CORRELATION BETWEEN MULTIVARIATE ENSO INDEX (MEI) AND PAKISTAN'S SUMMER RAINFALL

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Abstract:

The present paper deals with the Influence of El Nino event on the summer monsoon rainfall over Pakistan. The correlation between monthly rainfall of summer monsoon season and bi-Monthly Multivariate ENSO Index (MEI) has been calculated to see the influence of El Nino on the summer monsoon rainfall. While study the correlation's with the ENSO events out side the Pacific Ocean MEI is more appropriate than other indices like Southern Oscillation Index (SOI) as MEI integrates complete information on ENSO viz. six oceanic and meteorological variables over the tropical Pacific. The results of the study show that there is a tendency of reduction in summer monsoon rainfall over Pakistan during El Nino years. The deficiency in %rainfall is statistically significant up to 90 %level during July and September months. It is interesting to note that Pakistan receives more than normal rainfall during summer monsoon season in the immediate following year after the El Nino event.

Since topography plays an important role in the frequency, intensity and distribution of rainfall, correlation analysis is also performed for northern and Southern Pakistan region. Over Northern Pakistan the reduction in % rainfall departure is significant during July and September during El Nino years. Whereas in case of Southern Pakistan, July and August rainfall show significant reduction during El Nino years.

Key Words: El Nino, Multivariate ENSO Index (MEI), Summer Monsoon Rainfall, Pakistan

Introduction:

El Nino Southern Oscillation (ENSO) Events affect weather, climate, marine and terrestrial ecosystems worldwide. Since the early nineties climatologists have tried to understand the coupling of the Indian Monsoon with the Southern Oscillation in order to predict the monsoon rainfall over Asia. Webster and Yang (1992) review the historical background of Monsoon and ENSO coupling. They explain that "early studies identified the monsoon as a regional physical entity and naturally, attempt to understand its structure and variability focused on local effects. In recent decades, with the advent of more homogeneous data set from

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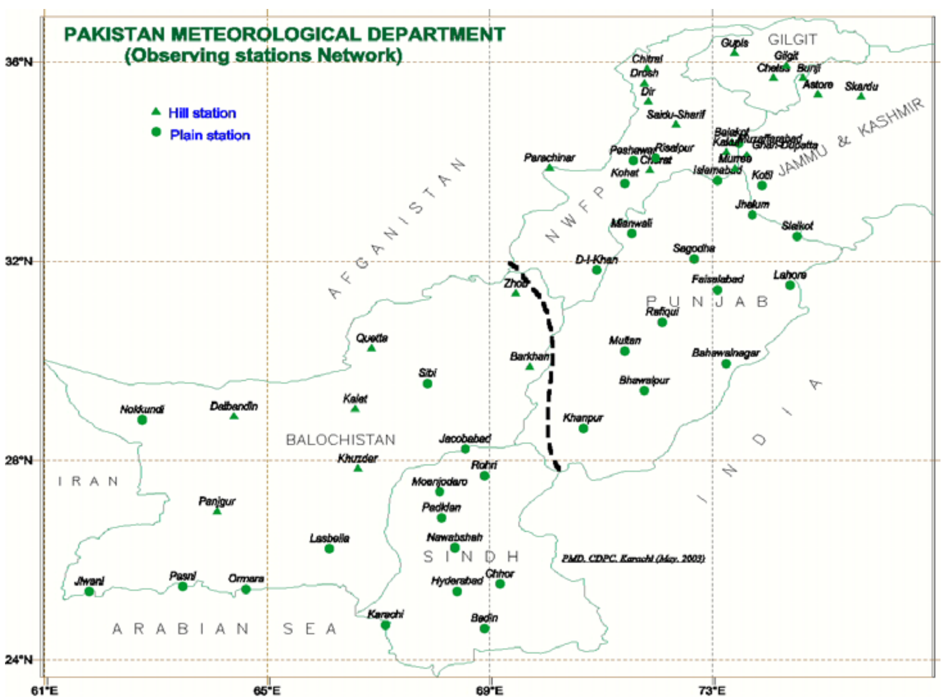
satellites and a more conventional data base, there has been little to counteract this global view of the monsoon. The response of the Indian Ocean to ENSO varies from season to season (Singh and Rout, 1999). According to the study (Singh et al., 2002), the frequency of monsoon depressions over the Bay of Bengal in July and August is higher during El Nino Years. For instance during the strongest El Nino event of 1982, six monsoon depressions were formed in July-August over the Bay of Bengal against the normal frequency of about three. This gives some indication of the type of relation between ENSO and monsoon depressions.

