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Spatial-Temporal Assessment of Drought in Punjab, Pakistan using SPI and SPEI with Mann-Kendall Trend Test

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ABSTRACT

Highly rainfall variations create problems of floods and droughts in any region. This study focuses on spatial rainfall variability and drought assessment in Punjab province of Pakistan using Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). Various indices like standard deviation, Variance were calculated from annual rainfall of 16 meteorological stations during period of 1960–2015. Mann-Kendall technique was applied to check the trend for both SPI and SPEI. Out of 16 meteorological Stations under study D G Khan, Gujranwala, Jhang, Sargodha, Mandi B D and Sahiwal show a decreasing trend in annual temperature. On the other hand, Faisalabad, Jhelum, Lahore, Multan and Sialkot show an increase in trend of annual temperature. Remaining met. Stations show a linear or no trend. Out of 16 meteorological Stations 6 show an increasing trend in annual precipitation, 3 show a decreasing trend and the remaining show no trend in data at all. The analysis of SPI and SPEI results are showing that there was dry period at different time in historic data of Punjab. Almost all the Station or regions show dry period from 1965 to 1975 and then a dry period can also be seen in all the Punjab from 1999 to 2007 according to SPI results According to SPEI results all the Punjab is under dry spell from 1999 to 2015.

Keywords: Drought · SPI ·SPEI- Mann–Kendall · Rainfall variability-Climate Change

1. INTRODUCTION

Drought is the deficiency of precipitation or water scarcity leading to famine (Nicholls, Drosdowsky, & Lavery, 1997). It is one of the under-ratted natural hazard among all however its effects and destructiveness is more than any other natural hazard (Nicholson, 2000). The reason behind getting less attention than other natural hazards due to its slow beginning as compared to other natural hazard but it causes destruction of livestock and human lives on the large scale and its impacts can be observed even when the climatic conditions return to normal (Haines & Patz, 2004). Drought is slow occurring phenomena and prevail in an area for years (Agnew, 2000). Droughts are not depended on environment, rather on the hydrological processes that feed moisture in the environment

(Tsakiris & Vangelis, 2004). Low relative moisture in atmosphere less possibility of rainfall, it is difficult to reach the saturation conditions for a regular low-pressure system to rainfall, enough moisture outside the dry region that will produce enough rain to eliminate dry conditions (Umran Komuscu, 1999).

To understand drought we should know first drought early warning and drought risk (Stagge, Tallaksen, Gudmundsson, Van Loon, & Stahl, 2015), in which better preparation and emergency planning are allowed (Livada & Assimakopoulos, 2007). By executing definition of drought, three main drought types were established: meteorological, agriculture, and hydrological drought (Sobral et al., 2019). The decrease in rainfall causes the rise of meteorological drought, which affects soil moisture material (i.e., agricultural drought). Rechargeable water features like pounds and lakes get dry and soil moisture rapidly decrease (Stagge et al., 2015; Abera, 2022).

Along with the precipitation data, more variables such as evapotranspiration and stream flow are more widely used to characterize drought (Li, She, Zheng, Lin, & Yang, 2020). Water balance / hydraulic model are used to get drought index (Danandeh Mehr, Sorman, Kahya, & Hesami Afshar, 2020). Such indications may include weather, hydraulic, or water supply in nature (Pei, Fang, Wang, & Yang, 2020). In this study, two different techniques are used to find out the drought severity in the province of Punjab, Pakistan. One is Standardized Precipitation Index (SPI) and second one is Standardized Precipitation Evapotranspiration Index (SPEI). The Standardized Precipitation Index (SPI), measures standardized irregularities in precipitation (Liu, Zhu, Pan, Bai, & Li, 2018)and has been prescribed as a key dry spell indictor by the World Meteorological Organization (WMO, 2006) and all-inclusive meteorological dry season file by the Lincoln Declaration on Drought (Sophie Bachmair, Svensson, Hannaford, Barker, & Stahl, 2016).

The SPI is gaining acceptance as a valuable tool for monitoring drought (Uddin, Hu, Islam, Eibek, & Nasrin, 2020). It is currently being used by National Drought Monitoring Cell of Pakistan Meteorological Department (PMD), and all around the world e.g. National Drought Mitigation Center, the Western Regional Climate Center, as well as the Colorado Climate Center (S Bachmair, Kohn, & Stahl, 2015).

Drought is common part of a dry climate, but it can prevail in any climate system around the world (Labudová, Labuda, & Takáč, 2017). It is a process commonly considered attached with dry climate conditions which is kind of a myth and a miss conception because drought can also prevail in wet climatic condition (Bonaccorso, Bordi, Cancelliere, Rossi, & Sutera, 2003). Drought is a disaster not a climatic condition (Pei et al., 2020).

Population growth and increasing demand of waters causes water shortage in big urban centers and it's a very slow phenomenon (Li et al., 2020). Other factors, such as climate change and water supply pollution have played more role in water scarcity (Sophie Bachmair, Svensson, Prosdocimi, Hannaford, & Stahl, 2017; Bhusa et al., 2021; Dangana et al., 2022; Wanjohi et al., 2022). Climate change is now recognized as one of the major risks for planet Earth in the twentieth century (Mustafa & Rahman, 2018).

Historically, Pakistan has a lot of severe drought, which resulted in decrease agricultural development and the overall GDP of the country (Ashraf & Routray, 2015). However, the frequency of drought event has been less than that of flood. Back to the historical records, Pakistan often experience several droughts (Ashraf & Routray, 2015). In 1899, 1920 and 1935 the Punjab experienced the worst droughts (Jamro, Dars, Ansari, & Krakauer, 2019). Khyber Pakhtunkhwa (KPK) faced the worst droughts in 1902 and 1951. However, Sindh and Balochistan had its worst droughts in 1871, 1881,1899,1931,1947 and 1999. There were 11 out of 21 drought years were El Nino years, above this more than hundred year's period between "1871-1988" (pmd.gov.pk and nmdc.pk 2013). Natural Disasters could not be stopped (Ahmed, Shahid, & Nawaz, 2018). Now it has been accepted that dry climate in the future makes vulnerable economic areas of world, especially agriculture and therefore, need to look at the possible effects of climate change on crop production at different levels (Lee et al., 2022). SPI accurately detect dry and wet events that occurred during a particular time based on rainfall records (Van Loon & Laaha, 2015). The versatility and strength of SPI make it relevant across various felds such as groundwater management, agriculture water, and sustainable management of biodiversity and it is more effective to assess drought in the dry region (Manatsa, Chingombe, Matsikwa, & Matarira, 2008). The drought has been conventionally divided into four types, i.e., hydrological, meteorological, socioeconomical, and agricultural (Chen, Tfwala, Wu, Chan, & Chou, 2018). This study focused on the meteorological drought that ensues due to the long-term shortage of precipitation (Wang et al., 2016). Several studies indicated that in near future the drought severity will increase due to warming effects of climate change (Touma, Ashfaq, Nayak, Kao, & Diffenbaugh, 2015). In terms of rainfall occurrences, arid and semi-arid condition is prevailing in the south and extreme northern part of the province, while the central, eastern, and western parts have comparatively semi-arid to sub-humid conditions (Khan, 2013).

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Study Area

Pakistan is extended longitudinal, the rainfall variability during different seasons is high (Sheikh, 2001). Climatologically, with the significant spatiotemporal variability in climatic parameters like precipitation, maximum, and minimum temperature most parts of Pakistan are arid to semi-arid (Abid, Schilling, Scheffran, & Zulfiqar, 2016). The country has a diversified climate due to the longitudinal extent of the country from 24ºN to 37ºN. More than (59%) of the annual rainfall is due to monsoon Rain (Amin et al., 2018). In Pakistan the arid, semi-arid and sometimes hyper-arid conditions prevail. Therefore, there is more sensitivity due to drought risk in most areas (Ali, Farid, & Khan, 2020). The focus area of our study is Punjab province in Pakistan. Punjab is most developed province and is the second largest province after Baluchistan in area which is the largest province of Pakistan (Khattak & Ali, 2015). It is the largest province of country according to population. Punjab cover about 25.8 percent of the total country, which covers 205,344 square kilometers. Punjab share its borders with Sindh in southern Sindh, in the southwest Baluchistan, northwestern Khyber Pakhtunkhwa, and west of the Kashmir. Topography of Punjab is plain with alluvial plains and the soil is surrounded by the Indus River and its four main tributaries (Anwar, Zafar, & Rashid, 2006). Punjab also contain mountain ranges in the northern side, plateaus in the eastern part of Punjab, in the southwest the Sulaimon mountains found and in the south a part of the desert is also present which tells us about the variable climate of the Punjab from arid climate in the south to very wet and humid climate in the northern part of Punjab and varying temperature between -2 and 45 degrees Celsius throughout the year from north to south and the precipitation ranges between 17-201 millimeters per year from south to north. Punjab contains lot of water. The study site consists of Multan, Bahawal Nagar, Faisalabad, Sargodha, Rawalpindi and Bahawalpur etc. These cities were chosen on the basis of their agriculture and elevation above the sea level (Waseem, Khurshid, Abbas, Ahmad, & Javed, 2022). The province of Punjab holds over 60% of Pakistan's total population and produces more than 55% of the country's agricultural supplies (Waseem et al., 2022). Therefore the shortage of water in Punjab can affect the life and survival of whole Pakistan. As we know all the life directly or indirectly depends on water and when if there is a shortage of water it will affect the life and survival could be impossible. This research will elaborate History of Droughts in Punjab, Pakistan and trends of Drought in Punjab (Cheema, Rasul, Ali, & Kazmi, 2011). So the Aims and Objectives of this study is To implement SPI & SPEI trends of different magnitudes and To analyze the frequency, intensity, trend and drought occurrences using different indices.

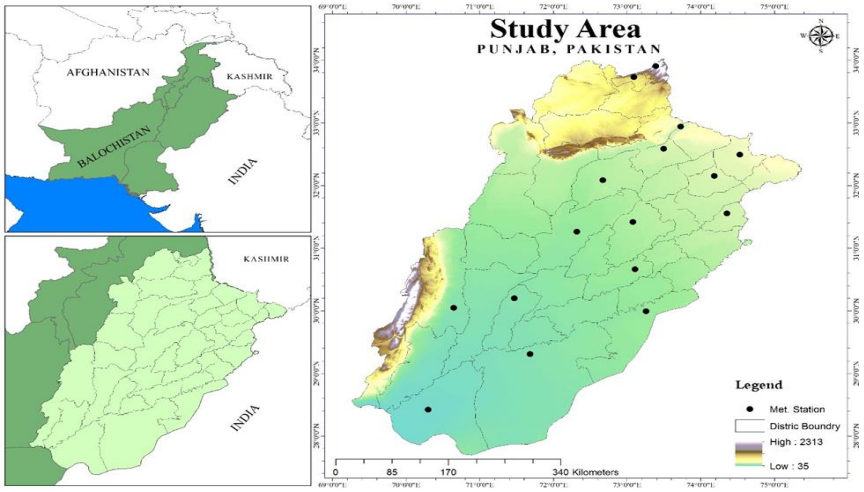

Figure 1 Study area

Table 1 Data Duration

Sr. No.	Met. Station	Longitude	Latitude	Data Duration
1	Bahawalnagar	73.258	29.992	1960-2015
2	Bahawalpur	71.683	29.309	1962-2015
3	D G Khan	70.646	30.047	2004-2015
4	Faisalabad	73.079	31.418	1976-2015
5	Gujranwala	74.184	32.154	2012-2015
6	Islamabad	73.093	33.729	1990-2015
7	Jhang	72.318	31.261	2003-2015

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8	Jhelum	73.727	32.941	1976-2015
9	Lahore	74.357	31.554	1976-2015
10	Mandi B D	73.497	32.588	2004-2015
11	Multan	71.468	30.198	1976-2015
12	Murree	73.391	33.907	1960-2015
13	R Y Khan	70.298	28.421	2002-2015
14	Sahiwal	73.108	30.661	2004-2015
15	Sargodha	72.671	32.083	2007-2015
16	Sialkot	74.531	32.492	1976-2015

2. METHODOLOGY

Data is collected from 16 different met. Stations of Punjab. The primary data required for the calculation of any drought index is of precipitation data. SPI only needs data of precipitation for its calculation other than that SPEI also requires potential evapotranspiration (PET) data. Precipitation and temperature data is obtained from Pakistan Metrological Department (PMD). Data is than further arranged properly according to months and years. For the calculation of SPEI of study area, data of potential evapotranspiration (PET) is required, which was originally not available to use for study purpose so we have used an approach known as Thornthwaite's method. This method helped us to get estimated PET for the region by using temperature data and elevation data. SPI only required precipitation data which was already provided by PMD.

Statistics of precipitation and temperature

Table 2 Statistics of precipitation and temperature

Metrological Stations	Temperature			Precipitation		
	Annual Temp. (oC)	Variance	Standard Deviation	Annual Ppt. (mm)	Variance	Variance
Bahawalnagar	25.52	2.170028	1.473101	249.9	20703.15	142.522
Bahawalpur	24.99	1.857628	1.362948	151.9	9897.597	99.48667
D G Khan	25.87	0.341655	0.584513	248.6	10431.42	102.1343
Faisalabad	24.09	0.382026	0.618082	401.2	19278.1	140.6385
Gujranwala	22.47	0.072979	0.270147	847.6	25096.28	158.418
Islamabad	21.16	7.477147	2.734437	1257.6	85031.12	291.601
Jhang	24.52	0.098994	0.314634	362.5	8570.23	92.57554
Jhelum	23.73	0.200069	0.447291	895.2	36513.02	191.0838
Lahore	24.64	0.382928	0.618812	734.1	74693.74	272.8646
Mandi B D	23.85	0.094178	0.306884	759.5	37895.41	194.6674
Multan	25.47	0.268714	0.518376	210.6	7280.48	82.77763
Murree	13.04	1.015181	1.014856	1753.3	94146.97	306.8338
R Y Khan	26.44	0.173409	0.416424	147.5	7976.669	89.3122
Sahiwal	24.27	0.227227	0.476683	388.2	15186.49	123.2335
Sargodha	24.90	0.138133	0.371663	524.3	27357.13	165.3999
	22.90	0.282267	0.531288	1004.8	86620.31	336.7557

However, on the other hand 9-moth to 24-month SPI and SPEI tells about the hydrological drought (Sunil Gurrapu, 2014) i.e. the condition of water reservoirs on-ground and under-ground (Anjum Bari Faooqi, 2005).

SPI

SPI can be calculated for different time-scales i.e. from 1-month to 24-months and onward tells us about different conditions or different types of droughts (Hua Xie, 2013; Khan & Gadiwala, 2013; Mckee & J. Doesken, 1993). 1-months SPI tells about the metrological drought (Hua Xie, 2013). 3-months and 6-months SPI tells us about the soil moisture and is useful for agriculture purpose (Hua Xie, 2013).

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Drought Intensity source McKee 1993

Table 3 Drought Intensity source McKee 1993

Drought Intensity	SPI Value
Extremely wet	2.00 to 3.00
Very wet	1.50 to 1.99
Moderately wet	1.00 to 1.49
Near normal	0.99 to -0.99
Moderately dry	-1.00 to -1.49
Very dry	-1.50 to -1.99
Extremely dry	-2.00 to -3.00

The table shows the drought intensity related to SPI values that ranges from +3 to -3. Positive values show wet condition while negative values show dry condition. For this study we have calculated SPI for 3, 6, 9, 12, and 24-months. The values of SPI are both Negative as well as Positive, which tells us about both the dry and wet spell (Hua Xie, 2013) (Muhammad Ashraf, 2015) (Sunil Gurrapu, 2014). Main strength of SPI is that it only need Precipitation data for its calculation and can calculate SPI for different time-scales but this is also its main weakness i.e. it only takes the precipitation data and consider other important metrological variables like temperature, wind speed, PET constant which effects the accuracy of SPI.

It is the probability of precipitation in the simplest of words which is then converted in normalized index using gamma distribution statistics (Muhammad Ashraf, 2015). Thom found the gamma distribution to fit the climatological time series well. The gamma distribution is defined by its frequency or probability density function (Thom, 1966).

$$(x) \;=\; 1\,\beta\alpha\partial\,(\alpha)\,x\,\alpha - 1e\; - x/\beta\,, for\; x \;>\; 0$$

where α and β are the positive parameters that represent the shape of the distribution, x is the precipitation amount, and ∂ is the gamma function.

