R E S E A R C H A R T I C L E c o h e r e n t

Influence of Teleconnections on the Precipitation

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Abstract

Precipitation plays vital role in the economy of agricultural country like Pakistan. Baluchistan being the largest province of Pakistan in term of land is facing reoccurring droughts as well as flashflood due unprecedent torrential precipitation pattern. It is quite intriguing to observe the changing pattern of precipitation in Baluchistan. Precipitation has become less frequent but intense in nature which results in flash flooding, landslides, damages to the infra-structure, trade, environment, and ecosystem. Decrease in precipitation are leading to droughts, crop destruction and food scarcity. The assessment of variability in the precipitation trend in Baluchistan is of paramount importance because among all the provinces, Baluchistan is the worst hit, it's under drought warning by Pakistan metrological department (PMD) and already facing water crisis. No substantive studies have been carried out in analyzing the trends in precipitation in Baluchistan. This situation might put China-Pakistan Economic Corridor (CPEC) at risk also. This study is performed on monthly precipitation time series from PMD for determining trends in precipitation on 41 years data from 1977 to 2017 over 13 selected stations in Baluchistan. Due to the non-linear nature of the precipitation data, non-parametric Mann-Kendall (MK) test was used to determine the increasing or decreasing trends in precipitations on monthly basis. Large scale atmospheric circulations and climate indices that affect precipitation were considered to determine their influence on precipitation. The linear association between the climatic indices and Global Precipitation climatology Project (GPCP) precipitation in the monthly time series is determined using Pearson's Correlation. The Partial Mann Kendall test was used to determine the variation in the trend under the influence of climate indices. This study shows that decreasing trends in precipitation are more pronounced rather than the increasing trends and this variation in trends have been explained by the moderate to the strong influence of climate indices on precipitation trends in Baluchistan.

KEYWORDS

Teleconnections, Precipitation, Mann Kendall, Partial Mann Kendall, Climate Indices, Trends

1. Introduction

Atmospheric linkage like climate indices strongly control the precipitation and droughts around the world. All around the globe, these climate indices/teleconnections are influencing far-flung as well as nearby regions predominantly through large scale, Qausi stationary atmospheric Rossby waves, consequent of which some regions receive more rainfall or are hotter than the prevailing global scale changes (IPCC.2014). Climate variations are mainly due to large scale ocean circulations, atmospheric circulations, moisture transportation, wind speed, wind direction and heat fluxes etc. Large scale ocean circulations are studied under the influence of teleconnections (Wallace and Gutzler 1981), which reflects our climate pattern (Lucas et al. 2011; Vermeer and Rahmstorf, 2009). Analysis of teleconnections its impact and influence can help apprehend climate and precipitation pattern (Krichak et al. 2014). Pakistan, Indian and China have experienced erratic flash flooding in past few decades due to unprecedented torrential precipitation, (Viterbo et al. 2016; IPCC 2014; Hussain MS, Lee S (2013;2014) Wang et al. 2011; Webster et al. 2011). Robust analysis of unpredicted precipitation is very important to figure out major issues, such as, flooding, landslides, crop destruction, property damage, Losses to the infra-structure, trade, communication, environment, economy and ecosystem, etc. (Bastiaanssen and Ali 2003).

This study is eminent for Pakistan because it is ranked 8th most affected country from 1998 to 2017 by Climate Risk Index (GCRI 2019), having the death toll of 512 people, with total the loss of US$ 3.8 Billion and the total 145 number of events that struck Pakistan in ten years 1998–2017 (GCRI 2019). Pakistan was also ranked as the third most affected country in 2012 by the impact of climate change (Kreft and Eckstein 2013). According to United Nations Development Program me (UNDP) and the Pakistan Council of Research in Water Resources (PCRWR) reports that by 2025 Pakistan will be water scare country from water stressed country if it does not take serious measure and steps now, the situation gets worsen in Baluchistan – the study area in particular due to the fact that water is even now scarce in the area and precipitation which is the main source of water is decreasing. Baluchistan also suffers from devastating, sporadical, catastrophic flash flood due to unprecedented precipitation. Additionally, the contemporary significance of the region is far more than ever before due to China-Pakistan Economic Corridor (CPEC) stretching throughout the province and due to Gawadar port. Moreover, this study would be useful for policy makers to comprehend the latest situation in view of climate change and make policies accordingly (IPCC, 2013).

Teleconnections indices are employed to study climate variability on monthly, seasonal, as well as large time periods. Arctic Oscillation (AO), Indian Ocean Dipole (IOD), El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Atlantic Multi-decadal Oscillation (AMO), Quasi-Biennial Oscillation (QBO) and Pacific Decadal Oscillation (PDO) are commonly used circulation indices to assess precipitation variability over Pakistan. Liu D., et al. 2012; Athar H., 2015; Wu et al. 2013 conducted research to study precipitation variation linked with large scale atmospheric and ocean circulation indices on South Asian region. Nevertheless, fewer studies have been undertaken to analyze precipitation variation linked with large scale atmospheric and ocean circulation indices regarding Pakistan, which is among the most vulnerable country according to Global Climate Risk Index (Krishnamurthy and Krishnamurthy (2017); Liess and Geller (2012).

Iqbal and Athar. (2017) uses Pearson’s correlation to determine the influence of climatic indices, namely NAO, AO, AMO, IOD, PDO, QBO and ENSO on precipitation with 80% and above significance level for the positive and negative phases of the indices separately. It was found out that IOD has a positive correlation for its positive phase, the Positive (Negative) phase of AO shows the correlation and PDO shows positive correlation and ENSO exhibits correlation in Baluchistan monthly.

In this study nonparametric Mann Kendall test is used to assess the monthly precipitation trend. The variation in trend in the presence of climate indices is determined by using Partial Mann Kendall, which is the best one step method that do the adjustment for the covariate and trend detection at the same time.

2. Study Area

The Province of Baluchistan is selected as the study area for this research. It is the largest province of Pakistan with an area of 347,190 square kilometers which is nearly 44 % of Pakistan’s totals land area and forms the southwestern part of the country as shown in Figure-1(Naz et al. 2020; Ashraf et al. 2017; Shahid et al. 2004). Baluchistan is arid, rugged with both plain and mountainous areas. The climate is hot desert type with extreme heat and cold (Ali et al. 2020; Butt and Iqbal 2009). The main financial, monetary, economic, and commercial source of growth of Baluchistan is its coastline on the Arabian Sea and renewable resources like natural gas, coal, precious stones, gems, zinc, lead, marble, and copper etc. Baluchistan is the area of great importance being part of CPEC nowadays and mainly depends on the sustainable rainwater.

The two important elements which affect the weather of Pakistan are monsoon and the Western Disturbance. Light to moderate precipitation in southern parts of the country while moderate to heavy precipitation with heavy snowfall in the northern parts of the country are caused by Western Disturbances typically occurs in the winter months. Monsoon occurs in summer from June till September in almost whole Pakistan excluding Western Baluchistan, FATA, Chitral and Gilgit–Baltistan. These monsoon rains are rather heavy by nature and can cause significant flooding if they interact with western disturbance in the Northern parts of the country. Tropical Storms usually occurs in pre-monsoon months from late April till June and then from late September till November forms usually and affect the coastal localities. When there is no precipitation then mostly Continental air prevails during that period (Hussain and lee 2014; Hanif et al. 2013; Maida and Ghulam 2011).

The weather of Baluchistan is mainly affected by Western Disturbances in winter and spring months. It is less affected by Monsoon in summers and to some extent with tropical storms in coastal areas in autumn (Naz et al. 2020; Gadiwala et al. 2019; Aamir and Hassan 2018; Ahmed et al. 2015; Ashraf et al. 2015).

3. Data Collection and Preparation

Precipitation Data

Monthly Precipitation data in millimeters, for this research was acquired from Pakistan Meteorological department (PMD). Thirteen stations throughout Baluchistan were carefully chosen based on accuracy, completeness and availability of data for the selected study period of 41 years. Thirteen stations all over Baluchistan are shown in Figure-1.

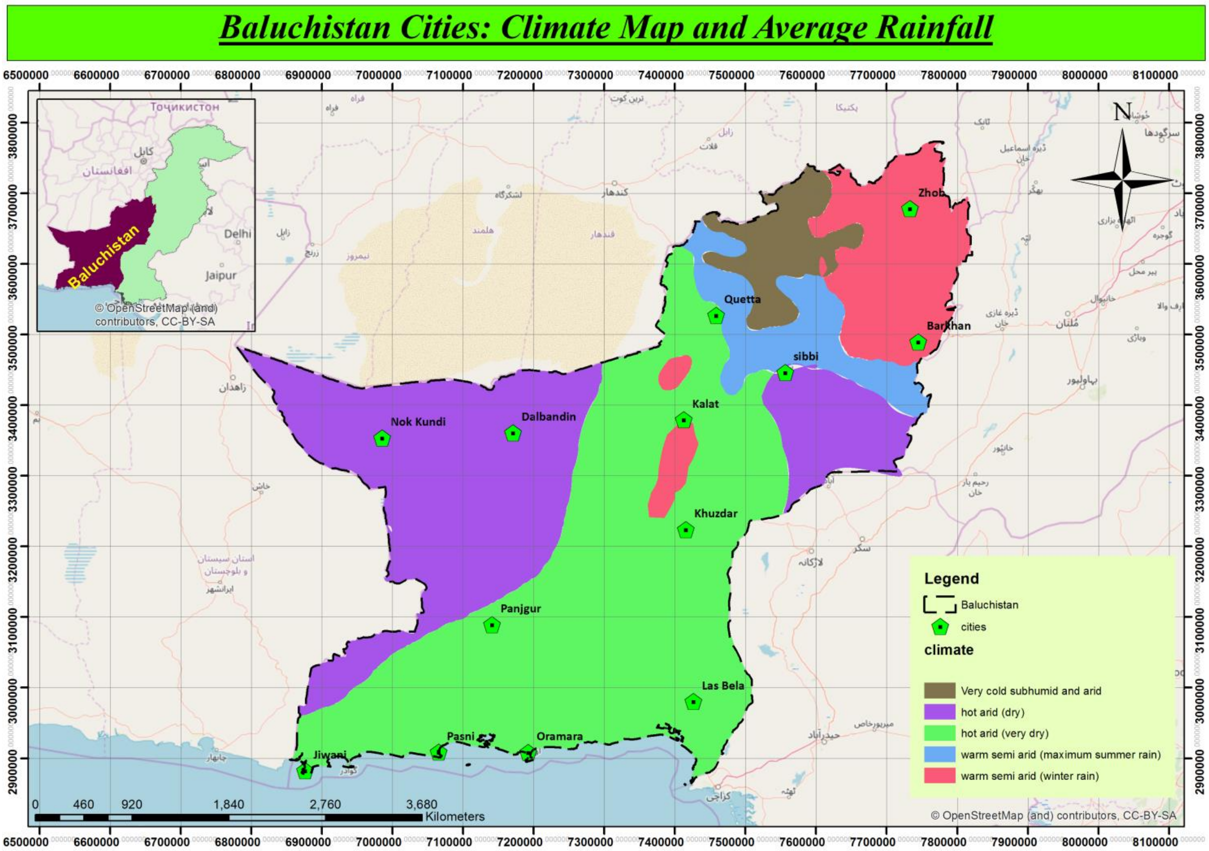


FIGURE 1 The Location Map of Selected PMD Stations in Baluchistan (Figure courtesy of PMD Pakistan).

