05***	0.04
Winter	0.28	106	**0.04***	0.06	0.35	132	**0.01***	0.03

Trend analysis using Parametric test								
Period	Total Flow		Max. Flow		Mean Flow		Min. Flow	
	Sen's slope	*p*	Sen's slope	*p*	Sen's slope	*p*	Sen's slope	*p*
Annual	15.72	0.25	0.85	0.46	0.04	0.24	0.025	**0.05***
Pre– monsoon	– 6.46	0.21	– 1.60	**0.05***	0.01	0.47	0.02	0.26
Monsoon	16.09	**0.06***	1.86	0.13	0.02	0.18	0.13	**0.06***
Post– monsoon	0.36	0.85	0.05	0.84	0.04	**0.01***	0.01	0.85
Winter	5.73	**0.10***	1.22	0.25	0.03	**0.01***	0.07	**0.10***

3.5 Results for Trend Analysis in Annual Temperature

Both parametric and non-parametric tests for mean max., mean min. and mean of the max. and min. temperature of Tarbela and Saidu Sharif exhibited an increasing trend. The increase in max. and min. temperature agrees with Rio et al. (2013) and Iqbal et al. (2017). Thus, increase in temperature in the study area will reduce the yield of various crops. With increase of temperature reduction in crops yield is also reported by Zhao et al. (2017). Trend of mean min. and mean temperature of Tarbela was significantly increasing at 10% significance level. Other trends were non-significant. Figure 4 and Table 4 summarises the results of trends analysis for temperature of Tarbela and Saidu Sharif gauge stations.

3.6 Results of Trend analysis for Seasonal Temperature

In pre-monsoon season, the temperature trend was increasing (Figure 4 and Table 4). Parametric test showed that mean max. and mean temperature of Saidu Sharif and mean and mean min. temperature of Tarbela was showing significantly increasing trend. While from non-parametric test it was inferred that except mean max. temperature of Tarbela, all other temperatures showed significantly increasing trend. In monsoon, increasing as well as decreasing trends exist but none of the trend was significant. In post-monsoon season, mean min. and mean temperature of Tarbela showed significantly increasing trend. Non-parametric test indicating significantly increasing trend for temperature of Tarbela station. In winter season, both parametric and non-parametric tests exhibited significantly increasing trend for Tarbela temperature. Increasing/decreasing trends was observed for Saidu Sharif temperature but were not significant. The results of this study agreed with the findings of Rio et al. (2013) where they concluded that the mean annual temperature increased in Pakistan at the rate of 0.036 °C/yr. Summer cooling, winter and spring warming trend was also reported by other researchers (e.g., Fowler and Archer, 2006; Khattak et al., 2011; Yaseen et al., 2014) and concluded that Mangla watershed mean and mean max. temperature showed increasing trend. Likewise, an increase in temperature was also reported by other researchers (e.g., Hussain et al., 2005; Rasul et al., 2008; Afzaal et al., 2009). An increase in precipitation is useful to both rain-fed and irrigated agriculture but could be disastrous to the humid areas (Ma et al., 2021). In addition, the rising temperature is inconducive for the crops growth and development, lowering the relative humidity in the ambient environment, increasing soil evaporation and leading towards drought.

