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THUNDERSTORM AND RAINFALL FREQUENCIES OVER SINDH, PAKISTAN FOR THE PERIOD 1961-2010

N. SADIQ

Institute of Space and Planetary Astrophysics, University of Karachi, Karachi, Pakistan

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The study is aimed to analyze the fifty years (1961-2010) data of Thunderstorm (TS) and Rainfall (RF) frequencies for the Sindh province via nine meteorological stations that are almost unevenly distributed over the region. Monthly, overall seasonal and station wise seasonal percentages are calculated and analyzed. In addition, percentage frequency comparison of TS and RF are also incorporated. Both the activities are observed with greatest frequency (59%) in monsoon while annual diversity of TS is found greater than RF. During monsoon period, Badin is the most while Jacobabad and Larkana are the least affected reported stations by frequent storms along with rainfall, respectively.

Keywords: Thunderstorm frequency, Rainfall frequency, Percentage analysis, Sindh, Pakistan

1. Introduction

A thunderstorm produced by a cumulonimbus cloud, usually induces rain and sometimes hail. The basic necessities required for its production are lifting of unstable air and moisture [1]. Although thunderstorms can occur at any time but they are most probable to occur in the spring and summer during the afternoon and evening. In comparison to hurricanes and winter storms, thunderstorms affect smaller areas, as their typical diameter is 15 miles and lasts for an average 30 minutes. According to estimates, about 40,000 thunderstorms occur daily over the globe i.e. 16 million per year [2]. All thunderstorms, despite of their size are dangerous and hazardous. The death rate due to thunderstorm is greater than tornadoes as a result of lightening each year. In addition to strong winds, hail and tornadoes are also associated dangers with some thunderstorms.

A thunderstorm is said to be severe if wind speed reaches 93.34 Kilometers per hour. They may occur in clusters, singly or in lines [3]. The situation is most severe if a single thunderstorm affects any location for extended period of time. Usually typical thunderstorms produce heavy rain for a brief period (thirty minutes to an hour). Warm and humid conditions are highly favorable for thunderstorm development.

As regards Pakistan, rainfall and thunderstorm are important parameters, particularly in monsoon and pre-monsoon. In contrast to few outdated thunderstorm studies [4, 5], present analyses comprises of the update investigation of TS along RF activity over the province of Sindh. This work is the extension of recent studies that have been carried out for the Khyber Pakhtunkhwa [6] and Punjab province [7].

1.1. Study Area

Sindh province is located on the western corner of South Asia, bordering Iranian plateau in the west. It is the third largest province of Pakistan, stretching about 579 km from north to south and 442 km at extreme or 281 km at average from east to west, covering an area of 140,915 km^2 of the country and lies roughly in between the ranges of 66^o to 72^oE longitude and 23^o to 29^oN latitude (Figure 1). It is bounded by the Kirthar Mountains to west, Thar Desert to east, and the Arabian Sea in the south, while the center is a fertile plain around the Indus River [8].

The province is situated in subtropical region with hot summers and cold winters. The minimum average temperature of 2^oC is frequent during December and January while maximum temperature often rises above 46^oC during May to August [9]. The average amount of annual rainfall is about 18 cm, falling mainly during the monsoonal months i.e. July and August.

2. Data and Methodology

The data of TS and RF frequencies for the period of 50 years (1961-2010) from nine meteorological stations viz. Badin, Hyderabad, Jacobabad, Karachi, Nawabshah, Chhor, Larkana,

* Corresponding author : nsadiq@uok.edu.pk

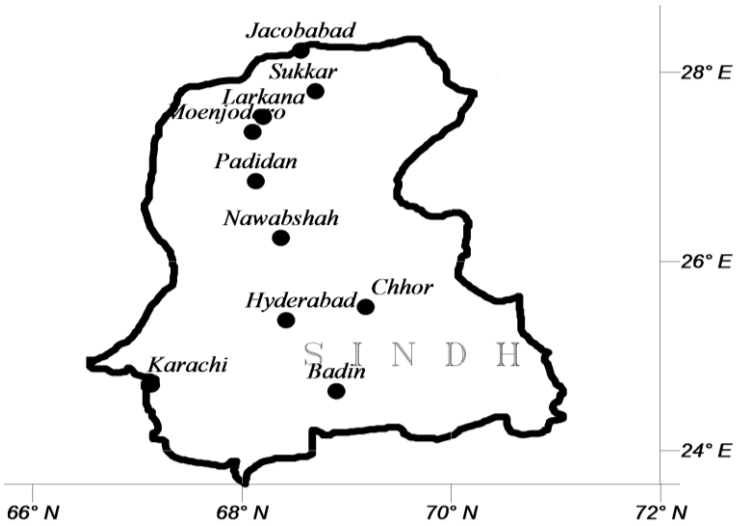

Figure 1. Meteorological station network in Sindh.

