Journal of Himalayan Earth Sciences Volume 50, No. 1A, 2017 pp. 66-75

Assessment of precipitation trends in Gilgit Baltistan (Pakistan) for the period 1980−2015: an indicator of climate change

Sajjad Ali[1], Muhammad Ajmal*[1], Muhammad Shahzad Khan[1] and Safeer Ullah Shah[2]
[1]Department of Agricultural Engineering, University of Engineering and Technology, Peshawar
[2]National Centre of Excellence in Geology, University of Peshawar
**Corresponding author's email: engr_ajmal@uetpeshawar.edu.pk*
Submitted: 17/11/2016, Accepted: 15/03/2017, Published Online: 30/03/2017

Abstract

Long-term seasonal and annual precipitation trends are among the effective tools to assess the climate change of a region. In this study, long-term seasonal and annual trends were assessed for six meteorological stations of the Gilgit Baltistan (GB) (a mountainous belt of Pakistan) during 1980−2015. Non parametric Mann-Kendall (MK) and Sen's slope (SS) techniques were applied to find strength and magnitude of trends at 10% significance level. Serial correlation in data was removed by using Trend Free Pre-Whitening (TFPW) technique. Results revealed increasing trends in mean annual precipitation at five stations (significant only at Gupis with a SS of 7.34 mm/year) and decreasing trend at one station (Astore) with a SS of -3.05 mm/year. The evidence of increasing trends in mean annual precipitation in five out of six hydro-climatic stations indicated perennial flow in the Indus River and which ensure sufficient ground water recharge for the downstream plain areas. All stations showed increasing trends in precipitation during monsoon season while in other seasons both positive and negative trends found were non-significant. Precipitation trend in post-monsoon season is decreasing in most parts of the GB that might cause temporary dry condition in the Indus River downstream. Based on the overall mean precipitation analysis for the entire GB, there were non-significant increasing seasonal and annual trends except the post-monsoon season. These seasonal variations in precipitation might affect water supply to the Indus River resulting in less availability of water for agriculture sector and in turn affecting crop production in the downstream plains. Seasonal trends in precipitation could directly affect agricultural activities which is a vital source of livelihood in Pakistan. To be on safe side, construction of water storage structures (dams) is highly needed to avoid possible floods during monsoon season and store most of the precipitation to meet off season demands especially in dry season.

Keywords: Mann-Kendall test; Sen'sslope; Precipitation; Monsoon; Climate change; Gilgit-Baltistan

1. Introduction

Winter and summer are the two major precipitation seasons in Pakistan. In winter, the mid-latitude westerly waves move across the lower latitudes and their troughs generally extend down to 35N, and sometimes even to the south of the country. Under the influence of westerly waves as well frontal system, the northern parts of Pakistan receives substantial rainfall over low elevations and snow fall at high elevation areas in the winter season (Raza et al., 2015). In Pakistan the total annual precipitation ranges from 500 mm to 800 mm. The northern half of the country receives sufficient amount of precipitation in both winter and summer but the southern half receives less than 50% of the amount received in the north (Rasul et al., 2012). Precipitation in the form of snow over the northern mountains melts in early summer and maintains sustainable river flow for power generation and irrigation before the onset of summer monsoon. In addition to this precipitation, winter rain bearing systems yield substantial rainfall in sub-mountainous and low elevation plains (Naheed and Kazmi, 2013). The northern part especially Gilgit Baltistan (GB) is host to the world's largest glaciers and is one of the major water sources of the Indus River, the leading river of the country (Raza et al., 2015).

Observed global data of precipitation during the period 1900−2011 showed that precipitation increased in eastern parts of North and South America, northern Europe and northern and central Asia whereas in the Mediterranean, southern Africa and parts of southern Asia it has decreased (IPCC, 2014). However for the longest common period (1901–2008), an increase in the globally averaged precipitation was observed (IPCC, 2013). The water balance on the earth surface is affected greatly by precipitation causing significant changes in water resources (IPCC, 2001a,b).