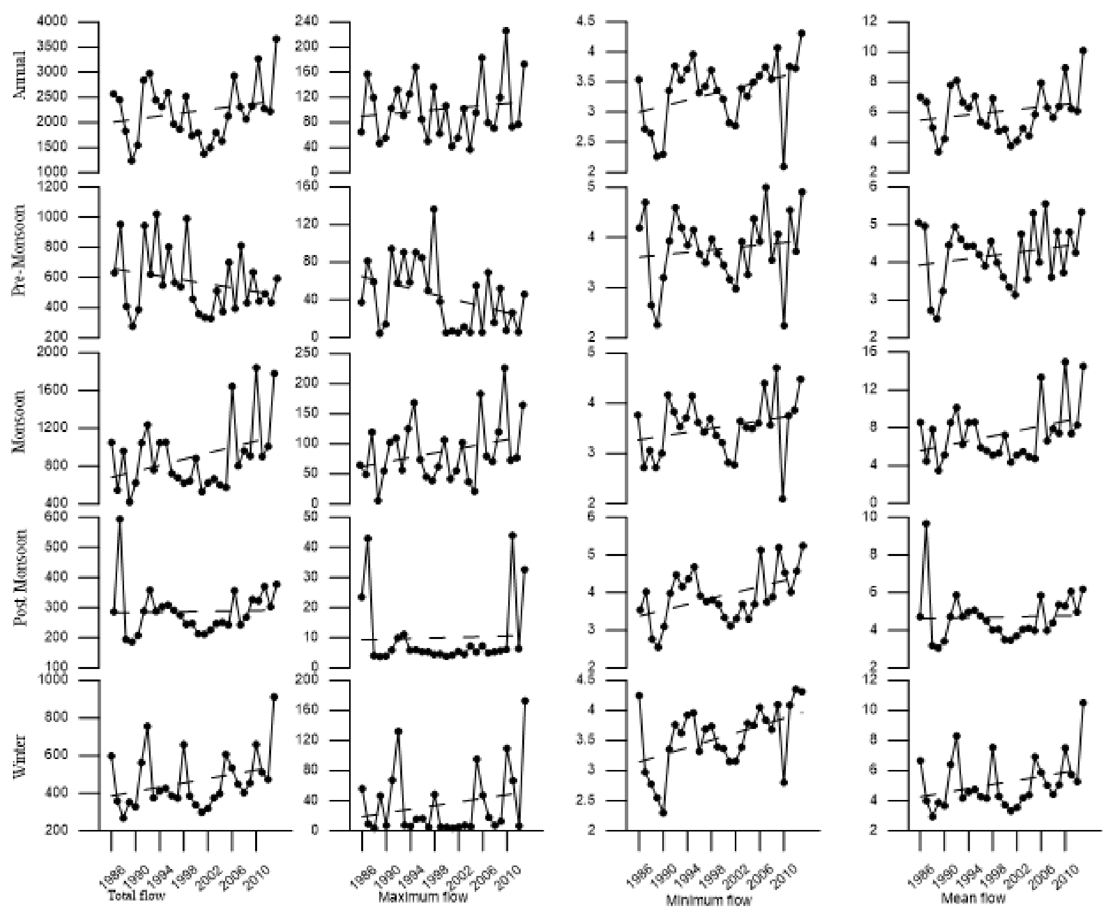

Fig. 3 Trend of annual and seasonal total, max., min. and mean stream flow (m3/sec) for Brandu river during 1986–2013.

Table 4. Summary of temperature trend analysis using non-parametric and parametric test during 1986–2013 for Saidu Sharif and during 1984–2003 for Tarbela.

Trend analysis using non-parametric test results								
Mean Max. Temperature								
Period	**Saidu Sharif**				**Tarbela**			
	Kendall's tau	*S*	*p*	Sen's slope	Kendall's tau	*S*	*p*	Sen's slope
Annual	0.17	64.0	0.22	0.03	0.16	25.0	0.37	0.04
Pre–	0.23	86.0	**0.09***	0.08	0.26	39.0	0.15	0.12
Monsoon	0.06	24.0	0.65	0.01	– 0.28	– 43.0	0.11	– 0.06
Post–	0.11	42.0	0.42	0.04	0.30	45.0	**0.09***	0.09
Winter	0.13	50.0	0.34	0.03	0.33	0.3	**0.07***	0.12
Mean Min. Temperature								
Annual	0.04	16.0	0.77	0.01	0.54	82.0	**0.00***	0.09
Pre–	0.33	126.0	**0.01***	0.06	0.50	75.0	**0.00***	0.20
Monsoon	– 0.05	– 18.0	0.74	– 0.01	0.28	43.0	0.11	0.07
Post–	– 0.04	– 14.0	0.80	– 0.01	0.40	61.0	**0.02***	0.17
Winter	– 0.12	– 46.0	0.38	– 0.02	0.39	59.0	**0.03***	0.19
Mean Temperature								
Annual	0.13	48.0	0.36	0.02	0.42	64.0	**0.02***	0.08
Pre-	0.25	96.0	**0.06***	0.08	0.34	52.0	**0.05***	0.15
Monsoon	0.02	6.0	0.92	0.00	– 0.04	-6.0	0.85	– 0.01
Post-	0.06	24.0	0.65	0.01	0.35	53.0	**0.05***	0.11
Winter	0.13	50.0	0.34	0.03	0.38	0.4	**0.03***	0.13

