ANALYSIS OF THUNDERSTORMS ACTIVITY OVER PAKISTAN DURING (1961-2000)

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Abstract:

In this paper, normal thunderstorms frequency (1961-1990) over various meteorological stations of Pakistan situated in Punjab, Sindh, North Western Frontier Province, Balochistan as well as Northern Areas and Azad Jammu & Kashmir is discussed on seasonal as well as annual basis. The mean annual thunderstorms frequency (1991-2000) is compared with the normal annual frequency (1961-1990) and the thunderstorms frequency trend during 1991-2000 is also discussed. Effort has also been made to examine the regions more vulnerable to thunderstorms activity. Thunder Storm frequency is comparatively much higher over the mountains and sub mountains regions which are exposed to the monsoonal currents coming from Bay of Bengal or Arabian Sea. The region experiences some of the most intense lightning on the planet. On seasonal basis, the frequency is much higher in the pre monsoon and monsoon seasons (especially in monsoon) as compared to the winter and post monsoon seasons over Pakistan. When compared with the normal (1961-1990), a net decrease of 5.3% in Thunder Storm frequency has been observed over Pakistan during 1991-2000. The graphical representation of the data is also given. Distribution of normal Thunder Storm frequency over Pakistan is also shown in the form of map.

Introduction:

Thunderstorm is one of the major aviation hazards and every day, about 40,000 thunders occur through out the world (William.J.et al). These storms develop from large cumulus / cumulonimbus clouds and characterized by lightning discharge. Observations indicate that thunder and lighting occur when large accumulations of liquid and solid water are carried to heights where the temperature is well below –20°C (Petersen, 1956). Clouds exist because of physical process of condensation, but condensation occurs mainly in response to dynamic process that includes widespread vertical air motion, convection and mixing. The pattern and the structure of clouds are influenced by dynamical factors such as instability, convergence and the proximity of the front and cyclones.

In this study effort has been made to analyze the TS frequency over Pakistan during 1961-2000. Data of 59 meteorological stations of Pakistan have been used, the Province / Region wise distribution of which is given as under:

♣ Pakistan Meteorological Department.

North Western Frontier Province (NWFP): Balakot, Cherat, Chitral, Dera Ismail Khan, Dir, Drosh, Kakul, Parachinar, Peshawar, Risalpur and Saidu Sharif

Punjab: Bahawalnagar, Bahawalpur, Faisalabad, Islamabad, Jhelum, Khanpur, Lahore (PBO), Lahore (Airport), Mianwali, Multan, Murree, Sargodha, Sialkot and Shorkot (Rafique).

Northern Areas & Azad Jammu and Kashmir (AJK): Astore, Bunji, Chilas, Ghari Dupatta, Gilgit, Gupis, Kotli, Muzaffarabad and Skardu. (Ghari Dupatta, Kotli & Muzaffarabad belong to AJK)

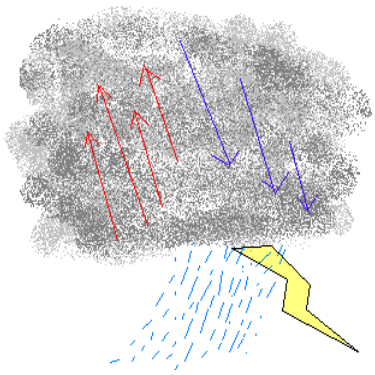
Balochistan: Barkhan, Dalbandin, Jiwani, Kalat, Khuzdar, Nokkundi, Panjgur, Pasni, Quetta, Sibbi and Zhob.

Sindh: Badin, Chhor, Hyderabad, Jacobabad, Karachi (Airport), Karachi (Faisal), Karachi (Masroor), Larkana, Moenjodaro, Nawabshah, Padidan and Sukkur (Rohri).

What is a Thunderstorm?

A thunderstorm is defined to be sudden electrical discharges manifested by a flash of light (lightning) and a sharp rumbling sound. Thunderstorms (TS) are associated with convective clouds (Cumulonimbus) and are more often accompanied by precipitation. They are usually short-lived and hit on only a small area. Generally, lifetime is half an hour to two hours. A TS day at a given location is a calendar day on which thunder is heard for at least once.

Fig.1: Up draft and down draft in a convective cloud



The basic ingredients which are needed for thunderstorms to form are moist air and presence of some mechanism for up lifting of that air (i.e. instability in the atmosphere, orography etc.). There are three stages in the formation of a storm viz; developing, mature, and dissipating stages.

Lightning occurs with every thunderstorm and must be expected as soon as thunderstorms form. Lightning results from the build-up and discharge of electrical energy between positively and negatively charged areas in the atmosphere and clouds (electric charges are built due to the updrafts and downdrafts in the clouds).