The Study period constitute of forty-one (41) years from 1977-2017 for the designated 13 different stations in Baluchistan, namely Barakhan, Dalbandin, Jiwani, Kalat, Khuzdar, Lasbella, Nokkundi, Ormara, Pasni, Punjgur, Quetta, Sibbi and Zhob. Data collected from PMD was on the monthly basis in (mm/month) for each of the weather stations, which were averaged to convert them to annual precipitation data for analysis.

The average rainfall monthly and annually within the study period from 1997-2017 over each of the 13 different stations in Baluchistan is tabulated below in Table-1.

Table-1 Average Precipitation from 1977-2017

Stations	Winter				Spring/Pre-Monsoon			Monsoon			Post-Monsoon	
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Barakhan	6.5	13.1	21.1	31.3	34.6	24.7	48.2	108.4	84.6	35	9.1	4.9
Dalbandin	9.4	16.8	16	20.5	4.8	1.3	3	3.7	0.7	0.1	2.2	3.1
Jiwani	20.2	22.9	22.5	14.3	3.7	0.1	7.6	3	2.3	0	1.1	3.6
Kalat	30.3	34.7	37.8	31	11	3.9	6.7	16.3	13.4	4.6	5	5.8
Khuzdar	14.7	16.5	30.9	29.3	16.3	14.1	16.5	51.2	56.6	9.1	6.5	4.3
Lasbella	7.3	4.8	11.4	10.4	7.4	19.7	11.2	53.2	39.3	8.6	5	1.9
Nokkundi	2	7.8	9.6	8.7	2.2	0.2	2	0.7	0.3	0	0.5	0.6
Ormara	11.8	10.7	10	9.9	1.6	0.2	9.7	11.3	3.8	0.3	2	0.5
Pasni	19.8	22	14.9	16.4	2.3	0.5	6.7	5.2	7.7	0.5	2.3	1.7
Punjgur	10	12.8	15	15.1	8.3	3.5	5	12.1	7.7	1.7	2.1	1.6
Quetta	30.8	53.8	51.7	55.5	26	7.5	4	12.5	11.1	3.1	5.7	8.8
Sibbi	5.6	10.1	17.9	22.3	9.8	6	15.7	38.6	39.1	12.4	3.1	1.6
Zhob	9.2	17.1	26.9	43.5	29.1	14.8	17.7	56.2	44.8	11.1	5.8	5.6
Monthly	13.7	18.7	22.0	23.7	12.1	7.4	11.8	28.6	24.0	6.7	3.9	3.4

Table-1 shows that western parts of Baluchistan such as Dalbandin, Jiwani, Kalat, Nokkundi, Ormara, Panjgur, Pasni, Quetta receives most of its rainfall in Winter Season due to the western disturbance and Eastern parts of Baluchistan such as Barakhan, Khuzdar, Lasbella, Sibbi and Zhob receives its most of the rainfall in Monsoon Season. Stations close to coastal areas also receives scattered rainfall in the post monsoon season when continental air prevails.

Climatic Indices and GPCP Data

Seven (7) different climatic indices, North Atlantic Oscillation (NAO), Artic Oscillation (AO), Atlantic Multi-decadal Oscillation (AMO), Indian Ocean Dipole (IOD), Quassi Biennial Oscillation (QBO), Pacific Decadal Oscillation (PDO), El Nino Southern Oscillation (ENSO-MEI), known to affect the precipitation in the study area through teleconnections were considered (Athar 2015, Iqbal et al. 2017; Athar 2015; Liu et al. 2012; Afzal et al. 2013). Climatic Indices data and Global Precipitation climatology Project (GPCP) Precipitation on 2.5º x2.5º global grid for months from January to December in the Baluchistan is obtained from NOAA/ESRL Physical Science division.

4. METHODOLOGY

In the monthly time series precipitation data at each of 13 stations trends are examined using Mann Kendall Tests. The reasons for adopting the Mann Kendall test is that it is strong and insensitive to the data with gaps and best for the data that is not normally distributed, The association between precipitation and climate indices is determined by Pearson’s correlation test; whereas the influence of climate indices (influencing variables) on Trends in precipitation is examined by the Partial Mann Kendall test. The tests are performed on individual stations for monthly time series data.

4.1. Mann Kendall for Trend Detection

Mann-Kendall (MK) statistical test was largely used in identifying trends in climate variables (Ahmad et al. 2015; Burn and Elnur 2002; Liu, Gao, Chen and Shao 2012; Chaouche, Neppel, Dieulin et al. 2010; Machiwal and Jha 2009; Verwon, Kramer, Becker and Pfister 2008; Yang, Xi, Liu, Li, Hu and Xia 2012; and Scarpati, Spescha, Lay and Capriolo, 2011).

The MK test is a procedure based on ranks and is not sensitive to sudden breaks in the uneven data. The nonparametric MK test is one of the strong methods of identifying monotonic trends in precipitation data where the data is skewed and/or where data is either consistently increasing or decreasing in a time series whereas MK test is not suitable when there are recurring trends.

In MK test, if (X1, X2,….., Xn) are a sample of n independent and identically distributed random variables of the rainfall data, then the Mann-Kendall statistic Sx of the series x is given (Yue. et al. 2002) as:

$$S = \sum_{i-l}^{n-1} \sum_{j=i+1}^{n} sgn\left(X_j - X_i\right)$$

$$sgn\left(X_j - X_i\right) = \begin{cases} +1 & \left(X_j - X_i\right) > 0 \\ 0 & \text{if } \left(X_j - X_i\right) = 0 \\ -1 & \left(X_j - X_i\right) < 0 \end{cases}$$

Where, i and j are the rank of observation of the xi and xj of the time series. The variance associated with Sx is given as

$$Var = \frac{n(n-1)(2n+5) - \sum_{i=1}^{g} t_i(t_i - 1)(2t_i + 5)}{18}$$

Where g is the groups of tied rank and t is ties in the group. For a sample size of n>10 or larger, the MK statistics Zmk is computed by

$$Z_{mk} = \begin{cases} \dfrac{S_x - 1}{\sigma} & for\ S_x > 0 \\ \dfrac{S_x + 1}{\sigma} & for\ S_x < 0 \\ 0 & for\ S_x = 0 \end{cases}$$

Positive Zmk values show increasing trends, while negative Zmk values reflect decreasing trends. If | Zmk | is greater than Z 1-α/2 for the chosen value of significance level, (α) then the trends are considered significant or when p-value is smaller than the significance level (α), the null hypothesis (Ho) of no trend is rejected in favor of alternative the hypothesis (Ha) and the trend is considered as a significant trend in the time series. Z 1-α/2 and p-value are obtained from the standard normal distribution table.

4.2. Pearson’s Correlation for Finding Linear Associations

Based on the method of covariance, Pearson's correlation is one of the best methods that measure the strength of linear association between the two variables. It provides the information about the magnitude and direction of the association. The direction can be positive or negative, and the magnitude ranges between +1, a perfect positive correlation and -1, a perfect negative correlation. A value of zero indicates that there is no linear correlation. It should be kept in mind that existence of significant correlation is not causation for the variables. The significance of the correlation is determined by the student t-test. The t-test establishes whether there is an evidence of significant correlation is present between the variables or not. The t-test is given by

$$t = \frac{r * \sqrt{n-2}}{\sqrt{1-r^2}}$$

Where, r and n are the correlation coefficient and number of observations in the data series respectively. For precipitation and climatic index being the two variables, Correlation is considered significant for the desired value of significance level (α) having n-2 degree of freedom if |t| is greater than the critical t1-α/2 or if p-value is smaller than the significance level (α). The null hypothesis of no correlation is rejected in favor of the alternative hypothesis that there is a significant correlation between the precipitation and climatic indices. The t1-α/2 and p-value are obtained from the student t-distribution table.

4.3. Partial Mann Kendall for Examining the Influence of Climatic Indices on Precipitation Trends

The influence of large-scale climatic and atmospheric indices (influencing variables) such as NAO, AO, AMO, IOD, QBO, PDO, ENSO-MEI on the precipitation time series was examined by adopting the partial Mann-Kendall (PMK) test. Libiseller and Grimvall 2002, Van Oldenborgh et al. 2005, Ashok et al. 2007, Hajani.E et al. 2017, Kumar N and Ouarda 2014, also used PMK in their studies.

PMK is one of the best one step procedures that do the adjustment for covariates (influencing variables) and trend testing simultaneously. In PMK, the effect of explanatory variables is studied on the response variable and the influence is calculated using the conditional mean and the conditional variance of the response variable. As given by Libiseller and Grimvall (2002), the test statistic for response variable y, with its covariate x being the explanatory variable is given by

$$PMK = \frac{S_y - \hat{\rho} S_x}{\sqrt{(1-\hat{\rho})n(n-1)(2n+5)/18}}$$

Where, Sy is the Mann Kendall statistics of response variable, Sx is the Mann Kendall statistics of explanatory variable, ρˆ denotes the conditional correlation between the MK statistics Sx and Sy. The PMK statistic is normally distributed with mean 0 and standard deviation 1. The details can be seen in Libiseller and Grimvall, 2002, studies.

