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Thunderstorm and rainfall frequencies over Pakistan

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ABSTRACT

Mean Monthly, seasonal and zonal percentages of thunderstorms (TS) and rainfall (RF) frequency obtained, analyzed and depicted using fifty years (1961–2010) data of 54 Pakistani observatories spread uniformly over the country. The study has revealed that there is a significant correlation between the frequencies of said parameters, while there is a one month time lag found in the occurrence of peak activity of TS and RF. Seasonal analysis of these two parameters suggests that rainfall yield associated with post-monsoon season is marginally more than TS activity and significantly more in winter season. Considering zones of the country during winter, apart form Sindh RF activity is significantly more than TS but during May to September (most of premonsoon and monsoon) TS activity is found more than RF in all zones. This behavior is consistent with the overall seasonal behavior of the country. The monthly study has revealed two marked peaks of TS and RF while rainfall activity in end of winter and start of premonsoon is greater than in peak monsoonal months. Overall seasonal analysis of these two parameters suggests that rainfall yield associated with post-monsoon season TS seems to be higher than the pre-monsoon season. Station wise seasonal analysis of winter suggested that all stations acquire much more RF accompanied with very little TS activity. The situation is reverse for premonsoon and monsoon while in postmonsoon, situation is rather complex. All data is also demoed in graphical representations and tabulated with characterized statistical and analytical values. The aim of this paper is to promote various components of TS and RF activity over Pakistan and to help the weather forecasters, aircraft pilots, agriculturists and planners in this respect. The study also emphasizes the need for more studies in this direction.

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Introduction

At any given time according to estimates about 2000 Thunderstorms (TS) are present over the planet. It is also estimated that nearly 45000 TS occur daily in the world i.e. 16 million TS each year (Khan & Arsalan, 2007). Due to their occurrence at anytime and anywhere, thunderstorms are considered as a parameter having a special importance among all meteorological events (William, 1961). They can lead to casualties and/or damage to public and property. Being the major hazard for aviation (Awadesh, 1992), climatologists and meteorologists ought to investigate its knowledge.

Many studies of thunderstorms in the past have been conducted in this regard (Sohoni, 1931; Rao and Raman, 1961; Raman and Raghavan, 1961; Williams, 1961; Chaudhury, 1961; Rao et al., 1971). In the past three decades many useful studies have appeared to explore this unique parameter (Balogun, 1981; Oladipo and Mornu, 1985; Prasad and Pawar, 1985; Sivaramkrishnan, 1990; Awadesh, 1992; Moid, 1995, 2001). For Pakistan Siddiquie and Rashid (2008) and Mir et. al. (2006) attempted basic study of thunderstorms.

TS frequently produce gusty winds, heavy rain, and hail. It may be produced by a single cumulonimbus cloud and influence only a small area, or it may be associated with clusters of cumulonimbus clouds covering a large area (Lutgens and Tarbuck, 2010). Although, by definition rainfall need not be associated with thunderstorm (in fact, in dry climates, TS often occur without measurable precipitation) (Oliver, 2002). However, in this work a possible long term relation between the two has been explored as observations show that RF follows TS very often. For this reason thunderstorm and related rainfall is of much importance and interest in Pakistan especially for Pre-monsoon and monsoon seasons over Pakistan. Almost all the months have thunderstorm occurrence in the country.

For Pakistan all the studies in past were restricted to TS activity and that also till 2000 (Mir et. Al., 2006), the present study also analyzes the RF activity along with TS up to very recent times. Further, it pertains to a large number of stations (54) which cover the whole Pakistan region. The purpose of this study is to focus attention on the general distribution of thunderstorm and rainfall on an annual, seasonal, monthly and zonal basis. This study also emphasizes the need for more studies in this direction.

Data and methodology

Mean monthly data of thunderstorm (TS) and rainfall (RF) frequency of 54 observatories/stations for 50 years (1961-2010) is used in this study. All the data used in this study is provided by Computerized Data Processing Center (CDPC), Pakistan Meteorological Department. The TS data comprises of all types of thunderstorms, i.e. convective, orographic and seasonal. The study however does not show the actual preferred time of occurrence, whether occurring in the morning, the after noon or during night time. Any number of occurrence in 24 hours has

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been counted as "one". The criterion for selection of these stations is that they cover whole of Pakistan and data should be available for the entire period. The location of stations is shown in Figure 1.