Mohenjodaro and Padidan is utilized in this study. The TS data comprises of all types of seasonal, orographic and convective thunderstorms. As the temporal resolution of data is 24 hours and hence not rivet on the exact time of occurrence, therefore, according to defined criteria during any considered day any number of occurrences is considered as one.

Variance standard deviation, minimum & maximum range and interquartile range are calculated to check the quality, variation, spreadness and suitability of data. As the employed statistical parameters propose that data is appropriate for the study, therefore, monthly totals, monthly mean and seasonal percentages of occurrence has been computed. For the analyses, seasons are cogitated as pre-monsoon (April to June); monsoon (July to September); post-monsoon (October and November) and winter (December to March) as suggested by Hussain et al. [10]. Moreover, analysis of seasonal percentages for each station is also carried out along seasonal comparisons.

3. Findings and Discussion

3.1. Annual TS and RF

Pre-analysis data quality check was initiated through the observed skewness and Kurtosis values. For the considered data period very small value of skewness is observed for both parameters pointing the normally distributed nature of the data. Moreover, kurtosis which shows the degree to which a data set is peaked, appear as slightly negligible negative value for RF and slightly greater than one for TS shows that distribution is little bit flatter than normal peak. Hence, the data is found to be used for further analysis. The Correlation Coefficient (CC) is calculated to view the correlation between TS and RF was found to be 0.972. The situation is not only different from Khyber Pukhtunkhwa where only sufficient correlation (0.571) was found [6] but it is also greater than the Punjab (0.90) [7]. The deviation of RF values from the standard is greater than TS, which shows the more scattered nature of TS activity than RF.

For estimation of the spreadness and central tendency, the data is further divided into quartiles i.e. in four equal parts. First quartile (Q1) presents 25% of the data are less than or equal to 1.81 (for TS) and 3.75 (for RF). Similarly third quartile (Q3) presents the mentioned state of the data for 75% with the outcome values 8.33 and 4.81 for TS and RF, respectively. The interquartile range (IQR) is the distance between the first and third quartiles (Q3-Q1); thus it spans the middle 50% of the data. It certified the variation almost according to standard deviation and in the present study, IQR for TS (8.33) is almost double than RF (4.81).

The values of standard deviation range are close. IQR indicates that understanding and prediction of TS activity require more precision than RF, as the TS activity is more varied than RF. Some important statistical parametric values including variance, standard deviation, minimum, maximum range and interquartile range are tabulated in Table 1. Q2 simply presents the median which has no such significance in this case, hence not included in Table1.

Table 1. Some characterized statistical and analytical values for TS and RF.

Parameter	Variance	St.Dev.	Min.	Max.	Range	Q1	Q3	IQR	Skewness	Kurtosis
TS	73.05	8.55	1.11	27.28	26.17	1.81	10.14	8.33	0.54	-1.03
RF	66.13	8.13	1.67	26.88	25.22	3.75	8.56	4.81	0.79	-0.17