Recent studies have brought the relationships between ENSO and rainfall in different areas of the world, which vary from area to area (Bhalme and Jadhav, 1984). It is well known that Indian summer monsoon is adversely affected by ENSO and Indian subcontinent seems to receive less than normal rainfall during ENSO monsoon years (Shukla and Paolino, 1983; Thapliyal, 1990). However, when we consider the rainfall on sub-seasonal and smaller spatial scales different relationships emerge. For instance ENSO does not seem to have any significant impact on the monsoon rainfall of eastern region of India and Bangladesh (SMRC, 1999). The enhanced frequency of depressions during El Nino years dampens the adverse impact of ENSO on the rainfall of Eastern coastal region of India and Bangladesh, which falls in the track of monsoon depressions. Interestingly, August rainfall of Bangladesh is higher than normal during warm phase of ENSO. This higher rainfall in August covers the deficiency of June rainfall during warm phase of ENSO years. Therefore, the general impression that the ENSO adversely affects the monsoon rainfall of entire Indian subcontinent is perhaps not correct.

Pakistan is also prone to the impulse of summer monsoon. But no attempt has been made to find out the impact of warm phase of ENSO on the monsoon rainfall of Pakistan on monthly scale basis. There have been some qualitative studies on the relationships between the El Nino years and the rainfall over Pakistan (Arif et al. 1994; Chaudhary, 1998). But none of them has looked into these relationships in a monthly and a quantitative manner. The main objective of present study is to look into the relationship between ENSO and summer monsoon rainfall of Pakistan on a monthly scale.

The El Nino/Southern Oscillation (ENSO) represent both atmospheric and oceanic phenomena. The ENSO system is a semi-periodic oscillator whose major parameters include the various sea surface temperature anomalies, pressure, the surface wind and upper layer thickness over the Pacific. The Southern Oscillation Index (SOI) gives a simple measure of the status of the Walker circulation (Tahiti-Darwin pressure), which may be more suitable for the study of weather anomalies over the Australia, Indonesia and the areas located in the Pacific Rim region. For other parts of the world, while study the correlation’s with the ENSO events, the Multivariate ENSO Index (MEI) would be more appropriate, which integrates complete information of six oceanic and meteorological variables over the tropical Pacific. Therefore, use of MEI in the studies relating to the linkage between MEI and different weather parameters in the subcontinents provides better understanding. In the earlier studies the MEI has already been used for studying the relationship with the rainfall of Bangladesh and Eastern coastal belt of India. In this study the relationship between MEI and summer monsoon rainfall over Pakistan in the individual monsoon months have studied. As the impact of El Nino on the atmospheric and oceanic processes depends upon the geographical location of the area, topography and as well as the climatic nature of the region. Keeping in view of the above mentioned factors, an effort has also been made to determine the relationship between MEI and % summer monsoon rainfall for the southern Pakistan and Northern Pakistan. For this purpose the whole Pakistan is divided into two regions, called Northern Pakistan and

Fig. 1: Map showing the study area and selected meteorological Stations



Southern Pakistan. The geographical position of Pakistan and the imaginary dashed bold line on the map representing the limits of two regions and the stations located in the Northern and Southern Pakistan are shown in Fig.1.

Data and Methodology:

Summer monsoon rainfall data was obtained from Pakistan Meteorological Department. Time series' of about 56 stations rainfall data are used during analysis. Stations are shown in Figure-1 located at both hilly and flat areas of Pakistan. Monthly rainfall departure over Pakistan has been computed for July, August and September for the period of 54 years 1950-2003. It may be noted that since in Pakistan monsoon rain starts from the last week of June or from the 1st week of July, June rainfall data is not used in this study.