5. Results and Discussions

Increasing or decreasing Trends were observed, when the uni-variate Mann Kendall test was run on the precipitation time series data. The effect of Climatic Indices as relevant covariates (influencing variables) was considered to assess the trends in precipitation by applying Partial Mann Kendall.

5.1. Trends in Precipitations

Monotonic Trends in precipitation from 1977 to 2017 at 13 stations of Baluchistan is found through Mann Kendall tests monthly at individual stations. Table-2 shows that out of 15 statistically significant trends, 10 were decreasing trends whereas 5 were increasing trends, which clearly shows that decreasing trend is dominating in most of the stations in Baluchistan which explained the decreasing rainfall prevailing in Baluchistan during the last couple of decades. Kalat, Lasbella, Nokkundi and Pasni showed no statistically significant trend in precipitation at 5% significance level. Barakhan showed decreasing trend in the month of January and November, Dalbandin, Jiwani and Khuzdar showed decreasing trends in December, Ormara showed decreasing trends in May, Panjgur showed decreasing trends in July and December, Quetta and Zhob showed decreasing trends in January. Barakhan showed the increasing trend in the month of June, Ormara showed increasing trends in May and October, Quetta showed increasing trends in June and September whereas Sibbi showed increasing trends in June.

TABLE 2
MONTHLY SIGNIFICANT INCREASING (DECREASING)
TRENDS IN PRECIPITATION – INDIVIDUAL STATIONS

Stations		Jan	May	Jun	Jul	Sep	Oct	Nov	Dec
Barakhan	S	(177)		175				(211)	
	p	4.62%		4.93%				1.07%	

Dalbandin	S								(208)
	p								1.65%
Jiwani	S								(245)
	p								0.37%
Khuzdar	S								(178)
	p								4.01%
Ormara	S		(205)				(407)		
	p		0.63%				0.00%		
Panjgur	S				(195)				(176)
	p				2.28%				3.51%
Quetta	S	(224)		206		153			
	p	1.19%		1.26%		3.14%			
Sibbi	S			186					
	p			2.59%					
Zhob	S	(201)							
	p	2.39%							

Where S is the Mann Kendall Statistics and p is the p-value of the Null Hypothesis (Ho) of no trend at 5% significance.

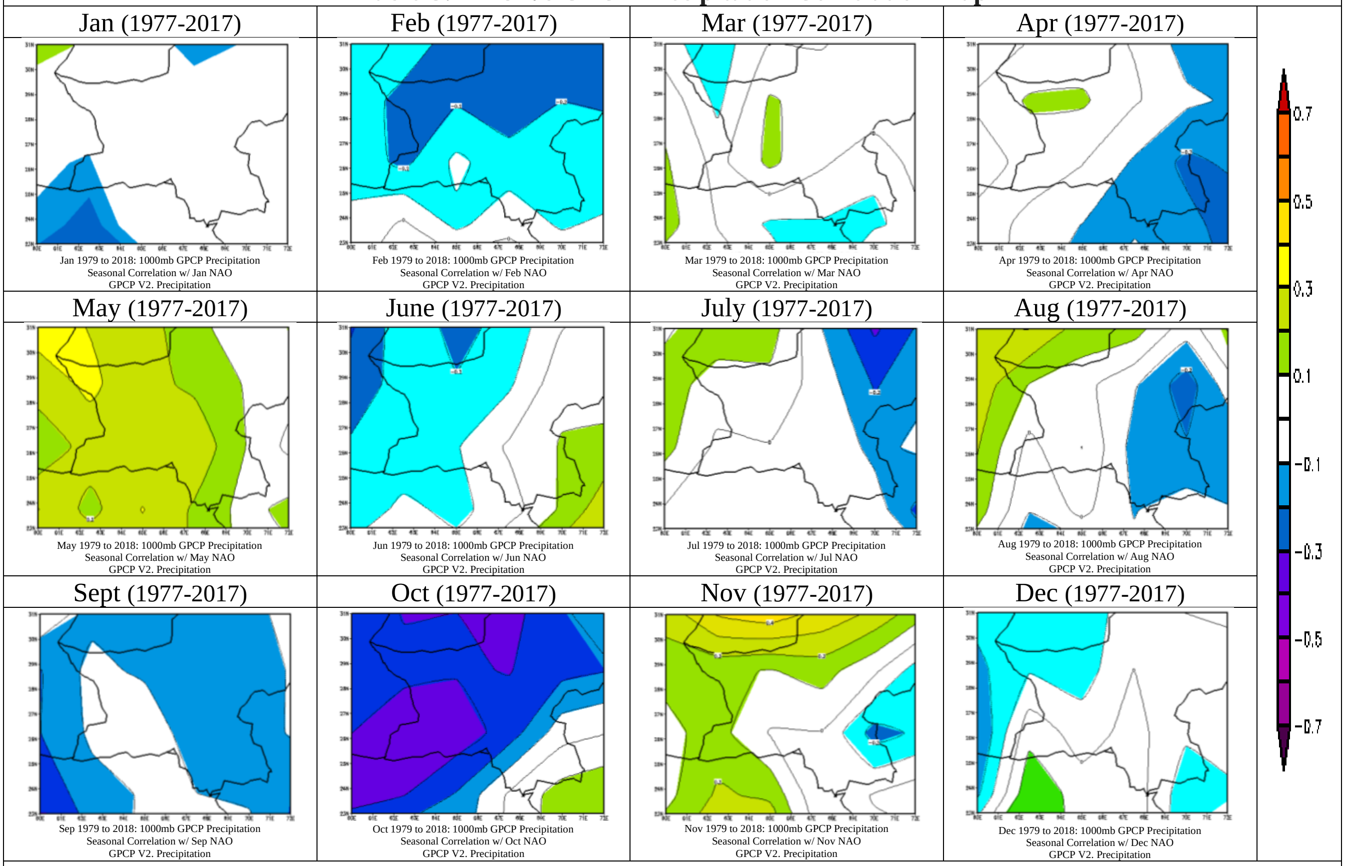
5.2. Linear Association of Climatic Indices with Precipitation

Pearson correlation is performed between the climate indices and GPCP gridded precipitation to check the association between the two variables. For a 41-year time series data, a correlation value of 0.316 (-0.316) or higher (lower) is considered significant for a two-tailed test at 5% significance level.

5.2.1. Association of NAO with Precipitation

The correlation contour map of Baluchistan (period 1977 to 2017 and months January to December) between NAO and GPCP for months from January to December in the Baluchistan. The correlation coefficient ranges from -0.4 to 0.4. The correlation map in Table-3 shows that NAO has a significant negative correlation with October GPCP precipitation.

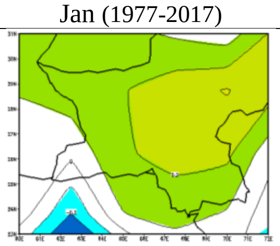
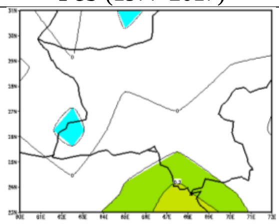
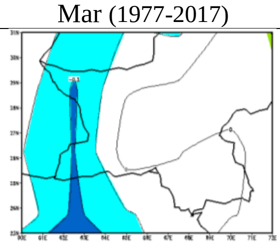
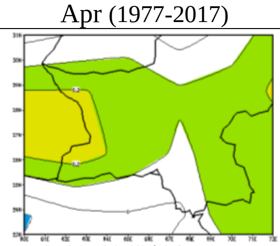
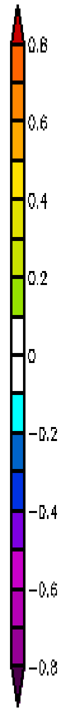
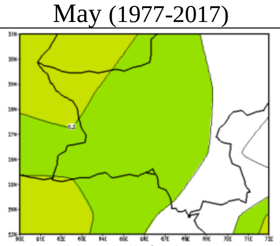
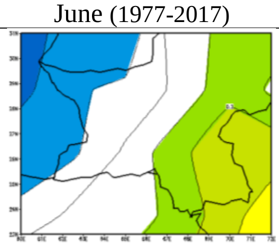
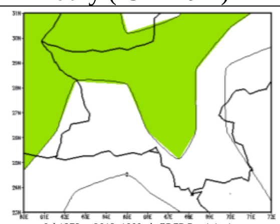
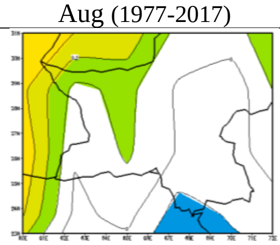
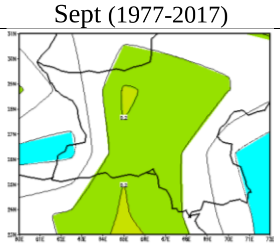
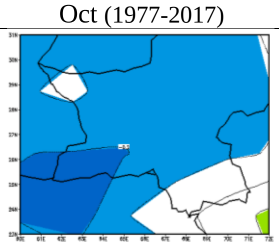
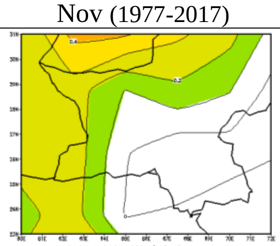
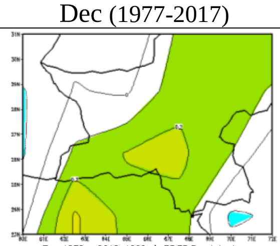
Table-3: NAO Vs GPCP Precipitation Correlation Map