For lightning to occur, the voltage differences between oppositely charged areas must be so great that they can overcome the insulating effect of the air and discharge between negative and positive may take place. Strokes can occur within the cloud (i.e. intra-cloud lightening), between clouds (referred to as inter-cloud lightening), or between clouds and the ground (called cloud-to-ground lightening). The most lightning occurs between clouds but it is the ground strikes that are dangerous.

Thunder is the sound produced by the explosive expansion of thin column of air heated by the lightning stroke to temperatures as high as 30,000°C (54000F) which is five times hotter than the surface of the sun (C. D. Ahrens, 2001). The air expands because of the heat with an explosive force that creates a sound wave we know as thunder. As thunder is the noise of the lightning discharge so it can be well delayed if the lightning is away owing to the great difference between the speed of light and the speed of sound (Byers. 1959). Any kind of thunderstorm can generate gust of wind that can trigger additional thunderstorm up to 160 km away.

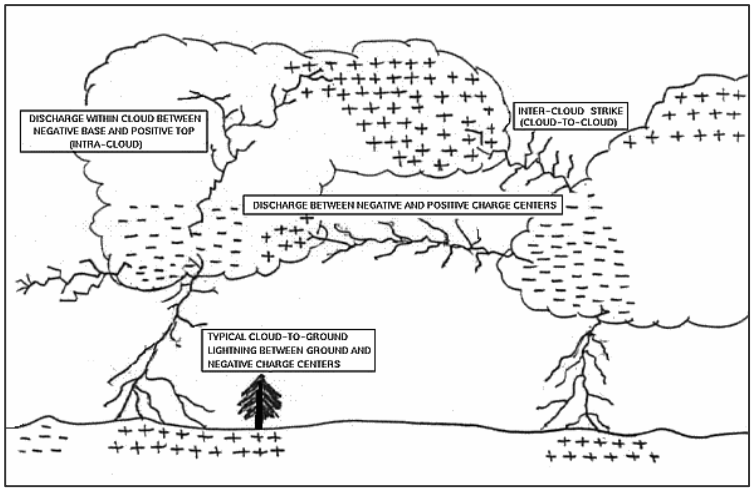


Fig.2: Electric charges in a cumulonimbus cloud and Intra-cloud, inter-cloud & cloud-to-ground lightning

Favourable Conditions for Formation of Thunderstorms:

For thunderstorms formation and growth, following atmospheric conditions are most favorable (D. S. lal, 2001).

Instability

Atmospheric instability is most important factor. Sun is the source of energy for the earth surface. The surface heating creates instability with warm humid and moist air lying close to the surface. It is one of the reasons that the air becomes unstable in spring and summer seasons.

Orographic Factor

This study shows that the thunderstorm frequency over the mountainous areas is greater as compared to the plain areas due to the fact that the air near the upper parts of mountain on wind word side is heated more than the adjoining lower parts of the mountains and lands causing widespread vertical motion to take place.

Unstable Air Mass

Frontal and orographic thunderstorms are produced from the up lift of potentially unstable air mass. This air mass releases latent heat in the atmosphere at mid tropopause level and maintains thunderstorm.

Warm and Moist Air

It is the most important factor for thunderstorm formation. Thunderstorm is produced by warm, humid and moist air in lower layers of the atmosphere. The existence of a steep lapse rate in the atmosphere is favourable condition for thunderstorm formation.

Thickness of the Cloud

Thickness of the cloud from the condensation level up to freezing level must be 300 meter. This is an additional factor to develop thunderstorm.

Classifications of Thunderstorm:

Thunderstorms are classified into two types.

a. Air mass thunderstorms.
b. Frontal thunderstorms

a. Air mass Thunderstorms

Vertical displacement of air with in air mass creates unstable air mass, releasing latent heat and hence causing thunderstorm. Local heat thunderstorm, orographic thunderstorm and upper level thunderstorm are the examples.

Local Heat Thunderstorms

Local heat thunderstorms are produced due to intense surface heating and occur mostly in afternoon. They originate as isolated cumulonimbus cell. Their horizontal length is about 5 to 10 kms (Byers.1959).

Orographic Thunderstorms

They originate as a result of forced uplift of warm, humid and moist air over a mountain barrier. These storms are mostly stationary. The intensity of rainfall is heavy and lifetime is very short.

Advective Thunderstorms

The advection of warm air at low level or cold air at higher level causes an increase in lapse rate. The high lapse rate produces severe thunderstorm.

b. Frontal Thunderstorms

Frontal thunderstorms are produced in the following three easily recognized patterns.

i. Cold front thunderstorm.
ii. Warm front thunderstorm
iii. Squall line thunderstorms.

i. Cold Front Thunderstorm

When the cold air mass is replaced by the warm air mass, cold front thunderstorms are produced. They are very intense and can be formed at any time during the day or night.

ii. Warm Front Thunderstorm

In warm front the air is warm, humid and unstable, thus causing thunderstorms. These warm front thunderstorms have less intensity as compared to the cold front thunderstorms.

iii. Squall line Thunderstorm.