The MEI, which is one of the measures of ENSO, integrates more information than other indices; it reflects the nature of the coupled ocean-atmosphere system better than either component. The MEI is calculated as the first principal component of six variables over the tropical Pacific such as sea surface temperature, sea level pressure, zonal and meridian components of the surface wind, air temperature and total cloudiness fraction of the sky. The MEI values are computed for every month based on the two preceding calendar months. Thus MEI values are bimonthly and pertain period from 1st week of pervious month to 1st week of the next month. The computation details of Multivariate ENSO Index may be seen in Wolter and Timlin (1993,1998). Thus MEI does a better job than other indices for the overall monitoring of the ENSO phenomenon, including worldwide correlations with surface temperatures and rainfall. Hence in this study Multivariate ENSO Index (MEI) is used to find any relationship between ENSO events with the percentage summer monsoon rainfall over Pakistan. The standardized departure of MEI values since 1950 is obtained from Climate Prediction Center, Washington D. C., USA (Figure-2).

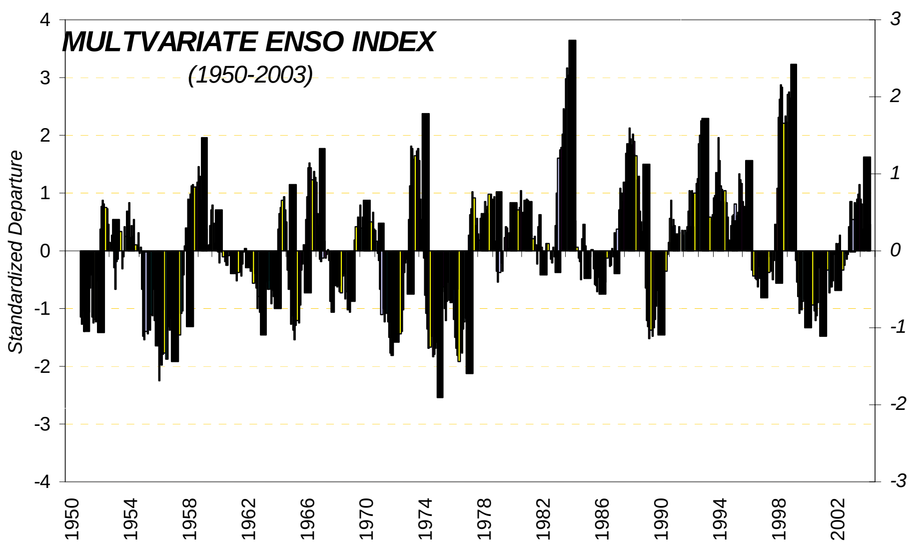


Fig. 2 Standardized departure of MEI since 1950

The information regarding El Nino (warm) and La Nina (cold) episodes for the last 54 years are obtained from NOAA/CIRES Climate Diagnostics Center, Boulder, USA. It may be noted that care has been made during the selection of El Nino years. The selection of El Nino years is based on the season to season breakdown conditions and the intensity of each event in the tropical Pacific. Breakdown is made on quarterly basis by dividing the year into four parts or seasons e.g. January-February-March, April-May-June, July-August-September and October-November-December. Thus those years are taken here in which April-May-June and July-August-September conditions were under strong to moderate El Nino episode. The El Nino years considered for this study are 1953, 1957, 1965, 1972, 1982, 1986, 1991, 1997. Monthly correlations of percentage departure of summer monsoon rainfall with MEI values pertaining to the period from the first week of previous month to the 1st week of the month under consideration have been computed. The time series of MEI values along with All Pakistan % rainfall departure since 1950 have been presented in Table-1.