Source: NOAA / ESRL Physical Science Division

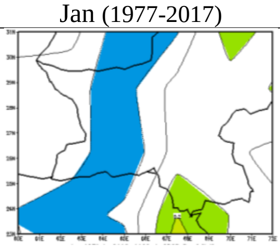
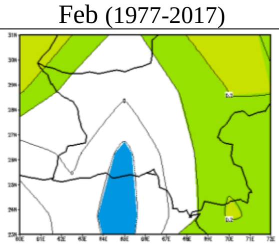
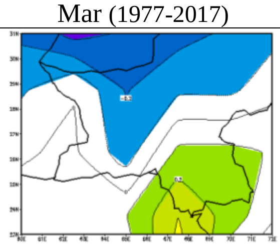
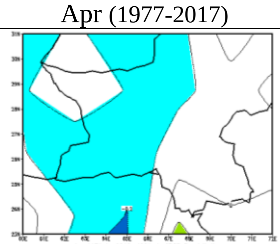
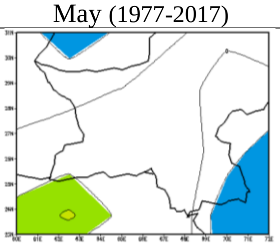
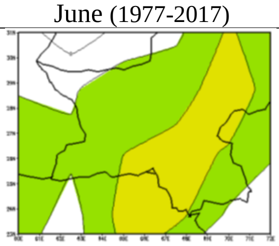
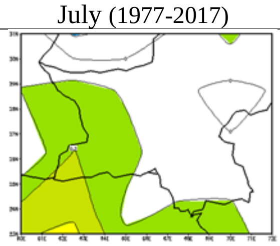
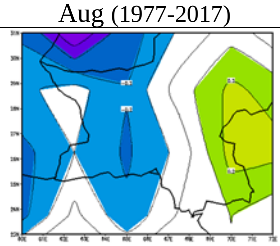
5.2.2. Association of AO with Precipitation

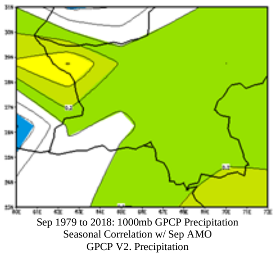
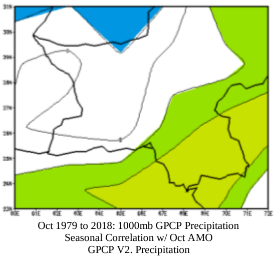
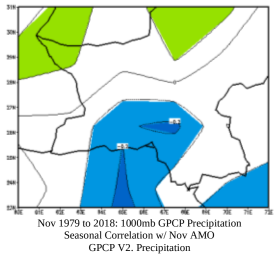
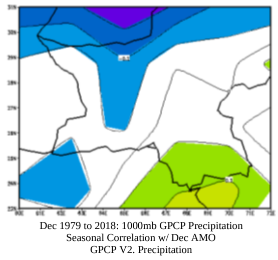
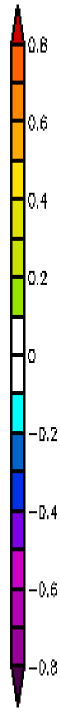
The correlation contour map of Baluchistan (period 1977 to 2017 and months January to December) between AO and GPCP Precipitation for months from January to December in the Baluchistan prepared from the NCPP. The correlation coefficient ranges from -0.35 to 0.35. The correlation map in Table-4 shows that AO has a significant negative correlation with October GPCP precipitation and significant positive correlation with January, November GPCP precipitation.

Table-4: AO Vs GPCP Precipitation Correlation Map				
Jan (1977-2017)	Feb (1977-2017)	Mar (1977-2017)	Apr (1977-2017)	
 Jan 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Jan AO GPCP V2. Precipitation	 Feb 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Feb AO GPCP V2. Precipitation	 Mar 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Mar AO GPCP V2. Precipitation	 Apr 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Apr AO GPCP V2. Precipitation	
May (1977-2017)	June (1977-2017)	July (1977-2017)	Aug (1977-2017)	
 May 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ May AO GPCP V2. Precipitation	 Jun 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Jun AO GPCP V2. Precipitation	 Jul 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Jul AO GPCP V2. Precipitation	 Aug 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Aug AO GPCP V2. Precipitation	
Sept (1977-2017)	Oct (1977-2017)	Nov (1977-2017)	Dec (1977-2017)	
 Sep 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Sep AO GPCP V2. Precipitation	 Oct 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Oct AO GPCP V2. Precipitation	 Nov 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Nov AO GPCP V2. Precipitation	 Dec 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Dec AO GPCP V2. Precipitation	
Source: NOAA / ESRL Physical Science Division				

5.2.3. Atlantic Multi-Decadal Oscillation (AMO)

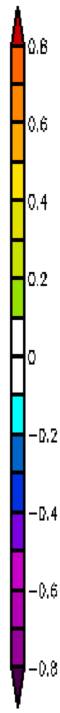
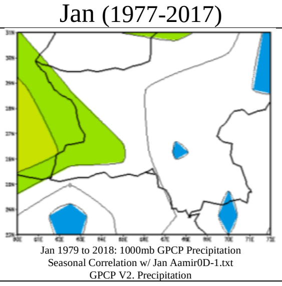
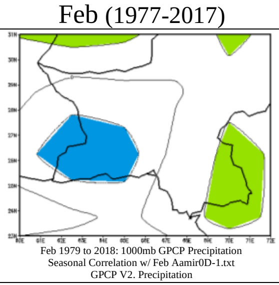
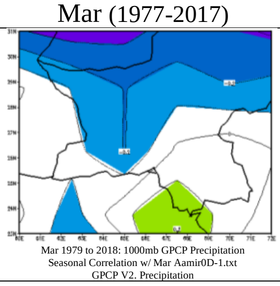
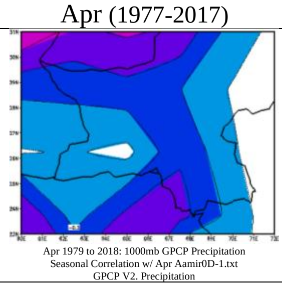
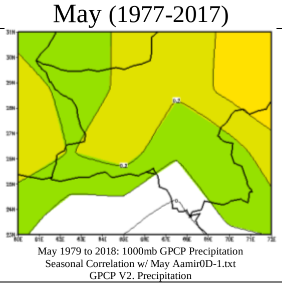
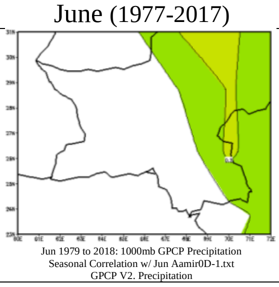
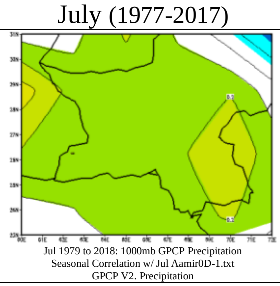
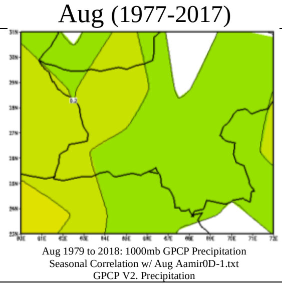
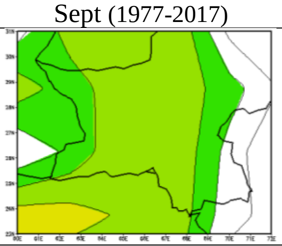
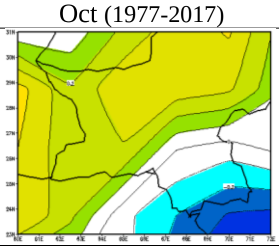
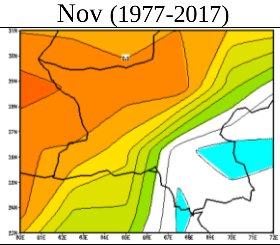
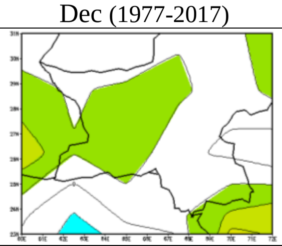
The correlation contour map of Baluchistan (period 1977 to 2017 and months January to December) between AMO and GPCP precipitation is attached below. The correlation coefficient ranges from -0.3 to 0.4. The correlation map in Table-5 shows that AMO has a significant positive correlation in June and October GPCP precipitation.

Table-5: AMO Vs GPCP Precipitation Correlation Map				
Jan (1977-2017)	Feb (1977-2017)	Mar (1977-2017)	Apr (1977-2017)	
 Jan 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Jan AMO GPCP V2. Precipitation	 Feb 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Feb AMO GPCP V2. Precipitation	 Mar 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Mar AMO GPCP V2. Precipitation	 Apr 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Apr AMO GPCP V2. Precipitation	
May (1977-2017)	June (1977-2017)	July (1977-2017)	Aug (1977-2017)	
 Mar 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Mar AMO GPCP V2. Precipitation	 Jun 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Jun AMO GPCP V2. Precipitation	 Jul 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Jul AMO GPCP V2. Precipitation	 Aug 1979 to 2018: 1000mb GPCP Precipitation Seasonal Correlation w/ Aug AMO GPCP V2. Precipitation	
Sept (1977-2017)	Oct (1977-2017)	Nov (1977-2017)	Dec (1977-2017)	