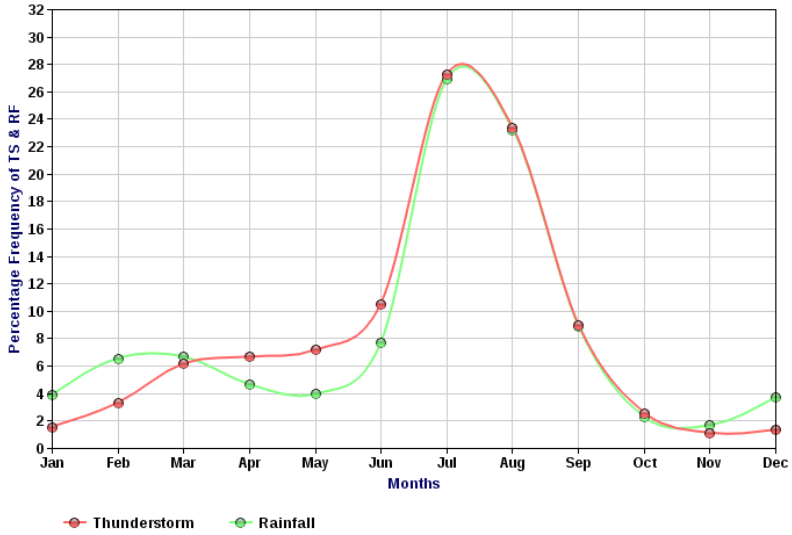

Figure 2. Annual percentages of TS and RF over Sindh.

Both the activities show analogous behavior in the beginning of monsoonal months. Total mean monthly annual percentage frequencies of TS and RF shows that peak thunderstorm activity (more than 26%) appears in the months of July, which also persist in August (with more than 22%) in contrast to the end of post-monsoon (November) and start of the winter season (i.e. from December to January) when least (less than 2%) activity is found. Such a minimal activity may be due to the fact that this period is dominated by westerlies in Sindh region [11]. Monthly time series pattern of TS activity shows gradual rise from May to June and rapid mounting from June to July, then gradually decrease up to September after which the sudden fall is observed (Figure 2).

During premonsoon, monsoon and at the beginning of post-monsoon seasons (i.e. from April to October), RF activity is lesser than TS while the situation is altogether different for the remaining months. It explores the maximum TS activity in these months, hence thunderstorms in Sindh are found highly associated with the premonsoon and monsoon seasons. Unlike TS it has two peaks; RF activity starts rising after November (1.67 to 3.70% in December) and continuously follows the same trend through January (3.90%) and February (6.56%) and reaches to its maximum value of 6.67% in March. It then starts decline and reaches to its second lowest value in May (3.96%) then shoots up again and reaches to its second peak in July (26.89%) with close value in August (23.21%). Finally occurrence of RF starts decreasing and reaches to its minimum value in November. The percentage distributions of the both parameters are shown in Figures 3 and 4.

Annual percentage of TS frequency over Sindh shows that more than 50% thunderstorm activity in the July and August. The contribution of post-monsoon is less than 4% and of winter is almost 12% while the TS in premonsoon is almost 24%. It further explores that maximum activity is in monsoon (59.57%) followed by premonsoon season. The same percentage hierarchy is observed for rainfall frequency. Rainfall activity is highest in monsoon season (59%). The other seasons contributes 20.83% for winter, 16.11% for premonsoon, 3.93% for post-monsoon. Figure 5 expresses the entire situation.

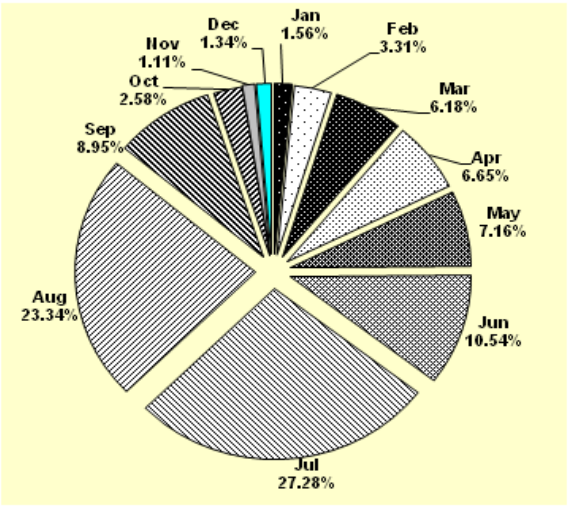

Figure 3. Annual percentages of TS over Sindh.