Using the data mentioned for TS and RF for all 54 stations, annual totals and monthly mean percentage of occurrence have been computed. Seasonal percentage of occurrence of TS and RF are also calculated. The seasons are premonsoon (April to June); monsoon (July to September); postmonsoon (October and November) and winter (December to March). Pakistan has been divided into five zones/regions as suggested by Hussain et.al, 2005. These regions are Sind, Punjab, Balochistan, Khyber Pukhtunkhwa (KP) and Gilgit Biltistan/Azad Jammu & Kashmir (GB&AJK) as depicted in Figure 4. The zonal/regional monthly mean percentages of occurrence of TS and RF have been computed. Monthly, seasonal and zonal mean percentages are useful to understand the distribution of the above two parameters across the country.

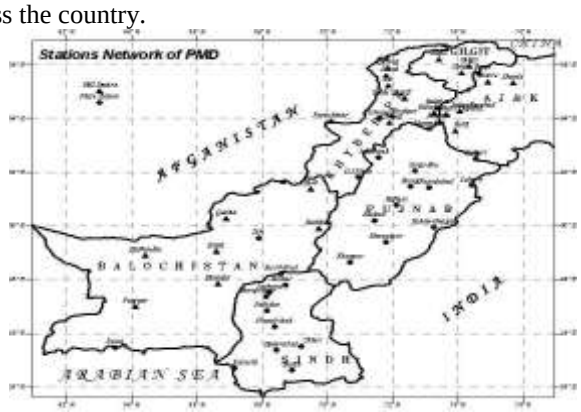


Fig 1: Map of Pakistan showing 54 observatory stations

Results and discussion

Monthly percentage of occurrence of TS and RF over Pakistan

Annual mean percentage of occurrence of TS and RF (average of all 54 stations) is depicted in figure 2. It is evident from this figure that least TS activity is in the month of December (0.9%) and then it increases consistently from the month of January and attains a peak in the month of July (18.9%). However, from May to June the TS activity trend shows a plateau. During this period the affects of the westerlies goes down and mixes with the onset of monsoon. TS activity slightly decreases in August (17.8%) and then goes down consistently to as low as 1.6% in November. Comparatively the behavior of RF activity shows a marked difference in view of the fact that there are two maxima and two minima. The least value is observed in November (2.9%) which gradually increases and reach up to first acme in March (11.5%) which decreases again till June (8.2%) while second peak is observed in July (14.4%). Like TS, the RF activity decreases in August (13.6%) and continues to diminish till November. It should also be noted that the June minimum of RF is closely placed with onset monsoon pattern of TS (the plateau mentioned above).

However, RF activity increases in December again. A careful examination of figure 2 suggests that from April to November TS leads RF while for rest of the months the situation is reversed.

Figure 2 also shows that rainfall pattern has two clear bumps as first occur in March. This behavior may appear due to the rainfall pattern in western parts of the country (Baluchistan and KP) where western disturbance cause usually more rain than monsoon. Reduced TS activity corresponding to a peak increase in the RF activity is again related with the setting up of summer monsoon over the country. The figure also suggests that during active monsoon period occurrence of TS is also more frequent. Also, it is seen that TS and RF activity is observed to be minimum in the end of post monsoon and start rising in winter months. The correlation coefficient in between these two parameters is found to be 0.814. Although, theoretically TS and RF need not be necessarily correlated but for the period of study in Pakistan the two are found sufficiently correlated.

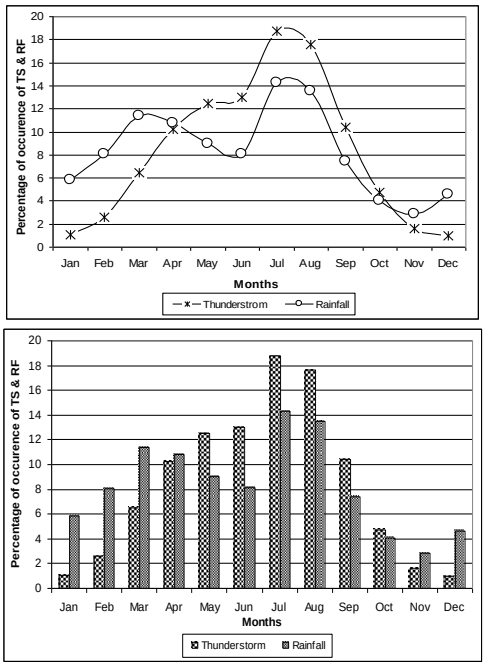


Fig 2: Annual percentage of thunderstorms (TS) and rainfall (RF) during 1961-2010 over Pakistan

