Int. J. Econ. Environ. Geol. Vol. 10 (4) 109-114, 2019
Journal home page: www.econ-environ-geol.org

Open Access
ISSN: 2223-957X

Seasonal and Regional Variations in Rainfall Distribution Over the Punjab-Pakistan

Saadia Sultan Wahla[1*], Safdar Ali Shirazi[2] , Sohail Abbas[3], Mian Sabir Hussain,[4] Mareena Khurshid[2]

[1] Department of Geography, Govt. Postgraduate College for Women, Bahawalnagar, Pakistan
[2] Department of Geography, University of the Punjab, Lahore, Pakistan
[3]Climate Research Institute, Konkuk University, Seoul, Korea.
[4]Climate Research Institute, Konkuk University, Korea.

*E mail: geosaadiasultan@gmail.com

Received: *02 December, 2019* ***Accepted:*** *27January, 2020*

Abstract: The purpose of present study is to investigate district and division wise annual rainfall variations over the province of Punjab, which is the largest in terms of population size as well important contributor in agricultural produce in Pakistan. The results revealed that the rainfall trend has shifted from upper and lower Punjab towards the south, west, north and east respectively. The statistical analysis has inferred an overall increasing trend for the period 1990 to 2000 and a decreasing trend during period 2001 to 2010 in Punjab province. The Z test value differences in the average rainfall for each district level meteorological station have detected three increasing and two decreasing trends during summers of 1981-2015.The data revealed a significant changed seasonal trend observed in Murree and Sialkot (northern Punjab), Faisalabad and Lahore (central Punjab). Particularly, the changes have been observed in the south Punjab and over the central Punjab, while the same rainfall variations have shown a southward shift. The trend of the rainfall had shifted in the Faisalabad division with the significant positive trend. In the Central Punjab, the positive trend has also been found in all the districts. In the lower Punjab, Multan, Dera Ghazi Khan districts has shown an increasing trend of rainfall. The findings are significant in changing agro-climatic zones in the Punjab and consequent shifting patterns of agriculture therefore can have net impact on the food security situation in the Punjab-Pakistan.

Keywords: Annual rainfall, variations, Kolmogorov Smironv test, districts, the Punjab.

Introduction

Punjab-Pakistan lies in between an arid and humid climatic regions of South Asia (Chaudhry and Rasul, 2004, Yao et al., 2008). Punjab experiences three well marked seasons with rainfall in both summers and winters.The proviance experience extreme continental climate with hot summers (April-June) while winter (Dec.-Feb.) is cold with fog in plain areas. The topography of the province ranges from sub mountanous Potwar region to plain and sandy areas in the south. The amount of rainfall varies from north to south as well as during summer and winter. Rainfall is critical to agriculture of the Punjab as it has agro-baed economy. A study on climatic zones of Puniab-Pakistan revealed that there was a lowering of temperature over northern and south-eastern Pakistan due to increase in monsoonal cloudiness and rainfall (Kruss, 1992; Abbas et al., 2018). An analysis of reconstructed long term temperature, time series from 1876 to 1993 have yielded occurrence of large variations in temperature of the country and warming since the beginning of the last century with a total change of temperature up to 0.2 $^{\circ}$C (Ahme et al., 2018). The climate change vulnerability is subject to the dilemma of understanding the multiple climate interaction which impact on health, commodity prices, water resources, agriculture and non-climate impact such as on institutional, political, economic, demographic, technological and social changes occurring at diverse scales (Seaman et al., 2014; Awan et al., 2015; Abbas et al., 2016). The temperature of the earth has risen since 1950, which have induced regional and temporal variation in rainfall. The rainfall trends brought long-term change in many places at the international and international levels. Many semiarid regions have been shifted into arid and vice versa (IPCC, 2007). During the 20th century, the amount of precipitation has been decreased in desert areas, while increased within the tropics (Gitry and Surez, 2002). The 87% of Pakistan is extremely arid to semi-arid in nature and about 5% decrease has been observed over the last 30 years, between 1981–2010 (Haider and Adnan, 2014). Due to such changes in patterns of precipitation, the Asian monsoon has been recognized as a basic component in the global climate variability. The climate was cold over the areas of the north of Pakistan, including Kashmir due to increase in monsoon cloudiness (Afzaal et al., 2009) therefore a long-term rainfall variability and changing the rainfall patterns have been observed in Pakistan (Storch, 2002).