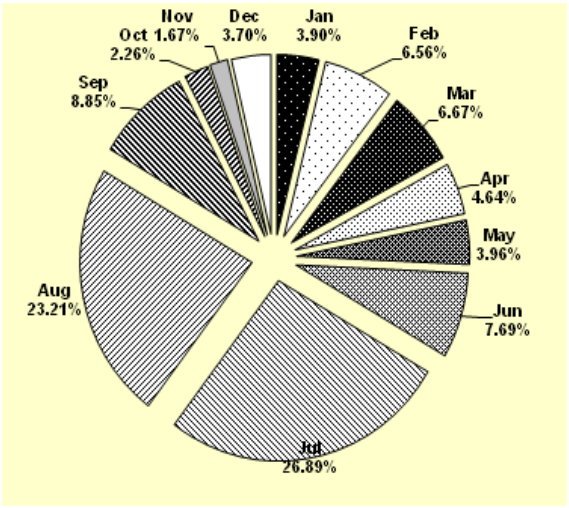

Figure 4. Annual percentages of RF over Sindh.

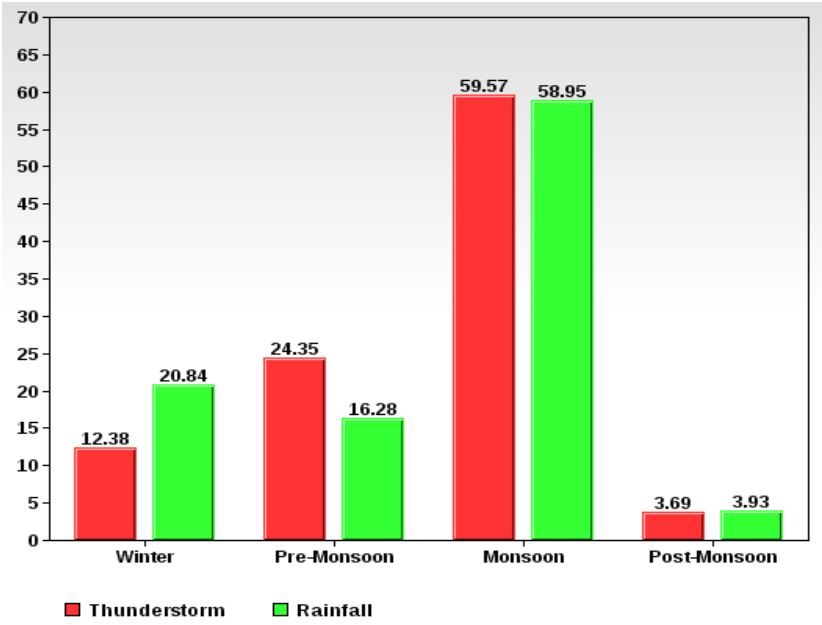

Figure 5. Seasonal percentages frequency of TS and RF over Sindh.

3.2. Seasonal TS and RF (overall)

The percentage of TS frequency appears to be higher than that of RF activity in the premonsoon and monsoon seasons whereas it is nearly equal in post monsoon seasons. RF activity is almost 8.46% higher and just 0.62% lesser than the TS in winter and monsoon respectively (Figure 5). The percentage occurrence of RF in premonsoon, monsoon, post-monsoon, and winter seasons are 16.28, 58.95, 3.93 and 20.84% respectively, whereas the corresponding TS occurrences are 24.35, 59.57, 3.60 and 12.38% respectively. From these percentages it appears that maximum TS activity is observed in the monsoon season (59.57%) while RF maximum appears in monsoon (58.95%). The result is different from Khyber Pukhtunkhwa where maximum TS activity is found in monsoon and maximum rainfall activity is found in winter season [6].

