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TRMM-Precipitation Data for Estimating Seasonal and Annual Trends over Peshawar City

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Abstract: Monitoring precipitation variability is important from both the scientific as well as social- economic point of view. This paper examined the statistical precipitation trends in Peshawar Pakistan. This study used, TRMM satellite based Precipitation (mm/month), and AIRS satellite based humidity (g/kg) and temperature (k) data sets of 29 years from 1980 to 2009. Adopting statistical tools commonly used to describe climate such as mean, standard deviation, linear trends and Standardized Anomaly Index (SAI) were used to examine for monthly, annual and seasonal variations. To compare seasonal precipitation variations, four seasons of winter (DJF), spring (MAM), summer or monsoon (JJA) and post-monsoon (SON) have been considered. Monthly analysis showed that Peshawar experiences bimodal (twice increased trends in year) mean monthly rainfall pattern throughout the year. Seasonal analysis showed significant positive (increasing) trends for winter season (DJF) where as negative (decreasing) trend for season spring (MAM). The results from SAI shows fluctuating precipitation pattern across the time under consideration. This study also examined the impact of temperature and humidity on precipitation by using simple correlation method. Positive correlation found between precipitation and humidity (0.07) where as correlation between precipitation and temperature found negative (0.32). All these findings can help in understanding the ecosystems of Peshawar.

Keywords: Rainfall; AIRS satellite data, TRMM satellite data, trend analysis, Standardized Anomaly Index, ecosystem.

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1. Introduction

Monitoring precipitation trends at various spatial and temporal scales has been given much attention by scientific community all over the world, because of the enhanced global climate change scenario (Longobardi and Villani, 2010). Precipitation alteration explains the rise and fall of the variations in environmental conditions i.e; hydrological or climatic (Amin et al., 2018; Andreo et al., 2006; Darand et al., 2017; Dibike et al., 2011; Huang et al., 2008; Jiang et al., 2007; Kang and Lin 2007; Kumar et al., 2009; Longobardi and Villani, 2009; Partal et al., 2006).

Precipitation levels are the significant factors influencing ecological structure in a region, therefore correct prediction of the precipitation trends can play an important role in the future economic development of the country (Ahmad et al., 2015). Change in yearly precipitation in a region decreases the runoff flow in the area, with subsequent implication on water resources / allocation and integrated watershed development (Ganguly et al., 2015). Precipitation variation has been noticed in different areas of Pakistan during the last couple of decades. Severe precipitation brought floods i,e; in 2010 heavy rain caused supper flood over the whole Pakistan (Gadiwala and Burke, 2013). Reduced precipitation brought droughts (in 1998-2001) that gripped Pakistan and its nearby countries (Kumar et al., 2010).

Therefore considering the potential importance of precipitation, globally many studies have been conducted for the assessment of the seasonal and annual precipitation trends (Castaneda and Gonzalez, 2008; Gadiwala and Burke, 2013; Ganguly et al., 2015; Ifeka and Akinbobola, 2015; Longobardi and Villani, 2009; Miao et al., 2012). However, such studies for Peshawar (study area) are short. Therefore it is the first time to use the TRMM satellite data sets for the seasonal and annual trends analysis of precipitation over Peshawar city, and AQUA-AIRS based temperature and humidity data sets were utilized to find correlation with precipitation.

2. Data and Methodology

2.1. Study Area

Peshawar is the capital city of Khyber Pakhtunkhwa province of Pakistan, and is located at latitude 34^{o}N and longitude 71.5^{o}E (Fig. 1). The total area of Peshawar is approximately 1.257 sq. km. Peshawar has moderate winters and very hot summers. Winter in Peshawar starts in November and ends in late March sometimes mid-April. Summer starts from mid-May to mid-September. Peshawar is located in a region where monsoon is not dominant. Comparatively, average rainfall is more during winter than in the summer (COP, 2018).

2.2. Data used Data Description

In this study we used satellite based meteorological data sets from two different sources; brief description of related data is as follows.

2.2.1. TRMM: Precipitation (mm/month)

The Tropical Rainfall Measuring Mission (TRMM), launched in late 1997, is a joint mission between The National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA). Active and passive microwave instruments and the processing made TRMM the world's first satellite for the study of precipitation and associated storms and climate processes (Braun, 2011). We used the TRMM monthly precipitation data of 29 years (1980-2009).