Seasonal percentage of occurrence of TS and RF

Figure 3 is a bar diagram of the seasonal percentage of occurrence of TS and RF over Pakistan. It is seen from this figure that the percentage of occurrence of TS activity appears to be higher than that of RF in the premonsoon and monsoon seasons whereas it is nearly equal in post monsoon seasons. In winter RF activity is almost 3 times than the number of days of TS activity, however, in prewinter or postmonsoon season frequencies of both activities are almost comparable. In premosnoon and monsoon seasons thunder is more frequent than rainfall. The percentage of occurrence of RF in premonsoon, monsoon, postmonsoon, and winter seasons is 28.3, 35.7, 7 and 30%, whereas the corresponding TS percentage is 36.1, 47.3, 6.4 and 11.2% respectively. From these percentages it appears that both RF and TS activity are observed to be maximum in the monsoon season (i.e. 35.7 and 47.3%) as compared to the other three seasons (Landsberg, 1971; Freier, 1978; Zipser, 1994; Manohar et al., 1999). Seasonal correlation coefficient (cc) value is computed and it is 0.9615. The observed higher value of CC may be an outcome of the maximum TS and RF activity during the monsoon season. This result appears to be consistent with the studies made by Manohar et al. (1999). These studies suggested that in the monsoon season the onset, withdrawal and revival of monsoon after the break are associated with merging of thunderstorm activity. Further, it is also seen that in the premonsoon season the percentage of occurrence of TS is 36.1% and that of RF is 28.3%. These higher and lower values of TS and RF for this season can be explained as the RF associated with certain TS is mainly due to convection. However, other factors may be involved that need to be explored further. Hence

the RF yield confined to certain TS depends upon the availability of moisture and in some cases RF yield may not be available due to lack of moisture (Koteswaram and Srinivasan, 1958).

During the post monsoon season, the percentage of occurrence of TS and RF activity is observed to be nearly the same (i.e. 6.4 and 7%, respectively). Percentage comparison of TS and RF between premonsoon and postmonsoon seasons (i.e. 36.1 and 28.3%) suggests that TS in post monsoon seasons produces more rainfall. Possibly the more RF activity is mainly due to the western disturbances (Sadiq and Qureshi, 2010).

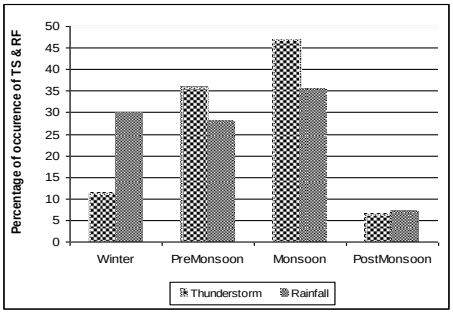


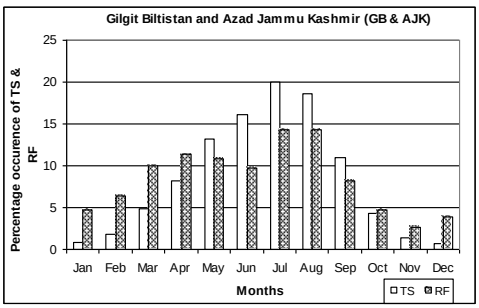
Fig3: Seasonal percentage occurrence of TS and RF over Pakistan region during 1961-2010