Trend analysis using parametric test results												
Period	**Saidu Sharif**						**Tarbela**					
	Max. Temperature		Min. Temperature		Mean Temperature		Max. Temperature		Min. Temperature		Mean Temperature	
	Sen's slope	*p*	Sen's slope	*p*	Sen's slope	*p*	Sen's slope	*p*	Sen's slope	*p*	Sen's slope	*p*
Annual	0.03	0.21	0.00	0.82	0.01	0.35	0.05	0.11	0.10	**0.00***	0.07	**0.01***
Pre-monsoon	0.07	**0.08***	0.04	**0.03***	0.06	**0.04***	0.10	0.15	0.11	**0.01***	0.13	**0.03***
Monsoon	0.00	0.99	-0.02	0.32	-0.01	0.40	– 0.07	0.12	0.03	0.47	– 0.02	0.56
Post-monsoon	0.03	0.58	– 0.02	0.51	0.00	0.93	0.08	0.14	0.11	**0.07***	0.09	**0.06***
Winter	0.02	0.43	– 0.02	0.37	0.00	0.90	0.11	**0.02***	0.12	**0.05***	0.11	**0.02***

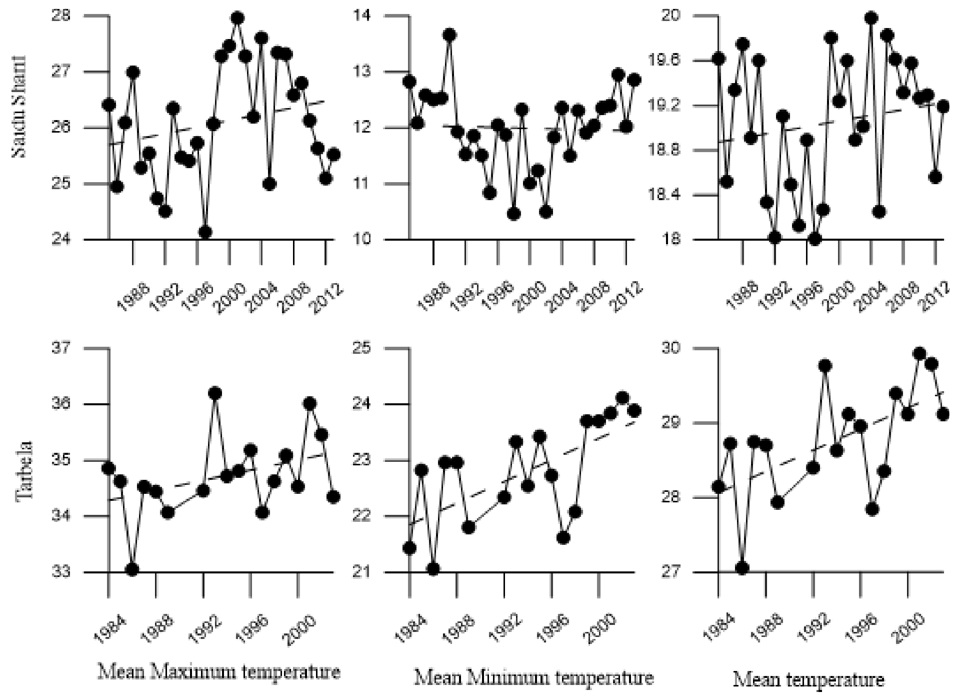

Fig. 4. Trend for the annual max., min. and mean temperature (oC) of Saidu Sharif during 1986–2013 and Tarbela during 1984-2003.