The variability of the precipitation trend investigates the climate impact over Asia in the season of the summer monsoon (Ahmed et al., 2017). The three rainfall variations included: seasonal, annual and regional were studied in India. Dimri (2019) identifies that the daily continuous precipitation in monsoon regions of India has a positive correlation with the crops like rice. The Indian weather organization has made an effort to investigate the rainfall variability in

South Asia therefore a correlation trend has been analysed between India and Bangladesh which identifies a linear and smooth trend (Kripliani et al., 1995; Rajeevan and Thapliyal, 2000). Further investigation into the inter-annual variations of monsoon rainfall (1953-1982) by using the observatory's data have revealed annual disparities of the monsoon rainfall period during summers are strongly correlated with the ESNO and its relation with regional and global rainfall index (Gity et al., 2009; Gregg and Garfin, 1999). It is agreed that the Indian annual wet season during summer has strong link with the agriculture and economy (Ghosh, 2009; Munot and Kothawale, 2000; Yadav, 2009). The spatio-temporal variability of the rainfall analyzed in Nepal and inferred significant and positive long term relationship between all Indian rainfall and southern oscillation index (Ichiyanagi et al., 2007). The increasing or decreasing trend of rainfall in annual, monsoon and pre-monsoon was investigated in Bangladesh, whereas seasonal rainfall declined in dry periods during monsoon and the pre-monsoon (Shahid, 2010). The main objective of the current study is to investigate the pattern of rainfall and its variations annually for district wise changes to assess the distributional patterns of rainfall using the Kolmogorov-Smirnov (Z) test. Furthermore, to find out annual trends among Punjab divisions and to identify various factors responsible for rainfall variations.

Materials and Methods

Punjab is the second largest province of Pakistan. Punjab shares 52.9 % of the total population of the country. Total area of the province is 205, 344 km^2, which is more than 26 percent of the total land area of Pakistan. Punjab consists of 37 districts and there are 22 meteorological stations across the study area of the Punjab.

The annual synoptic data for the period of (1981-2015) which used in the present study has been collected from the Pakistan Meteorological Department and Water and Power Development Authority (WAPDA). The analysis has been carried out using the Kilmogorov-Smirnov Z test. The test of Kolmogorov-Smirnov is statistically dependent on the distribution channel like empirical distribution function (ECDF). Given N ordered data points X_1, $X_{2,,}$,X_N. This function statistically defined by the

$EN= n(i)/X_N$ .... (1)

Where n (i) is the number of facts less than Xi and the Xi is ordered from small to a large value. This is a basic function that increases by 1/N at the value of each ordered data point

The Kolmogorov Smirnov measures the goodness of fit test, which is very easy to use (Storch, 1999, 2002; Krishnamurthy and Shukla, 2000; Wickramagage 2010). Let X_1, X_2, X_3….., X_n are the random parameters. Where,

CDF = F (a)

CDF = shows the cumulative distribution Function

$D_n = \sup [F_n (a) - F (a)]$……………………….. (2)

Sup = shows the standard value of different data sets

When the D_n value is smaller, goodness of fit test accepted, if D_n value is bigger, it rejected such statistical test.

The Kolmogorov Smirnov test is suitable for large numbers of sample values. When it applied to few sample values, no reliable result was found. Kolmogorov Smirnov test used for the measurement of the monsoon precipitation for the period of 1930-1990 (Chaudhary, 1992). The basic use of the uniform and normal distribution of the different datasets is to measure the goodness of fit test. The Kolmogorov Smirnov investigates goodness of fit statistics, which is also known as goodness-of-statistics, which differentiate between empirical and specific distribution functions.