Table 1: *MEI and Percent rainfall departure over Pakistan during Monsoon Months*

Year	MEIjj (1st week of Jun to 1st week of Jul)	July % rainfall departure	MEIja (1st week of Jul to 1st week of Aug)	August % rainfall departure	MEIas (1st week of Aug to 1st week of Sept)	September % rainfall departure
1950	-1.303	-10.1	-1.057	-13.6	-0.644	-11.9
1951	0.769	-52.5	0.876	-30.3	0.807	-96.7
1952	-0.191	11.9	-0.153	-51.7	0.348	-90.7
1953*	0.433	-24.0	0.251	16.4	0.547	-17.4
1954	-1.406	-48.1	-1.433	-55.1	-1.190	155.2
1955	-1.888	-68.6	-1.986	129.5	-1.788	149.5
1956	-1.182	177.2	-1.118	30.5	-1.345	-38.2
1957*	0.978	-64.7	1.115	-24.0	1.147	-76.5
1958	0.679	23.3	0.382	-56.9	0.077	125.8
1959	-0.209	103.9	0.071	-8.3	-0.015	314.2
1960	-0.311	8.2	-0.246	-38.2	-0.511	-44.9
1961	-0.262	63.4	-0.353	-11.5	-0.351	133.1
1962	-0.801	-15.6	-0.550	-12.1	-0.517	103.7
1963	0.379	-60.6	0.656	-44.1	0.752	-41.2
1964	-1.368	20.0	-1.539	-3.3	-1.301	-6.7
1965*	1.429	-29.8	1.514	-45.7	1.447	-80.0
1966	-0.118	-34.3	0.157	-53.9	-0.121	-32.6
1967	-0.615	6.6	-0.504	7.9	-0.698	-36.7
1968	-0.495	-55.4	-0.150	-42.8	0.186	-95.1
1969	0.419	-21.2	0.277	-56.7	0.222	-40.1
1970	-1.100	-42.3	-1.005	33.0	-1.237	118.6

1971	-1.232	-28.1	-1.260	-29.2	-1.463	-32.8
1972*	1.814	-46.9	1.764	-39.7	1.582	-33.1
1973	-1.076	56.9	-1.356	88.2	-1.693	-11.0
1974	-0.784	-22.1	-0.703	-55.7	-0.622	-30.1
1975	-1.504	17.7	-1.678	75.7	-1.812	76.4
1976	0.621	28.6	0.724	86.4	1.024	206.4
1977	0.847	33.1	0.698	-21.6	0.776	46.5
1978	-0.365	160.8	-0.217	11.6	-0.351	3.3
1979	0.360	-37.8	0.622	32.7	0.807	0.8
1980	0.786	-6.4	0.369	-44.1	0.265	-3.6
1981	-0.045	72.3	-0.152	2.2	0.127	-61.4
1982*	1.600	-46.1	1.749	21.9	1.794	-80.5
1983	1.788	1.4	1.232	119.5	0.527	102.8
1984	-0.200	-1.6	-0.233	68.7	-0.098	45.8
1985	-0.205	10.0	-0.422	-22.1	-0.542	-65.2
1986	0.384	-29.6	0.709	45.2	1.089	-51.1
1987*	1.824	-53.5	2.018	-43.4	1.905	-76.3
1988	-1.213	79.7	-1.307	23.4	-1.516	-23.6
1989	-0.489	81.3	-0.558	3.2	-0.268	-58.9
1990	0.094	-39.8	0.100	59.0	0.421	76.0
1991*	1.022	-62.9	1.041	-36.9	0.748	50.2
1992	1.020	30.0	0.596	84.1	0.480	159.5
1993	1.117	38.7	1.056	-70.2	1.006	-5.7
1994	0.814	98.4	0.610	79.3	0.658	268.0
1995	0.272	119.8	0.055	-11.9	-0.341	-54.2
1996	-0.175	-44.4	-0.262	8.4	-0.309	-46.1
1997*	2.633	-4.5	2.869	36.6	2.840	-27.8
1998	0.343	-27.2	-0.172	-35.1	-0.551	74.7
1999	-0.532	-30.4	-0.735	-21.9	-0.877	-8.5
2000	-0.226	-11.3	-0.165	-29.4	-0.232	-12.7
2001	0.133	33.9	0.274	-41.2	-0.222	-27.1
2002	0.544	-75.2	0.843	-43.6	0.787	-10.2
2003	0.022	94.9	0.265	18.7	0.455	7.2

* Strongest El Nino years since 1950

Regarding the mode of computation of the long-term trends, statistical analysis is performed by using the well known least squares method. The monthly linear trend coefficients have been calculated and Student-t test is performed to test the significance level.