2.2.2. AQUA-AIRS: Humidity (g/kg) and Temperature (k)

The Atmospheric Infrared Sounder (AIRS) is a hyperspectral infrared instrument on board the AQUA satellite. It is designed to monitor Earth's atmospheric water vapour, temperature profiles, total and vertical amount of trace gases like Carbon Monoxide (CO), Methane (CH_4) and Ozone (O_3) on a global scale. AIRS has 2378 infrared channels in the spectral range between 3.7 and 15.4 µm (Chahine et al., 2005), with a spatial resolution of 13.5 km. We used 29 years (1980-2009) AIRS Level-3 Monthly Global 1x1 degree data of Temperature and Humidity, acquired from GES-DISC Interactive Online Analysis Infrastructure (Giovanni) as part of the NASA Goddard Earth Sciences Information Services Center (DISC).

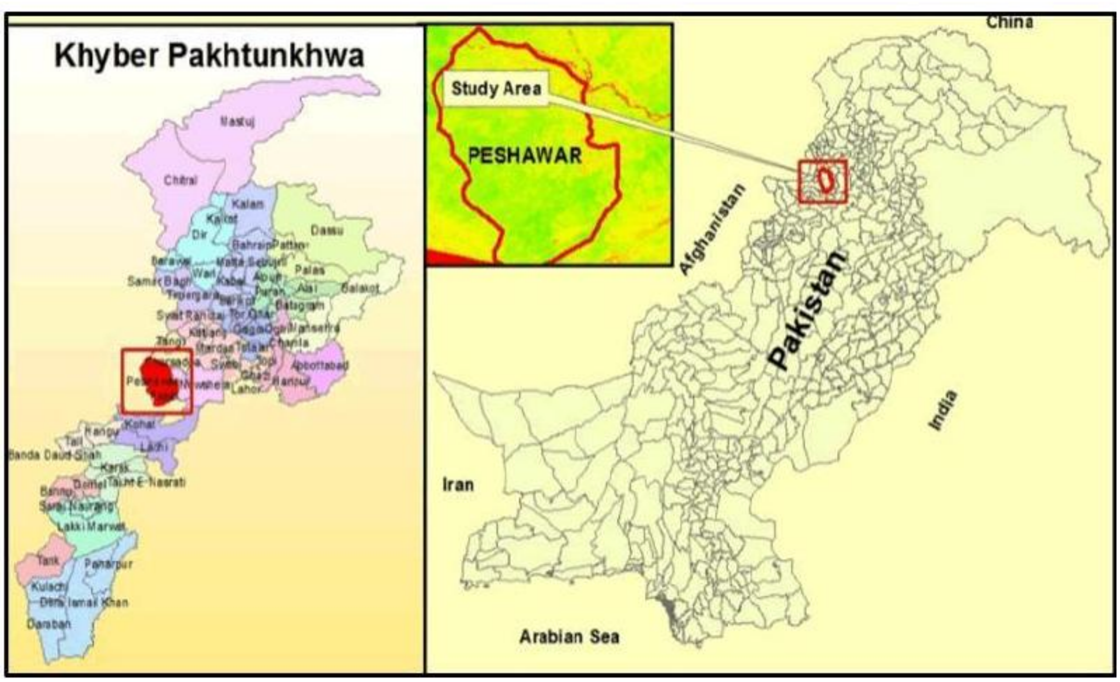

Fig. 1. Study Area source: www.omicsonline.org

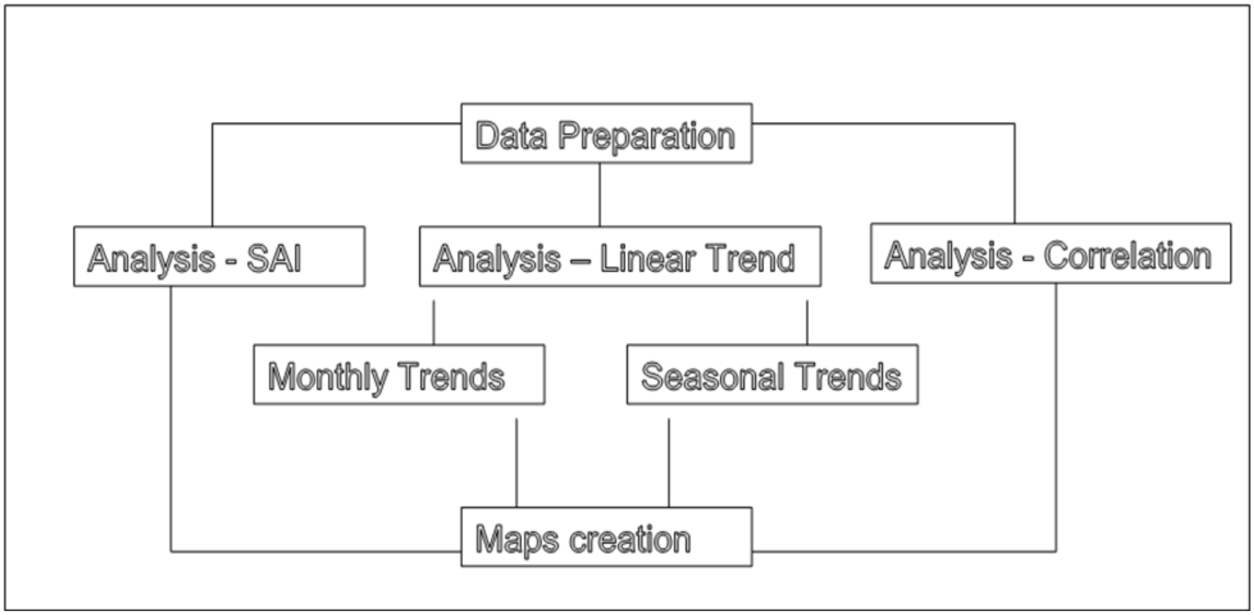

Fig. 2. Layout of data analysis

2.3. Methodology

Basic statistical procedure utilized to calculate the measure of central tendency (mean and range) and dispersion (standard deviation) for precipitation data of Peshawar. To examine the nature of the rainfall pattern, the Standardized Anomaly Index (SAI) is then used. Simple linear regression method is used to calculate trend in the precipitation data. Fig. 2 shows the layout of the analysis being adopted in this study.

2.3.1. Linear Regression

In order to analyzed trends in many climatic time series, simple linear regression method has been used (Abaje et al., 2012; Ayoade, 1973; Hutchinson, 1985).

Linear regression line can be presented by following equation,

$$Y = aX + b \qquad [1]$$