Results and Discussion

The seasonal rainfall change has been measured application of the Kolmogorov Smirnov Z test. This test investigates the change in district and region wise rainfall pattern. The Z value indicated the probability of different types of statistical datasets. The Z value of rainfall parameter describes that change in rainfall is significant or not. In lower Punjab, Khanewal district has more probability. While, a change in rainfall trend is not significant in Dera Ghazi Khan, Multan and

Table 1 Kolmogorov – Smirnov Z test for upper and lower Punjab.

	Stations (Z VALUE)													
Period	**BWN**	**BPR**	**BPR A/P**	**BHK**	**NPT**	**JHB**	**FSD**	**JHL**	**KPR**	**LHR (A.P)**	**LHR (BPO)**	**MLT**	**MBD**	**SKT**
1981-1985	0.54	0.37	0.91	0.90	0.53	0.61	0.55	0.85	0.64	0.43	0.53	0.37	0.53	0.53
1986-1990	0.54	0.65	0.62	0.61	0.55	0.43	0.73	0.93	0.53	0.55	0.83	0.69	0.65	0.43
1991-1995	0.57	0.69	0.93	0.22	0.83	0.55	0.83	0.61	0.73	0.73	0.92	0.78	0.83	0.53
1996-2000	0.64	0.83	0.45	0.53	0.43	0.65	1.97	0.69	1.87	0.82	0.23	0.87	0.42	0.73
2001-2005	1.47	0.42	0.95	1.47	0.53	0.75	1.47	0.73	1.29	0.93	0.83	0.55	0.53	1.87
2006-2010	1.21	0.93	0.65	0.55	0.67	0.83	1.57	0.82	0.53	0.45	0.75	0.69	0.85	0.85
2011-2015	1.12	0.81	1.77	0.69	1.84	1.94	0.55	1.94	1.44	1.57	1.77	0.87	1.24	1.32
1981-2015	0.87	0.67	0.90	0.71	0.77	0.82	1.10	0.94	1.00	0.78	0.84	0.69	0.72	0.89

Table 2 Kolmogorov –Smirnov Z Test for Upper and Lower Punjab.

	Stations (Z VALUE)													
Period	**SKT (A/P)**	**SGD**	**TTS**	**D.GK**	**DGK (AT)**	**JHNG**	**MGL**	**SHL**	**CHKL**	**GUJ**	**OKR**	**RYK**	**GUJ**	**MCLH**
1981-1985	0.62	0.52	0.80	1.26	0.93	0.68	0.68	0.62	0.93	0.42	0.38	0.75	0.42	0.51
1986-1990	0.83	0.66	0.53	0.73	0.64	0.65	0.83	0.61	0.64	0.73	0.83	0.77	0.73	0.64
1991-1995	0.33	0.99	0.83	0.73	0.65	0.85	0.53	0.64	0.97	0.65	0.69	0.78	0.93	0.65
1996-2000	0.43	0.68	0.85	0.103	0.640	0.93	0.73	0.35	0.98	0.55	0.38	0.89	0.72	0.66
2001-2005	0.83	0.66	0.83	0.53	0.67	0.53	0.92	0.67	0.65	0.62	0.66	0.34	0.53	0.67
2006-2010	1.67	1.13	0.39	0.79	1.32	0.79	0.69	0.84	1.14	1.47	1.33	1.77	1.94	1.47
2011-2015	0.81	0.71	1.48	0.83	0.92	0.65	0.31	0.74	0.98	1.48	0.90	0.97	0.41	0.21
1981-2015	0.79	0.76	0.82	0.71	0.82	0.73	0.67	0.64	0.90	0.85	0.74	0.90	0.81	0.69

Lodhran. While there is no positive change observed in upper Punjab. In the lower Punjab, all the districts have shown positive development, but Bahawalnagar with high Z value = 0.545 has also a positive change (Table 1). Furthermore, some districts of upper Punjab categorized as a significant positive trend like Jhelum with Z value = 0.85. In the upper Punjab, Rawalpindi and Attock districts show a negative trend. Though**,** Lahore in central Punjab and Rahim Yar Khan in the lower Punjab shows the decreasing trend (Table 2). The trend of the rainfall had shifted in the Faisalabad division with significantly positive. In central Punjab, the positive trend is found in all the districts. So, the rainfall trend changed downward for such duration (Table 2).