Different studies have been carried out to assess trends in meteorological variables in different parts of the world. One such study was carried out by Christopher et al. (2012) in Florida, USA which used monthly data of rainfall from 1895 to 2009 from 22 climatic stations. Results of this study were based on non-parametric Mann-Kendall test which showed negative seasonal rainfall trends in Florida. Keggenhoff et al., (2014) used extreme values of daily precipitation across entire Georgia (country located in South of Russia) for the period 1971−2010 and reported increasing trends in extreme precipitation events. Trends in daily precipitation over Philippines were assessed by Thelma et al. (2014) by using daily data of precipitation for a period 1951−2010. Trends in data were estimated by using Mann-Kendall test without removing serial correlation. Their results showed significant increasing trends in annual rainfall but only at few stations. Chen et al. (2007) identified hydro-climatic trends in Hanjiang Basin of China; using daily data of precipitation and stream flow of 14 climatic stations from 1951 to 2003.They found that stream flow tends to decrease despite the fact that rainfall trends were constant. Similarly, rainfall trends in the Orissa province of India were assessed by Arun et al., (2012) and they reported that January, May, June, September, October and November had positive trends in monthly precipitation while rest of the months had negative trends. These results indicate that precipitation trends have no areal uniformity and intensity at various locations within the same country.

Various studies analyzed rainfall trends in Pakistan. Among others, Salma et al. (2012) estimated rainfall trends in different climatic zones of Pakistan. They used monthly rainfall data for the period 1976−2005 and then applied analysis of variation (ANOVA) and Dennett T3 tests. Results of Salma et al., (2012) suggested that rainfall is decreasing at the rate of 1.18 mm/year and they concluded that it is a very clear indicator of climate change in Pakistan. Maida and Ghulam (2011) investigated the frequency of extreme rainfall events for the period 1965−2009 using daily data of rainfall of 41 climatic stations. To find the significance level of extreme rainfall, they used the non-parametric Kalmogorov−Smirnov test (KS test) and found that extreme events of rainfall were increasing in Punjab, Northern areas, Baluchistan, and Azad Kashmir. Thus Pakistan may face disasters in coming decades in the form of high intensity rainfall events causing floods and agricultural losses. Khattak and Ali (2015) carried out a detailed study to find trends in maximum monthly temperature and rainfall over Punjab province (Agricultural and Industrial hub) of Pakistan using Mann-Kendall test. They found increasing trends in both maximum monthly temperature (0.002°C/year) and total annual rainfall (3.23mm/year) over the region. Atif et al. (2015) analyzed changes in snow cover area over Upper Indus River Basin (GB included) and found that snow cover area did not suffer a significant change.

From the studies of global precipitation trends it can be concluded that increasing precipitation trends have been detected on global scale with more number of wet days, however dry periods have no spatial uniformity and it changes from region to region (Frich et al., 2002; Alexander et al., 2006). In addition, various techniques have been applied to detect trends associated with historical climatic parameters, e.g. Khattak et al., (2011) used non-parametric tests in Upper Indus Basin covering the GB as well but for the period 1960−2005. They found increasing trends in mean annual temperature and precipitation over Upper Indus Basin. From the above studies it is clear that changes in both precipitation and temperature (Meteorological drivers) are main indicators of climate change in Pakistan. Further precipitation trends have increased with increase in mean annual temperature in the hilly areas of Pakistan. All studies mentioned above used long term historical data while our interest was to analyze precipitation trends in the post-industrial era (the period of rapid industrial development starting from 1980). Similarly, precipitation over the GB is the major source of water supply to the Indus River which meets most of the irrigation and domestic water demands. Thus it was essential to carry out a detailed study to analyze trends in precipitation by using the most recent data that represent period of rapid growth in industries and selecting stations which cover the entire GB province. In addition, this study aimed to identify precipitation trends in the GB on seasonal and annual basis.