Where, X = explanatory variable; Y = dependent variable; a = slope of line (negative or positive), and b = intercept. In this study independent variable, Y is rainfall and explanatory variable X is year.

Microsoft Excel utilized to compute the trend lines and other statistical values like linear regression analysis for annual, monthly and seasonal variations. The value of R-square (R^2) or the square of the correlation coefficient from the regression analysis is between 0 and 1. The R^2 value of 1.0 presents strong correlation, where as 0 value of R^2 indicates no correlation and no linear relationship between X and Y.

2.3.2. Standardized Anomaly Index

To examine the nature of the rainfall pattern, the Standardized Anomaly Index (SAI) is then used.

SAI can be presented by following equation,

$$Z = \frac{X - \bar{X}}{S}$$

Where X is the rainfall observation for the year and, X and S is the mean and standard deviation of the entire series respectively in the study area. This statistic enable the researcher to determine the dry (-ve values) and wet (+ve values) years in the record as reported by Hulme (1990).

2.3.3. Correlation Analysis

Simple correlation analysis utilized to find the relation between precipitation with temperature and humidity.

3. Results and Discussion

3.1. Annual Trend Analysis

Long-term average pattern of the annual rainfall of Peshawar (Fig. 3) from 1980 to 2009 is 338.01 mm. The maximum annual rainfall was recorded in 1983 (541.01 mm) and the minimum rainfall recorded in 2000 (159.84mm). Similar results have been discussed for different countries (Akinyemi et al., 2013; Chibuike et al., 2014; Ganguly et al., 2015; Kumar et al., 2010; Lin et al., 2017; Merabtene et al., 2016; Ogunrayi et al., 2016;Wong et al., 2009).