SPEI

In SPEI the variable of Potential Evapotranspiration (PET) is considered (Rutema, 2002). It allow us to use other important variable in the calculation of drought for different time-scales like we calculate SPI (Sunil Gurrapu, 2014). In simple SPEI is improvement of SPI (Sergio M. Vicente-serrano, 2009). It is calculated by getting the difference between precipitation and PET. The PET is calculated by using Thornthwaite method that gives considerably higher estimates of PE and shows lower inter-annual variability (Myoung-Jin Um, 2017) (Rutema, 2002).

$$PET \;=\; 16K\,\{\,10T\,/I\,\}$$

Where T is the monthly mean temperature in °C; I is a heat index, which is calculated as the sum of 12 monthly index values i, the latter being derived from mean monthly temperature using the formula.

3. RESULTS AND DISCUSSION

To better understand the results obtained from calculation of SPI and SPEI we first must understand the distribution of precipitation and temperature in the region Punjab.

Precipitation and Temperature

Pakistan has almost all type of climatic conditions varying from hot desert to mountains covered in snow and plain areas. The topography of Punjab is mostly plain with mountains at north and northwest side of Punjab and Thar Desert in the southern Punjab while Cholistan desert in southwest. If we look at distribution of temperature and precipitation in the Metrological stations under study, we see that both precipitation and Temperature varies largely as we move from north to south.

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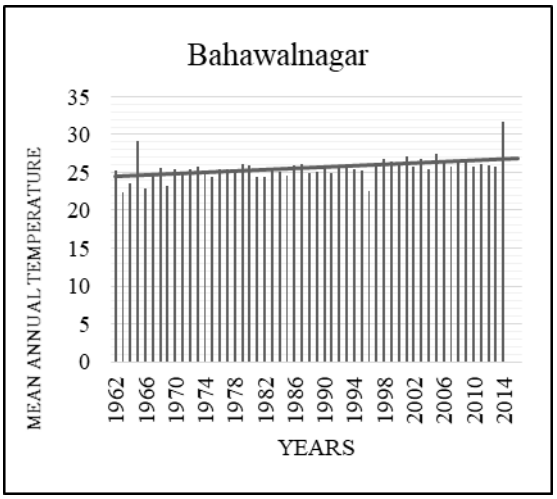

Figure 2.1 Bahawalnagar annual temperature

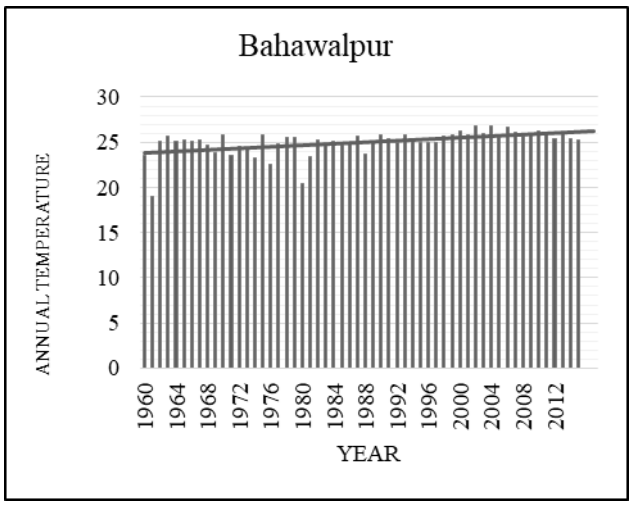

Figure 2.2 Bahawalpur annual temperature

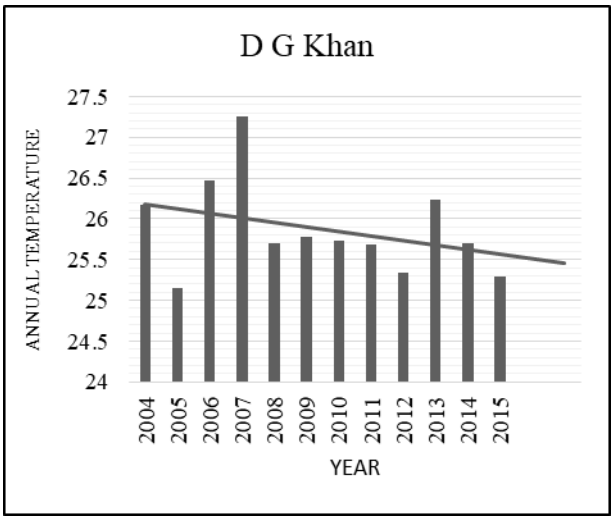

Figure 2.3 D G Khan Annual Temperature

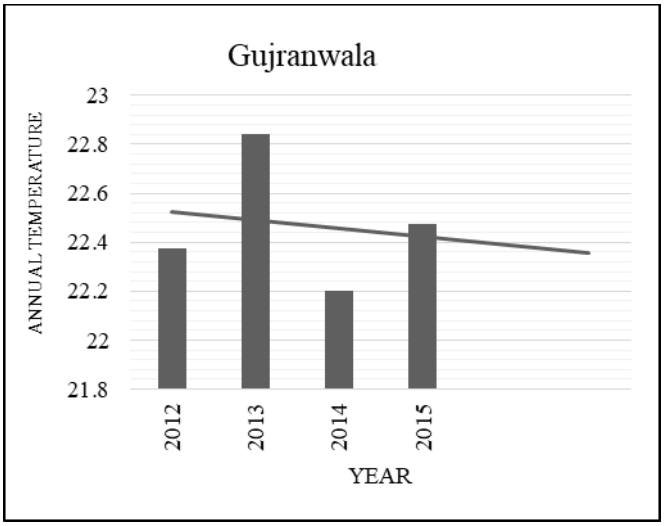

Figure 2.4 Gujranwala Annual Temperature

Graphs shown above and below are annual temperature graphs of data of met. Stations present in study area the line in the graph is indicating trend of temperature in a specific met. Station based on the historic data of that station. Out of 16 met. Stations under study D G Khan, Gujranwala, Jhang, Sargodha, Mandi B D and Sahiwal show a decreasing trend in annual temperature. On the other hand, Faisalabad, Jhelum, Lahore, Multan and Sialkot show an increase in trend of annual temperature. Remaining met. Stations show a linear or no trend.

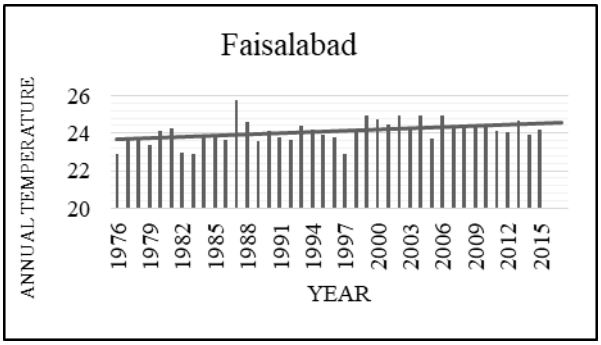

Figure 2.5 Faisalabad Annual

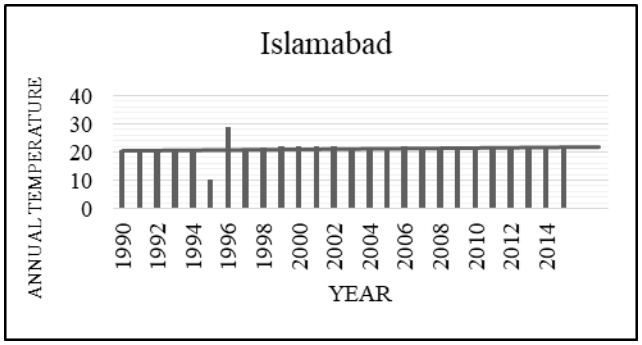

Figure 2.6 Islamabad Annual

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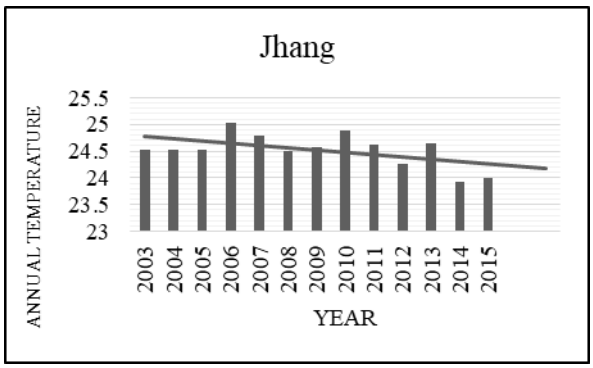

Figure 2.7 Jhang Annual Temperature

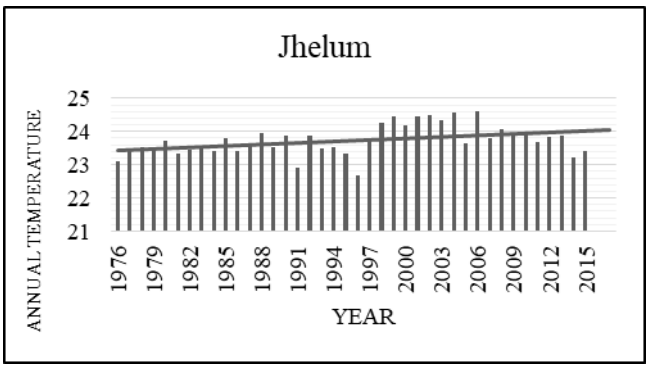

Figure 2.8 Jhelum Annual Temperature

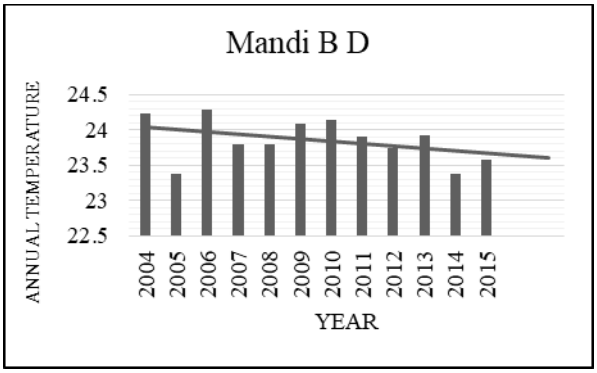

Figure 2.9 Mandi B.D Annual Temperature

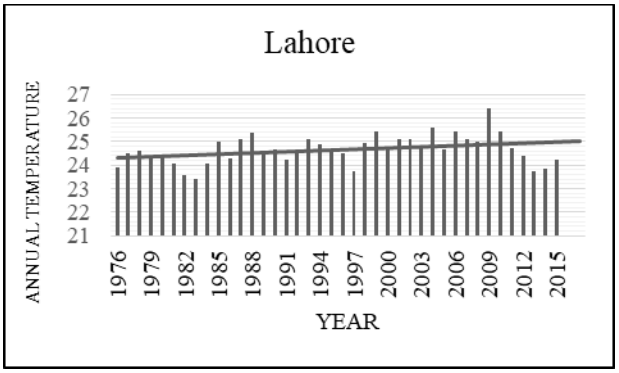

Figure 2.10 Lahore Annual Temperature

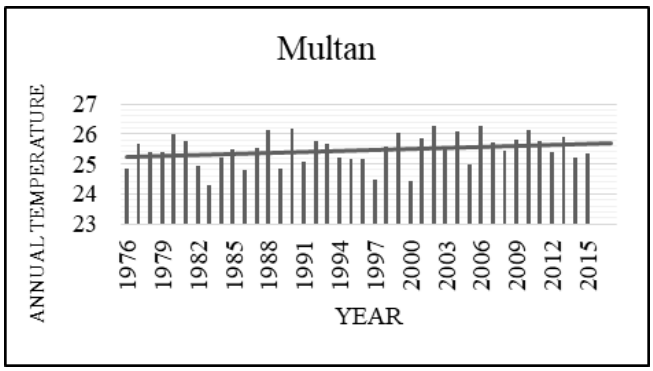

Figure 2.11 Multan Annual Temperature

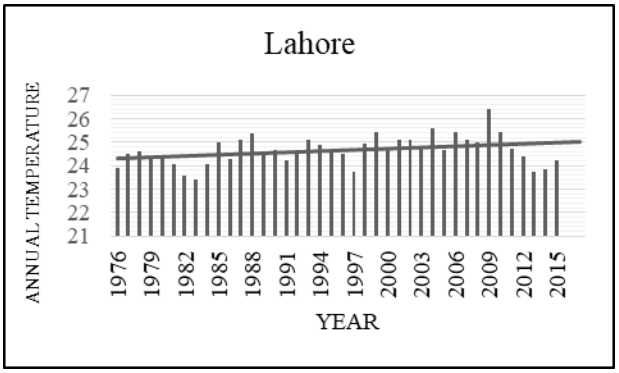

Figure 2.12 Murree Annual Temperature

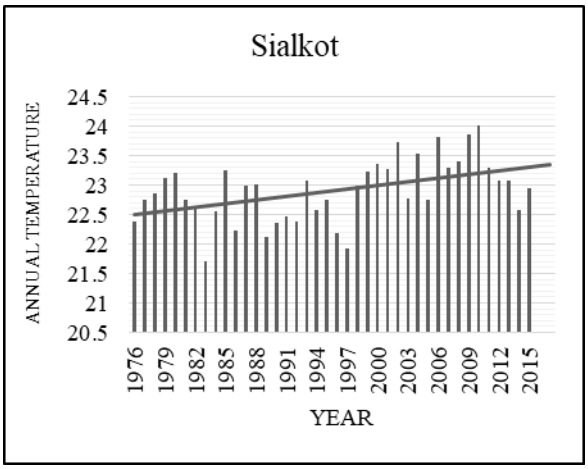

Figure 2.13 Sialkot Annual Temperature

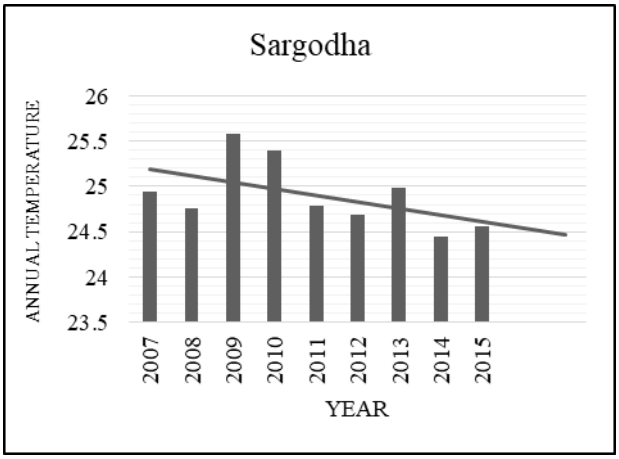

Figure 2.14 Sargodha Annual Temp

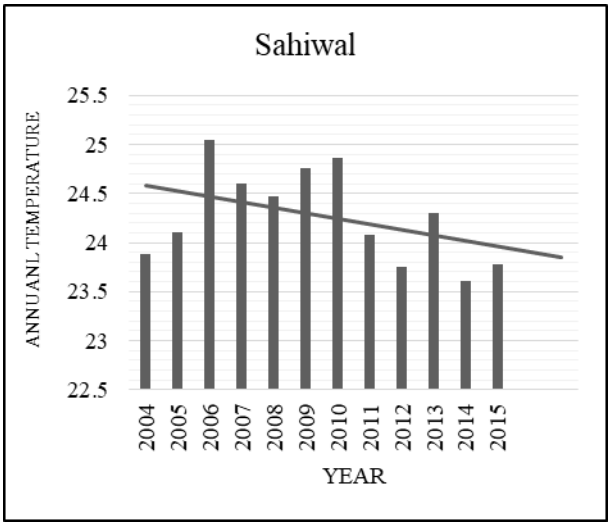

Figure 2.15 Sahiwal Annual Temp.

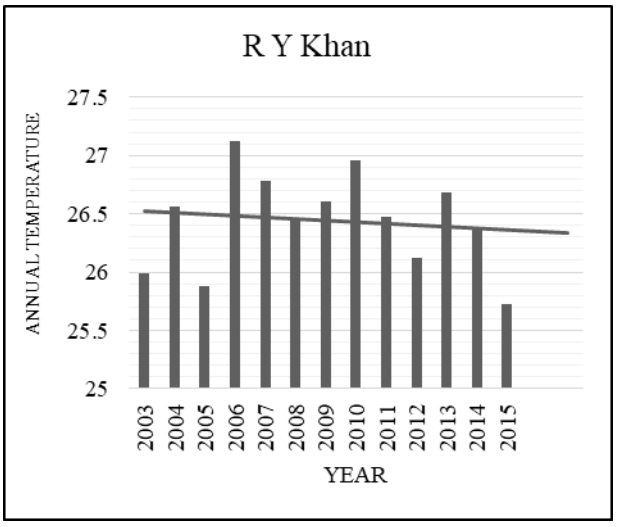

Figure 2.16 R Y Khan Annual Temp.