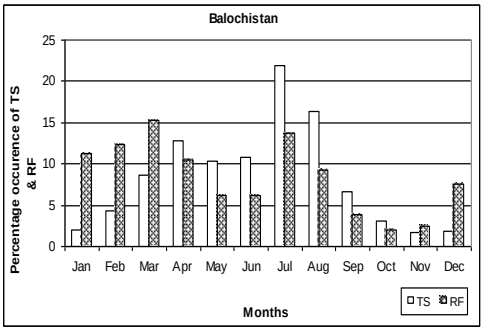
The correlation coefficient between TS and RF is computed for all seasons together as well as for individual seasons. For all seasons the mean value of cc, 0.9615, is significant at 0.1% level, and for individual seasons the values for premonsoon, monsoon, postmonsoon, and winter seasons are 0.976, 1, 0.914 and 0.956, respectively. Here, it is interesting to note that the correlation coefficient between TS and RF during the monsoon season is even higher.

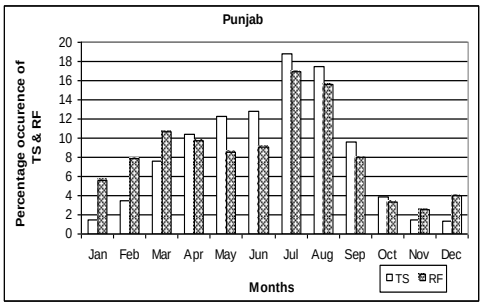
Monthly percentage of occurrence of TS and RF for six different zones

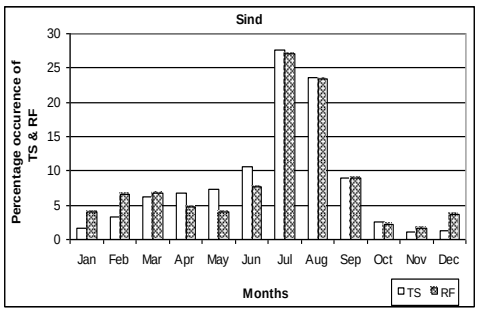
Figure 4 shows the five different zones of the Pakistan region and the corresponding stations. Figure (a-f) gives the monthly percentage of occurrence of TS and RF in five different zones, GB&AJK, Baluchistan Fig 5(b), Punjab Fig 5(c), Sind Fig 5 (d) and KP Fig 5 (e). In these figures the open bar represents TS and the dark shaded bars represent RF. The characteristics of TS and RF noticed from Figures (a-e) are described in Table 1.

Fig 4: Map showing five different zones/provinces of Pakistan









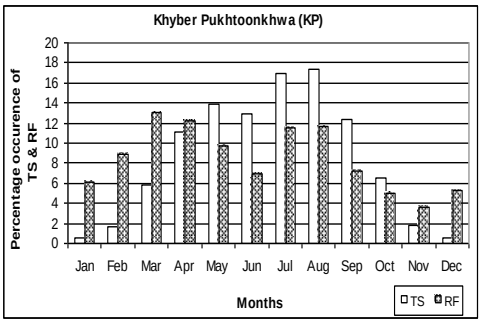


Fig 5: Percentage occurrence of TS and RF for five different zones/provinces

From this table and Fig 5 it is seen that TS maxima for GB&AJK, Balochistan, Punjab and Sind occurred in same peak month of monsoon season i.e. July while in KP its value is in August. A careful observation of KP and Balochistan shows two maximums (i.e. higher and lower maxima) per year for TS. The lower maximum of Balochistan is in April while for KP it is in May. Regarding rainfall, all zones of Pakistan have two maxima. Punjab, Sind and GB&AJK have extreme RF value in July while KP and Balochistan get maximum rainfall frequency in March. The lower maximum values are quite variable. For Punjab and Sind it occurs in March, for GB& AJK in April, for Balochistan in July and for KP in August. The least maximum appears for Sind probably because of the fact that this region gets less rain during winter under the influence of westerlies.

The details of figure 5 are summarized in Table1. It comes out that the regions with more occurrence of rainfall in peak months of monsoon have high correlation coefficient (cc) values (at significant level 0.1%) compared to those with more rain in

winter months i.e. KP and Baluchistan which are the western parts of Pakistan. (Fig 4).