In the lower Punjab, the rainfall trend shows no significant change during the period of 1986. Even there is no significant trend measured for the upper Punjab. In the Bahawalpur division, the 66 % to 65 % trend has shifted in the Bahawalnagar district. The Kolmogorov Smirnov investigated Bahawalpur districts with Z value = 0.65 with a positive significant change (Table 2).The highest trend change was found in the Multan district from 71 % to 77%. Khanewal district in the Multan division with the Z value = 0.69 shows the negative trend (Table 1).

In lower Punjab, the rainfall during 1992 shows the significant and positive trend like the Bahawalnagar district with Z value = 0.57 (Table 1). However, the change in rainfall trend is insignificant in Faisalabad and Lahore districts with Z value = 0.83 and 0.73 respectively. In upper Punjab, the Kolmogorov Smirnov measured the positive trend in the Sialkot district with Z value = 0.53. In lower Punjab, the rainfall trend is increasing in Bahawalpur division.

In lower Punjab, Dera Ghazi Khan district shows an increasing trend with Z value = 0.103 (Table 2). Hence, a significant positive 60 % change has been observed. However, no change occurred in rainfall pattern over Faisalabad and Lahore divisions. While, there is no such positive as well as significant change has been observed in northern Punjab. It was further deduced that an increasing trend of rainfall has shifted in south Punjab but in southern Punjab, the rainfall trend rate had also shown a decreasing trend before 1995 (Table 2). In 1998, the negative rainfall trend occurred in lower Punjab. The rainfall rate has also increased over upper Punjab. However, there is no change occurred in the Jhelum district. In the lower Punjab, the rainfall trend has shifted from 83% to 95 % in the Khanpur and Multan with Z value = 1.44 and 0.87 respectively (Table 2). The Kolmogorov Smirnov test observed positive and significant trends in the lower Punjab except for the Dera Ghazi Khan division that has a negative and insignificant trend. During this period, the rainfall pattern seems to be changing down to the Multan and Vehari districts. The positive or significant change occurred in Jhang, Chiniot, Faisalabad and Toba Tek Singh districts.

In upper Punjab, a positive and significant trend observed in Islamabad, Jhelum and Chakwal districts during 2001. The 17 % increased trend found through the statistical test in the Sialkot, Mianwali and Narowal districts and capital terority of Islamabad, also shows a significant change (Table 1). Similarly, in lower Punjab, increasing rainfall trend is seen in the Bahawalnagar district with Z value = 1.34 with respect to 1.12 in 1998 (Table 2). The Kolmogorov Smirnov test indicates no significant trend observed in Sialkot in upper Punjab and Multan in the lower Punjab with Z value = 1.87 and 0.55 respectively (Table 1). In the upper and central Punjab, the rate of the rainfall has been increased (Table- 2). The rainfall trend increased in this period with the significant shift from 78% to 84% in the divisions of Rawalpindi, Faisalabad and Bahawalpur.

In the lower Punjab, rainfall has the lowest increasing rate during the period of 2007 like Multan, Dera Ghazi Khan and Bahawalnagar districts show the insignificant trend. The increasing trend is seen in the central Punjab as compared to upper Punjab. The Sialkot district shows a significant and positive trend from 72 % to 87 %. This increasing trend is moving towards lower Punjab whereas decreasing trend is shifting towards the Sahiwal division (Table 2).