Results and discussion:

The correlation coefficients (CC) between the MEI and % monthly rainfall departure during summer monsoon season over Pakistan is computed here. Due to the typical nature of the topography, geographical position and as well as the climatic nature of Pakistan, the whole area is dived into two regions, called Northern Pakistan and Southern Pakistan. Therefore, statistical analysis is performed on both regions so as to get analysis on regionwise.

The correlation coefficients between monthly summer rainfall and corresponding MEI values for Northern Pakistan, Southern Pakistan and for all Pakistan are presented in Table-2. While performing the correlations for Indian Ocean region, it is proved that ENSO does have influence on the atmospheric and oceanographic processes in this region with some lag (Singh et al., 2000, Khan et al., 2002). In this study it may be noted that due to the nature of MEI values, all CCs are lagging from monthly % rainfall by one month.

Table 2: *Correlation Coefficient (CCs) between MEI and Summer Monsoon Rainfall*

CORRELATION Coefficient (CCs)			
	MEIjj – July % Rainfall	MEIja – August % Rainfall	MEIas – September % Rainfall
Pakistan	-0.183*	-0.157	-0.167*
Northern Pakistan	-0.188*	-0.118	-0.193*
Southern Pakistan	-0.170*	-0.175*	-0.110

*Significant up to 90%level

The negative CCs indicates less than normal rainfall, where as the positive CCs show the higher than normal rainfall.

Correlation between MEI and all Pakistan % Rainfall Departure:

During summer monsoon for all Pakistan basis, the July, August and September % rainfall are deficient having negative correlation -0.183, -0.157 and –0.167 respectively (Table 2). However, deficiency in rainfall during July and September is significant upto 90% during El Nino Years. The time series of July, August and September % rainfall departures and corresponding MEI values are shown in Figure-3, Figure-4 and Figure-5 respectively. In all selected El Nino years Pakistan received deficient rainfall during month of July. Same is true for the months of August and September also. However, relatively week correlation in these months suggest that it is not always true as in case of 1997 El Nino years

(Figure-4). The rainfall over Pakistan during July of 1957, 1987 and 1991 were very much deficient i.e. –64.7 %, -53.5 % and -62.9 % respectively. July rainfall was also below normal during other El Nino years.

Similarly almost the same pattern in rainfall is observed during September of El Nino years. During September of severe El Nino years such as 1957, 1965, 1982 and 1987, Pakistan received much below rainfall than the normal and the % departures were –76.5, -80, -80.5 and -76.3 respectively. This type of trends during El Nino Years shows that there is a tendency of reduction in monsoon rainfall during the September of El Nino years. Time series analysis for the month of September (Figure-5) also shows some interesting results. It may be interesting to note that deficient rainfall (-95.1) was also observed during some non-ENSO years such as 1968. However, during statistical analysis it would not be correct to expect always one-to-one relationship between ENSO and rainfall departure.

The correlation between MEI and August % rainfall departure over Pakistan during El Nino years is not significant statistically (-0.157). Thus the Impact of El Nino on August rainfall of El Nino years is not significant. But can be seen in the time series given in Figure-4, there is a tendency of subdued rainfall over Pakistan during August of El Nino years. Maximum deficiency of August rainfall i.e. –70.2 was observed during the period of long ENSO epochs 1991-1993 in the year 1993. Similarly highest excessive rainfall, which is about +119.5 was also observed during the period of ENSO event 1982-1983 in the year of 1983. This simply shows that ENSO does not have any significant adverse impact on August rainfall over Pakistan.

Careful analysis of rainfall departure over Pakistan and corresponding MEI values indicates that Pakistan receives more than normal rainfall during summer monsoon season in the immediate following year after the El Nino event. During all months of summer monsoon season (July, August and September) of 1983 and 1992, which are the flowing years of El Nino events 1982 and 1991, Pakistan receives higher than normal rainfall. However, in some cases its not true for all summer monsoon months, but the over all total summer rainfall is always excessive in the following year just after the El Nino events (year).For example during July and August of 1973 just following year of 1972 El Nino event %departure of rainfall were +56.9 and +88.2 respectively. While in the same year September rainfall was -11.0.Thus the much excessive rainfall in July and August overshadowed September deficiency of rainfall and total summer monsoon rainfall is higher than normal. Same is true for

1958, 1973 and 1988 years just after the El Nino years of 1957, 1972 and 1987 respectively, where excessive rainfall in some monsoon months overshadowed the deficiency in rainfall in the remaining monsoon months.