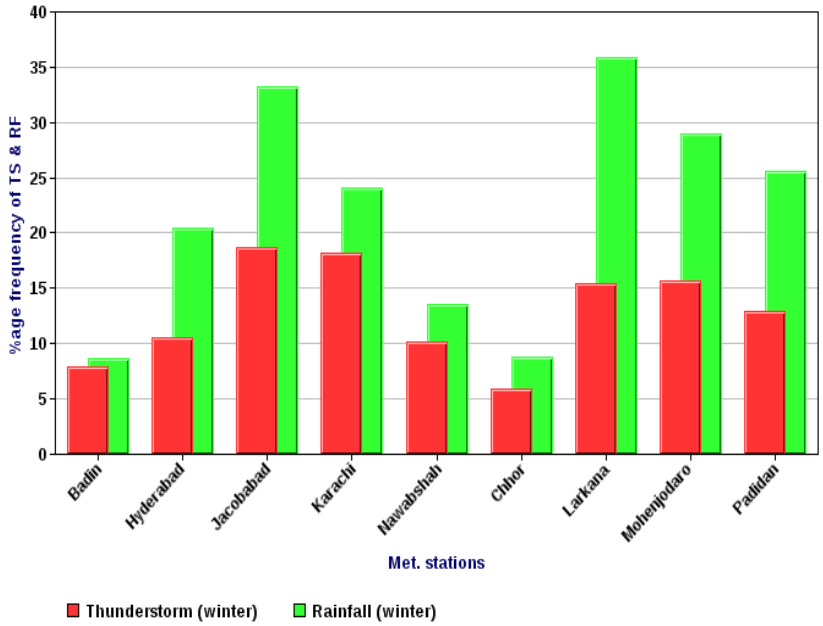

Figure 6. Percentage frequency of TS and RF in winter over Sindh.

To check the seasonal strength of the linear relationship between TS and RF, Pearson Product Moment correlation coefficients (PMCC) or Correlation Coefficients (CC) are also computed for all the seasons with the help of following formula.

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{(n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2)(n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2)}}$$

Where *n* is the total number of samples, x_i *(*x_1*,* x_2*, .. ,*x_n*)* are the x values and y_i are the y values. Oftenness of RF and TS are very strongly correlated in winter (0.84) and monsoon (0.91). Premonsoon shows the higher degree of correlation with the value of (0.69) while least correlation comes out for post-monsoon (0.36) season. Obviously, no specific trend in correlations is found.

Premonsoon and monsoon seasons appear as merging with the activity of TS. Further, it is also seen that in the premonsoon season the percentage of occurrence of TS is 24.35% and that of RF is 16.28%. The higher values of TS in this season as compared to RF may be explained in terms of RF association with certain TS, which is mainly due to the convection phenomena. Because the RF yield confined to given TS depends upon the moisture availability. In a few cases RF yield may not be available due to lack of moisture availability. TS and RF percentage frequencies for the post-monsoon season are observed to be nearly the same (i.e. 3.69 and 3.93%, respectively) while the percentage comparison of both parameters for premonsoon and post-monsoon seasons (i.e. 20.66 and 12.35%) suggests more RF in post-monsoon seasons due to RF. Possibly the more RF activity is mainly due to the western disturbances [12].

3.3. Seasonal TS and RF (station-wise)

Throughout the winter season RF remain dominating over TS for any reported meteorological station (Figure 6). The occurrence range of RF for this season is 4.9% higher than the TS. RF maximum activity occurs at Larkana which is almost double than maximum TS activity over Jacobabad in this season. Least RF is observed at Badin which is 2.76% greater than the minimal activity of TS over Chhor. Values of variance, standard deviation and range predict more variation in rainfall as compared to thunder that describes the highly variant nature of rainfall frequency. Second and third highest TS activities are observed at Karachi (18.15%) and Mohenjodaro (15.72%) with the corresponding RFs 24.04% and 29%, respectively.

In comparison to winter, TS activity is found greater than RF in premonsoon season for every recorded station. Further, stations reporting higher TS frequencies also reported higher RF activities (Figure 7). Mohenjodaro got highest occurrence of TS (32.70%) with 23.67% RF while Larkana appeared with second highest (22.01%) RF along