Data of temperature shows us different types of variations in data the temperature in most of Punjab met stations is in increasing trend. Out of 16 met. Stations under study D G Khan, Gujranwala, Jhang, Sargodha, Mandi B D and Sahiwal show a decreasing trend in annual temperature. On the other hand, Faisalabad, Jhelum, Lahore, Multan and Sialkot show an increase in trend of annual temperature. Remaining met. Stations show a linear or no trend. While the data of precipitation shows the following results.

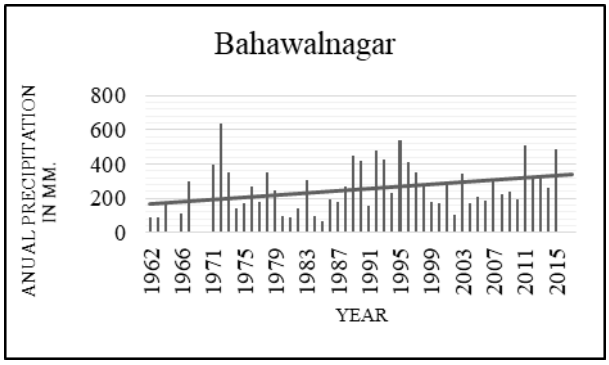

Figure 3.1 Bahawalnagar Annual ppt.

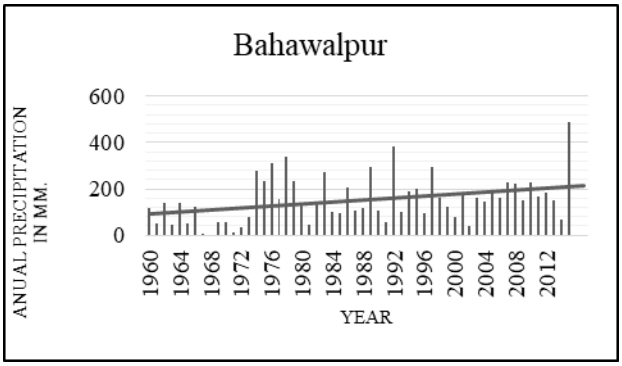

Figure 3.2 Bahawalpur Annual ppt.

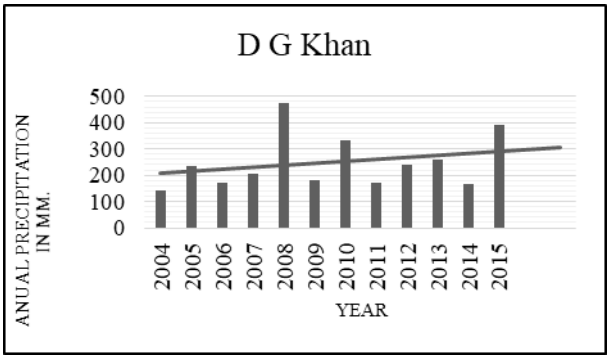

Figure 3.3 D G Khan Annual ppt.

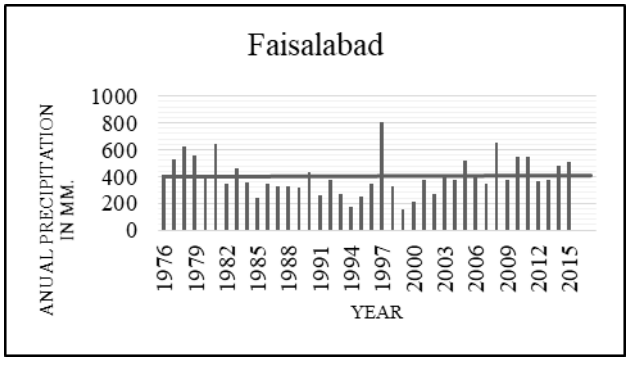

Figure 3.4 Faisalabad Annual ppt.

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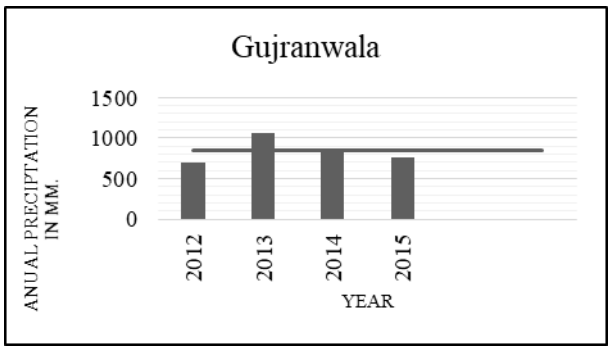

Figure 3.5 Gujranwala Annual ppt.

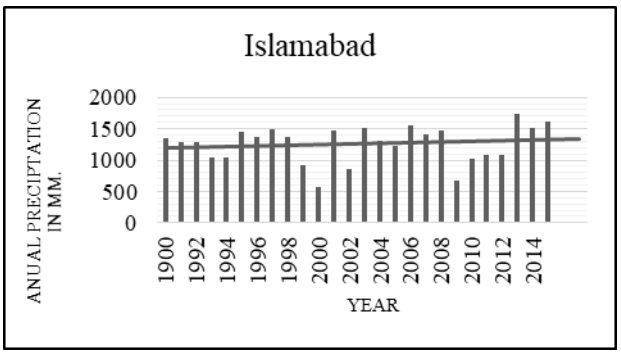

Figure 3.6 Islamabad Annual ppt.

Above and below shown graphs are representing annual precipitation of met. Stations under study in Punjab and the line in the graph show trend in data. Out of 16 met. Stations 6 show an increasing trend in annual precipitation, 3 show a decreasing trend and the remaining show no trend in data at all.

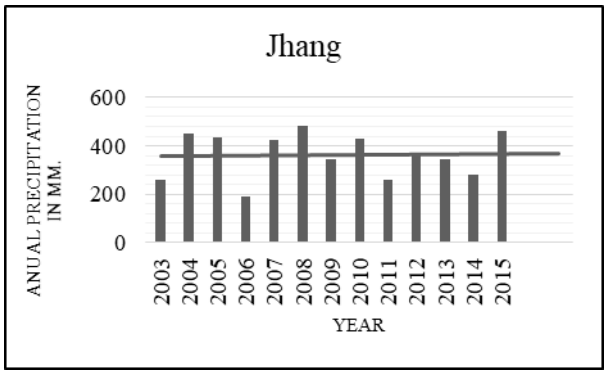

Figure 3.7 Jhang Annual ppt.

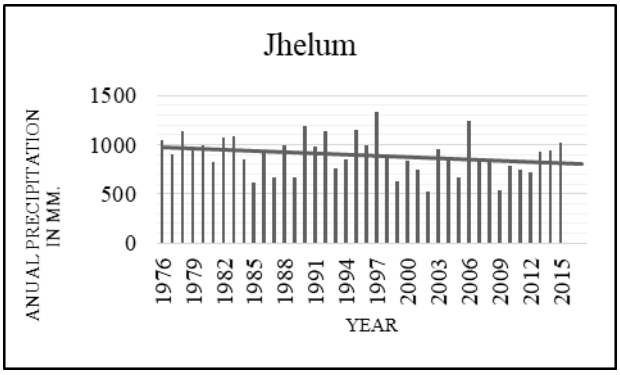

Figure 3.8 Jhelum Annal ppt.

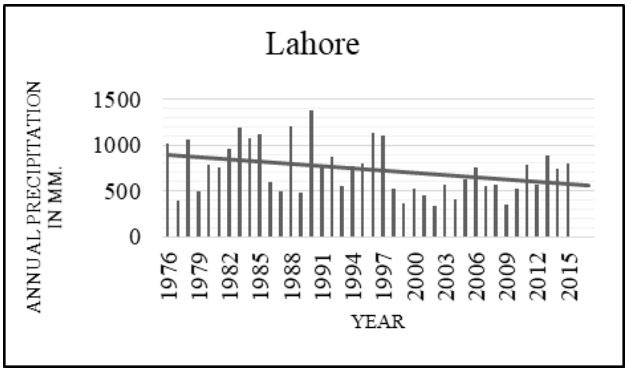

Figure 3.9 Lahore Annual ppt.

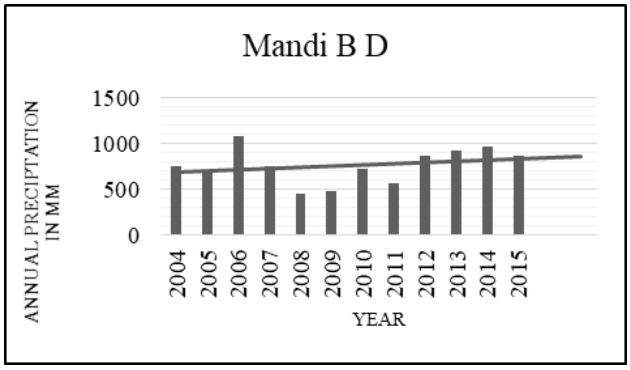

Figure 3.10 Mandi Annual ppt.

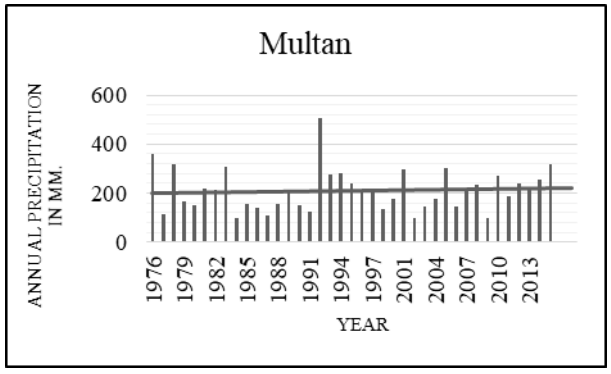

Figure 3.11 Multan Annual ppt.

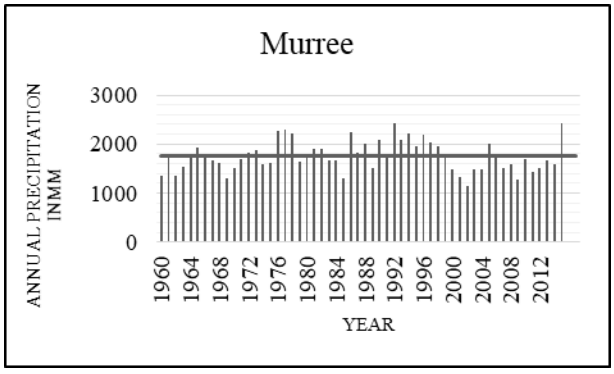

Figure 3.12 Murree Annual ppt.

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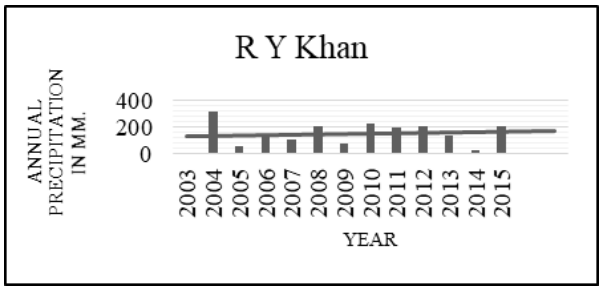

Figure 3.13 R Y Khan Annual ppt.

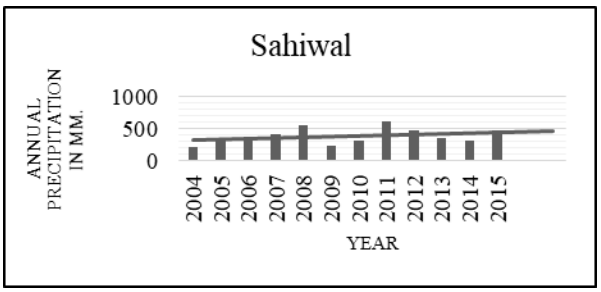

Figure 3.14 Sahiwal Annual ppt.

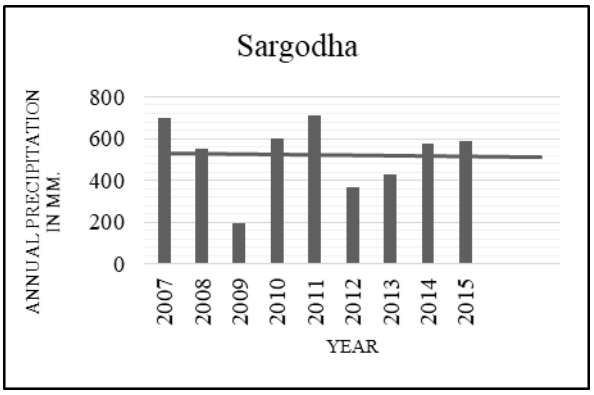

Figure 3.15 Sargodha Annual ppt.

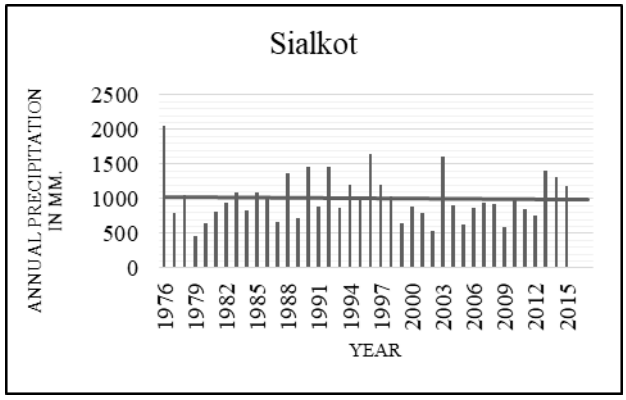

Figure 3.16 Sialkot Annual ppt.

The annual graphs of precipitation and temperature for all Metrological station shows us following variations,

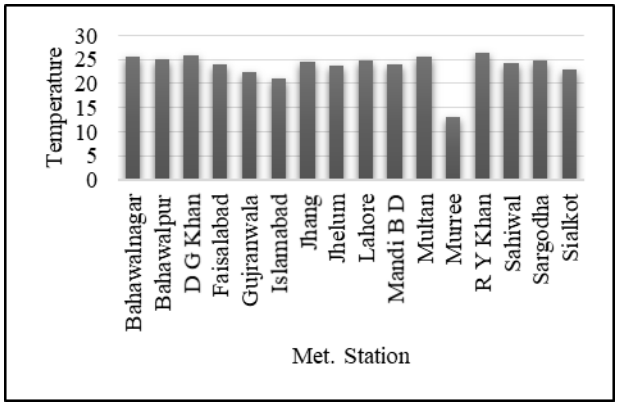

Figure 4 .1 Annual temperature of met. Stations in study area

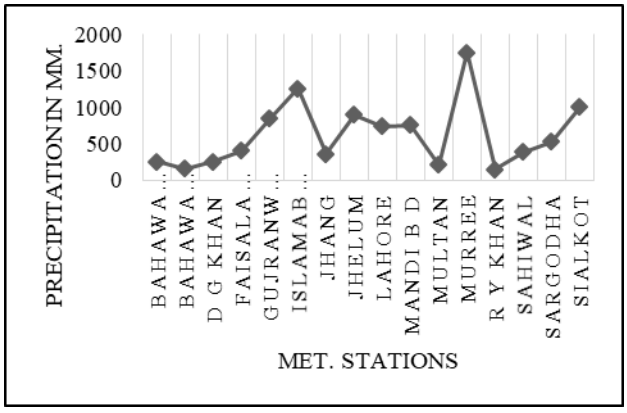

Figure 4.2 Annual precipitation of met. Stations in study area

The trend or distribution present in data of precipitation and temperature from north to south is clear in the map. The inverse relation present in temperature and precipitation is visible in maps of annual temperature and precipitation. As we move from south to north temperature decreases while precipitation increase. Major reason behind this change is the topography of Punjab.

South side of Punjab start with desert as we move up towards north region converts from desert to plain region and furthermore in mountainous region. As we get closer to mountainous region temperature drops and precipitation increase.