Correlation between MEI and Northern and Southern Pakistan % Rainfall Departure:

The topography of Pakistan is very complex. Northern Pakistan consists of mainly hilly areas and plateau including famous mountain ranges such as Himalayan, Koh Hindukash and Karakrum ranges. Whereas Southern Pakistan is mainly plain land with some hilly areas in the northwestern side. The orographic effect and wind pattern in the mountainous areas play important role in the frequency, intensity and distribution of rainfall in the Northern and Southern Pakistan.

Therefore, to see the correlation pattern between MEI and % summer monsoon rainfall departure area wise, the selected meteorological stations were divided into two parts, northern Pakistan and southern Pakistan. During analysis for both regions (Northern and Southern Pakistan), only those stations data were used which are located in the Northern and Southern areas respectively.

While analyzing the Table-2, it may be noted that July rainfall in both regions during El Nino years are less than normal and reduction in rainfall is significant. Statistically the correlation between MEI and % July rainfall departure for Northern Pakistan and Southern Pakistan are –0.188 and –0.170 respectively. Therefore, it is clear that there is a strong tendency of reduced rainfall during July of El Nino years regardless of region.

Very interesting results are noted when correlation was made for August and September months for both regions. In northern areas very week negative correlation (-0.118) indicate that the reduction in the August rainfall during monsoon years is not significant.Whereas for southern region it is September, where a very week and not significant correlation exists (-0.11). In other words over Northern areas the reduction in % rainfall departure is significant during July and September during El Nino years, whereas in case of southern Pakistan, July and August rainfall show significant reduction during El Nino years.

In view of the above mentioned analysis it is clear there is an adverse impact of ENSO on the summer monsoon rainfall over Pakistan. Though in this complex system of atmosphere and ocean one to one relationship does not exist always, but it is certain that ENSO imply a bad monsoon over Pakistan and Pakistan receive deficient rainfall during monsoon months. One of the reasons may be the low intensity of cyclogenesis over Bay of Bengal and they dissipate without reaching to Northern India or Pakistan.