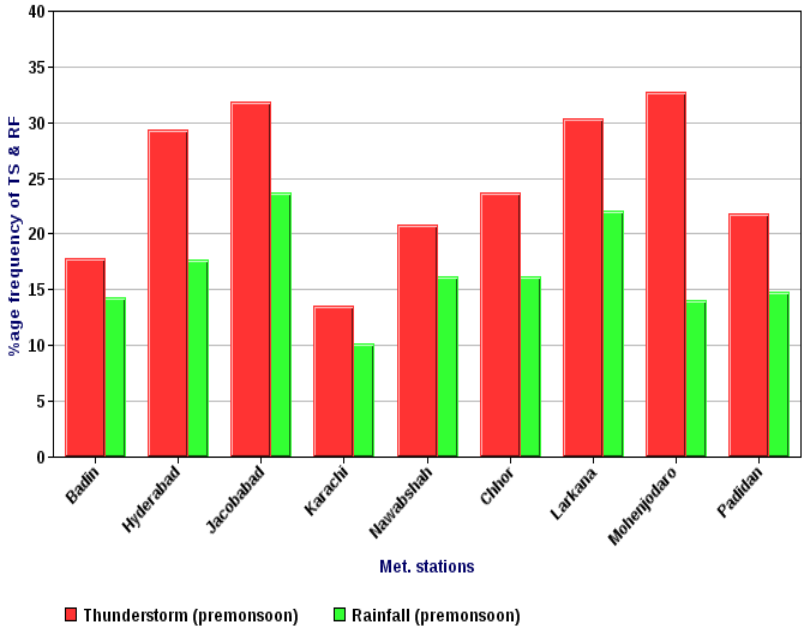

Figure 7. Percentage frequency of TS and RF in premonsoon over Sindh.

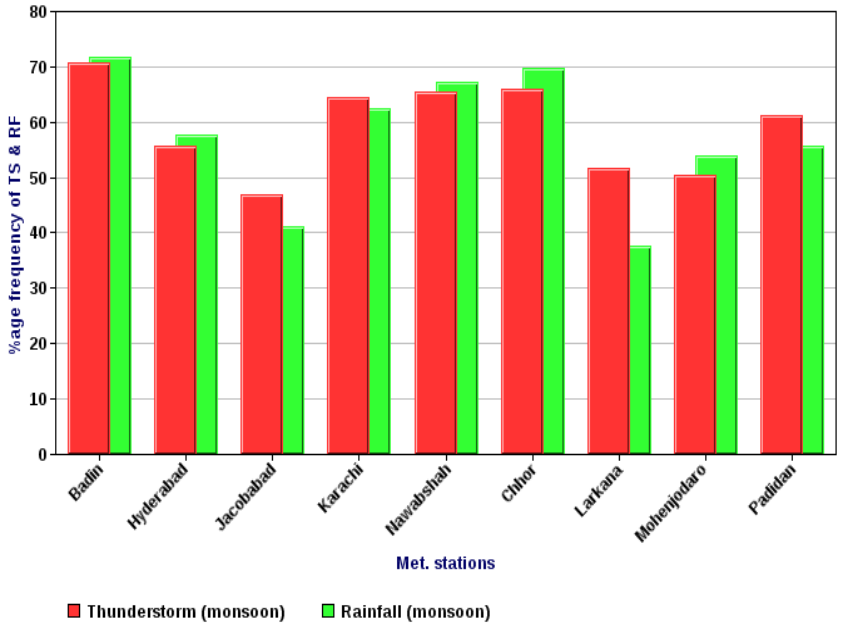

Figure 8. Percentage frequency of TS and RF in monsoon over Sindh.

with 30.32% TS activity. Noticeable lowest degree frequencies of the TS and RF in this season are observed over Karachi (13.53% with corresponding rainfall 10.20%) and Badin (17.74% with corresponding rainfall as 14.24%), respectively. For this season, percentage range of TS is found about 25% more in comparison to RF (Table 2).

Figure 8 depicts the situation of monsoon. Generally, overall activities of both the variables are found more in this season in comparison to pre-monosoon seasons. Oftenness of thunderstorms are uniformly spread over all the reported stations with the outcome range (Table 2) of 23.74% (i.e. between 46.91% and 70.65%), while range of rainfalls' is slightly stretched (34.04%) than former parameter (between 37.74% and 71.77). Badin acquires maximum TS activity (70.65%) with 71.77% RF while highest RF appears at Badin (71.77%) with 70.65% TS.