2. Study area

Six climatic stations within the GB province are shown in Figure 1 and Table1. GB is located in the high-altitude Himalaya and Karakoram ranges of Pakistan. The seasonal and stable snowfields and glacierized area above 3500m in elevation causes perennial flow in River Indus downstream. Almost 90% of the flow in River Indus originates from these mountain ranges located in and around GB (Messerli et al., 2004). Thus GB can be considered as a major region in Pakistan which ensures sustainable water flow in River Indus. This region covers a greater volume of snowpacks outside the poles and Alaska (Phillips et al., 2000). The water flow in River Indus is characterized by snowmelt within GB which is high in summers. It has been estimated that the snowmelt within GB contributes more than 50% of the total flow in the River Indus while the remaining is contributed by the mountains outside GB (Messerli et al., 2004). Because of the highest altitude agriculture is not fairly possible though orchards and small fields do exist. The region has greater number of glaciers which are largest in terms of area and volume like Siachin, Baltoro, Biafo etc. The most famous is the Siachin glacier which is 75 km long and covers a total area of 1181 Km^2 (Phillips et al., 2000). Thus GB is a mountainous belt of Pakistan which assists in sustainable agricultural productivity under the effect of snowmelt and perennial river flow downstream.

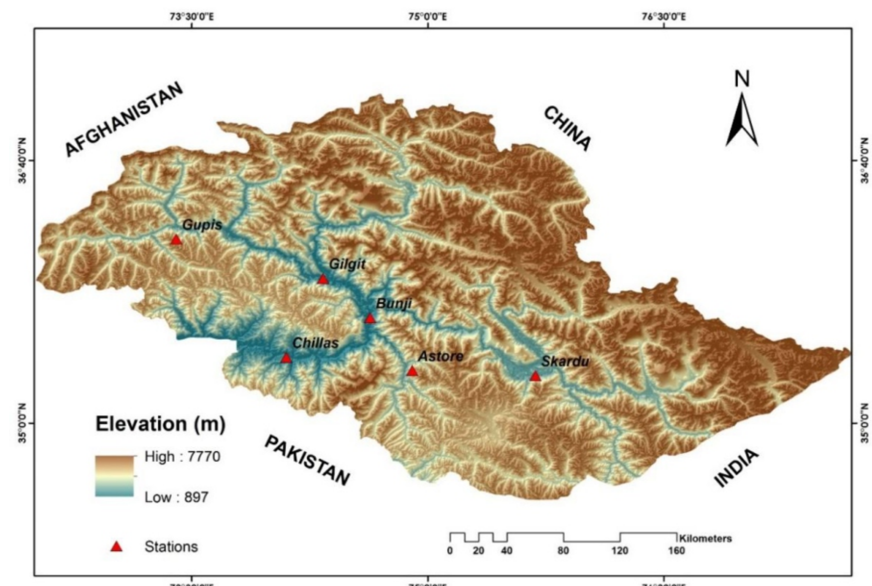

Fig. 1. Locations of six weather stations in the study area.

Table 1. Climatic stations with location and elevation above mean sea level (a.m.s.l.) in meters.

Study area	Station	Latitude	Longitude	Average Altitude a.m.s.l. (m)
Gilgit Baltistan (Pakistan)	Astor	35°20′	74° 54′	2168
	Bunji	35°40′	74°38′	1372
	Chilas	35°25′	74° 06′	1251
	Gilgit	35°55′	74° 20′	1460
	Gupis	36°10′	73° 24′	2155
	Skardu	35°18′	75° 41′	2210

Table 2. Seasons of Gilgit-Baltistan based on variations in monthly precipitation.

Season	Months
Winter	November, December, January, February, and March
Pre-monsoon	April, May and June
Monsoon	June, July, August and September
Post-monsoon	October and November

3. Data and methodology

Historical daily precipitation data for six stations of the GB province was provided by the Pakistan Meteorological Department (PMD).The period from 1980 to 2015 being latest was chosen for trend analysis. Monthly precipitation was aggregated from the daily precipitation. These monthly values of precipitation were used to calculate the seasonal and annual precipitation. The regional precipitation index was developed using monthly precipitation of the six weather stations in the GB. Keeping in mind the monthly variation in precipitation amount, we divided the seasons of the GB into four categories as shown in Table 2. This classification helped us to identify months and seasons with highest and lowest precipitation amounts and their associated trends. In this study, we used the non-parametric Mann-Kendall (MK) test which does not depend on the assumption that data belongs to some specific probability distribution.