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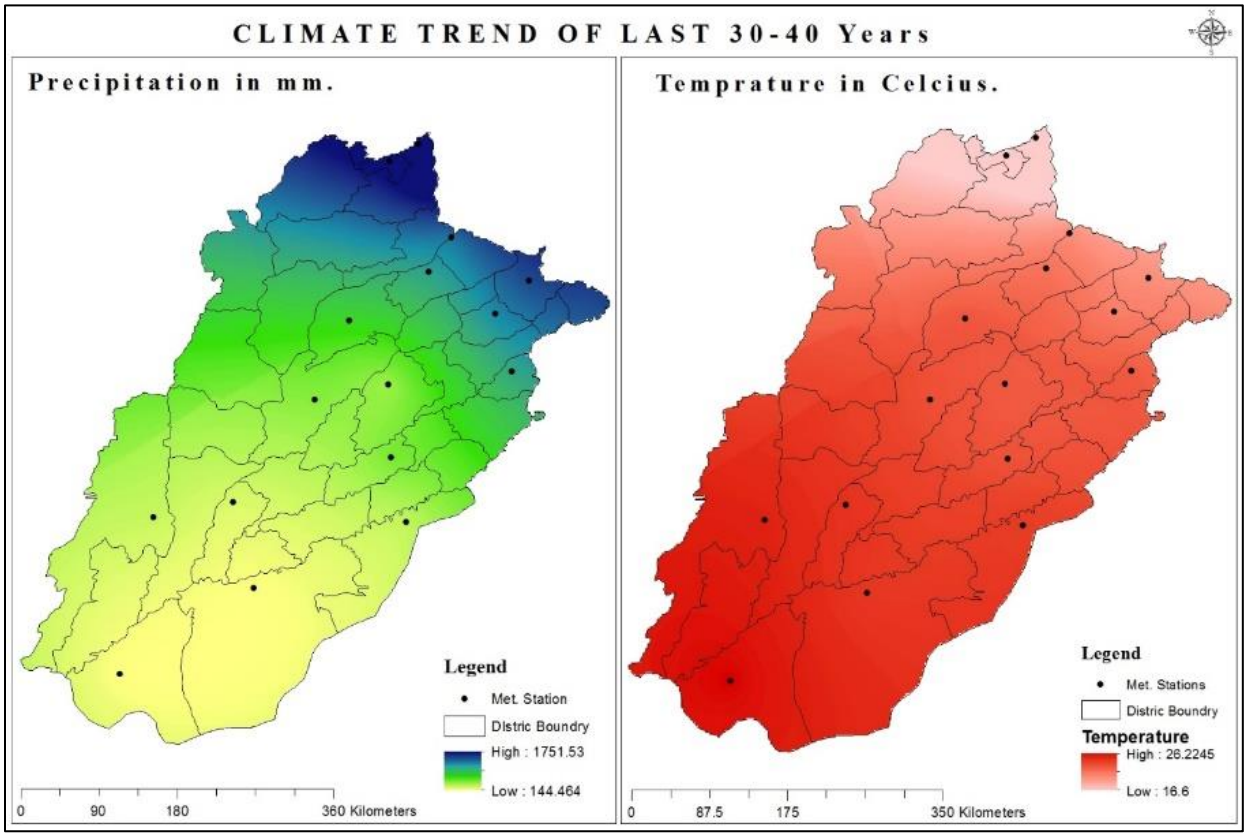

Figure 5.1 Climate Trend of Last 30-40 Years

SPI

SPI is calculated for 3 months, 6 months, 9 months, 12 months and 24 months.

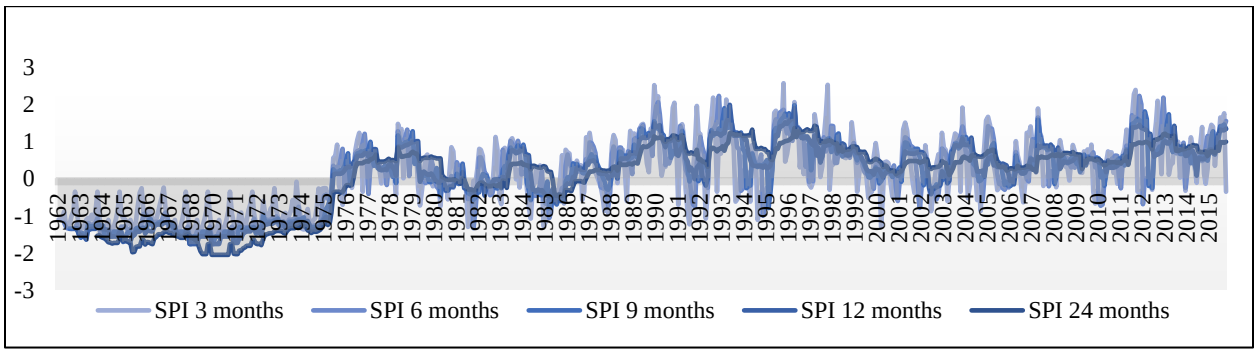

Figure 6.1 Bahawalnagar SPI

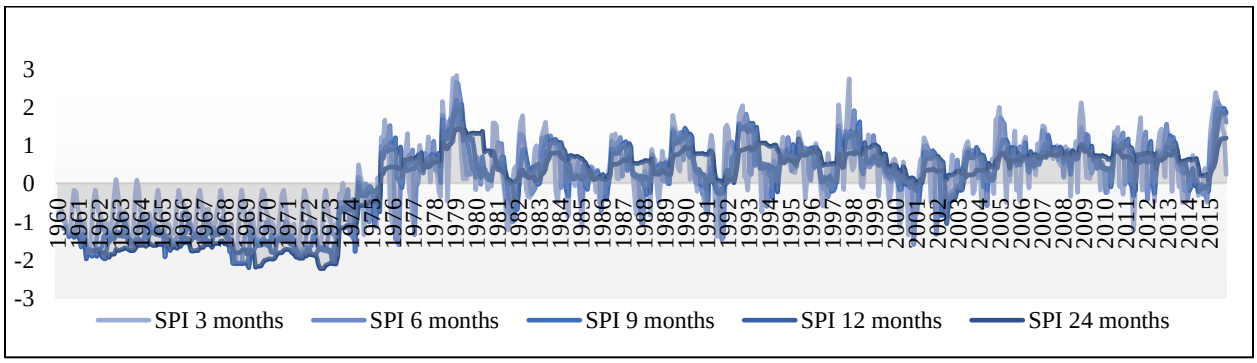

Figure 6.2 Bahawalpur SPI

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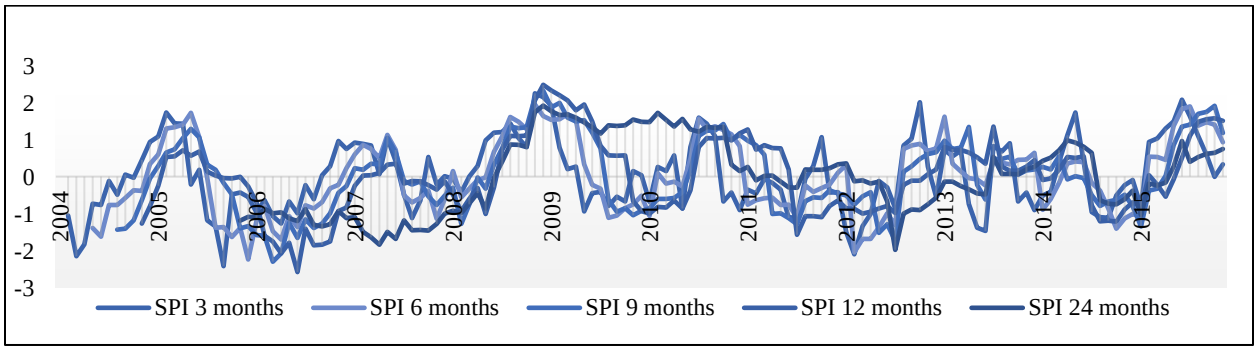

Figure 6.3 DG Khan SPI

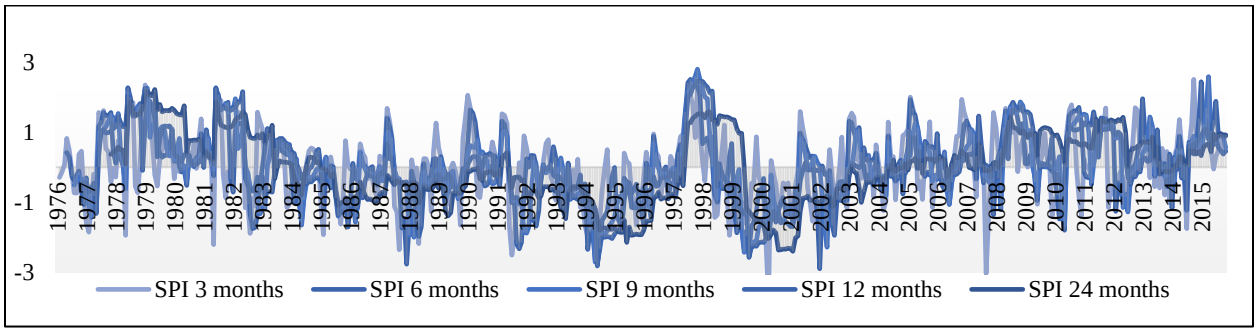

Figure 6.4 Faisalabad SPI

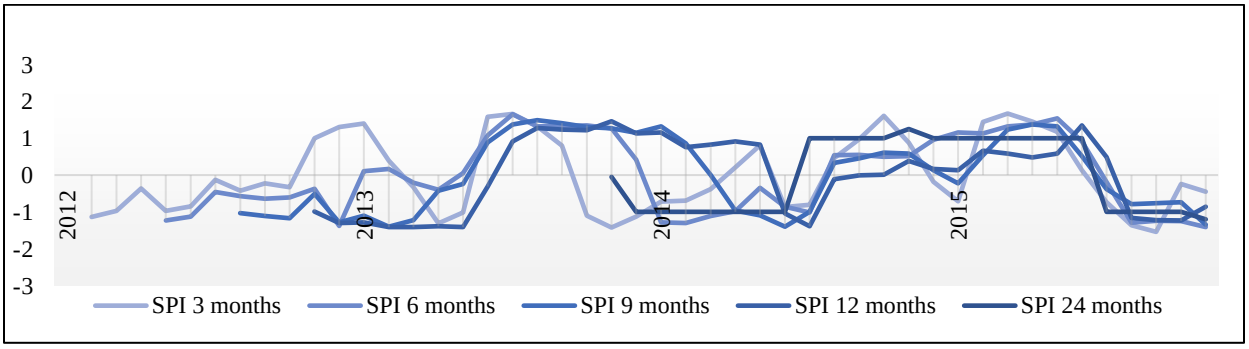

Figure 6.5 Gujranwala SPI

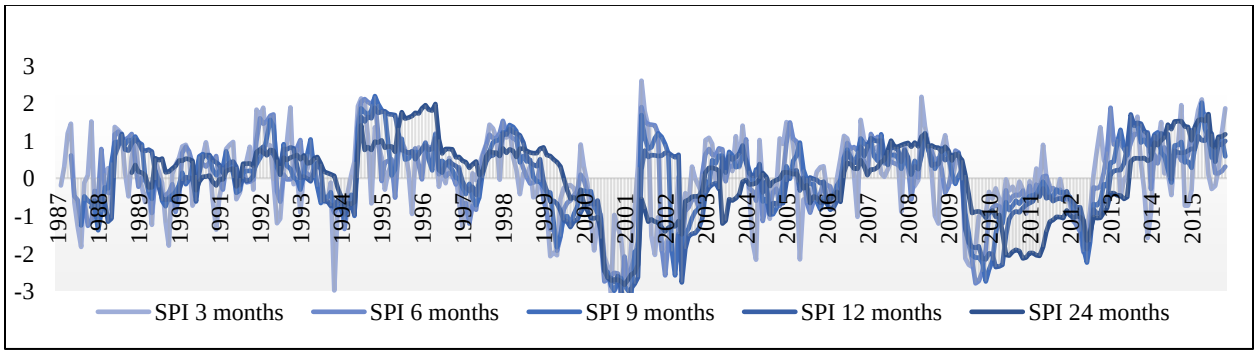

Figure 6.6 Islamabad SPI

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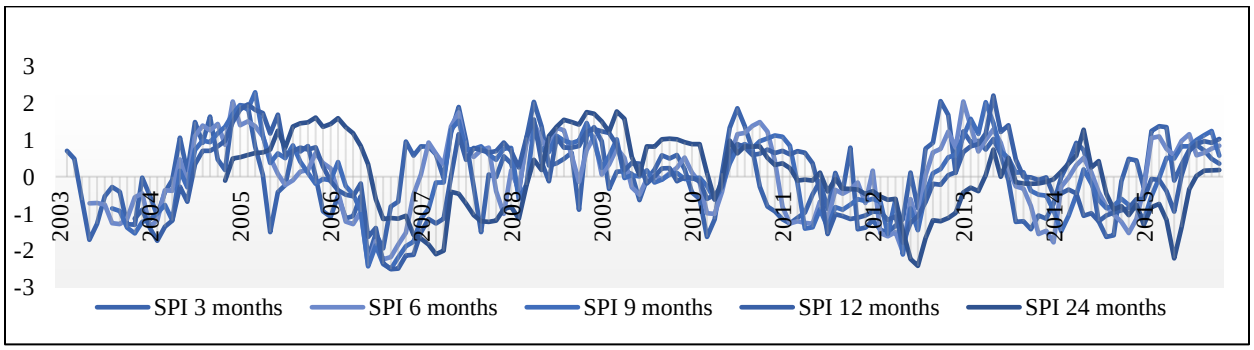

Figure 6.7 Jhang SPI

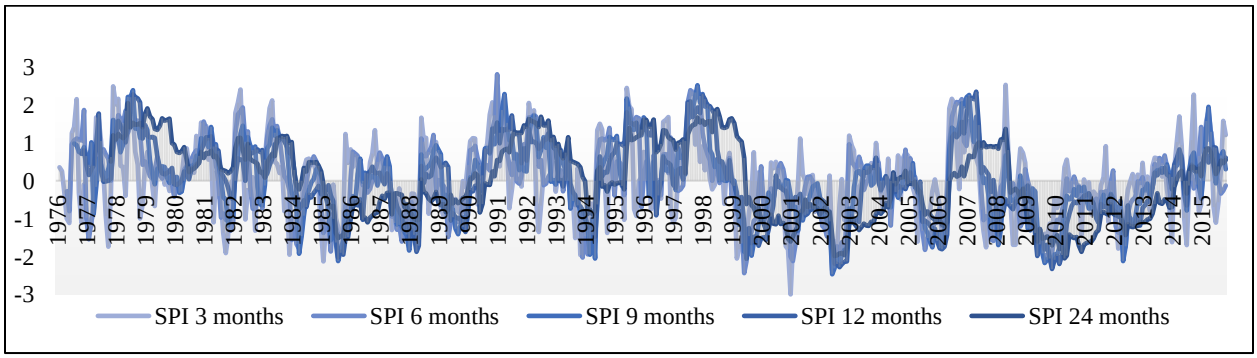

Figure 6.8 Jhelum SPI

SPI results show that there is a dry condition over Bahawalnagar from 1962 to 1975 and the intensity of dryness range from (-1.0 to -2.0) which is moderately dry. There are some other years where the SPI hit negative value, but the data stay in range of (grater then -1.0) which is considered normal. Bahawalpur the next station in list exhibits a long period of dryness from 1960 to 1975 the intensity of drought during this period is (-1.0 to -2.3) which is moderately to very dry like condition, other than that there is no major dryness period in Bahawalpur. SPI values of D G Khan show some period of dryness from 2006 to 2008 and 2011 to 2013 with intensity of drought ranging from moderate to very dry (-1.0 to -2.5). Faisalabad according to SPI results are from 1992 to 1997 and 1999 to 2003 and the intensity of drought during these periods is moderately dry with values ranging from (-0.9 to -2.0) other than that, there are some minor dry years throughout the data with intensity ranging from (-0.2 to -1.5) and the years are 1977, 1983, 1986, 1992, 2008, 2010, 2012, and 2014. Gujranwala shows no major dry era the negative value is greater than -1.0 which means it is under normal conditions. There are two major era of dryness in historic data of Islamabad from 1999 to 2004 and 2009 to 2013 with intensity of dryness ranging from moderate to extreme dry (-0.9 to -2.8), some minor dry years can also be seen in the data i.e.1988, 1990, 1994, 1997and 2006 intensity of dryness during these years is mostly moderate. In Jhang SPI calculations show that there is dry spell in region from 2006 to 2008 than from 2011 to 2013 and then in 2015 with intensity of drought ranging from moderate to very dry like condition (-0.9 to -2.2). In Jhelum there are two major dry periods from 1999 to 2005 and 2008 to 2013 with intensity of moderate dryness i.e. (-0.8 to -2.1), some other dry period in data of Jhelum are 1977, 1982, 1984, 1986, 1988 and 1990 with intensity of normal to moderate dry (-0.2 to -1.2).