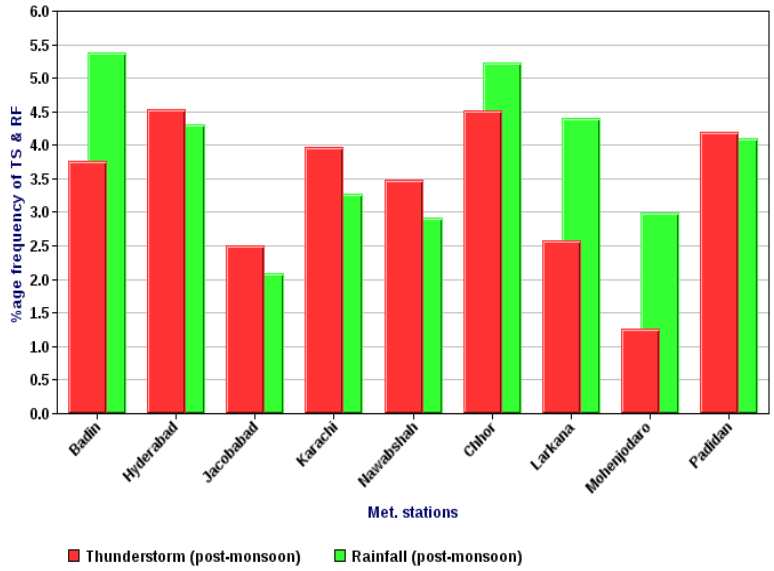

Figure 9. Percentage frequency of TS and RF in post-monsoon over Sindh.

Table 2. Analytical percentage values for TS and RF frequencies.

Parameter	Variance	St.Dev.	Min (Met. St.)	Max (Met. St.)	Range	Q1	Q3	IQR
Winter TS	20.54	4.53	5.84 (Chhor)	18.72 (Jacobabad)	12.88	9.00	16.94	7.94
Winter RF	101.32	10.07	8.60 (Badin)	35.85 (Larkana)	27.24	11.18	31.09	19.91
Premon TS	45.67	6.76	13.53 (Karachi)	32.70 (Mohenjodaro)	19.17	19.30	31.09	11.79
Premon RF	17.18	4.15	10.20 (Karachi)	23.67 (Jacobabad)	13.47	14.12	19.85	5.73
Monsoon TS	68.41	8.27	46.91 (Jacobabad)	70.65 (Badin)	23.74	50.96	65.73	14.77
Monsoon RF	144.15	12.00	37.74 (Larkana)	71.77 (Badin)	34.04	47.53	68.56	21.03
Post-monTS	1.21	1.10	1.26 (Mohenjodaro)	4.53 (Hyderabad)	3.42	2.55	4.35	1.80
Post-mon RF	1.23	1.11	2.09 (Jacobabad)	5.38 (Badin)	3.29	2.96	4.82	1.86

Among all the seasons, the RF and TS activities are least in post-monsoon seasons with very small difference (i.e. 0.13%) in range. It is evident from Figure 9 that highest frequencies of both the parameters are close (4.53% for TS and 5.38% for RF) for the corresponding Hyderabad and Badin stations. Minimum TS (1.26% for Mohenjodaro) and RF (2.09% for Jacobabad) values are also close to each other. The condition of this season is rather relatively complex; for Badin, Chhor, Larkana and Mohenjodaro TS occurrence is lesser than RF while for rest of the stations TS activities are higher than RF. Some useful values regarding station-wise seasonal analysis are summarized in Table 2.

3.4. Seasonal TS and RF (comparison)

The thunder activity comparison shows that in the post-monsoon and winter seasons the activity is under 10 and 20% of occurrence only. Comparison of TS for different seasons explored that the stations reported higher TS values for premonsoon exhibits relatively lower values for monsoon. This effect appears somewhat like mirror symmetry over the graph (Figure 10). The activity for all the cities is greater than 20% in winter except the coastal urban city, Karachi while monsoon percent is almost greater than 50% throughout the stations except Jacobabad where its value is slightly less.