Mann-Kendall test is a rank-based non-parametric test having greater power to deal with outliers in the data of hydrological events (Onoz and Bayazit, 2003). The test is least sensitive to abrupt breaks due to in homogeneous time series. In general MK test is capable to deal non-normal data of any hydrological process or extreme events. The MK test has been widely used by various researchers for evaluating trends of various hydro-metrological parameters (e.g., Chen et al., 2007; Khattak et al., 2011; Arunet al., 2012; Christopher et al., 2012; Thelma et al., 2014; Khattak and Ali, 2015).

In time series analysis it is necessary to take into account autocorrelation or serial correlation, defined as the correlation of a variable with itself over successive time intervals, prior to testing for trends. Autocorrelation in any data increases the chances of detecting significant trends even if they do not exist and vice versa. To overcome this problem, Yue et al. (2002) suggested the Trend Free Pre-Whitening (TFPW) approach for taking into account the effect of serial correlation. The TFPW has been recognized as the most reliable technique to incorporate the effect of serial correlation on the outcome of the trend identification tests (Khaliq et al., 2009). In this study, the data series was tested for serial correlation effect at 10% significance level. The non-zero slope (β) of a trend in sample data was estimated using the Theil (1950) and Sen (1968) approach. The test statistic of MK test (Zmk) is used as a measure of significance of trend. Upward trend is observed when Zmk has a positive value and vice versa. The critical value of Zmkat 10% significance level is 1.65. Trend is considered significant at 10% level if Zmk> 1.65 and vice versa.

4. Results and discussions

The MK test statistic (Zmk) and Sen's slope (SS)(mm/year) were calculated for pre-whitened data of rainfall (mm/year) on seasonal and annual basis for six climatic stations of the GB. Mean annual and mean seasonal (winter, pre-monsoon, monsoon and post-monsoon) precipitation amounts along with maximum and minimum values were calculated to depict seasonal and annual variations at different stations.

4.1. Trends in precipitation at climatic stations

4.1.1 Annual trends at stations

Figure 2 shows the time series data and their corresponding trends. Increasing trends were observed in mean annual precipitation at five stations namely Bunji, Chilas, Gilgit, Gupis and Skardu in which only Gupis observed significant trend (7.348 mm/year) as seen in Table 3. Only one station namely Astore suffered non-significant decreasing trend with a SS of -3.055 mm/year. On annual basis 83% area has increasing trends in mean annual precipitation while 17% area showed decreasing trends (Table 3). These increasing trends in mean annual precipitation at five climatic stations will ensure adequate water supply to the Indus River if continue in future. Further that ground water recharge will be sufficient to meet domestic and industrial water demands in downstream areas. However poor water management may lead to flood in the Indus River causing considerable damage to crops, agricultural land and humans in plains of Punjab and Sindh.

In Table 3, bold values indicate significant results at 10% significance level while Zmk denotes MK test statistic, NS means Not Significant, S means Significant.

4.1.2. Seasonal trends at stations

Results of the MK test revealed an increasing trend in monsoon precipitation at all climatic stations in which only two stations namely Gupis (0.59 mm/year) and Skardu (1.49 mm/year) had significant trends while the rest had non-significant trends (Table 4). This increasing trend in monsoon precipitation clearly shows the approach of monsoon winds arising from Bay of Bengal and causing rainfall in the GB. Monsoon rainfall often causes floods in the Indus River and results in great financial and human losses in Punjab and Sindh Provinces. Increasing trend in winter precipitation was seen at all stations except Astore and Chilas where it was decreasing. Among all stations, significant increasing trend in winter precipitation was observed only at Gupis with an SS of 2.15 mm/year, the rest being non-significant (Table 4). This increasing trend in winter precipitation will result in greater snow stocks which will ensure continuous water supply in the Indus River. Snowmelt is the main source of perennial flow in major rivers of Pakistan providing water for all sectors especially irrigation and hydro-power generation. As far as the post-monsoon precipitation is concerned, it observed increasing trends at Bunji and Gupis and decreasing trends at rest of the stations (all being insignificant) as shown in Table 4. Since water demands for irrigation are not considerable in the post-monsoon period (October, November), therefore changing trends in rainfall may not affect crop productivity downstream.