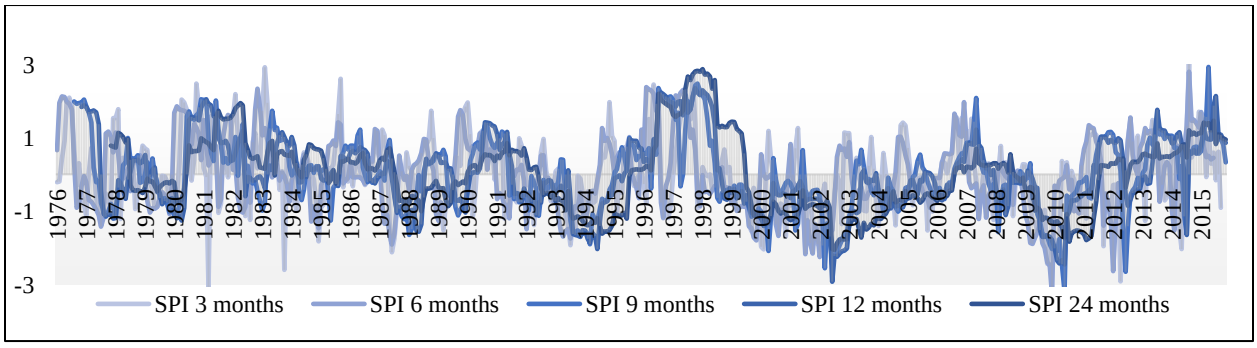

Figure 6.9 Lahore SPI

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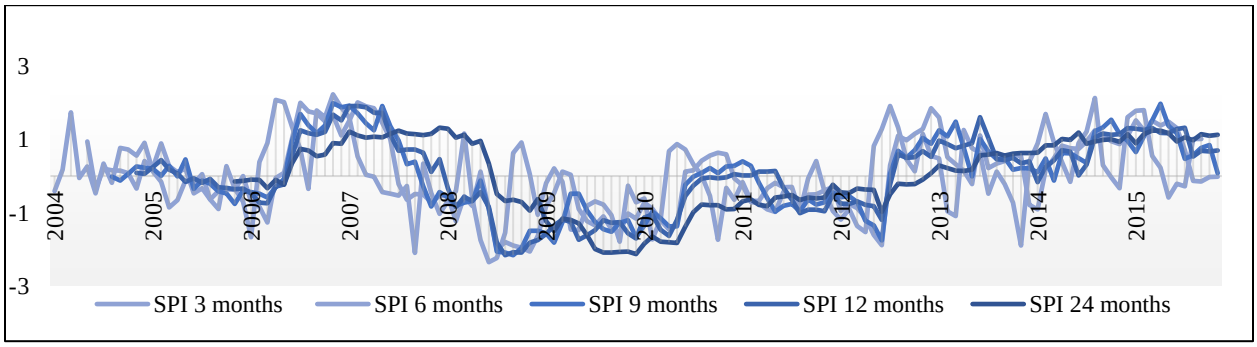

Figure 6.10 Mandi B.D SPI

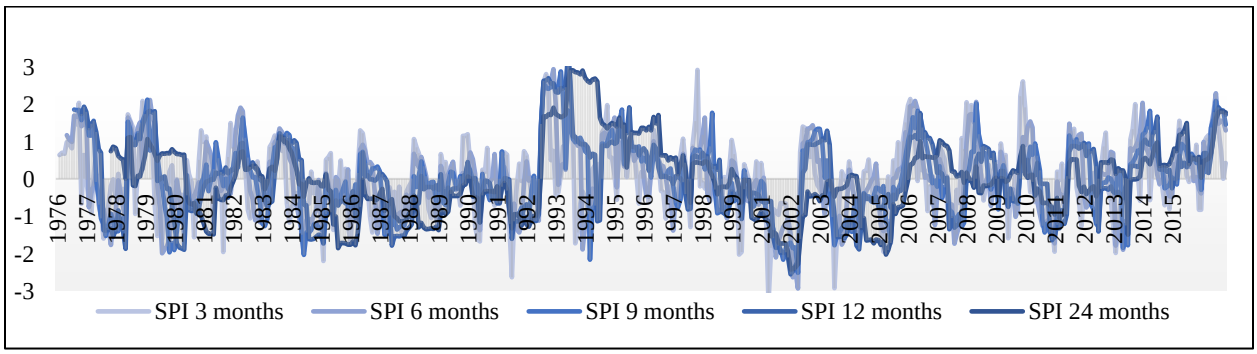

Figure 6.11 Multan SPI

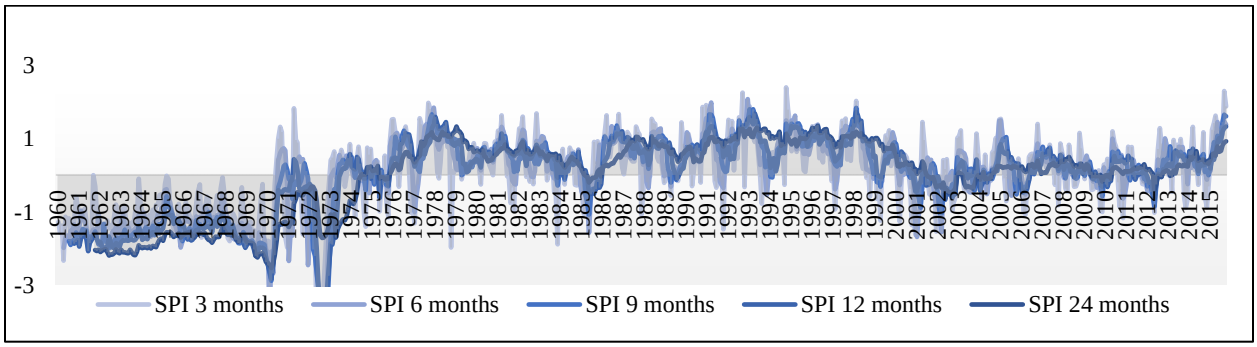

Figure 6.12 Murree

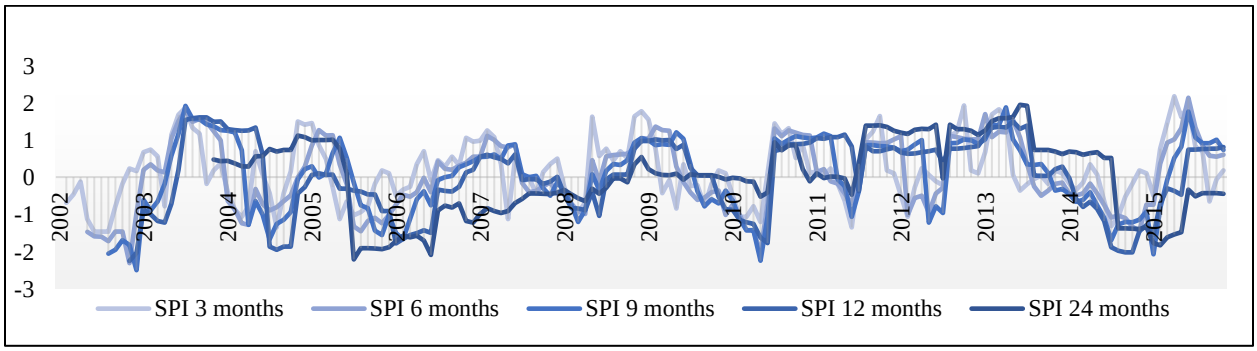

Figure 6.13 R.Y Khan SPI

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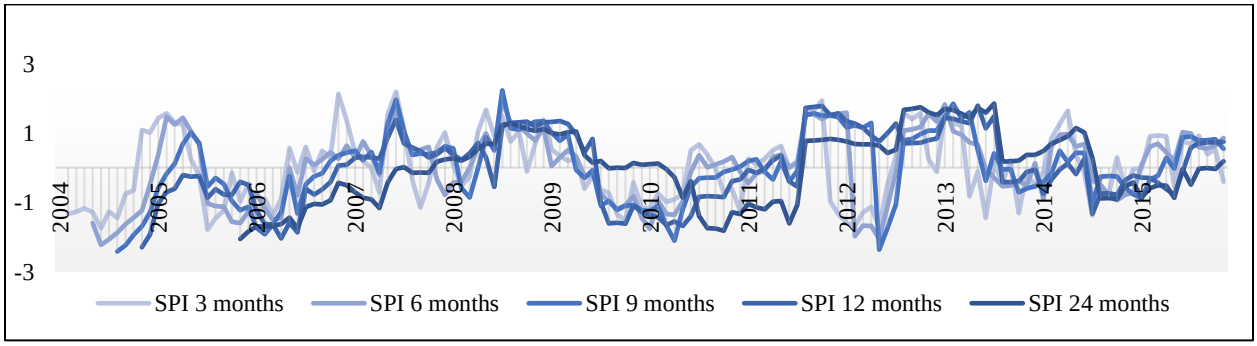

Figure 6.14 Sahiwal SPI

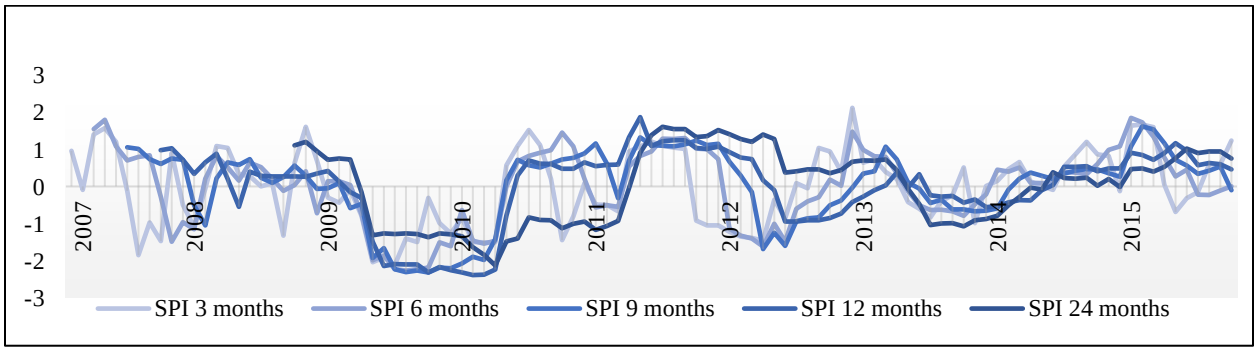

Figure 6.15 Sargodha SPI

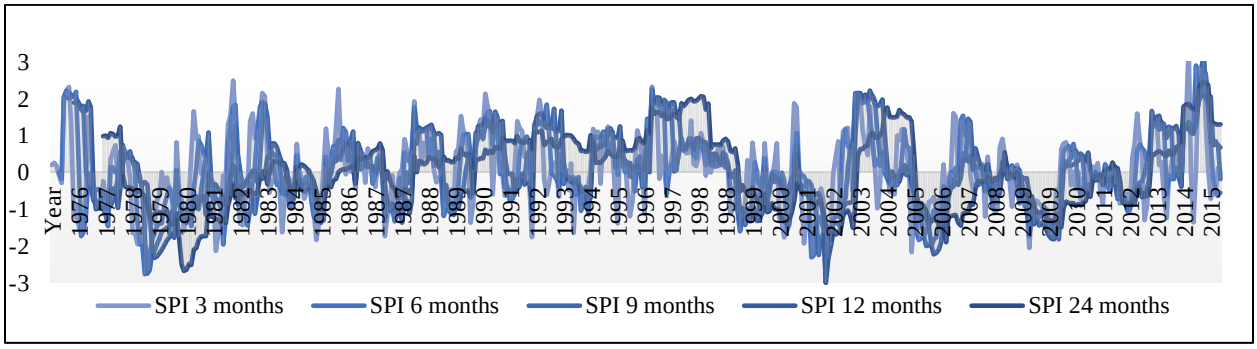

Figure 6.16 Sialkot SPI

Lahore show three major dry periods 1991 to 1995 than 1999 to 2006 and then 2009 to 2012, drought intensity during this period is from moderate to extreme dry i.e. (-1.2 to -2.8), some other dry years in data are 1978, 1983, 1988, 1990 and 2014 with intensity of (-0.2 to -1.2). Only dry spell in Mandi B D is from 2008 to 2012 with moderately dry (-0.4 to -2.0). Multan has several dry periods throughout data starting from 1978 than 1980 to 1981, 1983 to 1985, 1990 to 1992, 2001 to 2002, 2004 to 2006, 2011 and then in 2014 with moderate to very dry like condition (-0.5 to -2.1). Murree show a single long dry period in its data starting from 1960 to 1974 intensity during this era is moderate to extreme dry (-1.2 to -2.8). R Y Khan show some dry years in data 2004, 2006 to 2007, 2010 and 2014 to 2015 with moderate intensity of dryness (-0.2 to -1.9). Sahiwal show two major dryness periods 2006 to 2007 and 2010 to 2011 with moderate drought intensity (-0.5 to -1.5). Sargodha show dryness in period of 2009 to 2011 and in 2014 with drought intensity ranging from (-0.5 to -2.5) moderate to very dry. There are several dry years in historic data of Sialkot starting from 1976 to 1982, 1985, 1987, 1989, 1994, 1998 to 2003, 2005 to 2007 and in 2009 with intensity of drought ranging from (-0.5 to – 2.9) moderate to extreme dry.

SPEI

SPEI is simply calculated by finding the difference b/w precipitation and PET. Results of SPEI varies largely from SPI in some regions of study area. SPEI is calculated for 3 months, 6 months, 9 months, 12 months and 24 months.

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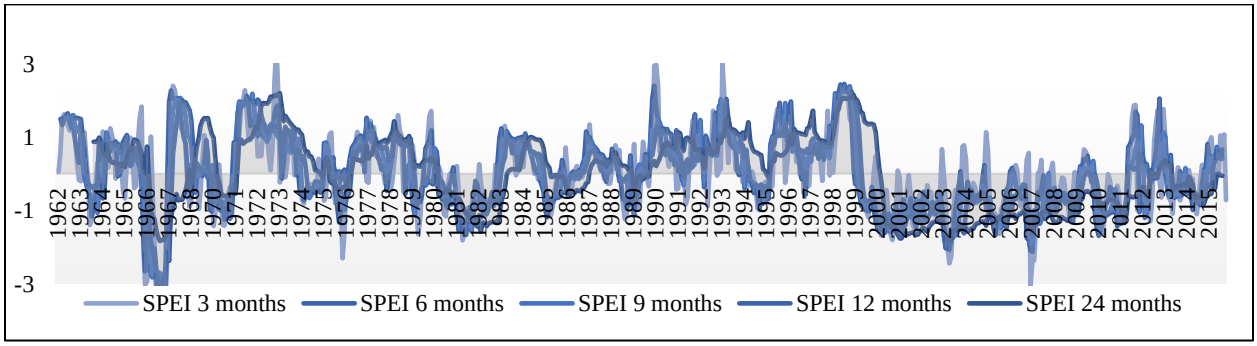