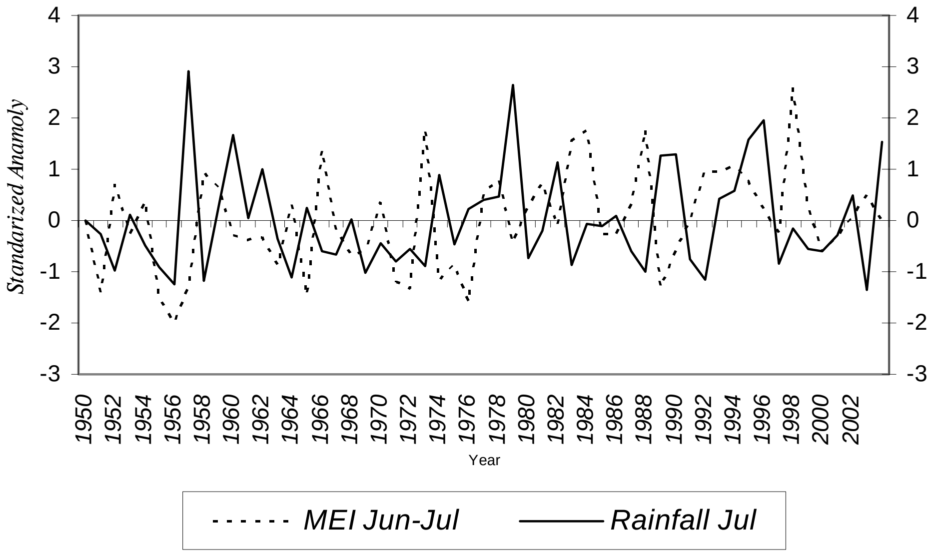


***Figure-3**. Time series of MEI Jun-Jul and Rainfall-Departure Jul all over Pakistan*

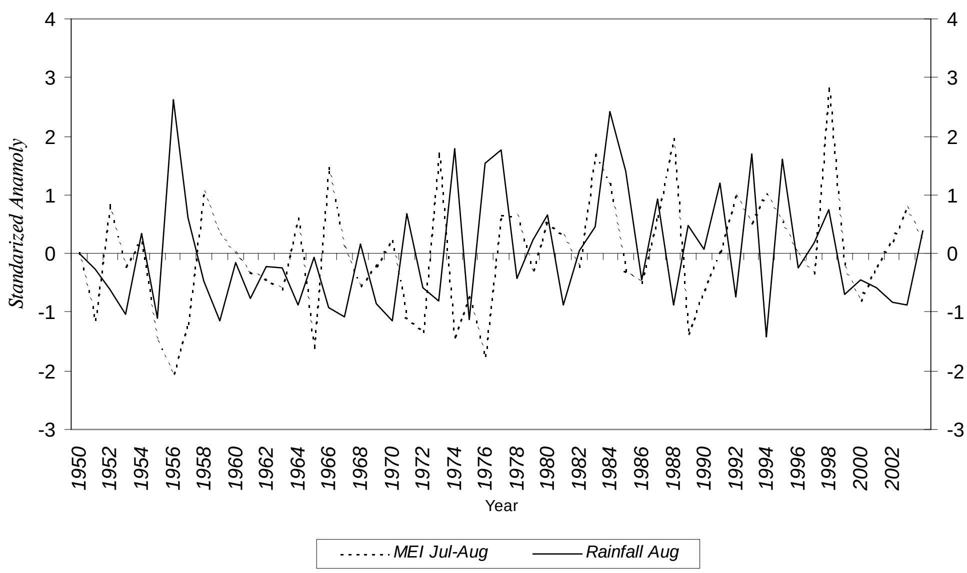


***Figure-4**. Time series of MEIJul-Aug and Rainfall-DepartureAug all over Pakistan*

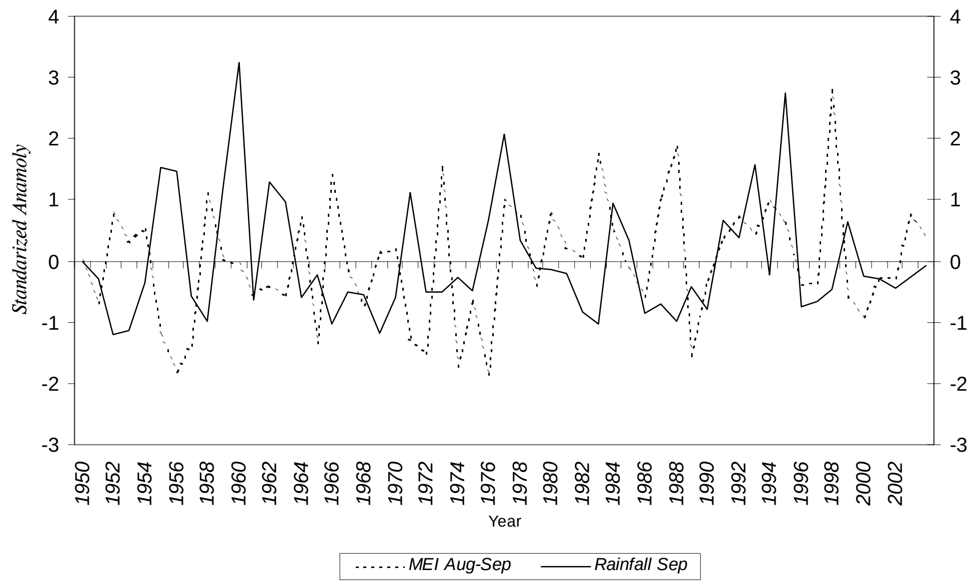


Figure-5*. Time series of MEIAug-Sep and Rainfall-DepartureSep all over Pakistan*

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