				
Source: NOAA / ESRL Physical Science Division				

5.2.4. Association of IOD with Precipitation

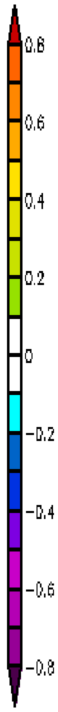
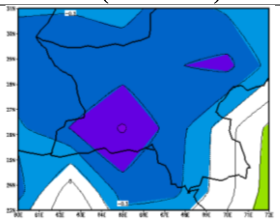
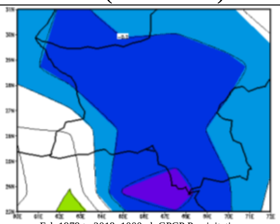
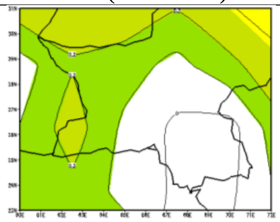
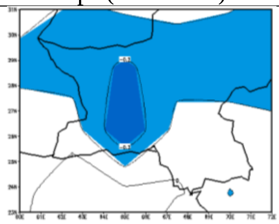
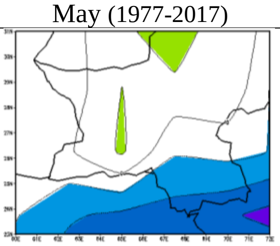
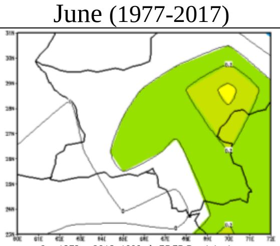
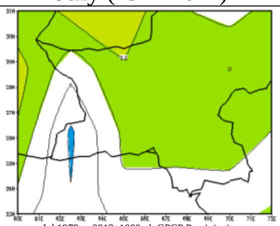
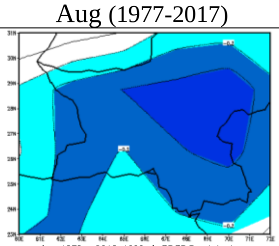
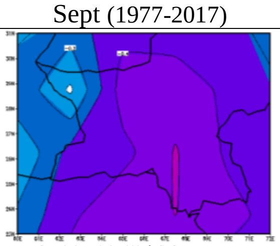
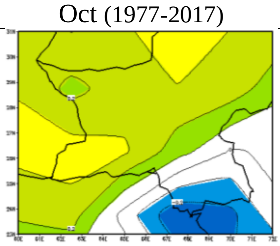
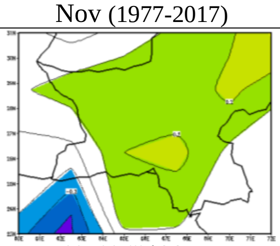
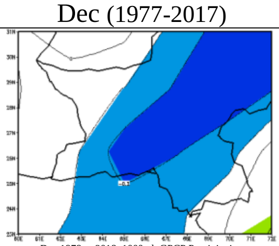
The correlation contour map of Baluchistan (period 1977 to 2017 and months January to December) between IOD and GPCP precipitation is attached below. The correlation coefficient ranges from -0.6 to 0.6. The correlation map in Table-6 shows that IOD has a negative significant correlation with April GPCP precipitation and the positive significant correlation with May, October, and November GPCP precipitation.

Table-6: IOD Vs GPCP Precipitation Correlation Map				
Jan (1977-2017)	Feb (1977-2017)	Mar (1977-2017)	Apr (1977-2017)	
				
May (1977-2017)	June (1977-2017)	July (1977-2017)	Aug (1977-2017)	
				
Sept (1977-2017)	Oct (1977-2017)	Nov (1977-2017)	Dec (1977-2017)	
				

<table>
<tr><td>Sep 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Sep AamirOD-1.txt
GPCP V2. Precipitation</td><td>Oct 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Oct AamirOD-1.txt
GPCP V2. Precipitation</td><td>Nov 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Nov AamirOD-1.txt
GPCP V2. Precipitation</td><td>Dec 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Dec AamirOD-1.txt
GPCP V2. Precipitation</td><td></td></tr>
<tr><td colspan="5">Source: NOAA / ESRL Physical Science Division</td></tr>
</table>

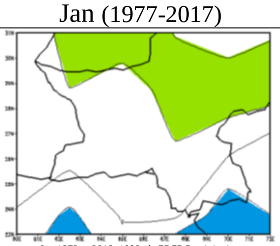
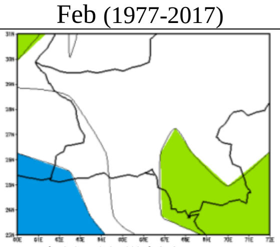
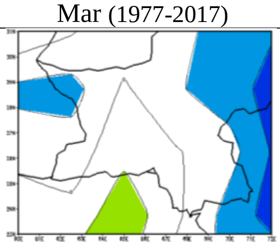
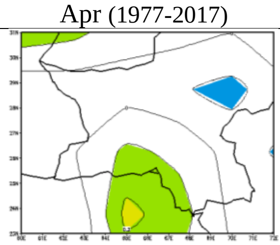
5.2.5. Association of PDO with Precipitation

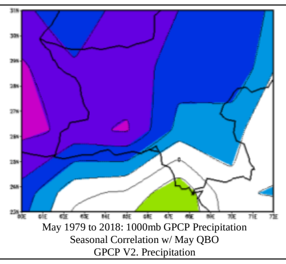
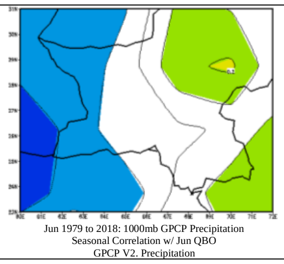
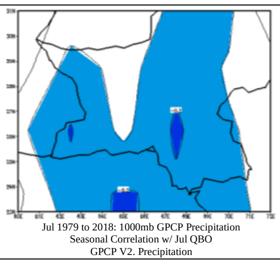
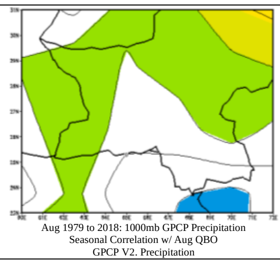
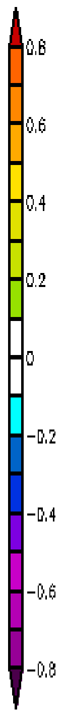
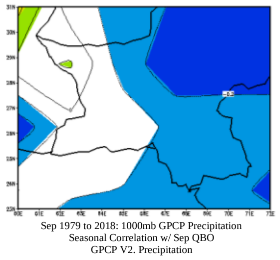
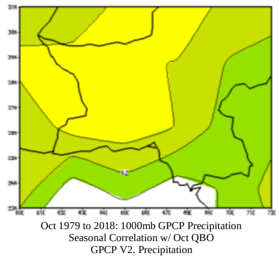
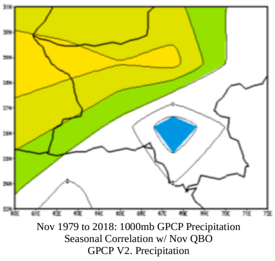
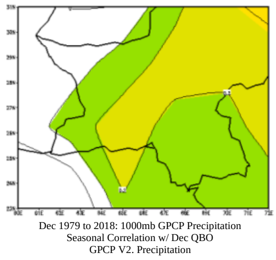
The correlation contour map of Baluchistan (period 1977 to 2017 and months January to December) between PDO and GPCP precipitation is attached below. The correlation coefficient ranges from -0.6 to 0.5. The correlation map in Table-7 shows that PDO has a negative significant correlation with January, February, August, September and December GPCP precipitation and the positive significant correlation with October GPCP precipitation

<table>
<tr><th colspan="5">Table-7: PDO Vs GPCP Precipitation Correlation Map</th></tr>
<tr><td>Jan (1977-2018)</td><td>Feb (1977-2018)</td><td>Mar (1977-2018)</td><td>Apr (1977-2018)</td><td rowspan="6">
</td></tr>
<tr><td>
Jan 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Jan PD0
GPCP V2. Precipitation</td><td>
Feb 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Feb PD0
GPCP V2. Precipitation</td><td>
Mar 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Mar PD0
GPCP V2. Precipitation</td><td>
Apr 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Apr PD0
GPCP V2. Precipitation</td></tr>
<tr><td>May (1977-2017)</td><td>June (1977-2017)</td><td>July (1977-2017)</td><td>Aug (1977-2017)</td></tr>
<tr><td>
May 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ May PD0
GPCP V2. Precipitation</td><td>
Jun 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Jan PD0
GPCP V2. Precipitation</td><td>
Jul 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Jul PD0
GPCP V2. Precipitation</td><td>
Aug 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Aug PD0
GPCP V2. Precipitation</td></tr>
<tr><td>Sept (1977-2017)</td><td>Oct (1977-2017)</td><td>Nov (1977-2017)</td><td>Dec (1977-2017)</td></tr>
<tr><td>
Sep 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Sep PD0
GPCP V2. Precipitation</td><td>
Oct 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Oct PD0
GPCP V2. Precipitation</td><td>
Nov 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Nov PD0
GPCP V2. Precipitation</td><td>
Dec 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Dec PD0
GPCP V2. Precipitation</td></tr>
<tr><td colspan="5">Source: NOAA / ESRL Physical Science Division</td></tr>
</table>

5.2.6. Association of QBO with Precipitation

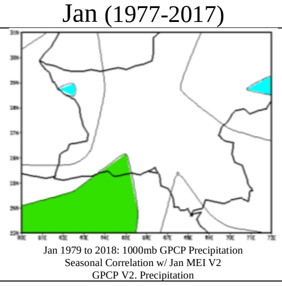
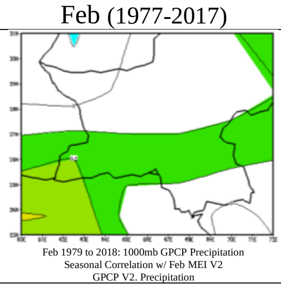
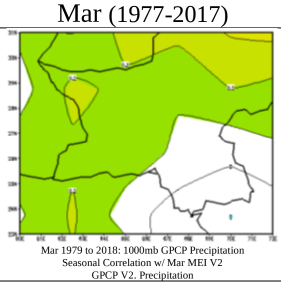
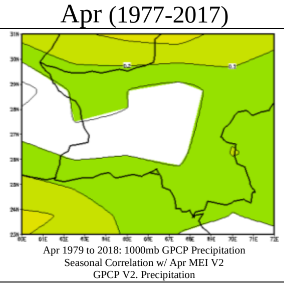
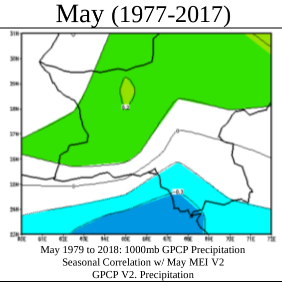
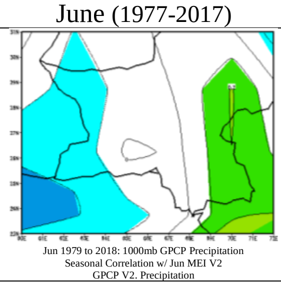
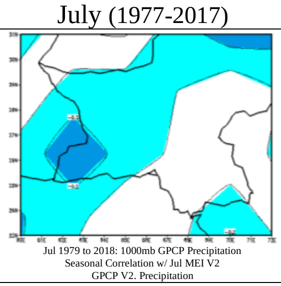
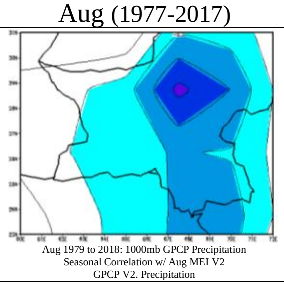
The correlation contour map of Baluchistan (period 1977 to 2017 and months January to December) between QBO and GPCP precipitation is attached below. The correlation coefficient ranges from -0.5 to 0.5. The correlation map in Table-8 shows that QBO has a negative significant correlation in May and September GPCP precipitation and positive significant correlation with October, November, and December GPCP precipitation