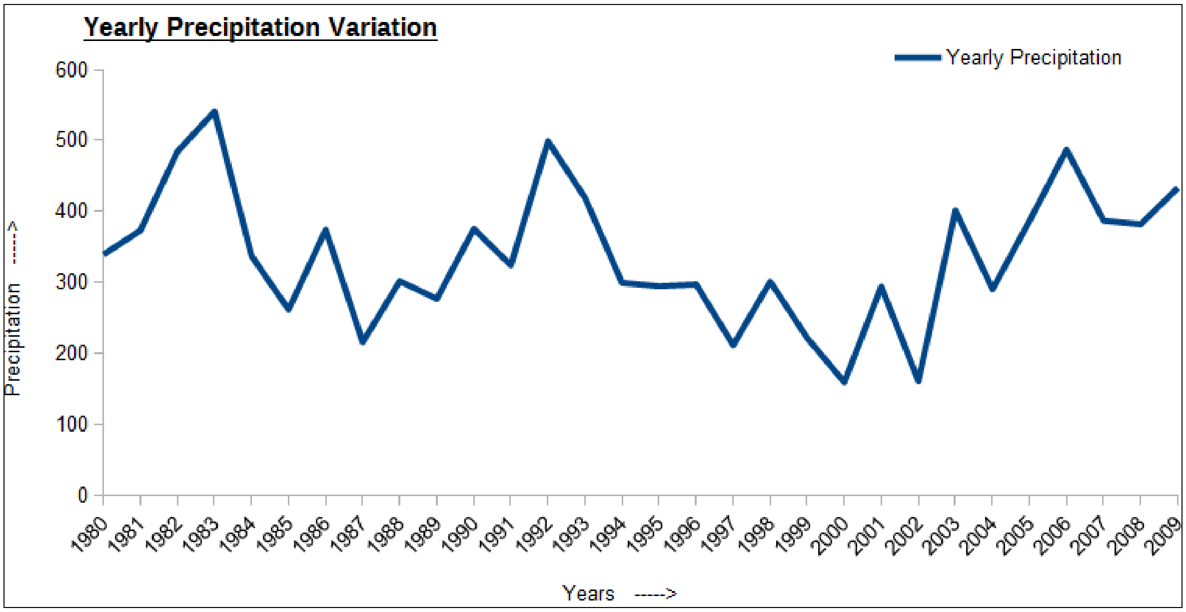

Fig. 3. Annual precipitation trend over Peshawar city (1980-2009).

3.2. Monthly Trend Analysis

Figure 4, shows the mean monthly precipitation over Peshawar during the period 1980-2009 (29 years). It shows that Peshawar experiences bimodal mean monthly rainfall pattern throughout the year. The maximum amount of average monthly rainfall was recorded in March contributes to 19% of annual rainfall, followed by July (13.48%), and the minimum was in October with 1% of annual total followed by November (2%). Rainfall decrease gradually from the month of December to January, then start increasing until March then again decreased until June. With maximum in July start again decreasing in the month of August to November.