4. Conclusion

From the trend analysis study, it was concluded that the following trends were increasing/ decreasing significantly. From non-parametric test it was concluded that total and mean rainfall of both annual and pre-Monsoon season of Daggar station showed decreasing trend (9.49 mm/yr, 0.03 mm/yr) and (7.7 mm/yr, 2.56 mm/yr), respectively. While Parametric test showed that in pre-monsoon, total rainfall and mean rainfall has decreasing trend at 7.84 mm/yr and 2.61mm/yr respectively. These trends were statistically significant. Saidu Sharif station in pre-monsoon season total, maximum and mean rainfall exhibited decreasing trend (11 mm, 1.33 mm and 3.65 mm/yr respectively). Post monsoon maximum rainfall also showed decreasing trend at 0.84 mm/yr. Parametric test showed that in pre monsoon season total, maximum and mean rainfall has decreasing trend (11.21 mm/yr,1.16mm/yr and 3.74 mm/yr respectively). Annual total and mean rainfall also showed decreasing trend (11.94 mm/yr and 0.25 mm/yr respectively). Post-Monsoon maximum rainfall also showed decreasing trend at slope of 0.81 mm/yr.

From non-parametric test it was concluded that in pre-monsoon season of Tarbela station, total and mean rainfall has decreasing at the rate of 3.3 mm/yr and 1.08 mm/yr and in Post monsoon season, total and maximum rainfall has decreasing trend (1.52 mm/yr and 0.88 mm/yr respectively). The parametric test showed that in pre-monsoon rainfall trend has decreasing at the rate of 3.84 mm/yr (total rainfall) and 1.14 mm/yr (mean rainfall) while in post-monsoon season it was decreasing at 2.21 mm/yr (total rainfall) and 1.12 mm/yr (maximum rainfall). However, monsoon rainfall has increasing trend at the rate of 5.79 mm/yr and 0.22 mm/yea of total and mean rainfall. All the trends above were statistically significant.

Winter total flow has increasing trend 5.17 m3/sec/yr (non-parametric) and 5.73 m3/sec/yr (parametric). Minimum flows also have increasing trend 0.03 m3/sec/yr (annually), 0.03 m3/sec/yr (Post Monsoon) and 0.03 m3/sec/yr (winter) using non-parametric test and 0.025 m3/sec/yr (annually), 0.13 m3/sec/yr (Monsoon) and 0.07 m3/sec/yr (winter) using parametric test. In Pre-monsoon maximum flow has decreasing trend 1.50 m3/sec/yr (parametric) and mean flow in post monsoon and in winter has increasing trend 0.04 m3/sec/yr for both. There is decrease in annual rainfall but despite increase of flows may be due to increase in temperature in the upper regions. Because major sources of flows in the basin are springs.

In Pre-monsoon mean max. mean min. and mean temperature of Saidu Sharif has increasing trend at 0.08 °C/yr, 0.06 °C/yr and 0.08 °C/yr using non-parametric test and 0.07 °C/yr, 0.04 °C/yr and 0.06 °C/yr using parametric test. Tarbela mean maxi. temperature in Post-monsoon and Winter season has increasing slopes i.e., 0.09 °C/yr and 0.12 °C/yr respectively (non-parametric test). Mean temperatures of; annual, Pre-monsoon, Post-monsoon and Winter slopes showed increasing trends and slopes were 0.09 °C/yr, 0.20 °C/yr, 0.17 °C/yr and 0.19 °C/yr respectively (non-parametric). Mean mini. temperatures slopes of; annual, Pre-monsoon, Post-monsoon and Winter were 0.10°C /yr, 0.11°C /yr, 0.11°C /yr,0.12°C /yr (using parametric) and 0.08°C /yr, 0.15°C /yr, 0.11°C /yr, 0.13°C /yr respectively (using non-parametric). Increasing slopes of mean temperature were 0.07°C /yr (annual), 0.13°C /yr (Pre-monsoon), 0.09°C /yr (Post-monsoon) and 0.11°C /yr (Winter) using parametric test. With the increase of maximum rainfall, probability of flood risk also increases. The increasing temperature will reduce yields of various crops in the area. The findings could be further refined by inculcating data of other hydrometeorological parameters.

Authors' Contribution

Salah Ud Din collected data and screened it, analyzed and wrote the manuscript. Mujahid Khan supervised the study and was involved in the writeup. Muhammad Ajmal helped in structuring of the manuscript and its contents and reviewed it before submission. Muhammad Shahzad Khattak helped in analyzing the data and the concept of application of different statistical tests.

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