The rainfall pattern shifted mostly in areas of upper and lower Punjab included Bahawalnagar, Chakwal and Jhelum districts with Z value = 1.21, 114 and 1.30 respectively (Table 1). In central Punjab, the rainfall trend declined in the Sialkot district. The Kolmogorov Smirnov test measured no change in rainfall trends in Bahawalpur and Mianwali districts during the study period. The test indicates a significant change in the Khanewal district with a value of 84 %. The Islamabad region of upper Punjab, Mianwali and Bahawalpur,

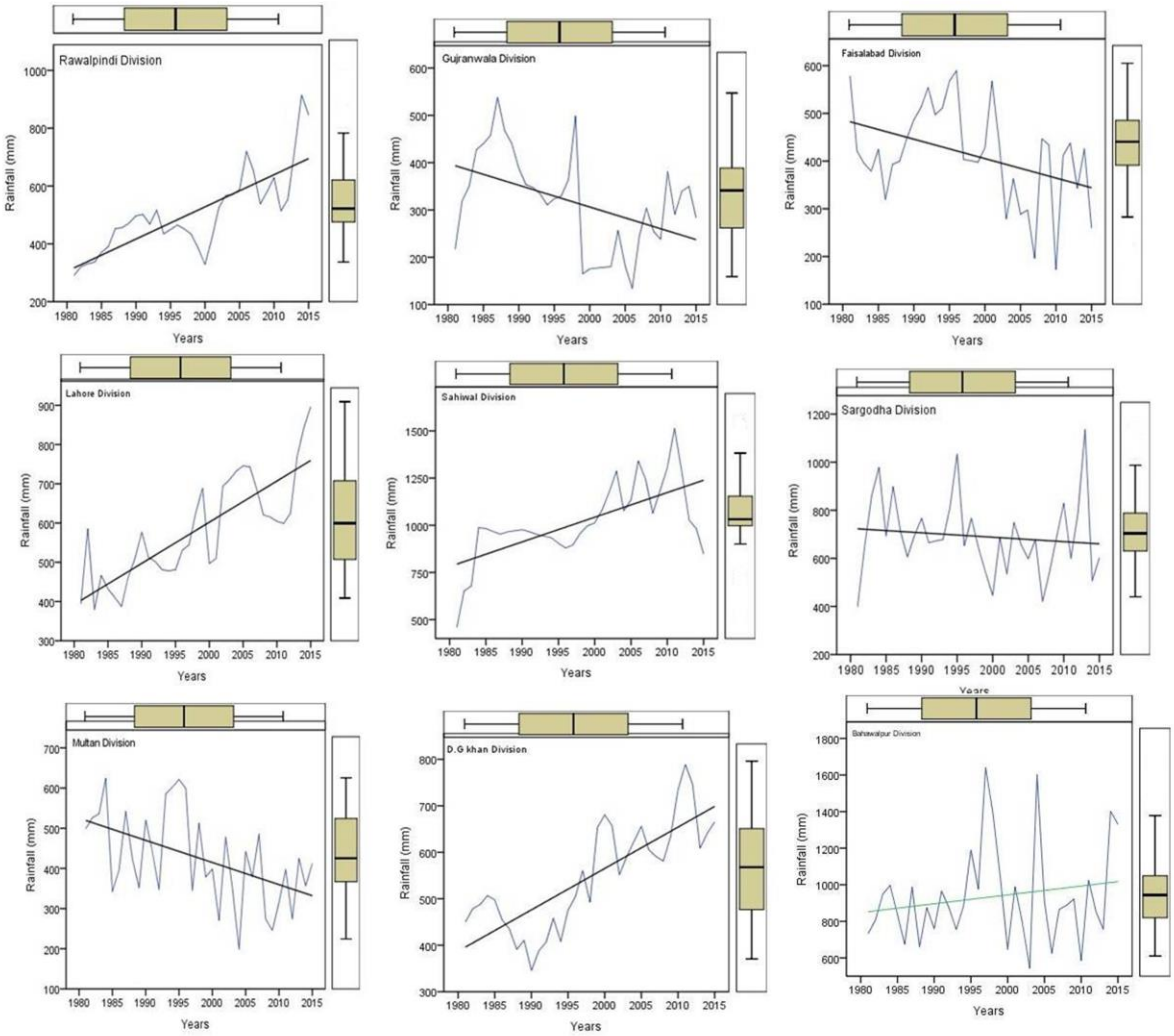

Fig. 1 Shows the rainfall variation experienced in nine divisions of the Punjab, Pakistan.