Figure 7.1 Bahawalnagar SPEI

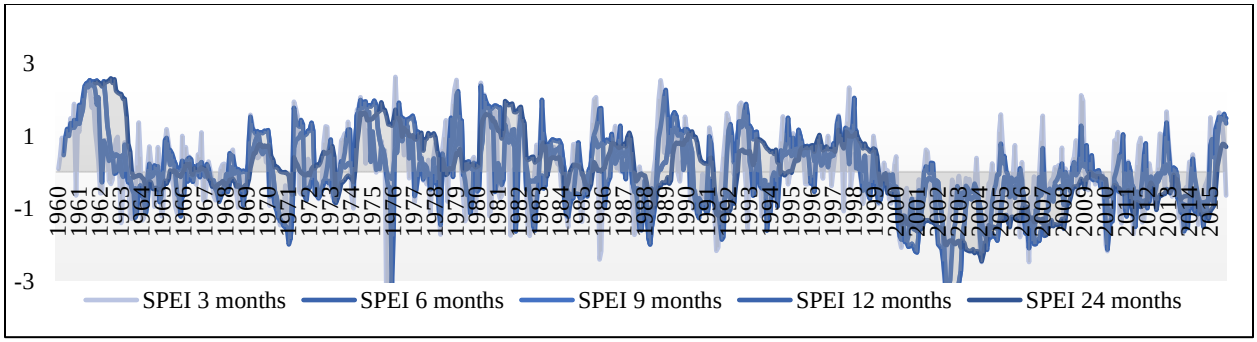

Figure 7.2 Bahawalpur SPEI

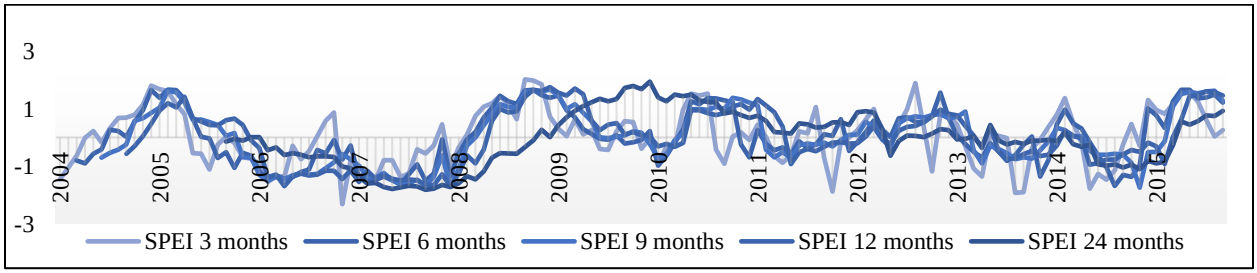

Figure 7.3 DG Khan SPEI

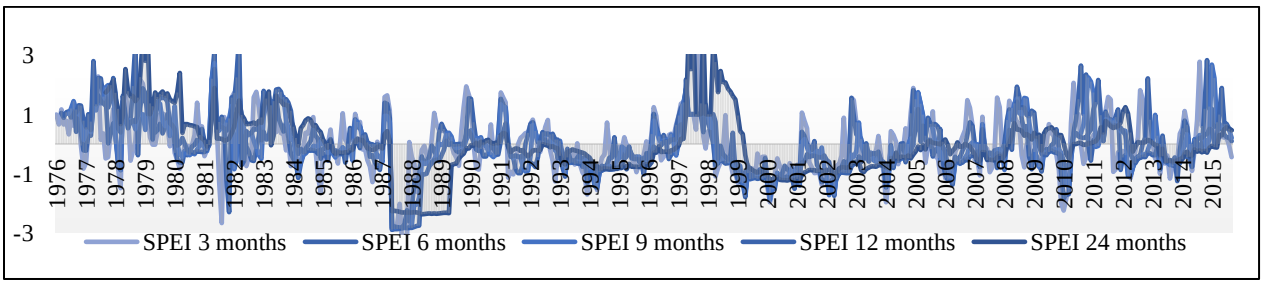

Figure 7.4 Faisalabad SPEI

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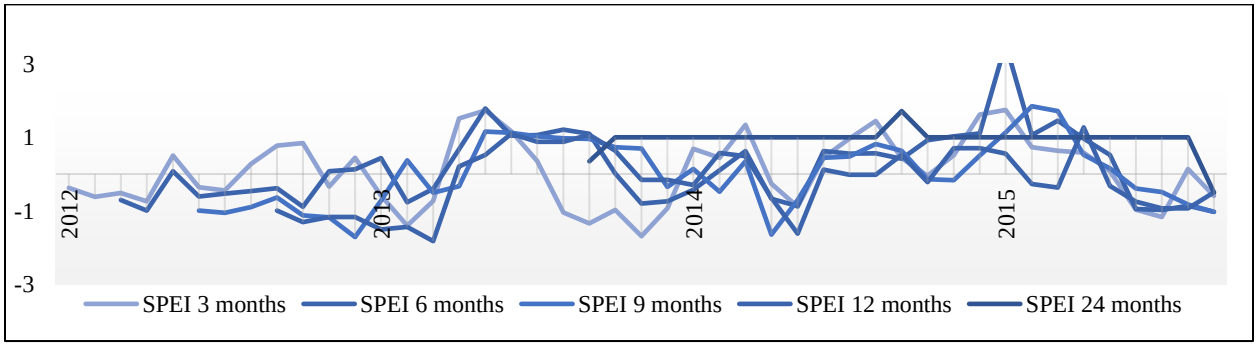

Figure 7.5 Gujranwala SPEI

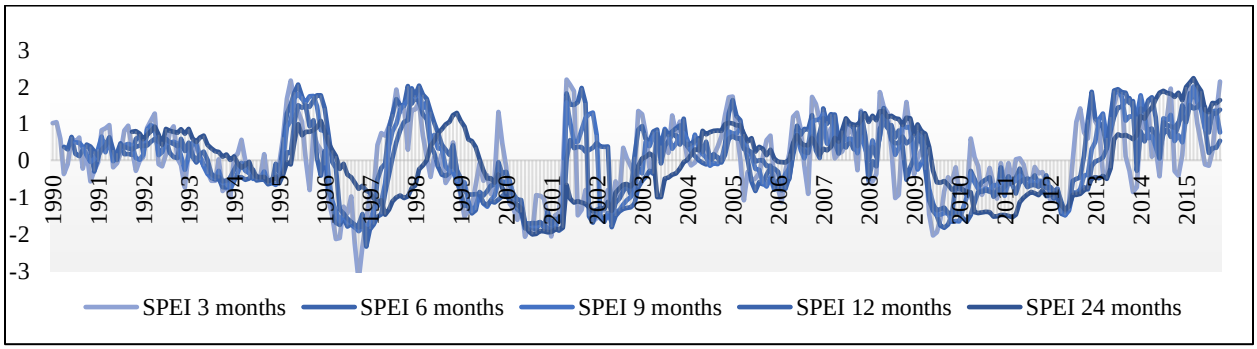

Figure 7.6 Islamabad SPEI

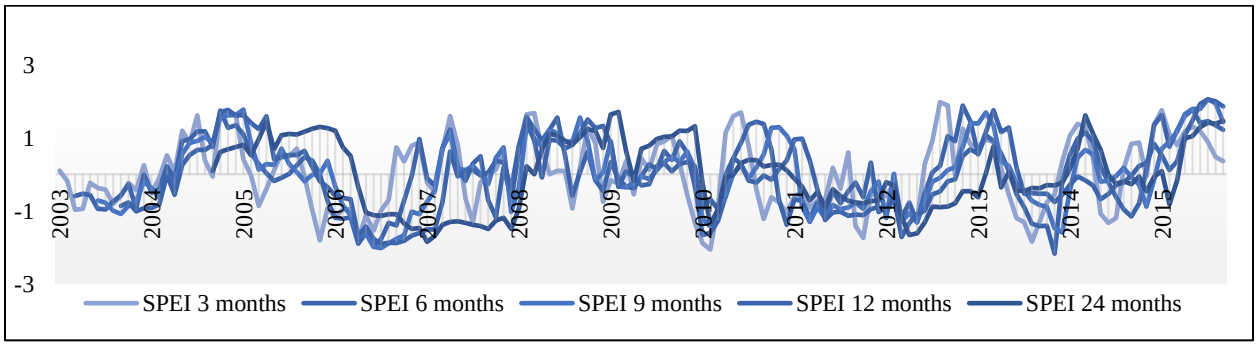

Figure 7.7 Jhang SPEI

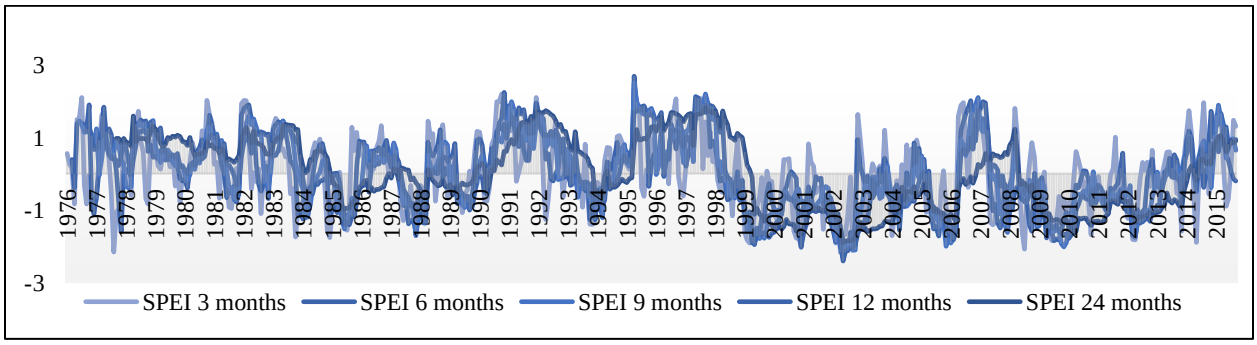

Figure 7.8 Jhelum SPEI

SPEI results show that there is one dry spell in Bahawalnagar region started from 1999 to 2015 with intensity of moderate to extreme dry condition, two minor dry periods can also be seen in the data 1966 to 1968 and 1980 to 1983 extreme and moderate dryness respectively. In Bahawalpur the major dry period is from 2000 to 2015 with intensity of moderate to very dry (-0.2 to -2.5),

some other dry years are present in the data with moderate dry intensity (-0.9 to -1.9) i.e. 1964, 1971, 1976, 1983, 1988, 1992 and 1994. Only dry period in D G Khan is from 2006 to 2008 with dryness ranging from (-0.6 to -1.8) moderate dryness. In Faisalabad 1978 to 1990 is the era of dryness with moderate to very dry intensity (-0.9 to -2.5), some other dry periods are also present in data but the intensity of drought during those periods are near normal. Like SPI in SPEI there is no major dry spell in Gujranwala. In Islamabad there are there major dry periods 1996 to 1999, 2001 to 2003 and 2010 to 2013 with intensity of moderate to very dry. In Jhang dry period is from 2006 to 2008 and then in 2010 with drought intensity of moderate dryness (-0.2 to -1.9). Jhelum show two periods of dryness 1999 to 2006 and 2008 to 2014 with intensity ranging from (-0.5 to -2.2) moderate to very dry. Other than that, there are some dry years with moderate intensity i.e. 1984, 1986, 1988 and 1994.

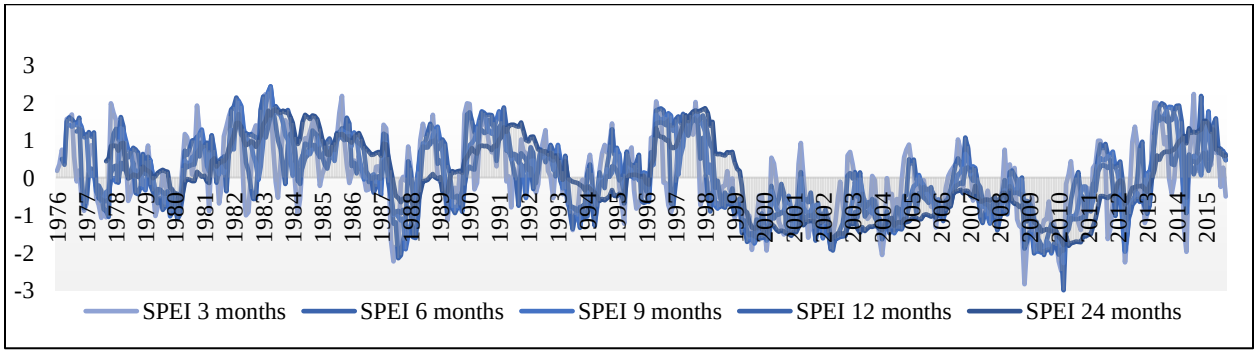

Figure 7.9 Lahore SPEI

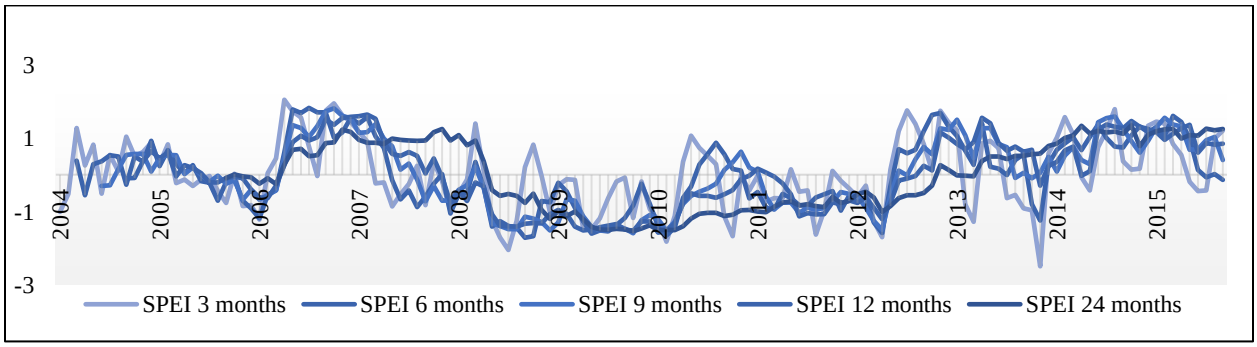

Figure 7.10 Mandi BD SPEI

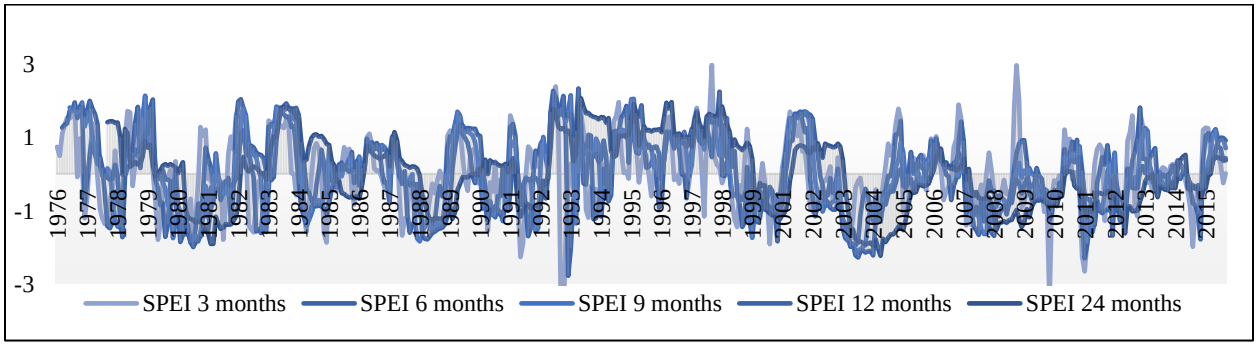

Figure 7.11 Multan SPEI

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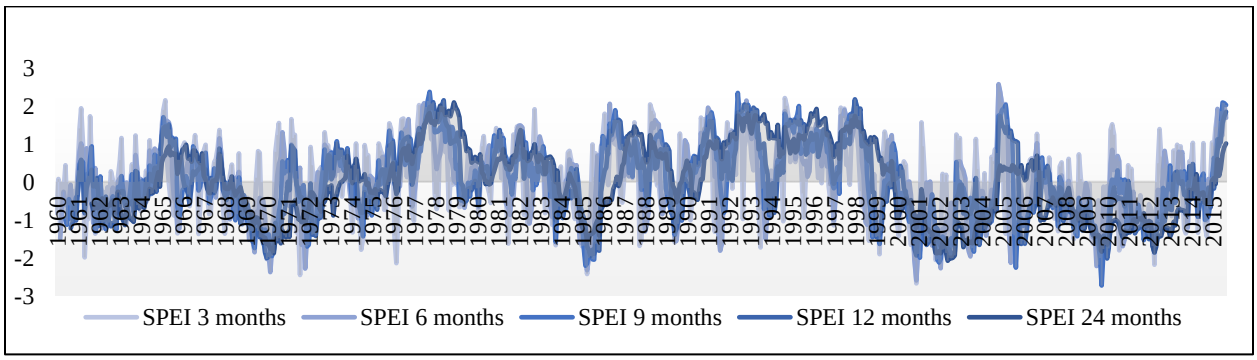