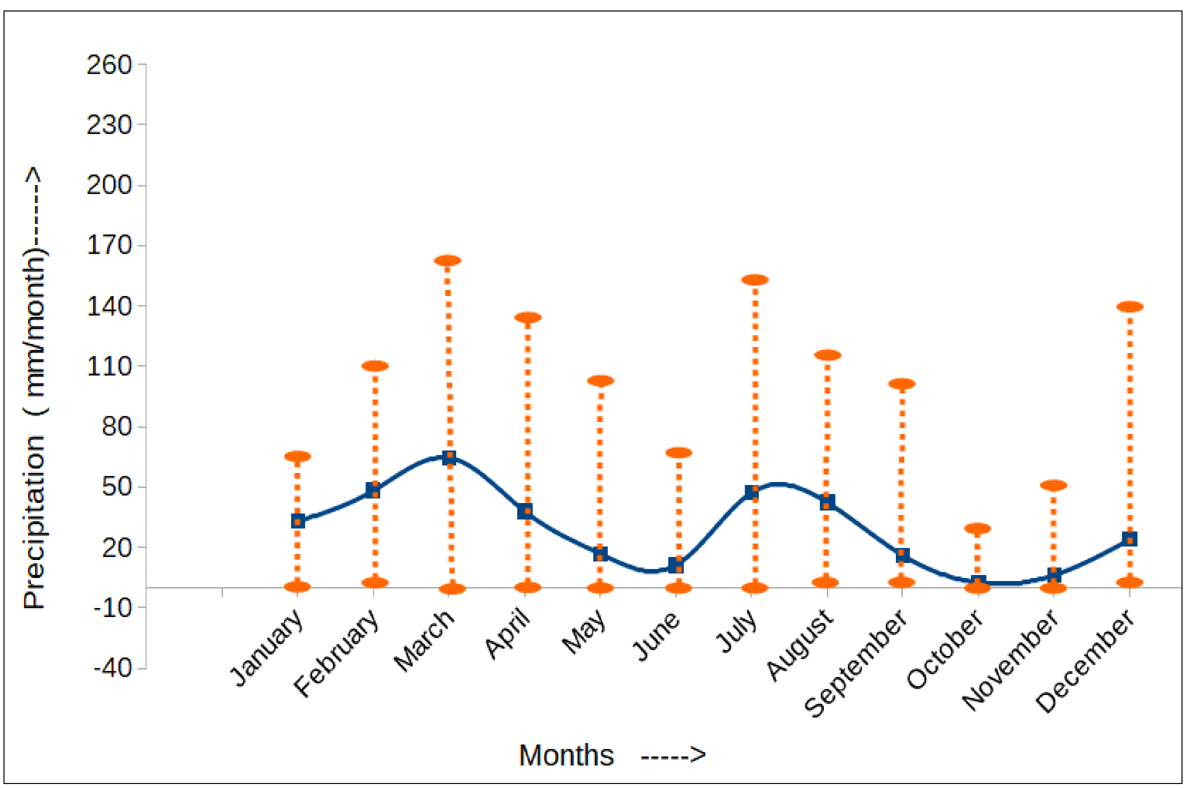

Fig. 4. Mean monthly (with maximum and minimum) precipitation.

Table 1 shows statistical characteristics of monthly precipitation for Peshawar. Generally, the monthly rainfall distribution in Peshawar is variable. Standard deviation (St. Dev) is suitable measure of variability of precipitation. The monthly St. Dev for this area lies between 4.20 and 43.04. The St. Dev is highest during March (43.04) and minimum during October (4.20).

The result of the linear regression trend analysis is also presented in Table 1. In this trend test, trend of precipitation for 29 years from January to December has been calculated for each month individually. The linear trend lines of the monthly rainfall shows decreasing trend in March and April and increasing trend for other months. The R-squared statistic also indicates a very weak relationship between the variables, i.e, precipitation and year. Results are in agreement with the previous studies conducted for other countries (Akinyemi et al., 2013; Chibuike et al., 2014; Feng et al., 2016 Merabtene et al., 2016).

3.3. Seasonal Trend Analysis

Fig. 5 shows seasonal variation as well as linear trends analysis of precipitation in Peshawar. Generally results shows increasing trends for three seasons with significant positive (increasing) trends for seasons DJF and JJA, and slightly increasing trend for season SON where as significant negative (decreasing) trend for season MAM. Similar studies have been done for other countries (Feng et al., 2016; Krishnakumar et al., 2009; Merabtene et al., 2016).

3.4. Standardized Anomaly Index

Fig. 6 shows the graphical presentation of the standardized anomaly index for monthly precipitation. Results showed non-significant increasing trend of precipitation in the study area. The increase does not show a distinct trend because of fluctuations. These results are in agreement with the previous studies conducted in other countries (Ahmad et al., 2016; Akinyemi et al., 2013; Eshetu et al., 2015; Ionita et al., 2016).

Table 1. Statistical properties of monthly precipitation (1980-2009) over Peshawar.

	Mean	St. Dev	Linear Trends	R^2
Jan	33.56	22.14	Y=0.50X+32.68	0.000
Feb	46.18	32.17	Y=1.00X+31.99	0.074
Mar	66.27	43.04	Y=-2.69X+107.75	0.320
Apr	40.17	34.69	Y=-1.64X+64.57	0.175
May	16.17	25.19	Y=0.04X+15.78	0.000
Jun	11.18	16.49	Y=0.55X+3.172	0.089
Jul	40.93	33.08	Y=0.58X+31.34	0.026
Aug	35.42	27.54	Y=0.54X+25.99	0.032
Sep	15.10	24.14	Y=0.060X+13.95	0.000
Oct	2.54	4.20	Y=0.077X+1.46	0.027
Nov	6.56	10.61	Y=0.15X+4.62	0.017
Dec	24.02	26.10	Y=-0.03X+24.60	0.000