Further analyzing the trend of precipitation indicated that half of stations (Astore, Bunji and Chilas) exhibited decreasing insignificant trends and the remaining stations were found with the increasing trends for the post-monsoon precipitation (All insignificant). All significant and increasing trends (four) were observed only at Gupis (winter, pre-monsoon and monsoon) and Skardu (monsoon). From this we deduced that the Northern (Gupis) and Southern parts (Skardu) of the GB have been more affected by climate change and this resulted in increasing seasonal trends in precipitation. The effect of climate change due to multiple factors is more focused towards monsoon and post-monsoon seasons.

4.2. Annual and seasonal trends over the whole region (GB)

Results from the MK test for entire region of the GB revealed increasing trends in all seasons (except post-monsoon season) and on annual basis, all being insignificant. However

Table 3. Results of MK statistic (Zmk) with trend slope (mm/year) for mean annual precipitation at six climatic stations of GB.

Station	Z_{mk}	Statistical Nature	Sen's Slope
Astor	-1.13	NS	-3.055
Bunji	0.51	NS	0.716
Chilas	0.85	NS	0.756
Gilgit	1.13	NS	1.309
Gupis	**3.46**	**S**	**7.348**
Skardu	0.95	NS	1.756

among all non-significant results, the strongest change (positive trend) was seen in mean annual precipitation with an SS of 1.47 mm/year over the GB (Table 5). Among seasons, the strongest positive trend was observed in monsoon season with an SS of 0.62 mm/year (Table 5). A non-significant decreasing trend in post-monsoon precipitation was noticed at the rate of -0.10 mm/year over the GB. Similarly, on regional basis most trends (both seasonal and annual) were found positive during the period 1980−2015 (Table 5). . These increasing trends in monsoon precipitation may pose a serious threat in the form of floods.