Figure 7.12 Murree SPEI

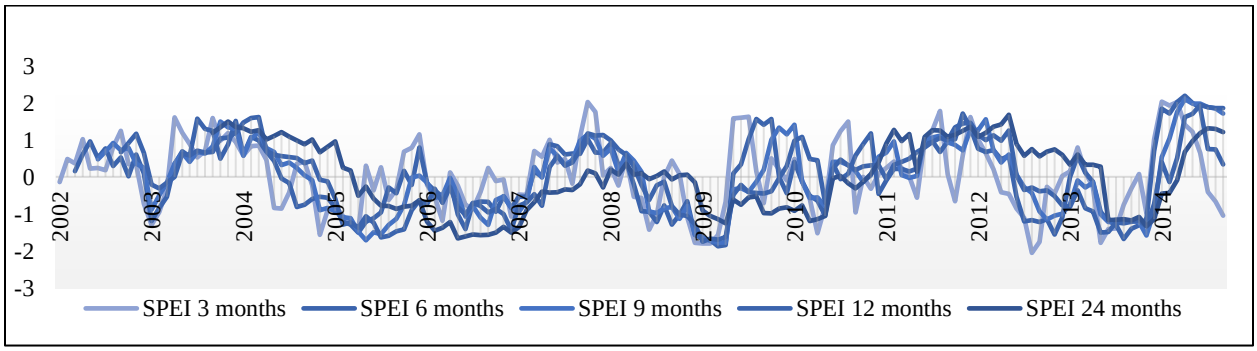

Figure 7.13 R.Y Khan SPEI

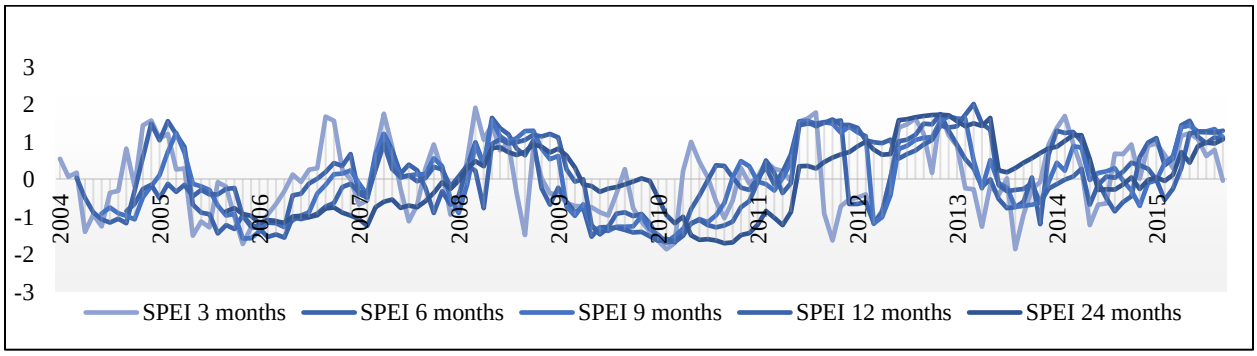

Figure 7.14 Sahiwal SPEI

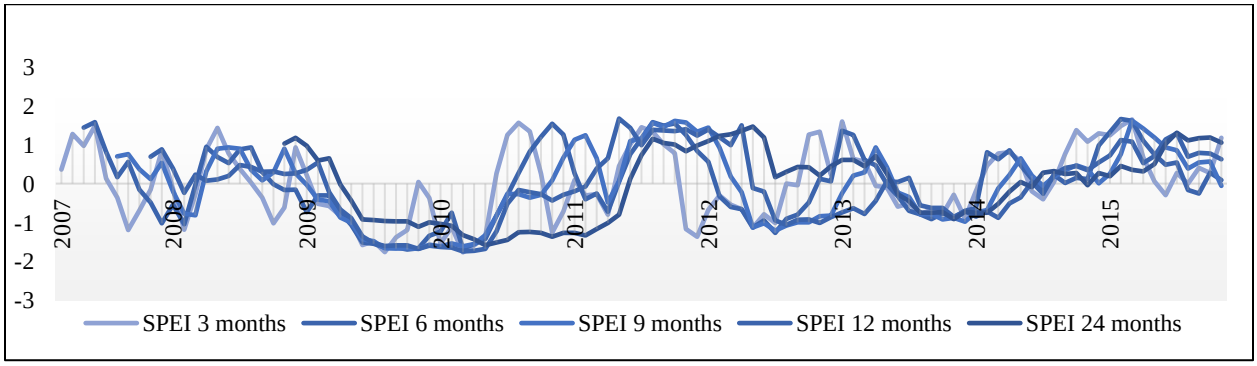

Figure 7.15 Sargodha SPEI

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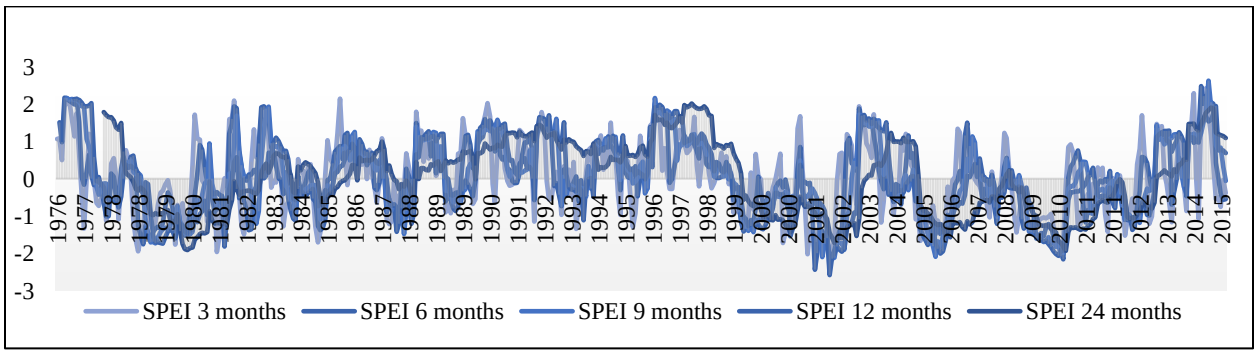

Figure 7.16 Sialkot SPEI

Lahore show two major dry periods in SPEI ranges from 1999 to 2006 and 2009 to 2013 with intensity of drought ranging from (-0.9 to -2.5) moderate to very dry like condition, other minor dry years can also be seen in the data 1988, 1994 and 2014 with moderate dryness. Mandi B D show a moderate intensity drought (-0.2 to -1.5) from period of 2008 to 2012. Multan show drought like condition in 1980 to 1983, 1987 to 1989, 2002 to 2005 and 2007 to 2010 with moderate intensity (-0.5 to -1.5), some minor dry years in data can also be seen with moderate intensity i.e. 1985, 1978, 1993, 1999 and 2001. Murree has a major dry spell starting from 1999 till 2015 with moderate to very dry like condition (-0.9 to -2.5) also a minor dry period in data from 1968 to 1973 with moderate drought intensity. There is no major dry period in R Y Khan only 2009 show normal to moderate dryness. In Sahiwal dry spell in data is present from 2006 to 2008 and then in 2009 to 2012 with moderate drought intensity (-0.5 to -1.9). Sargodha has a dry period lasting from 2009 to 2011with moderate to vary dry drought intensity (-0.5 to -2.4). Sialkot show several dry periods in data i.e. 1978 to 1982, 1988, 1999 to 2003, 2005 to 2007, 2009 to 2012 with drought intensity of (-0.9 to -2.8).

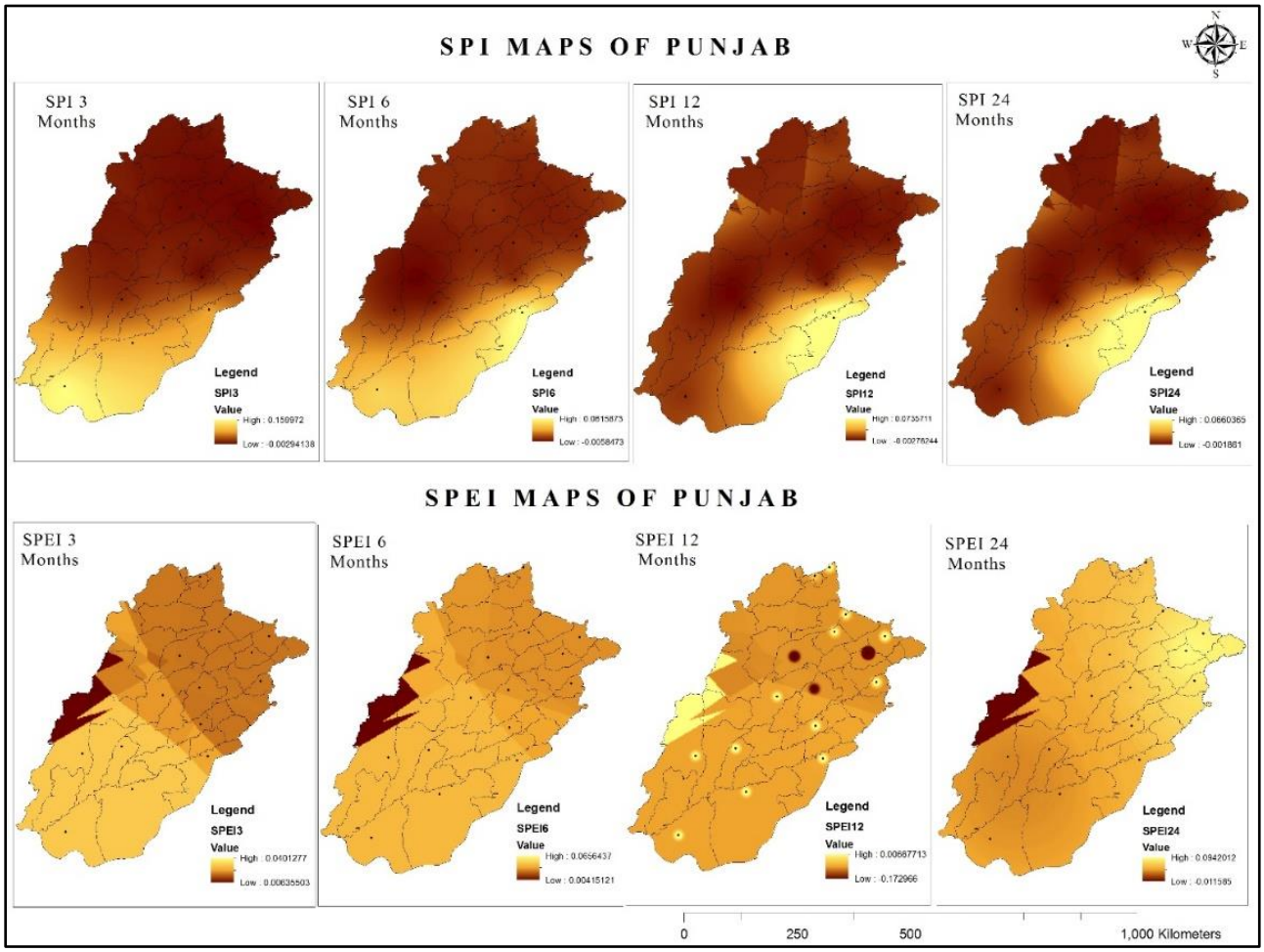

Figure 8.1 SPI and SPEI map of Punjab

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The periods shown dry in SPI are also dry in SPEI i.e. in SPI 3 months there is a dry spell from 2009 to 2011 and same dry spell in also present in SPEI from 2009 to 2011. The only major difference is that there is a difference in intensity of drought i.e. the intensity of drought shown in SPI 3 month from 2009 to 2011 is ranging from (-0.5 to -2.8) while the same dry period is also present in SPEI but with less intensity ranging from (-0.5 to -1.9). Both the SPI and SPEI are well developed and known indices for the calculation and monitoring of Drought but it's hard to say and pick a better one both index has their pros and cons. SPI only use precipitation data and it is easy to calculate but some people also argue that using only Precipitation data is a weakness too, a weakness which is improved in SPEI which is not depending on precipitation data but also PET which means that the factor of temperature also included in this. The given below graphs show the comparison of data of Lahore taken by SPI and SPEI.

Mann Kendal Trend Test

Mann-Kendal trend test is used in this study to see the trend in data of calculated SPI and SPEI. Two tailed trend has used in this study which means there are three possibilities of this test i.e. increasing trend or positive trend, decreasing trend or negative trend and no trend in data at all.

SPI Trend Test

The table shown below show the calculated trend in data with help of Kendall trend test.

Table 4 SPI Trend Test 3&6 Month

Met. Stations	SPI 3 Months			SPI 6 Months		
	Kendall's tau	p-value	Trend	Kendall's tau	p-value	Trend
Bahawalnagar	0.400	< 0.01	Positive	0.45302	< 0.0001	Positive
Bahawalpur	0.363	< 0.01	Positive	0.39702	< 0.0001	Positive
D G Khan	0.047	0.4395	No Trend	0.14903	0.01553	Positive
Faisalabad	0.028	0.365	No Trend	0.02911	0.35323	No Trend
Gujranwala	0.14	0.342	No Trend	0.1	0.50289	No Trend
Islamabad	-0.004	0.911	No Trend	0.00338	0.92795	No Trend
Jhang	-0.025	0.667	No Trend	-0.0558	0.34150	No Trend
Jhelum	-0.084	0.006	Negative	-0.1344	< 0.0001	Negative
Lahore	-0.056	0.072	No Trend	-0.0593	0.05841	No Trend
Mandi B D	0.104	0.091	No Trend	0.17198	0.00524	Positive
Multan	0.036	0.249	No Trend	0.05421	0.083841	No Trend
Murree	0.2234	< 0.01	Positive	0.23333	< 0.0001	Positive
R Y Khan	0.0651	0.2477	No Trend	0.10994	0.05048	No Trend
Sahiwal	0.0122	0.8437	No Trend	0.09459	0.12486	No Trend
Sargodha	0.2339	0.0015	Positive	0.23456	0.00152	Positive
Sialkot	0.0024	0.9381	No Trend	0.03484	0.26654	No Trend

According to the results of Mann-Kendall trend test SPI calculate for 3 months show a positive or increasing trend in Bahawalnagar, Bahawalpur, Murree and Sargodha, 6-Months SPI show increasing trend in Bahawalnagar, Bahawalpur, D G Khan, Mandi B D, Murree and Sargodha, 9-Months SPI show positive or increasing trend in Bahawalnagar, Bahawalpur, D G Khan, Mandi B D, Murree, Multan, Sargodha and Sialkot. 12-Months SPI show Increasing or positive trend in Bahawalnagar, Bahawalpur, D G Khan, Mandi B D, Murree, Multan, Sargodha and Sialkot. 24-Months SPI show increasing trend in Bahawalnagar, Bahawalpur, D G Khan, Mandi B D, Murree, R Y Khan, Sahiwal, Sargodha and Sialkot.

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Table 5 SPI Trend Test 9&12 Month

Met. Stations	SPI 9 Months			SPI 12 Months		
	Kendall's tau	p-value	Trend	Kendall's tau	p-value	Trend
Bahawalnagar	0.4755	< 0.0001	Positive	0.4860	< 0.001	Positive
Bahawalpur	0.4082	< 0.0001	Positive	0.4122	< 0.001	Positive
D G Khan	0.1668	0.006755	Positive	0.1305	0.0342	Positive
Faisalabad	0.0423	0.1767	No Trend	0.0608	0.052	No Trend
Gujranwala	-0.176	0.2244	No Trend	-0.347	0.016	Negative
Islamabad	-0.011	0.74988	No Trend	-0.041	0.263	No Trend
Jhang	-0.095	0.1026	No Trend	-0.143	0.014	Negative
Jhelum	-0.167	< 0.0001	Negative	-0.194	< 0.001	Negative
Lahore	-0.037	0.2293	No Trend	-0.046	0.136	No Trend
Mandi B D	0.2034	0.001	Positive	0.2361	0	Positive
Multan	0.0707	0.02	Positive	0.0858	0.006	Positive
Murree	0.2451	< 0.0001	Positive	0.2441	< 0.001	Positive
R Y Khan	0.0892	0.1122	No Trend	0.0847	0.131	No Trend
Sahiwal	0.0935	0.1293	No Trend	0.1128	0.067	No Trend
Sargodha	0.2187	0.0031	Positive	0.1967	0.007	Positive
Sialkot	0.0663	0.0343	Positive	0.0860	0.006	Positive

Table 6 SPI Trend Test of 24 Month

Met. Stations	SPI 24 Months		
	Kendall's tau	p-value	Trend
Bahawalnagar	0.5093	< 0.0001	Positive
Bahawalpur	0.4117	< 0.0001	Positive
D G Khan	0.1707	0.005564	Positive
Faisalabad	0.0285	0.3628	No Trend
Gujranwala	0.0418	0.8164	No Trend
Islamabad	-0.0718	0.0539	No Trend
Jhang	-0.2157	0	Negative
Jhelum	-0.2678	< 0.0001	Negative
Lahore	-0.1157	0	Negative
Mandi B D	0.2229	0	Positive
Multan	0.0563	0.072	No Trend
Murree	0.2723	< 0.0001	Positive
R Y Khan	0.1680	0.0027	Positive
Sahiwal	0.2146	0	Positive
Sargodha	0.1922	0.0094	Positive
Sialkot	0.0931	0.0029	Positive

SPEI Trend Test

Trend test of SPEI 3 months show that increasing trend is present in D G Khan, Sahiwal and Sargodha and a decreasing trend can be seen in Bahawalnagar, Bahawalpur, Faisalabad, Jhelum and Lahore while all other stations show no trend in data at all. 6-Months SPEI show increasing trend in D G Khan, Islamabad, Sahiwal and Sargodha. Decreasing trend is present in Bahawalnagar, Bahawalpur, Faisalabad, Jhelum, Murree and Lahore while all other stations show no trend in data.