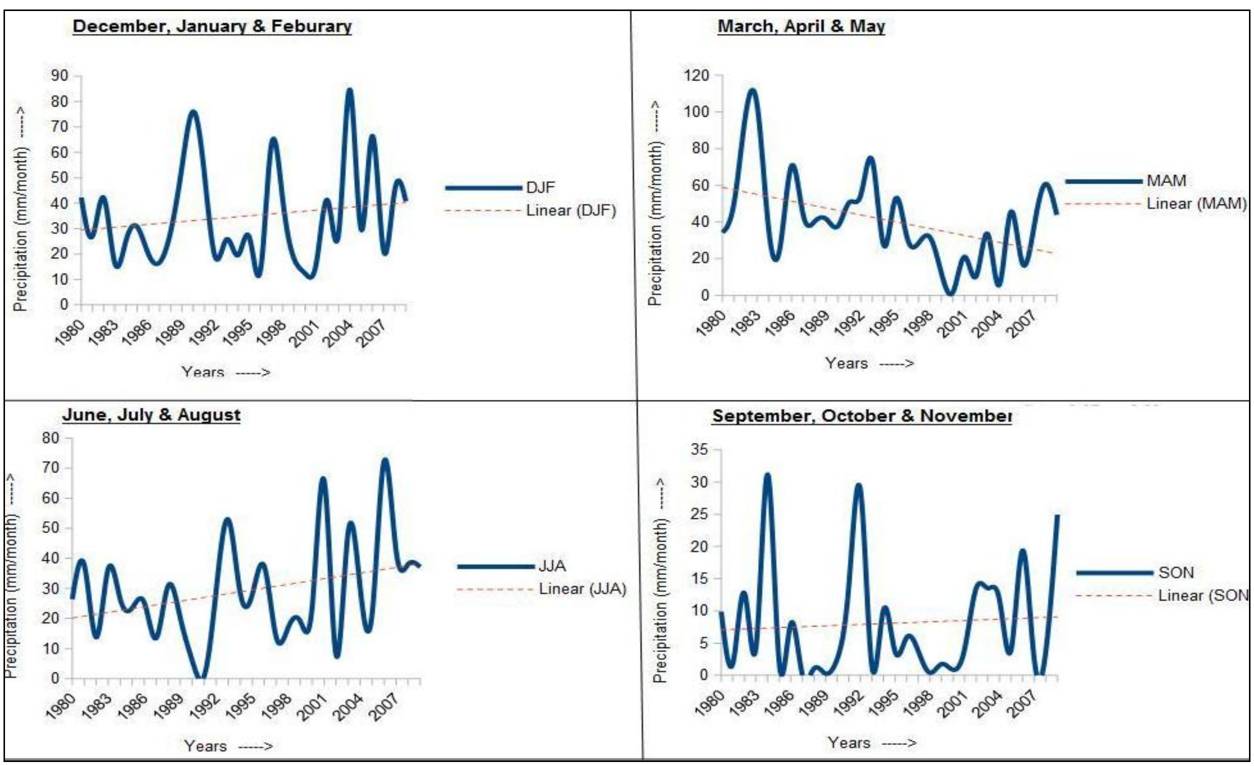

Fig. 5. Seasonal precipitation trends over Peshawar (1980-2009).