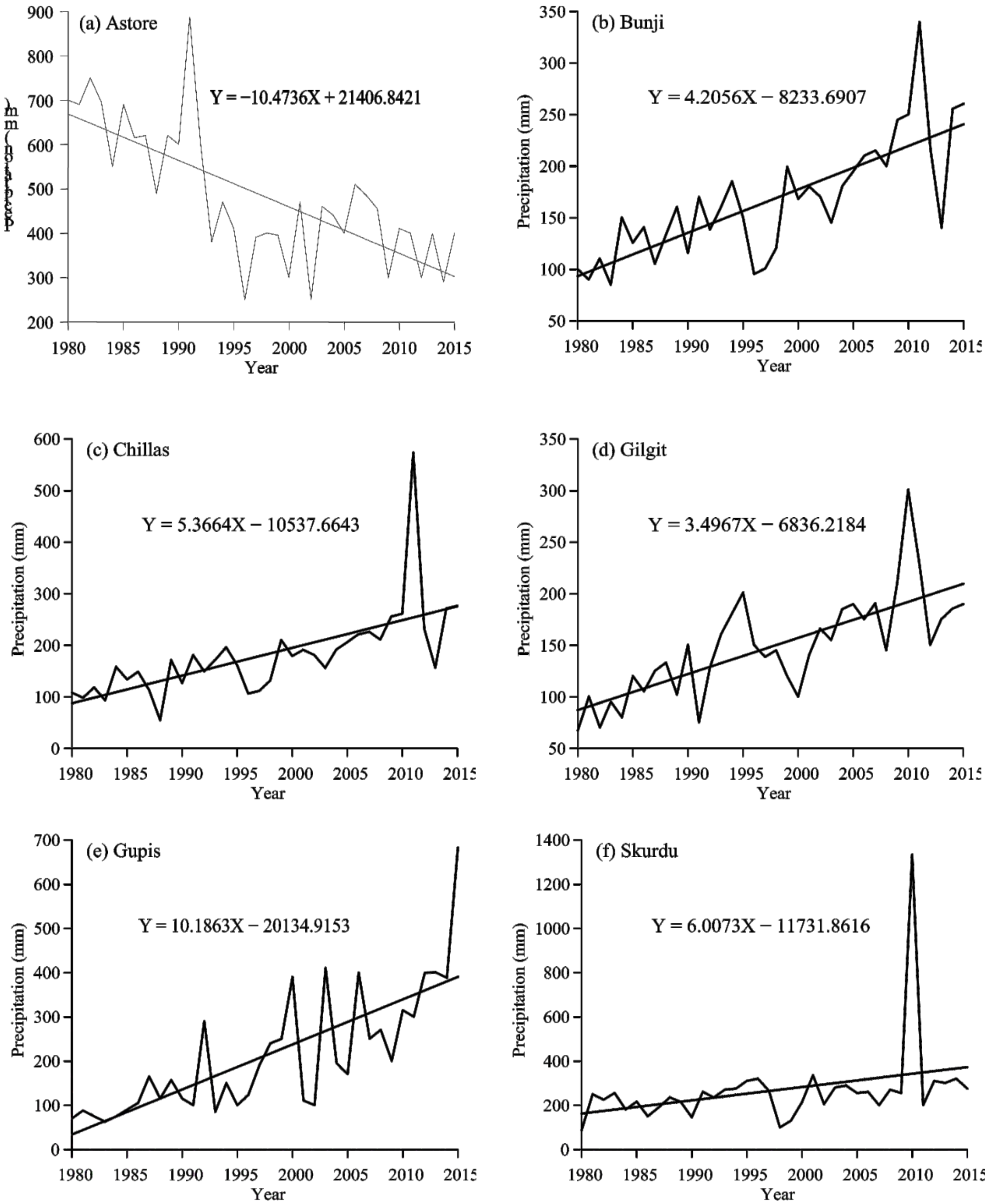

Fig. 2. Rainfall trends at different weather stations of the study area.

Table 4. Results of MK statistic (Zmk) with trend slope (mm/year) for mean seasonal precipitation at six climatic stations

Station	Season	Z_{mk}	Statistical Nature	Sen's Slope
Astor	Winter	-0.08	NS	-0.15
	Pre-monsoon	-0.33	NS	-0.39
	Monsoon	0.88	NS	0.53
	Post-monsoon	-1.27	NS	-0.57
Bunji	Winter	0.82	NS	0.42
	Pre-monsoon	-0.50	NS	-0.18
	Monsoon	0.93	NS	0.60
	Post-monsoon	0.30	NS	0.00
Chilas	Winter	-1.12	NS	-1.03
	Pre-monsoon	-0.64	NS	-0.33
	Monsoon	1.07	NS	0.41
	Post-monsoon	-0.08	NS	0.00
Gilgit	Winter	0.62	NS	0.32
	Pre-monsoon	0.08	NS	0.12
	Monsoon	0.91	NS	0.12
	Post-monsoon	-0.45	NS	-0.04
Gupis	Winter	**3.56**	**S**	**2.15**
	Pre-monsoon	**1.80**	**S**	**1.22**
	Monsoon	**2.18**	**S**	**1.49**
	Post-monsoon	1.46	NS	0.17
Skardu	Winter	0.76	NS	0.93
	Pre-monsoon	0.81	NS	0.48
	Monsoon	**1.89**	**S**	**0.59**
	Post-monsoon	-1.57	NS	-0.16

Table 5. Results of MK statistic (Zmk) with trend slope for mean annual and seasonal precipitation over the whole region (GB)

Season	Z_{mk}	Statistical Nature	Sen's Slope
Winter	0.76	NS	0.44
Pre-monsoon	0.20	NS	0.15
Monsoon	1.31	NS	0.62
Post-monsoon	-0.27	NS	-0.10
Annual basis	0.961	NS	1.47

In Table 4 and 5, bold values indicate significance results at 10% significance level while Zmk denotes MK test statistic, NS means Not Significant, S means Significant.