As wind shear organizes the convection, new thunderstorms form as a result of parent thunderstorm outflows converging with warm, moist inflow creating new updrafts. Multi cell storms can form in a line known as a squall line, where continuous updrafts form along the leading edge of the outflow, or gust front. Multi cell clusters indicate new updrafts are forming where the low-level convergence is strongest, usually at the right, or right-rear flank of existing cells.

Squall line is formed well ahead of cold front in a narrow belt. This particular line is also called surge line. The thunderstorm cell forms a line, which can be several hundred kilometers long. The lifetime of this line is several (6 to 8) hours. This kind of thunderstorm is more severe than isolated thunderstorm. Wind speed is about 160km/hour. In many cases the squall line is so short that they cannot be detected except in a dense network of meteorological station (Patterssen. 1956).

Data and Methodology:

- Thunderstorms (TS) data collected from Computerized Data Processing Center, (Pakistan Meteorological Department), Karachi.
- Compilation and Processing of TS data in four seasons namely Winter (Dec., Jan., Feb. and Mar.), Pre Monsoon (Apr., May. and Jun.), Monsoon (Jul., Aug. and Sep.) and Post Monsoon (Oct. and Nov.) seasons was carried out and graphs were prepared by using MS Excel software.
- The seasonal and yearly averages of data for the periods 1961-1990 and 1991-2000 are referred to as normal and mean respectively
- Ranking of various regions/met. stations was performed according to the observed number of TS days per year (Table.01) as per following criteria. The criteria are adopted on the basis of percentiles and are in close approximation to the criteria used for ranking the stations with respect to the occurrence of dust storms over Pakistan (Hussain A. et al, 2005

Number of Thunderstorms Days (Per year)	Ranking
≤ 10.0	Very Low Frequency
10.1 to 30.0	Low Frequency
33.1 to 60.0	Moderate Frequency

60.1 to 90.0	High Frequency
≥ 90.1	Very High Frequency

Discussion & Results:

Firstly, the normal TS data of various meteorological (met.) stations of NWFP, Punjab, N/Areas & AJK, Balochistan and Sindh has been discussed on seasonal as well as on annual basis and secondly, the mean annual data have also been compared with the normal annual data. Various regions/met. Stations are also classified as given in methodology.

NWFP:

Winter season:

During winter season TS frequency is observed to be the lowest in NWFP as compared to the other seasons. It varies from 0.3 (at Chitral) to 12.1 days (at Kakul). The second and third highest values are 6.7 and 6.5 days for Peshawar and Risalpur

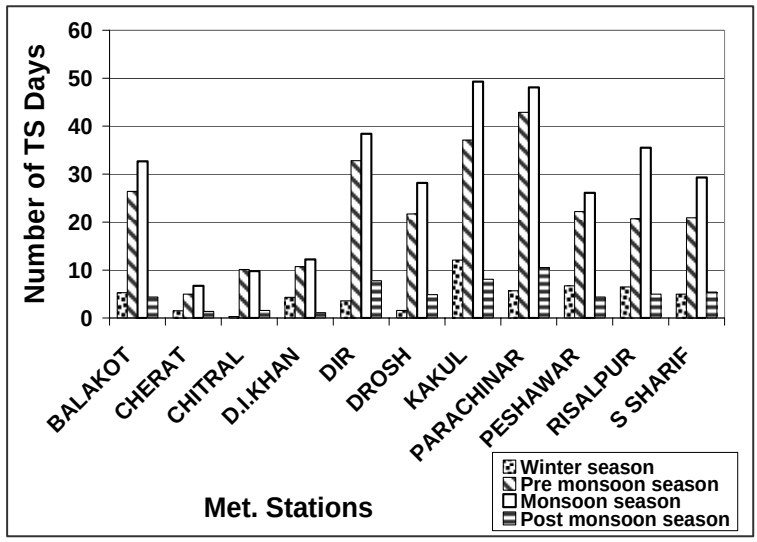


Fig.3: NWFP: Seasonal Normal (1961-1990) TS frequency

respectively. TS frequency observed to be more in March as compared to the other three months of the season. The reason might be that temperatures near the surface (i.e. in the lower atmosphere) are comparatively higher in this month but the air in the upper atmosphere is still cold which creates instability that causes the formation of Thunderstorm especially when western disturbance is passing over the region.