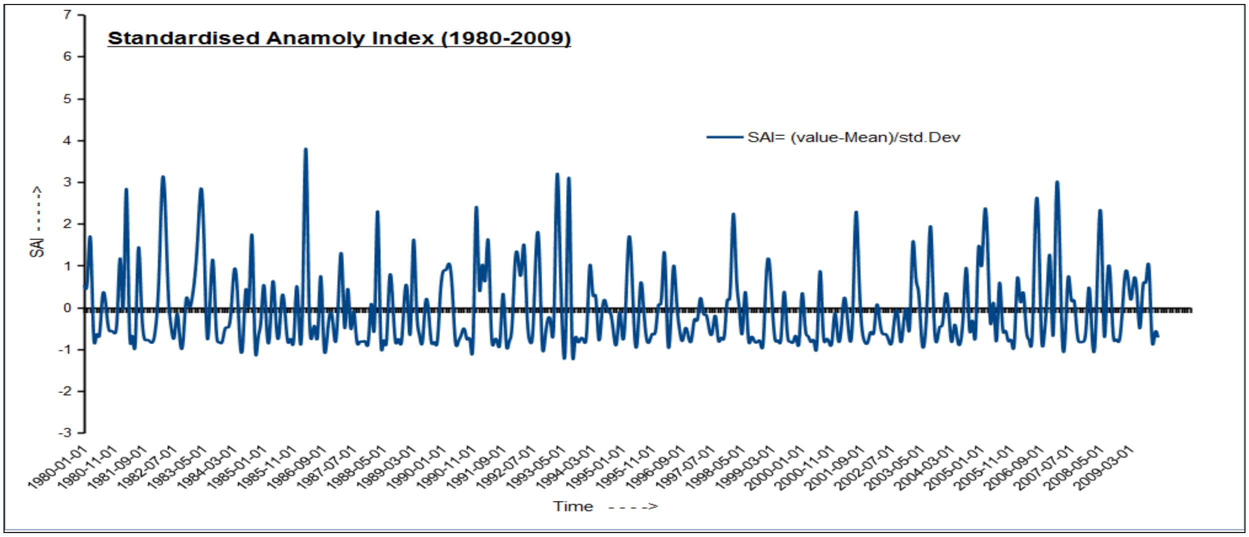

Fig. 6. Standardize Anomaly Index (1980-2009).

3.5. Correlation Analysis

3.5.1. Relation Between Precipitation and Humidity

Fig. 7 shows the annual precipitation and humidity variations for 29 years (1980-2009) in Peshawar. The left side of figure refers to precipitation and the right side to humidity. Linear trends analysis for both variables show decreasing trend in the study area. Results also show positive correlation (0.77) between precipitation and humidity. Similar studies have been carried out for several countries around the world (Bhuiyan et al., 2015; Mawonike and Mandonga, 2017; Salau, 2016).

3.5.2. Relation Between Precipitation And Temperature

Fig. 8 shows precipitation and humidity variation for 29 years (1980-2009) in Peshawar. The left side of figure refers to precipitation and the right side to temperature. Linear trends analysis for both variables show decreasing trend in the study area. Results also show negative correlation (0.32) between precipitation and temperature. Similar results have been found for other countries (Ahmad et al., 2016; Bhuiyan et al., 2015; Mawonike and Mandonga, 2017).

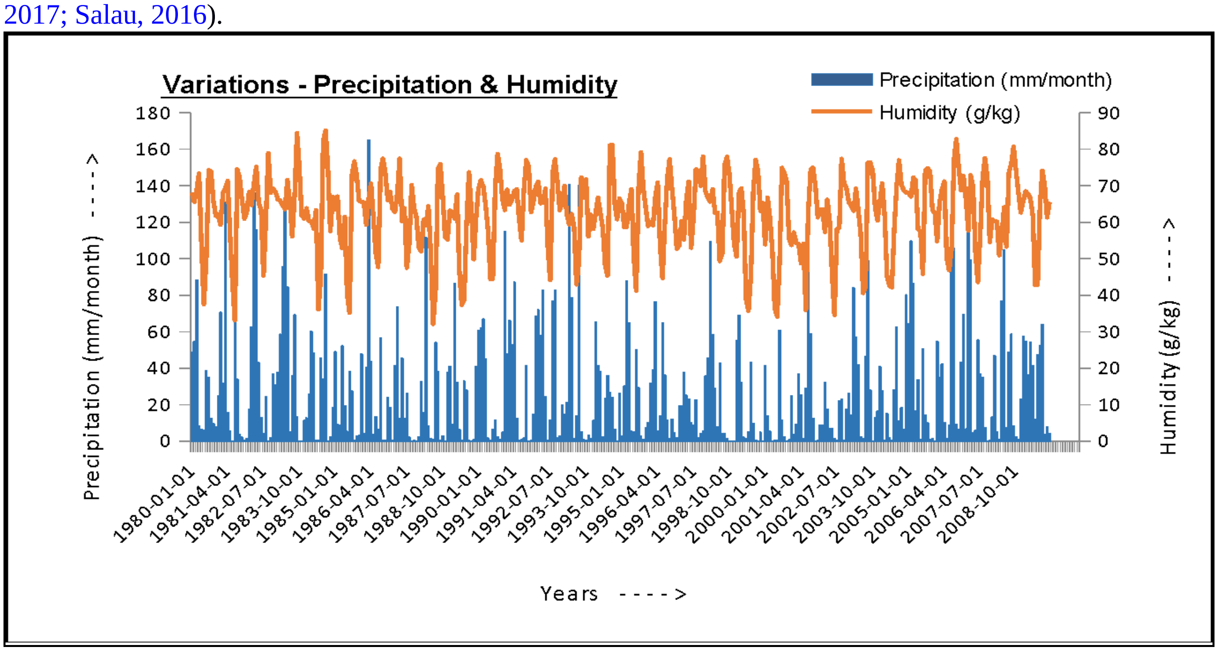

Fig. 7. Variation in precipitation and humidity over Peshawar (1980-2009).