Upstream water supply is crucial to sustain downstream water reservoir system, which is used to store and release water for irrigation when needed. Indus Basin Irrigation System is the world largest irrigation network, which is regulated through two major storage dams (Tarbela dam on the Indus River and Mangla dam on the Jhelum River). Both are located in the upper Indus basin and are fed predominantly by snowmelt water. Any change in upstream water supply will have profound effect on millions of people living downstream. Nearly 70% population of Pakistan depends on agriculture for their livelihood. Thus any negative change in water supply in the Indus River will directly impact the lives of this population segment. This study investigated variability in seasonal and annual precipitation at 6 stations in the upper Indus basin over a 36-year study period (1980−2015). The results of this study are contrary to those reported by Salma et al. (2012) indicating that the GB is not affected by country level decreasing rainfall trends. It is also interesting to note that two provinces in Pakistan namely Punjab and the GB have observed positive trends in precipitation though country level trend was negative. In this study an increasing trend of annual precipitation was observed which might be considered as one of the cause of increasing trends in stream flow in the Indus River. Increasing precipitation trends in the GB will cause sufficient water supply for agriculture and other sectors in Punjab and Sindh. However, increasing precipitation trends in monsoon season in the GB might result in severe floods and considerable damage to property and cultivated lands in downstream areas.

5. Conclusions

Using the daily precipitation data from the Pakistan Meteorological Department, this study identified the seasonal and annual trends for the period 1980−2015 for six climatic stations of the GB and then the entire region. Trends identification was carried out using the non-parametric MK test and SS. All positive and negative trends in precipitation might be attributed to regional climate changes, local land use and global warming in general. It is strongly emphasized that water resource planners must consider these changes while framing policies related to effective water management. Following specific conclusions were derived from this study:

1. At station level, five out of six climatic stations have experienced increasing trends in rainfall on annual basis in which only one station (Gupis) has revealed significant value, i.e. at the rate of 7.34 mm/year. The only negative trend among all stations was seen at Astore having an SS of 3.05 mm/year.
2. At station level, increasing trend in monsoon precipitation at all climatic stations was noticed in which only two stations namely Gupis (1.49 mm/year) and Skardu (0.59mm/year) had significant values. Among all stations, significant increasing trend in winter precipitation was observed only at Gupis with an SS of 2.15 mm/year, the rest being non-significant. The post-monsoon precipitation observed increasing trends at Bunji and Gupis and decreasing trends at rest of the stations (all being insignificant). In addition, half of the stations experienced decreasing insignificant trends and in the remaining stations increasing trends for the post-monsoon precipitation (All insignificant).
3. Precipitation trend in the post-monsoon season was decreasing in almost all areas of the GB with gradually getting drier season.
4. The overall mean seasonal and annual precipitation results for the GB were found having insignificant increasing trends. Highest positive trend found was the mean annual precipitation at the rate of 1.47 mm/year (Table 5).
5. Increasing precipitation trends in the GB could ensure sufficient water supply for agriculture and other sectors in the Punjab and Sindh province. However, increasing precipitation trends in monsoon season in the GB could be one reason for severe floods in the Indus River and might result

in considerable damage to property and cultivated lands in downstream areas.

Acknowledgment

We would like to express our sincere gratitude and appreciation to the Pakistan Meteorological Department (PMD) for providing precipitation data.

Author's contribution

Muhammad Shahzad Khattak supervised this research work during MSc Engineering. Sajjad Ali has studied the literature and developed the methodology to accomplish all the necessary analyses. He is the main author of this manuscript. Muhammad Ajmal has structured the paper, drew figures, and carried out the possible proof reading. Safeer Ullah Shah was involved in GIS based maps development and his expertise have been utilized to identify stations used in this study.

References

Arun, M., Sananda, K.,Anirban, M., 2012. Rainfall trend analysis by Mann−Kendall Test: A case study of North-Eastern part of Cuttack District, Orissa, India. International Journal of Geology, Earth and Environmental Sciences, 2(1), 70 -78.