<table>
<tr><th colspan="5">Table-8: QBO Vs GPCP Precipitation Correlation Map</th></tr>
<tr><td>Jan (1977-2017)</td><td>Feb (1977-2017)</td><td>Mar (1977-2017)</td><td>Apr (1977-2017)</td><td></td></tr>
<tr><td>
Jan 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Jan QBO
GPCP V2. Precipitation</td><td>
Feb 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Feb QBO
GPCP V2. Precipitation</td><td>
Mar 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Mar QBO
GPCP V2. Precipitation</td><td>
Apr 1979 to 2018: 1000mb GPCP Precipitation
Seasonal Correlation w/ Apr QBO
GPCP V2. Precipitation</td><td></td></tr>
<tr><td>May (1977-2017)</td><td>June (1977-2017)</td><td>July (1977-2017)</td><td>Aug (1977-2017)</td><td></td></tr>
</table>

				
Sept (1977-2017)	Oct (1977-2017)	Nov (1977-2017)	Dec (1977-2017)	
				
Source: NOAA / ESRL Physical Science Division				

5.2.7. Association of ENSO-MEI with Precipitation

The correlation contour map of Baluchistan (period 1977 to 2017 and months January to December) between ENSO-MEI and GPCP precipitation is attached below. The correlation coefficient ranges from -0.5 to 0.5. The correlation map in Table-9 shows that ENSO-MEI has a negative significant correlation with August GPCP precipitation and the positive significant correlation in October and November GPCP precipitation.

Table-9: ENSO-MEI Vs GPCP Precipitation Correlation Map			
Jan (1977-2017)	Feb (1977-2017)	Mar (1977-2017)	Apr (1977-2017)
			
May (1977-2017)	June (1977-2017)	July (1977-2017)	Aug (1977-2017)
			
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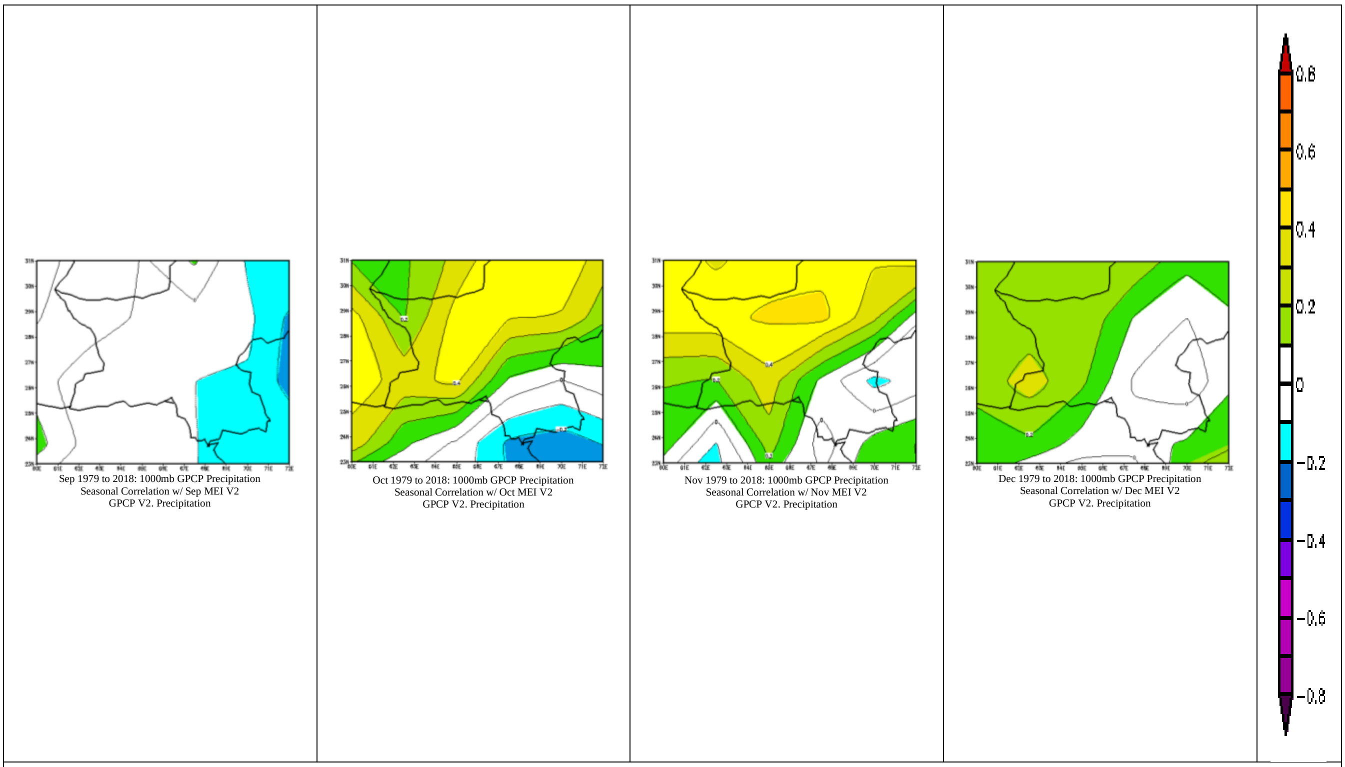

Source: NOAA / ESRL Physical Science Division

5.2.8. Summarized Results of the Association of Climatic Indices with Monthly Precipitation

Within Baluchistan, NAO shows a significant negative correlation in October, AO shows a significant positive correlation in January, November and a significant negative correlation in October, AMO shows a significant positive correlation in June, October, IOD shows a significant positive correlation in May, October, November and significant negative correlation in April, PDO shows significant positive correlation in October, and significant negative correlation in January, February, August, September, December, QBO shows significant positive correlation in October, November, December and significant negative correlation in May, September whereas ENSO-MEI shows significant positive correlation in October, November and significant negative correlation in August.

TABLE 10
SIGNIFICANT ASSOCIATION OF CLIMATIC INDICES WITH PRECIPITATION

Months	NAO	AO	AMO	IOD	PDO	QBO	ENSO-MEI
January		*			(*)		
February					(*)		
March							
April				(*)			
May				*		(*)	
June			*				
July							
August					(*)		(*)
September					(*)	(*)	
October	(*)	(*)	*	*	*	*	*
November		*		*		*	*
December					(*)	*	

Where * is the significant positive correlation and (*) is the significant negative correlation at 5% significance.

5.3. Influence of Climatic and Atmospheric Indices on Precipitation Trends

Several studies emphasize ENSO and NAO has affected the weather of Pakistan regionally and locally. Yadav. et al. (2009) suggests that the effect of ENSO has increased as compared to NAO. Afzal. M. et al. (2013) emphasizes that fresh studies needs to be carried out to study the recent influence of NAO on different regions of the globe. Rashid (2004) studied the impact of ENSO and state that ENSO has the negative effect on winter rainfall of Pakistan. Discussed that the rainfall in winter over Pakistan shows below normal behavior under the influence of ENSO (-ve) phase (i-e La Nina Condition). Arif, Tariq and Nadeem (2004) found out that ENSO does not have any significant adverse impact on August rainfall over Pakistan.

Iqbal and Athar (2017) investigated the correlation between precipitation and climatic indices through Pearson's correlation at 5%, 10% and 15% significant level. They found out that NAO shows a correlation with Baluchistan, positive phase of IOD have positive correlation, positive (negative) phase of AO shows correlation, PDO shows positive correlation and ENSO exhibits correlation in Baluchistan on monthly basis.

Pearson correlation only measures the strength of linear association between two variables. For a non-linear series, if correlation reports series, are insignificantly correlated, that simply means that there is no linear correlation between the two variables and there may be non-linear relationship. Precipitation and climate are greatly non-linear in nature and can upswing to butterfly effect (Abraham et al. 2001). Hence, the use of linear correlation to study the effect of climatic indices on precipitation may not yield reasonable results. Another approach to study the influence of climatic indices on precipitation is to study the variation in Trends in precipitation in the presence of climatic indices which are the covariates. Libisellar and Grimmvall, 2002 established that the correct Trends in precipitation can be assessed in the presence of the relevant covariates.

In this study the correct assessment of Trends in precipitation in the presence of influencing variables such as NAO, AO, AMO, IOD, PDO, QBO and ENSO-MEI is determined through the PMK test on monthly precipitation at individual station level. The Influence of response variables for the purpose of this study through the PMK test is classified in to insignificant, weak, moderate, and strong influence as described in the Table-11 below.

TABLE 11
CLASSIFICATION OF INFLUENCE TYPE

S. No	Condition	Influence Type
1	MK and PMK shows no significant trend	Insignificant
2	MK shows no significant trend, PMK shows significant trend or vice versa; OR both MK and PMK shows significant trend; the addition of influencing variable changes the MK-Statistics by up to 10%.	Weak
3	MK shows no significant trend, PMK shows significant trend or vice versa; OR both MK and PMK shows significant trend; the addition of influencing variable changes the MK-Statistics from 10% to 20%.	Moderate
4	MK shows no significant trend, PMK shows significant trend or vice versa; OR both MK and PMK shows significant trend; the addition of influencing variable changes the MK-Statistics greater than 20%.	Strong

5.3.1. Climatic Indices on Monthly Precipitation at Individual Stations

PMK test was run on the monthly precipitation time series being the response variable and the climatic indices being explanatory variables including NAO, AO, AMO, IOD, PDO, QBO and ENSO-MEI. The statistically significant trend in the presence of the relevant influencing variables is tabulated in the Table-11 to Table-16.

a) Influence of NAO on Precipitation

The PMK test shows that NAO has insignificant influence on precipitation of February, March, April, and August in Baluchistan. It shows that NAO has weak influence on precipitation of January, May, September, November, and December over some stations in Baluchistan. It also shows that NAO has weak to moderate (+ve) influence on June and moderate (-ve) influence on precipitation of July whereas NAO has strong (-ve) influence on October precipitation over Panjgur station in Baluchistan. The p-values of PMK at 5% significance level along with Statistics and the influence of NAO are shown in the Table-11 below.