Dera Ghazi Khan districts from the lower Punjab has a significant and positive trend (Table 2).

In upper Punjab, the Z value indicates an insignificant trend in Jhelum, Gujranwala and Hafizabad districts due to shifted trend towards the west of upper Punjab. Similarly, in the lower Punjab, the rainfall trend has been shifted towards the southern parts of lower Punjab. An overall increasing trend has been observed in the central Punjab divisions (Table 1). In central Punjab, the rainfall decreasing trend has been observed in Lahore and Faisalabad districts in the year 2015. The Dera Ghazi Khan district of the lower Punjab has the same decreasing trend over the study period. While the Z test indicated the negative and significant trend in all the districts of lower Punjab. In central Punjab, Faisalabad, Sahiwal are part of it.The division wise rainfall variations analyzed by dividing the Punjab into three upper levels, central and the lower Punjab**.**

The decreasing trend occurred due to the relatively drier period from 1998 to 2001, especially in the southern and northern districts of the Punjab. However, the Kolmogorov Smirnov test used for the district wise trend measurement has predicted an increasing trend in a southward direction. The Z test value differences in the average rainfall for each station detected the three increasing and two decreasing trends during summer 1981-2015. The decreasing trends were found from the period 1991-2005. Whereas, a total rainfall change of 20.27 mm was observed. The results revealed a significant trend in Murree and Sialkot (north Punjab), Faisalabad and Lahore (central Punjab). Particularly, the change occurs in the south Punjab over the central Punjab and then the same rainfall variations shifted downward. Thirty-six-year average annual rainfall trend revealed that if the rainfall trend increases in future, then variations relevant to rainfall will shift in north Punjab from south eastern direction and in a south westerly direction for the south Punjab. When the rainfall trend move up and downward, it will affect directly to the green sector activities specially the cropping variations in the specific region. During the period of the 1983, in the lower Punjab, all the districts show a positive trend and Bahawalnagar with high Z value = 0.545 has also a positive trend. Furthermore, some districts of the upper Punjab show significant positive trend like Jhelum with Z value = 0.93.

The trend of the rainfall had shifted in the Faisalabad division with the significant positive trend. In the central Punjab, the positive trend is found in all the districts. The rainfall trend changed downward for short duration. During the period of 1995, In the lower Punjab, Multan, Dera Ghazi Khan districts show an increasing trend with Z value = 0.105. Hence, significant positive 60 % change was observed. However, there is no change occurred in the rainfall pattern over Faisalabad and Lahore divisions. In the northern Punjab, there is no such positive as well as significant changes. It was found that the increasing trend of rainfall has been shifted upward in south Punjab but in the southern Punjab, the rainfall trend rate was decreasing before 1995. In the central Punjab, the rainfall decreasing trend has been seen in the Lahore and Faisalabad districts during the 2016. The Dera Ghazi Khan district of the Lower Punjab has the same decreasing trend. While the Z test indicated the negative and significant trend in all the districts of the Lower Punjab. In the Central Punjab, Faisalabad, Sahiwal and Lahore divisions have a significant and positive trend.

Conclusion

This study is based on the statistical analysis and interpolation technique for period of 36 years from 1981 to 2016. From this investigation, it has been concluded that decadal rainfall distribution has shown increasing and decreasing trends over all the districts and divisions of Punjab. These changing trends are likely to be caused by anthropogenic activities in the fastest growing province of Punjab. It is therefore inferred that the regional rainfall quantity and its contrast among districts and divisions of the Punjab is likely to be increased in future due to overall climate variability in Pakistan. There is a need to carry out micro level investigations further into Monsoon and winter rainfall phenomenon, trends and a real shift in the Punjab on scientific grounds. This may will bring greater understanding of new emerging agro-climatic regions in Punjab with foreseeable future socio-economic changes in many districts.

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