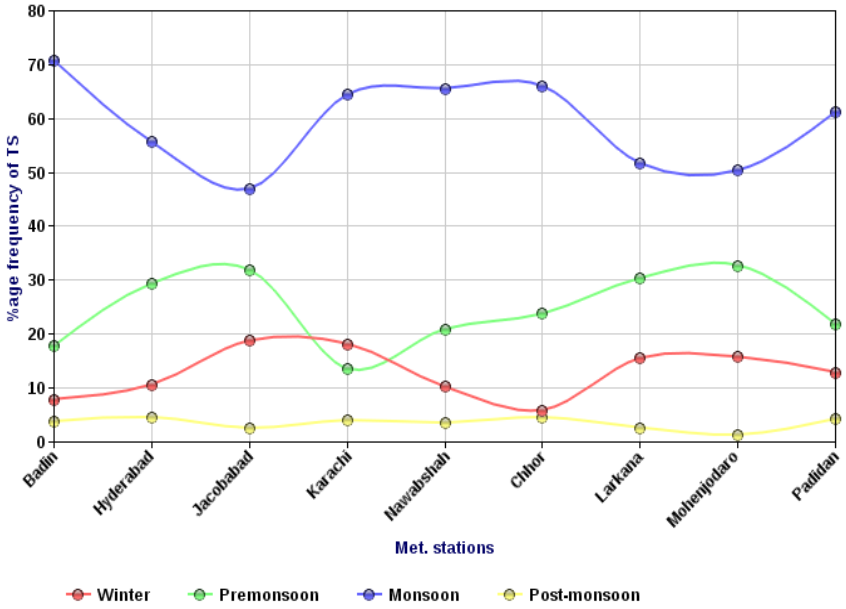

Figure 10. Percentage frequency comparison of TS for different seasons over Sindh.

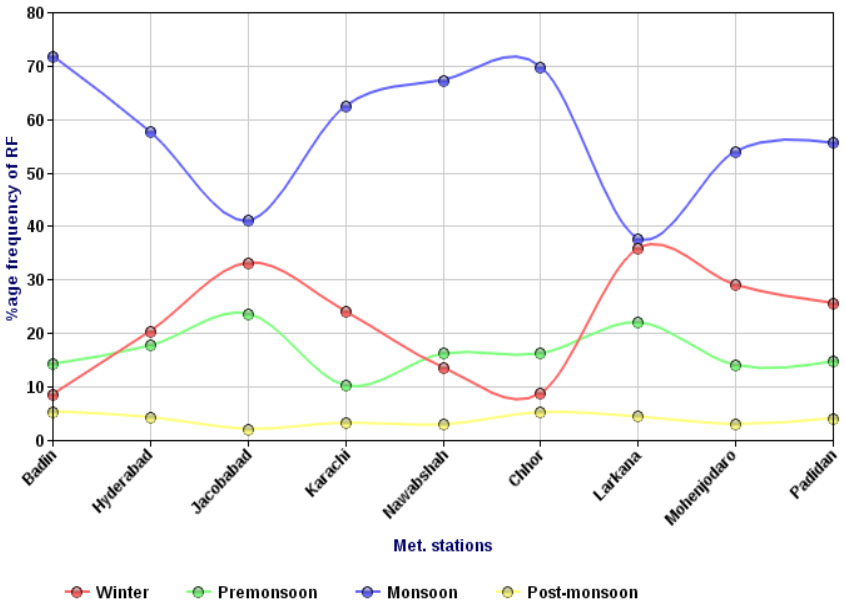

Figure 11. Percentage frequency of comparison of RF for different seasons over Sindh.

The rainfall activity is less than 10% throughout the post-monsoon season. For premonsoon this value is in between 10 and 23%. Much more station wise variations are observed in winter and monsoon as compared to post-monsoon and premosnoon seasons. Like TS comparison (Figure 10) here in this case also, the stations reporting higher RF values during winter reported relatively lower values in monsoon, hence the appearing symmetrical pattern on the graph is same as in case of TS activity (Figure 11). The lowest and highest percentage frequencies are observed over Larkana (1.89%) and Chhor (61.05%), respectively.

4. Conclusions

The following conclusions are drawn by this study:

1. Annual comparison depicts more variance and dispersive nature of TS than RF while for

monsoon season both the parameters exhibits merging and analogous behavior.

2. At the time of pre-monsoon, monsoon and beginning of post-monsoon seasons, RF activity is lesser than TS while altogether different situation observed for rest of the seasons.
3. Almost 59% of TS & RF activity observed in monsoon only while post-monsoon contribution is less than 4%
4. Stations that reported relatively lesser frequencies of TS and RF in premonsoon season show relatively higher frequencies in monsoon and vice versa.
5. RF has greater frequencies over TS for all reported stations in winter while diametric activity is observed during monsoon
6. Most affected station during maximum activity (in monsoon) is Badin while southern meteorological stations of the province suffer with higher frequencies of TS and RF than the northern observatories in this season.
7. Very close and least variance, deviation, range and IQR are observed in post-monsoon.

Acknowledgement

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