Figure 6 shows the pie diagrams for TS and RF for five different zones as discussed in Table 1. These pie diagrams represent the 50 years mean percentage of occurrence of TS and RF in different zones. From this figure it is seen that the highest percentage (35%) of occurrence of TS is noticed in KP and Punjab while the lowest (4%) in Sind, whereas the percentage of occurrence of TS in the other four zones is 17% in GB&AJK and 9% in Baluchistan. Similarly for RF the highest (35%) mean percentage of occurrence is observed in KP, the lowest (3%) in Sind. In the other zones the percentages are 31% in Punjab, 23% in GB&AJK and 8% in Baluchistan. This figure also suggests that although both parameters (TS and RF) show a wide range of variation month after month, as discussed in Figure 5(a-f), their 50 years mean percentage of occurrence seems to be more or less equal in each zone, i.e. 35% in KP; 35 and 31% in Punjab, 17 and 23% in GB&AJK; 9 and 8% in Baluchistan and 4 and 3% in Sind.

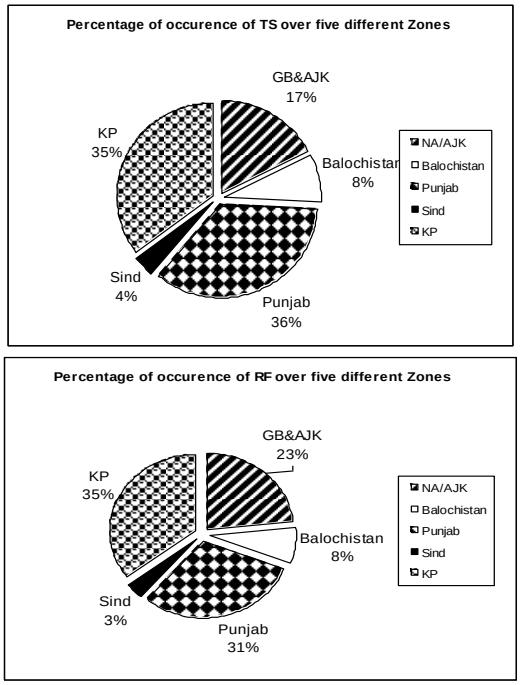


Fig 6: Pie diagram showing the percentage of occurrence of TS and RF (percentage obtained from all Pakistan TS and RF activity)

Conclusions

After analyzing 50 years (1961–2010) of mean TS and RF data for 54 stations well distributed all over the country we can conclude that:

(i) The monthly mean percentage of occurrence of TS and RF suggests that from the mid of premonsoon (May) to start of postmonsoon (October) TS activity is higher than RF which may be due to prime period of onset of the SW monsoon over the Pakistan region. For rest of the months the situation is reversed as that period related to western disturbance over the region.

(ii) Seasonal percentage of occurrence of TS and RF shows that (a) in the monsoon season both parameters show higher percentage of occurrence, (b) rainfall activity associated with TS in the winter season is higher than that of the premonsoon season; it is also due to the fact that the region acquire winter rain due to westerlies phenomena over the region (Sadiq and Qureshi, 2010).

(iii) Monthly percentage of occurrence of TS and RF at five different zones shows that, except for Baloshistan and KP, both parameters are highly correlated. These two regions are at the western border of Pakistan and hence are affected more by westerlies than the monsoon.

(iv) Five zone/provincial analysis of TS and RF has suggested that there exists a wide range of variation in both parameters month after month in respective zones, but the 50 year mean percentage of occurrence of TS and RF seems to be more or less equal in magnitude for each zone.

The marked difference shown by the patterns for Balochistan and KP suggest that a more comprehensive study of western disturbance phenomena should be conducted beyond local borders in order to have a better understanding.

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Table 1: Characteristics of percentage of occurrence of TS and RF for five zones during 1961-2010

Zones	%age Range TS	%age Range RF	TS maxima higher/lower	RF maxima higher/lower	Average %age of TS/RF occurred b/w June and September	CC values
Punjab	1.3-18.8	2.4-16.9	July	July/March	14.7/12.4	0.90*
KP	0.5-17.3	3.6-13	August/May	March/August	14.8/9.3	0.57
Sind	1.1-27.6	1.6-27.1	July	July/March	17.7/16.8	0.97*
Bal	1.7-16.4	1.9-15.2	July/April	March/July	13.9/8.2	0.42
GB&AJK	0.6-20	2.6-14.2	July	July/April	16.4/11.6	0.87*