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Table 7 SPEI trend test of 3&6 month

Met. Stations	SPEI 3 Months			SPEI 6 Months		
	Kendall's tau	p-value	Trend	Kendall's tau	p-value	Trend
Bahawalnagar	-0.15	< 0.0001	Negative	-0.1875	< 0.0001	Negative
Bahawalpur	-0.1295	< 0.0001	Negative	-0.1756	< 0.0001	Negative
D G Khan	0.159	0.009545	Positive	0.2181	0.00039	Positive
Faisalabad	-0.0674	0.03131	Negative	-0.0776	0.01316	Negative
Gujranwala	0.1266	0.39220	No Trend	0.0333	0.83553	No Trend
Islamabad	0.0766	0.05225	No Trend	0.0803	0.04174	Positive
Jhang	0.0827	0.15848	No Trend	0.0574	0.32788	No Trend
Jhelum	-0.1218	< 0.0001	Negative	-0.1660	< 0.0001	Negative
Lahore	-0.2058	< 0.0001	Negative	-0.2088	< 0.0001	Negative
Mandi B D	0.0884	0.15099	No Trend	0.17603	0.004	Positive
Multan	-0.0386	0.223	No Trend	-0.02473	0.43572	No Trend
Murree	-0.0459	0.08020	No Trend	-0.05739	0.02874	Negative
R Y Khan	0.0045	0.93953	No Trend	0.08452	0.14949	No Trend
Sahiwal	0.1429	0.02016	Positive	0.2352	0	Positive
Sargodha	0.2974	< 0.0001	Positive	0.2756	0	Positive
Sialkot	-0.0447	0.15284	No Trend	-0.0213	0.494765	No Trend

9-Months SPEI show a positive trend at stations of D G Khan, Islamabad, Mandi B D, Sahiwal and Sargodha, decreasing trend is present in stations of Bahawalnagar, Bahawalpur, Faisalabad, Jhelum, Murree and Lahore while other stations show no trend in data. 12-Months SPEI show Increasing trend in region of D G Khan, Islamabad, Mandi B D, Sahiwal and Sargodha, decreasing trend in present at stations of Bahawalnagar, Bahawalpur, Faisalabad, Gujranwala, Jhelum, Multan, Murree and Lahore while other regions show no trend in data of 12-month SPEI.

Table 8 SPEI trend test of 9&12 month

Met. Stations	SPEI 9 Months			SPEI 12 Months		
	Kendall's tau	p-value	Trend	Kendall's tau	p-value	Trend
Bahawalnagar	-0.198	< 0.0001	Negative	-0.203	< 0.0001	Negative
Bahawalpur	-0.2214	< 0.0001	Negative	-0.2637	< 0.0001	Negative
D G Khan	0.1972	0.0013	Positive	0.1446	0.01877	Positive
Faisalabad	-0.0947	0.0024	Negative	-0.1232	< 0.0001	Negative
Gujranwala	-0.14	0.3427	No Trend	-0.2866	0.04670	Negative
Islamabad	0.0848	0.0315	Positive	0.0918	0.01988	Positive
Jhang	0.0396	0.4997	No Trend	0.0043	0.94262	No Trend
Jhelum	-0.2044	< 0.0001	Negative	-0.2357	< 0.0001	Negative
Lahore	-0.2150	< 0.0001	Negative	-0.2282	< 0.0001	Negative
Mandi B D	0.2013	0.001	Positive	0.2022	0.001	Positive
Multan	-0.0455	0.1508	No Trend	-0.0765	0.01590	Negative
Murree	-0.0673	0.0103	Negative	-0.0708	0.00696	Negative
R Y Khan	0.0815	0.1643	No Trend	0.0909	0.12108	No Trend
Sahiwal	0.2471	< 0.0001	Positive	0.2661	< 0.0001	Positive
Sargodha	0.2952	< 0.0001	Positive	0.2689	0	Positive
Sialkot	-0.0098	0.7524	No Trend	-0.0085	0.78473	No Trend

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24-months SPEI trend test show increasing trend in regions of Mandi B D, Sahiwal and Sargodha, decreasing trend is present in regions of Bahawalnagar, Bahawalpur, Faisalabad, Jhelum, Multan, Murree and Lahore while other regions show no trend in data at all.

Table 9 SPEI trend test of 24 month

Met. Stations	SPEI 24 Months		
	Kendall's tau	p-value	Trend
Bahawalnagar	-0.1875	< 0.0001	Negative
Bahawalpur	-0.3075	< 0.0001	Negative
D G Khan	0.0787	0.2008	No trend
Faisalabad	-0.1535	< 0.0001	Negative
Gujranwala	-0.006	1	No trend
Islamabad	0.0701	0.0754	No trend
Jhang	-0.0086	0.8840	No trend
Jhelum	-0.2957	< 0.0001	Negative
Lahore	-0.2772	< 0.0001	Negative
Mandi B D	0.2162	0	Positive
Multan	-0.1583	< 0.0001	Negative
Murree	-0.0716	0.0063	Negative
R Y Khan	0.0758	0.195	No Trend
Sahiwal	0.3666	< 0.0001	Positive
Sargodha	0.2380	0.001	Positive
Sialkot	-0.0432	0.169	No Trend

4. CONCLUSIONS AND DISCUSSIONS

Drought is mainly caused by precipitation variability in specific area. It has created adverse effects on water supply, agriculture, socio-economic situation on that area. To calculate it, two indices were utilized namely SPI and SPEI. In this research work we focused on Punjab province of Pakistan and the nominated indicators were analyzed and the results of SPI and SPEI were run through Mann Kendall trend test to see the trend in results. Results of SPI and SPEI were then generalized for the whole province through interpolation method.

Out of 16 met. Stations under study D G Khan, Gujranwala, Jhang, Sargodha, Mandi B D and Sahiwal show a decreasing trend in annual temperature. On the other hand, Faisalabad, Jhelum, Lahore, Multan and Sialkot show an increase in trend of annual temperature. Remaining met. Stations show a linear or no trend. Out of 16 met. Stations 6 show an increasing trend in annual precipitation, 3 show a decreasing trend and the remaining show no trend in data at all.

The analysis of SPI and SPEI results are showing that there was dry period at different time in historic data of Punjab. Almost all the Station or regions show dry period from 1965 to 1975 and then a dry period can also be seen in all the Punjab from 1999 to 2007 according to SPI results According to SPEI results all the Punjab is under dry spell from 1999 to 2015. During this era in some region there is also extensive Precipitation which caused flood. All these variations in climate indicate Climate Change and Global Warming.

In Precipitation pattern a shift can also be seen, according to the data we have observe that the Northern part of Punjab is receiving less amount of precipitation with each passing year. This trend is found out by trend test. This test show that in almost half of the Punjab drought is going to increase in intensity as well as duration with the passage of time. The reason that the effect of drought is not that prominent in region of Punjab. Its good Irrigation System and most of the agriculture depend on rivers. But we need to preserve water and use it smartly for both agriculture purpose and for regular use. A major problem we faced in the process of monitoring drought more accurately is that there is not enough data. The number of Metrological stations covering Punjab are less. We need to increase the number of data collection center so we can monitor climate shifts properly weather it is Drought or Flood. We need to store as much water as we can to cope with the water shortage problem which is a real threat.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Abera, T. (2022). Evaluating the Performance of 50mm Accumulated Rainfall Threshold for the Determination of the Start of Wet Season over Selected Stations, Ethiopia. Discovery, 58 (316), 318-339
2. Abid, M., Schilling, J., Scheffran, J., & Zulfiqar, F. (2016). Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan. Science of the Total Environment, 547, 447-460.
3. Agnew, C. (2000). Using the SPI to identify drought.
4. Ahmed, K., Shahid, S., & Nawaz, N. (2018). Impacts of climate variability and change on seasonal drought characteristics of Pakistan. Atmospheric Research, 214, 364-374.
5. Ali, A., Farid, H. U., & Khan, M. M. H. (2020). Divergent effect of rainfall, temperature and surface water bodies on groundwater quality in Haveli Canal Circle of Multan Irrigation Zone, Southern Punjab. Pakistan. Journal of Environmental and Agricultural Sciences, 22 (4), 25-36.
6. Anwar, F., Zafar, S. N., & Rashid, U. (2006). Characterization of Moringa oleifera seed oil from drought and irrigated regions of Punjab, Pakistan. Grasas y aceites, 57 (2), 160-168.
7. Ashraf, M., & Routray, J. K. (2015). Spatio-temporal characteristics of precipitation and drought in Balochistan Province, Pakistan. Natural Hazards, 77 (1), 229-254.
8. Bachmair, S., Kohn, I., & Stahl, K. (2015). Exploring the link between drought indicators and impacts. Natural Hazards and Earth System Sciences, 15 (6), 1381-1397.
9. Bachmair, S., Svensson, C., Hannaford, J., Barker, L., & Stahl, K. (2016). A quantitative analysis to objectively appraise drought indicators and model drought impacts. Hydrology and Earth System Sciences, 20 (7), 2589-2609.
10. Bachmair, S., Svensson, C., Prosdocimi, I., Hannaford, J., & Stahl, K. (2017). Developing drought impact functions for drought risk management. Natural Hazards and Earth System Sciences, 17 (11), 1947-1960.
11. Bhusal, B., Oli, M., Adhikari, B., Neupane, P. (2021). Monthly and seasonal variation on particulate matter (PM2.5) and meteorological parameters over Beijing. Discovery, 57 (306), 479-494
12. Bonaccorso, B., Bordi, I., Cancelliere, A., Rossi, G., & Sutera, A. (2003). Spatial variability of drought: an analysis of the SPI in Sicily. Water resources management, 17 (4), 273-296.
13. Cheema, S. B., Rasul, G., Ali, G., & Kazmi, D. H. (2011). A comparison of minimum temperature trends with model projections. Pakistan Journal of Meteorology, 8 (15), 39-52.
14. Chen, S.-C., Tfwala, S., Wu, T.-Y., Chan, H.-C., & Chou, H.-T. (2018). A hooked-collar for bridge piers protection: Flow fields and scour. Water, 10 (9), 1251.
15. Danandeh Mehr, A., Sorman, A. U., Kahya, E., & Hesami Afshar, M. (2020). Climate change impacts on meteorological drought using SPI and SPEI: case study of Ankara, Turkey. Hydrological sciences journal, 65 (2), 254-268.
16. Dangana, K., Nwaerema, P., Fred-Nwagwu, WF. (2022). Climate Parameters and Particulate Matter (PM2.5): Implication for Air Quality Index of Port Harcourt, Minna and Maiduguri of Nigeria. Discovery, 58 (316), 310-317
17. Haines, A., & Patz, J. A. (2004). Health effects of climate change. Jama, 291 (1), 99-103.
18. Jamro, S., Dars, G. H., Ansari, K., & Krakauer, N. Y. (2019). Spatio-temporal variability of drought in Pakistan using standardized precipitation evapotranspiration index. Applied Sciences, 9 (21), 4588.
19. Khan, A. N. (2013). Analysis of 2010-flood causes, nature and magnitude in the Khyber Pakhtunkhwa, Pakistan. Natural Hazards, 66 (2), 887-904.
20. 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.
21. Labudová, L., Labuda, M., & Takáč, J. (2017). Comparison of SPI and SPEI applicability for drought impact assessment on crop production in the Danubian Lowland and the East Slovakian Lowland. Theoretical and applied climatology, 128 (1), 491-506.
22. Lee, J. E., Azam, M., Rehman, S. U., Waseem, M., Anjum, M. N., Afzal, A., Ahmed, R. (2022). Spatio-temporal variability of drought characteristics across Pakistan. Paddy and Water Environment, 1-19.
23. Li, L., She, D., Zheng, H., Lin, P., & Yang, Z.-L. (2020).

ISSN 2278–5469 EISSN 2278–5450 I OPEN ACCESS

Elucidating diverse drought characteristics from two meteorological drought indices (SPI and SPEI) in China. Journal of Hydrometeorology, 21 (7), 1513-1530.
24. Liu, X., Zhu, X., Pan, Y., Bai, J., & Li, S. (2018). Performance of different drought indices for agriculture drought in the North China Plain. Journal of Arid Land, 10 (4), 507-516.
25. Livada, I., & Assimakopoulos, V. (2007). Spatial and temporal analysis of drought in Greece using the Standardized Precipitation Index (SPI). Theoretical and applied climatology, 89 (3), 143-153.
26. Manatsa, D., Chingombe, W., Matsikwa, H., & Matarira, C. (2008). The superior influence of Darwin Sea level pressure anomalies over ENSO as a simple drought predictor for Southern Africa. Theoretical and applied climatology, 92 (1), 1-14.
27. Mustafa, A., & Rahman, G. (2018). Assessing the spatio-temporal variability of meteorological drought in Jordan. Earth Systems and Environment, 2 (2), 247-264.
28. Nicholls, N., Drosdowsky, W., & Lavery, B. (1997). Australian rainfall variability and change. Weather, 52 (3), 66-72.
29. Nicholson, S. E. (2000). The nature of rainfall variability over Africa on time scales of decades to millenia. Global and planetary change, 26 (1-3), 137-158.
30. Pei, Z., Fang, S., Wang, L., & Yang, W. (2020). Comparative analysis of drought indicated by the SPI and SPEI at various timescales in inner Mongolia, China. Water, 12 (7), 1925.
31. Sheikh, M. M. (2001). Drought management and prevention in Pakistan. Paper presented at the COMSATS 1st meeting on water resources in the south: present scenario and future prospects, Islamabad.
32. Sobral, B. S., de Oliveira-Junior, J. F., de Gois, G., Pereira-Júnior, E. R., de Bodas Terassi, P. M., Muniz-Júnior, J. G. R., Zeri, M. (2019). Drought characterization for the state of Rio de Janeiro based on the annual SPI index: trends, statistical tests and its relation with ENSO. Atmospheric Research, 220, 141-154.
33. Stagge, J. H., Tallaksen, L. M., Gudmundsson, L., Van Loon, A. F., & Stahl, K. (2015). Candidate distributions for climatological drought indices (SPI and SPEI). International Journal of Climatology, 35 (13), 4027-4040.
34. Touma, D., Ashfaq, M., Nayak, M. A., Kao, S.-C., & Diffenbaugh, N. S. (2015). A multi-model and multi-index evaluation of drought characteristics in the 21st century. Journal of Hydrology, 526, 196-207.
35. Tsakiris, G., & Vangelis, H. (2004). Towards a drought watch system based on spatial SPI. Water resources management, 18 (1), 1-12.
36. Uddin, M., Hu, J., Islam, A. R. M., Eibek, K. U., & Nasrin, Z. M. (2020). A comprehensive statistical assessment of drought indices to monitor drought status in Bangladesh. Arabian Journal of Geosciences, 13 (9), 1-10.
37. Umran Komuscu, A. (1999). Using the SPI to analyze spatial and temporal patterns of drought in Turkey. Drought Network News (1994-2001), 49.
38. Van Loon, A., & Laaha, G. (2015). Hydrological drought severity explained by climate and catchment characteristics. Journal of Hydrology, 526, 3-14.
39. Wang, H., Vicente-Serrano, S. M., Tao, F., Zhang, X., Wang, P., Zhang, C., El Kenawy, A. (2016). Monitoring winter wheat drought threat in Northern China using multiple climate-based drought indices and soil moisture during 2000–2013. Agricultural and Forest Meteorology, 228, 1-12.
40. Wanjohi, L., Mwamburi, L., Mwasi, S., Meso, D., Isaboke, J. (2022). Use of multistage phytoremediation technique in wastewater treatment. Discovery, 58 (316), 252-263
41. Waseem, M., Khurshid, T., Abbas, A., Ahmad, I., & Javed, Z. (2022). Impact of meteorological drought on agriculture production at different scales in Punjab, Pakistan. Journal of Water and Climate Change, 13 (1), 113-124.

ISSN 2278–5469 EISSN 2278–5450 I OPEN ACCESS