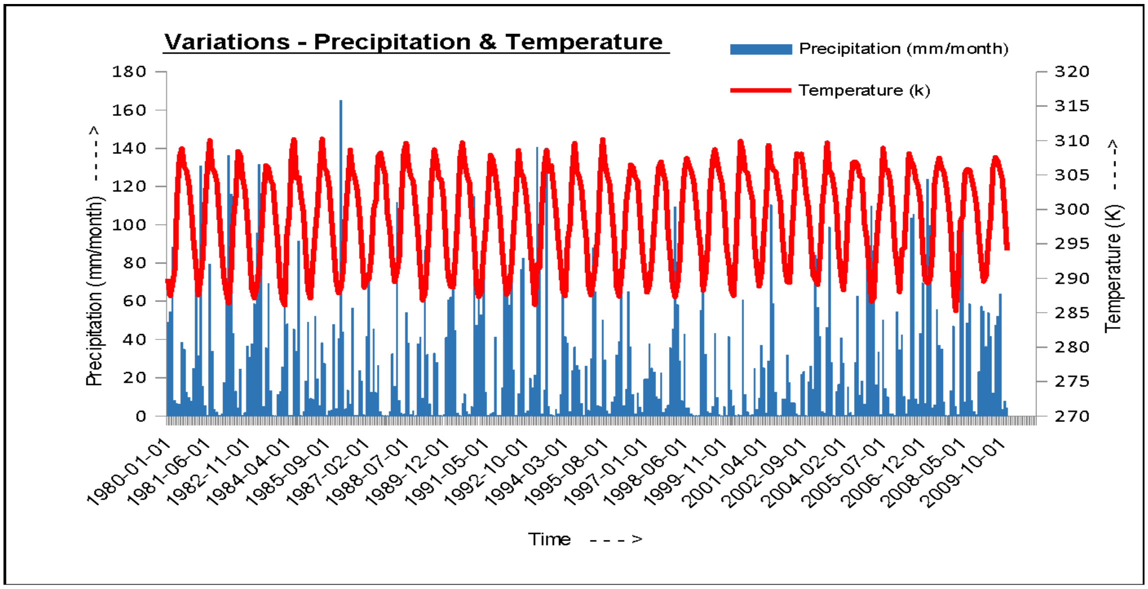

Fig. 8.Variation in precipitation and temperature over Peshawar (1980-2009).

4. Conclusion

For rapidly growing cities like Peshawar, the precipitation behavior particularly the variation and trend are important for the proper designing of water related system such as drainage and clean water supply system. Present study identify some interesting results regarding the long term trends of precipitation as well as association of precipitation with temperature and humidity in Peshawar. It is clear from the analysis that the trend in precipitation is generally increasing on annual basis whereas the annual mean rainfall over Peshawar from 1980 to 2009 is 338.01 mm. Monthly analysis show that Peshawar experiences bimodal (twice increased trends in year) mean monthly rainfall pattern throughout the year. Seasonal analysis shows significant positive (increasing) trends for season DJF where as negative (decreasing) trend for season MAM. The results from SAI shows fluctuating precipitation pattern across the time under consideration. Results also shows positive correlation exist between precipitation and humidity (0.07) where as correlation between precipitation and temperature found negative (0.32). Further detailed studies are required to be conducted to monitor other rainfall related characteristics such as extreme precipitation, total rain days and other climate change parameters for Peshawar city.

List of abbreviations: DJF: December-January-February; MAM: March-April-May; JJA: June-July-August; SON: September-October-November; SAI: Standardized Anomaly Index; TRMM: Tropical Rainfall Measuring Mission; St. Dev: Standard Deviation; AIRS: Atmospheric Infrared Sounder..

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Author Contribution: L.R. and S.T. initiated and designed the research and analyzed the data, B.M., L.R. and S.T. wrote the manuscripts; and all authors discussed the results and implications and commented on the manuscript at all stages. All authors contributed extensively to the work presented in this paper.

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