TABLE 11
INFLUENCE OF NAO ON PRECIPITATION TRENDS

Months	Stations	Mann Kendall			Partial Mann Kendall with NAO as Covariate			% Change in MK-Statistics due to NAO as Covariate	Influence Type
		P-value	MK-Statistic	Trend Type	P-value	PMK-Statistic	Trend Type		
January	Barakhan	0.0462	-177	Decreasing	0.048	-174.1	Decreasing	1.64%	Weak
	Quetta	0.0119	-224	Decreasing	0.0121	-223.4	Decreasing	0.27%	Weak

	Zhob	0.0239	-201	Decreasing	0.0245	-196.8	Decreasing	2.09%	Weak
May	Ormara	0.0063	-205	Decreasing	0.0084	-195.9	Decreasing	4.44%	Weak
June	Barakhan	0.0493	175	Increasing	0.0576	168.8	Increasing	3.54%	Weak
	Quetta	0.0126	206	Increasing	0.0338	165.5	Increasing	19.66%	Moderate
July	Panjgur	0.0228	-195	Decreasing	0.0427	-171.7	Decreasing	11.95%	Moderate
September	Quetta	0.0314	153	Increasing	0.0258	156.8	Increasing	2.48%	Weak
October	Panjgur	0.1313	-76	Decreasing	0.0491	-92	Decreasing	21.05%	Strong
November	Barakhan	0.0107	-211	Decreasing	0.0063	-222.1	Decreasing	5.26%	Weak
December	Dalbandin	0.01648	-208	Decreasing	0.0215	-197.8	Decreasing	4.90%	Weak
	Jiwani	0.0037	-245	Decreasing	0.0063	-221.6	Decreasing	9.55%	Weak
	Khuzdar	0.0401	-178	Decreasing	0.0574	-162	Decreasing	8.99%	Weak
	Panjgur	0.0351	-176	Decreasing	0.0349	-176.2	Decreasing	0.11%	Weak

b) Influence of AO on Precipitation

The PMK test shows that AO has insignificant influence on precipitation of February, March, April, August, and October in Baluchistan. It shows that AO has weak influence on precipitation of January, May, June, November, and December over some stations in Baluchistan. It also shows that AO has moderate (-ve) influence on precipitation of July but moderate (+ve) influence on precipitation of September over some stations in Baluchistan. The p-values of PMK at 5% significance level along with Statistics and the influence of AO are shown in the Table-12 below.

TABLE-12
INFLUENCE OF AO ON PRECIPITATION TRENDS

Months	Stations	Mann Kendall			Partial Mann Kendall with AO as Covariate			% Change in MK-Statistics due to AO as Covariate	Influence Type
		P-value	MK-Statistic	Trend Type	P-value	PMK-Statistic	Trend Type		
January	Barakhan	0.0462	-177	Decreasing	0.0397	-179	Decreasing	1.13%	Weak
	Quetta	0.0119	-224	Decreasing	0.0113	-225.4	Decreasing	0.63%	Weak
	Zhob	0.0239	-201	Decreasing	0.0268	-196.1	Decreasing	2.44%	Weak
May	Ormara	0.0063	-205	Decreasing	0.0069	-202.5	Decreasing	1.22%	Weak
June	Barakhan	0.0493	175	Increasing	0.0457	176.5	Increasing	0.86%	Weak
	Quetta	0.0126	206	Increasing	0.0112	207.5	Increasing	0.73%	Weak
	Sibbi	0.0259	186	Increasing	0.0259	186	Increasing	0.00%	----
July	Panjgur	0.0228	-195	Decreasing	0.0351	-174.7	Decreasing	10.41%	Moderate
September	Quetta	0.0314	153	Increasing	0.0489	137.7	Increasing	10.00%	Moderate
November	Barakhan	0.0107	-211	Decreasing	-0.0046	-225.3	Decreasing	6.78%	Weak
December	Dalbandin	0.01648	-208	Decreasing	0.0132	-213	Decreasing	2.40%	Weak
	Jiwani	0.0037	-245	Decreasing	0.0041	-240.3	Decreasing	1.92%	Weak
	Khuzdar	0.0401	-178	Decreasing	0.0215	-179.3	Decreasing	0.73%	Weak
	Panjgur	0.0351	-176	Decreasing	0.0317	-178.9	Decreasing	1.65%	Weak

c) Influence of AMO on Precipitation

Both Mann Kendall and Partial Mann Kendall tests shows no significant increasing or decreasing Trends in any of the 13 stations of Baluchistan as such AMO does not have any significant influence on precipitation in Baluchistan.5.2.1.2 Influence of AO on Precipitation

d) Influence of IOD on Precipitation

The PMK test shows that IOD has insignificant influence on precipitation of February, March, April, August and October in Baluchistan. It shows that IOD has weak influence on precipitation of January, June, July and December over some stations in Baluchistan. It also shows that IOD has moderate (-ve) influence on precipitation of May, moderate to strong (-ve) influence on precipitation of November and weak to moderate (-ve) influence on precipitation over some stations in Baluchistan whereas NAO has strong (+ve) influence on September precipitation over the Quetta station in Baluchistan. The p-values of PMK at 5% significance level along with Statistics and the influence of IOD is shown in the Table-13 below.

TABLE 13
INFLUENCE OF IOD ON PRECIPITATION TRENDS

Months	Stations	Mann Kendall			Partial Mann Kendall with IOD as Covariate			% Change in MK-Statistics due to IOD as Covariate	Influence Type
		P-value	MK-Statistic	Trend Type	P-value	PMK-Statistic	Trend Type		
January	Barakhan	0.0462	-177	Decreasing	0.0338	-188	Decreasing	6.21%	Weak
	Quetta	0.0119	-224	Decreasing	0.0086	-233.4	Decreasing	4.20%	Weak

	Zhob	0.0239	-201	Decreasing	0.0124	-221	Decreasing	9.95%	Weak
May	Ormara	0.0063	-205	Decreasing	0.0132	-182.6	Decreasing	10.93%	Moderate
	Barakhan	0.0493	175	Increasing	0.0485	175.6	Increasing	0.34%	Weak
June	Quetta	0.0126	206	Increasing	0.0151	200.3	Increasing	2.77%	Weak
	Sibbi	0.0259	186	Increasing	0.0304	180.5	Increasing	2.96%	Weak
July	Kalat	0.0541	-167	Decreasing	0.0424	-175.5	Decreasing	5.09%	Weak
	Panjgur	0.0228	-195	Decreasing	0.0198	-199.4	Decreasing	2.26%	Weak
September	Quetta	0.0314	153	Increasing	0.1222	102.1	Increasing	33.27%	Strong
	Barakhan	0.0107	-211	Decreasing	0.0018	-251.3	Decreasing	19.10%	Moderate
November	Jiwani	0.24	-72	Decreasing	0.035	-121.1	Decreasing	68.19%	Strong
	Khuzdar	0.0645	-151	Decreasing	0.0362	-170.2	Decreasing	12.72%	Moderate
	Dalbandin	0.01648	-208	Decreasing	0.0116	-217.6	Decreasing	4.62%	Weak
	Jiwani	0.0037	-245	Decreasing	0.0027	-252.2	Decreasing	2.94%	Weak
December	Khuzdar	0.0401	-178	Decreasing	0.0205	-197.5	Decreasing	10.96%	Moderate
	Panjgur	0.0351	-176	Decreasing	0.0202	-191.4	Decreasing	8.75%	Weak
	Quetta	0.0574	-169	Decreasing	0.0369	-183.6	Decreasing	8.64%	Weak
	Zhob	0.0663	-160	Decreasing	0.0413	-175.6	Decreasing	9.75%	Weak

e) Influence of PDO on Precipitation

The PMK test shows that PDO has insignificant influence on precipitation of February, March, April, August and October in Baluchistan. It shows that PDO has weak influence on precipitation of January, June, November and December over some stations in Baluchistan. It also shows that PDO has moderate influence on precipitation of May, moderate (-ve) influence on precipitation of July but moderate (+ve) influence on precipitation of September over some stations in Baluchistan. The p-values of PMK at 5% significance level along with Statistics and the influence of PDO is shown in the Table-14.

TABLE 14
INFLUENCE OF PDO ON PRECIPITATION TRENDS

Months	Stations	Mann Kendall			Partial Mann Kendall with PDO as Covariate			% Change in MK-Statistics due to PDO as Covariate	Influence Type
		P-value	MK-Statistic	Trend Type	P-value	PMK-Statistic	Trend Type		
	Barakhan	0.0462	-177	Decreasing	0.0325	-185.9	Decreasing	5.03%	Weak
January	Quetta	0.0119	-224	Decreasing	0.0097	-228.8	Decreasing	2.14%	Weak
	Zhob	0.0239	-201	Decreasing	0.0219	-203.5	Decreasing	1.24%	Weak
	Ormara	0.0063	-205	Decreasing	0.0116	-174.6	Decreasing	14.83%	Moderate
May	Quetta	0.0607	165	Increasing	0.0246	190.1	Increasing	15.21%	Moderate
	Sibbi	0.0678	154	Increasing	0.0254	180	Increasing	16.88%	Moderate
	Barakhan	0.0493	175	Increasing	0.0357	183.4	Increasing	4.80%	Weak
June	Quetta	0.0126	206	Increasing	0.0103	210.5	Increasing	2.18%	Weak
	Sibbi	0.0259	186	Increasing	0.0258	186.2	Increasing	0.11%	Weak
July	Panjgur	0.0228	-195	Decreasing	0.0408	-173.4	Decreasing	11.08%	Moderate
September	Quetta	0.0314	153	Increasing	0.0536	135.6	Increasing	11.37%	Moderate
November	Barakhan	0.0107	-211	Decreasing	0.0124	-205.9	Decreasing	2.42%	Weak
	Dalbandin	0.01648	-208	Decreasing	0.0139	-210.9	Decreasing	1.39%	Weak
	Jiwani	0.0037	-245	Decreasing	0.0038	-242.7	Decreasing	0.94%	Weak
December	Khuzdar	0.0401	-178	Decreasing	0.0304	-182.7	Decreasing	2.64%	Weak
	Panjgur	0.0351	-176	Decreasing	0.0294	-179.3	Decreasing	1.88%	Weak
	Zhob	0.0663	-160	Decreasing	0.0469	-165.9	Decreasing	3.69%	Weak

f) Influence of QBO on Precipitation

The PMK test shows that QBO has insignificant influence on precipitation of February, March, April, August and October in Baluchistan, whereas it shows that NAO has weak influence on precipitation of January, May, June, July, September, November and December over some stations in Baluchistan. The p-values of PMK at 5% significance level along with Statistics and the influence of QBO is shown in the Table-15 below.