Atif, I., Mahboob, A.M., Iqbal, J., 2015. Snow cover area change assessment in 2003 and 2013 using MODIS data of Upper Indus Basin, Pakistan. Journal of Himalayan Earth Sciences, 48(2), 117-128.

Chen, H., Guo, S., Xu, C., Vijay, P.S., 2007. Historical temporal trends of hydro−climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin. Journal of Hydrology, 344, 171-184.

Christopher, J.M., Jerome, J.M., Martin, F.M., 2012. Trends in precipitation and temperature in Florida, USA. Journal of Hydrology, 452- 453, 259-281.

Frich, P., Alexander, L.V., Delaa-Marta P., Gleason, B., Haylock, M., Klein, T.A.M.G., Peterson, T., 2002. Observed coherent changes in climate extremes during the second half of 20th Century. Climate Research, 19, 193-212.

Keggenhoff, I., Elizbarashvili, M., Farahani, A.A., King, L., 2014. Trends in daily temperature and precipitation extremes over Georgia (1971- 2010). Weather and Climate Extremes, 4, 75-85.

Khaliq, M.N., Ouarda, T.B.M.J., Gachon, P., Sushama, L., St−Hilaire, A., 2009. Identification of hydrologic trends in the presence of serial and cross correlations: A review of selected methods and their application to annual flow regimes of Canadian rivers. Journal of Hydrology, 368, 117-130.

Khattak, M.S., Babel, M.S., and Sharif, M., 2011. Hydro-meteorological trends in the upper Indus basin in Pakistan. Climate Research, 46, 103-119.

Khattak, M.S., Ali, S., 2015. Assessment of temperature and rainfall trends in Punjab province of Pakistan for the period 1961-2014. Journal of Himalayan Earth Sciences, 48(2), 42-61.

Messerli, B., Viviroli, D., Weingartner, R., 2004. Mountains of world: water towers for 21st century. Berne (Switzerland): Paul Haupt. Special Report Number 13. The Royal Colloquium: Mountain Areas: A Global Resource, 29-34

Maida, Z., Ghulam, R., 2011. Frequency of extreme temperature and precipitation events in Pakistan 1965-2009. Science International (Pakistan), 23(4), 313-319.

Naheed, G., Kazmi, D. H., 2013. Seasonal variation of rainy days in Pakistan. Pakistan Journal of Meteorology, 9(18), 9−13.

Onoz, B., Bayazit, M., 2003. The power of statistical tests for trend detection. Turkish Journal of Engineering Environmental Sciences, 27, 247–251.

Phillips, W., Sloan, V., Shroder, J., Sharma, P., Clarke, M., Rendell, H., 2000. Asynchronous glaciation at Nanga Parbat, Northwestern Himalaya Mountains Pakistan. Geology, 28(5), 431−434.

Rasul, G., Mahmood, A., Sadiq, A., Khan, S.I., 2012. Vulnerability of the Indus delta to climate change in Pakistan. Pakistan Journal of Meteorology, 8(16), 89−107.

Raza, M., Hussain, D., Rasul, G., Akbar, M., Raza, G., 2015. Variation of surface temperature and precipitation in

Gilgit−Baltistan (GB), Pakistan from 1955 to 2010. Journal of Biodiversity and Environmental Sciences, 6(2), 67−73.

Salma, S., Rehman, S., Shah, M.A., 2012. Rainfall trends in different climate zones of Pakistan. Pakistan Journal of Meteorology, 9(17), 37-47.

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of American Statistical Association, 63, 1379–1389.

Theil, H., 1950. A rank invariant method of linear and polynomial regression analysis, Part 3. Netherlands Akademie van Wettenschappen, Proceedings, 5, 1397–1412.

Thelma, A.C., Rusalina, G.D.G., Flaviana, D.H., David, M. W., 2014. Long−term trends and extremes in observed daily precipitation and near air surface temperature in the Philippines for the period 1951−2010. Atmospheric Research, 145−146, 12−26.

Yue, S., Pilon, P.J., Phinney B., Cavadias, G., 2002. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrological Processes, 16(9), 1807-1829.