TABLE 15
INFLUENCE OF QBO ON PRECIPITATION TRENDS

Months	Stations	Mann Kendall			Partial Mann Kendall with QBO as Covariate			% Change in MK-Statistics due to QBO as Covariate	Influence Type
		P-value	MK-Statistic	Trend Type	P-value	PMK-Statistic	Trend Type		
January	Barakhan	0.0462	-177	Decreasing	0.047	-176.2	Decreasing	0.45%	Weak
	Quetta	0.0119	-224	Decreasing	0.0108	-226.2	Decreasing	0.98%	Weak
	Zhob	0.0239	-201	Decreasing	-0.0251	-197.6	Decreasing	1.69%	Weak

May	Ormara	0.0063	-205	Decreasing	0.0062	-205.1	Decreasing	0.05%	Weak
	Quetta	0.0607	165	Increasing	0.0394	165.8	Increasing	0.48%	Weak
June	Barakhan	0.0493	175	Increasing	0.0419	175.3	Increasing	0.17%	Weak
	Quetta	0.0126	206	Increasing	0.0123	205.9	Increasing	0.05%	Weak
	Sibbi	0.0259	186	Increasing	0.0251	185.9	Increasing	0.05%	Weak
July	Panjgur	0.0228	-195	Decreasing	0.0232	-193.3	Decreasing	0.87%	Weak
September	Quetta	0.0314	153	Increasing	0.0303	150.7	Increasing	1.50%	Weak
November	Barakhan	0.0107	-211	Decreasing	0.0074	-208.5	Decreasing	1.18%	Weak
December	Dalbandin	0.01648	-208	Decreasing	0.0166	-207.1	Decreasing	0.43%	Weak
	Jiwani	0.0037	-245	Decreasing	0.0036	-245.1	Decreasing	0.04%	Weak
	Khuzdar	0.0401	-178	Decreasing	0.0406	-177.2	Decreasing	0.45%	Weak
	Panjgur	0.0351	-176	Decreasing	0.0355	-174.5	Decreasing	0.85%	Weak

g) Influence of ENSO-MEI on Precipitation

The PMK test shows that ENSO-MEI has insignificant influence on precipitation of February, March, April, August and October in Baluchistan, whereas it shows that ENSO-MEI has weak influence on precipitation of January, May, June, July, and September over some stations in Baluchistan. It also shows that ENSO-MEI has strong to moderate negative influence on precipitation of November and December over some stations in Baluchistan. The p-values of PMK at 5% significance level along with Statistics and influence of ENSO-MEI is shown in the Table-16 below.

TABLE 16
INFLUENCE OF ENSO-MEI ON PRECIPITATION TRENDS

Months	Stations	Mann Kendall			Partial Mann Kendall with ENSO-MEI as Covariate			% Change in MK-Statistics due to ENSO-MEI as Covariate	Influence Type
		P-value	MK-Statistic	Trend Type	P-value	PMK-Statistic	Trend Type		
January	Barakhan	0.0462	-177	Decreasing	0.0437	-182.5	Decreasing	3.11%	Weak
	Quetta	0.0119	-224	Decreasing	0.0161	-213	Decreasing	4.91%	Weak
	Zhob	0.0239	-201	Decreasing	0.0362	-183.7	Decreasing	8.61%	Weak
May	Ormara	0.0063	-205	Decreasing	0.0046	-211.4	Decreasing	3.12%	Weak
June	Barakhan	0.0493	175	Increasing	0.041	181	Increasing	3.43%	Weak
	Quetta	0.0126	206	Increasing	0.0416	200.8	Increasing	2.52%	Weak
	Sibbi	0.0259	186	Increasing	0.0298	180.5	Increasing	2.96%	Weak
July	Kalat	0.0541	-167	Decreasing	0.0472	-169.1	Decreasing	1.26%	Weak
	Panjgur	0.0228	-195	Decreasing	0.0207	-196.5	Decreasing	0.77%	Weak
September	Quetta	0.0314	153	Increasing	0.0241	159.8	Increasing	4.44%	Weak
November	Barakhan	0.0107	-211	Decreasing	0.0239	-165.3	Decreasing	21.66%	Strong
December	Dalbandin	0.0165	-208	Decreasing	0.0384	-171.7	Decreasing	17.45%	Moderate
	Jiwani	0.0037	-245	Decreasing	0.0104	-202.2	Decreasing	17.47%	Moderate
	Khuzdar	0.0401	-178	Decreasing	0.0751	-150.5	Decreasing	15.45%	Moderate
	Panjgur	0.0351	-176	Decreasing	0.0724	-144.9	Decreasing	17.67%	Moderate

5.3.2. Summarized Results of Climatic Indices on Monthly Precipitation at Individual Stations

The Table-17 shows that NAO, AO, IOD, PDO, and ENSO-MEI mostly has weak influence on precipitation in Baluchistan except they have moderate to strong effect in some months. NAO has moderate influence in June and July but strong influence in October, AO has moderate influence in July and September, IOD has a moderate effect in May, November and December, but has a strong effect in September and November, PDO has a moderate effect in May, July and September, QBO has weak influence all year whereas ENSO has a moderate effect in December but has a strong effect in November.

TABLE 17
SUMMARIZED RESULTS OF INFLUENCE OF CLIMATIC INDICES ON MONTHLY PRECIPITATION AT INDIVIDUAL STATIONS

Months	Stations	Covariates-Atmospheric and Climatic Indices					
		NAO	AO	IOD	PDO	QBO	ENSO-MEI
January	Barakhan	Weak	Weak	Weak	Weak	Weak	Weak
	Quetta	Weak	Weak	Weak	Weak	Weak	Weak
	Zhob	Weak	Weak	Weak	Weak	Weak	Weak
May	Ormara	Weak	Weak	Moderate	Moderate	Weak	Weak
	Quetta	-----	-----	-----	Moderate	-----	-----
	Sibbi	-----	-----	-----	Moderate	-----	-----
June	Barakhan	Weak	Weak	Weak	Weak	Weak	Weak
	Quetta	Moderate	Weak	Weak	Weak	Weak	Weak
	Sibbi	-----	-----	Weak	Weak	Weak	Weak
July	Kalat	-----	-----	Weak	-----	-----	Weak

September	Panjgur	Moderate	Moderate	Weak	Moderate	Weak	Weak
	Quetta	Weak	Moderate	Strong	Moderate	Weak	Weak
October	Panjgur	Strong	-----	-----	-----	-----	-----
November	Barakhan	Weak	Weak	Moderate	Weak	Weak	Strong
	Jiwani	-----	-----	Strong	-----	-----	-----
	Khuzdar	-----	-----	Moderate	-----	-----	-----
December	Dalbandin	Weak	Weak	Weak	Weak	Weak	Moderate
	Jiwani	Weak	Weak	Weak	Weak	Weak	Moderate
	Khuzdar	Weak	Weak	Moderate	Weak	Weak	Moderate
	Panjgur	Weak	Weak	Weak	Weak	Weak	Moderate
	Quetta	-----	-----	Weak	-----	-----	-----
	Zhob	-----	-----	Weak	Weak	-----	-----

6. Conclusions

The results of linear correlation are in line with the partial Mann Kendall in some instances and different in others because of the nonlinear nature of the precipitation which is indicative of that the Partial Mann Kendall is most suitable method to determine the influence in precipitation rather than the linear correlation. Alternatively, the correlation shall be performed on the positive (negative) phases of the explanatory variable (climate indices) separately with the corresponding year precipitation time series.

Baluchistan receives its greater portion of the Precipitation in winter and spring months. Decreasing Trends in precipitation are observed in the winter and Spring Months of November, December January and May, when the time series data is analyzed from 1977 to 2017 through Mann Kendall Test, which confirms that the Baluchistan is receiving lesser precipitation since the past few decades. It is also observed ENSO-MEI and IOD has strong to moderate influence on the precipitation Trends in these months while NAO, AO, PDO and QBO has weak influence on precipitation when tested with Partial Mann Kendall test using precipitation as the response variable and climatic indices as explanatory variables. This confirms the findings in the previous study with respect to ENSO and NAO that in recent years ENSO is affecting the climate more than AO/NAO and the latter is losing control in determining the variability in climate in the winter months on North Western Indian precipitation which is adjacent to Pakistan. Decreasing trends are observed in the months of October when continental air prevails, and NAO has a strong influence on precipitation in this month. Increasing Trends are observed in the months of June and September whereas decreasing trends are observed in the month of July in the areas close to Punjab and Sindh, but in these Monsoon months the amount of rainfall is lesser which would affect the overall rainfall in Baluchistan to a lesser extent. It is observed that NAO, AO and PDO have strong to a moderate influence on precipitation in these months whereas ENSO-MEI, IOD and QBO has a weak influence on precipitation.

The study also shows that QBO and AMO do not directly influenced precipitation in the Baluchistan, but the linear combination of AMO with NAO/AO, QBO with IOD (EQUINOO/DMI) and ENSO may have noticeable influence on the winter and Monsoon rainfalls. Similarly, the linear combination of PDO with IDO (EQUINOO/DMI) and ENSO may also be studied.

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