Pre-Monsoon season:

In Pre Monsoon season normal TS frequency varies from15.0 (at Cherat) to 42.9 days (at Parachinar). The second and third highest values are 37.1 and 32.8 days for Kakul and Dir respectively. TS frequency observed to be slightly more in May as

compared to the other two months of the season during 1961-2000. On the average, each of the met. stations of NWFP (except Cherat, Chitral and D.I. Khan) experience more than 20 TS days during the season. After Monsoon, this season has the highest number of TS days in a year.

Monsoon Season:

Monsoon is the season when TS frequency is observed to be the highest in the province. It varies from 6.7 (at Cherat) to 49.3 days (at Kakul). The second and third highest normal values being 48.1 and 38.4 days for Parachinar and Dir respectively. Again, each of the met. stations of NWFP (except Cherat, Chitral and D.I. Khan) experience more than 20 TS days during the season also. However, TS frequency is much more at Kakul, Parachinar, Dir and Balakot as compared to the other stations. Normal TS frequency observed to be higher in the months of July & August than that of September (in Monsoon season) during 1961-2000.

Post Monsoon:

In this season TS frequency is low but slightly higher than the frequency in winters. It varies from 1.1 (at D.I. Khan) to 10.5 (at Parachinar). The second and third highest values being 8.1 and 7.8 days for Kakul and Dir respectively. Although Post monsoon season consists of two months (i.e. October & November only, yet TS frequency is observed to be more than three times higher in the month of October than in November which is the second least active month (after December) with respect to the formation of thunder storms. (Fig.3).

Annual:

In NWFP annual TS frequency varies from 14.6 (at Cherat) to 107.2 days (at Parachinar). The second and third highest normal values being 106.6 and 82.6 days

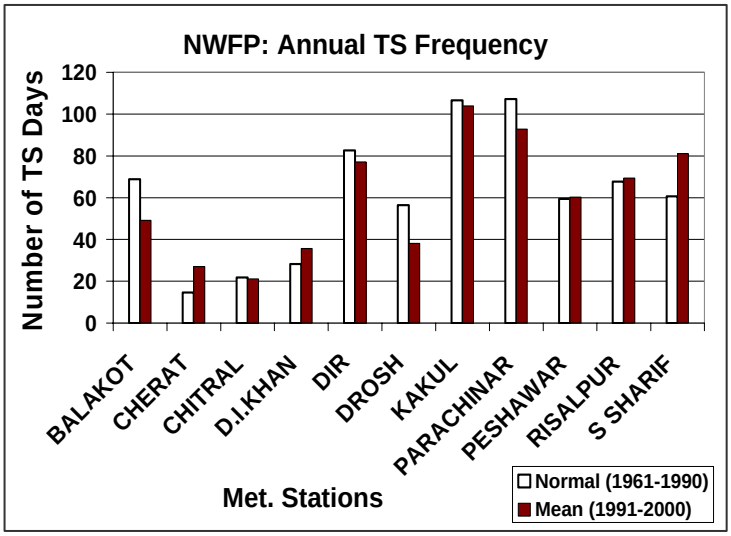


Fig.4: NWFP: Annual TS frequency Normal *versus* Mean

for Kakul and Dir respectively.

The annual mean (1991-2000) TS frequency was compared with the respective normal (1961-1990) frequency. Most of the met. Stations of NWFP showed decreasing tendency in the TS frequency during 1991-2000. The highest decrease was observed to be –19.7 days at Balakot. The other significant decreases are –18.3 days (at Drosh) and –14.4 days (at Parachinar). While increase in TS frequency was observed at Saidu Sharif (+20.5 days), Cherat (+12.4 days), D.I. Khan (+7.4 days) and Peshawar (+0.9 days). The increase of +20.5 TS days at Saidu Sharif found to be the second highest increase in whole Pakistan (the first one being for Mianwali). A net decrease of 2.7% in TS frequency was observed in the province during 1991-2000. On seasonal basis, however, TS frequency was observed to be increased in winter (12.9 %) and post monsoon (9.9 %) seasons and decreased in monsoon season (10.2 %). The tendency is negligibly small in pre monsoon season with just 0.7 % increase during 1991-2000.

TS frequency at Kakul and Parachinar observed to be the highest in whole Pakistan during 1961-2000. There is no station in NWFP having very low TS frequency (i.e. TS days $\leq$ 10 per year) (Fig.4).

Punjab:

Winter Season:

In Punjab, normal TS frequency for winter season vary from 1.9 (Bahawalpur) to 11.3 days (at Islamabad). The second and third highest values are 10.0 and 9.7 days for Jhelum and Murree respectively.

Pre Monsoon Season:

In this season TS frequency vary from 4.0 (at Khanpur) to 29.4 (at Murree). The second and third highest values are 26.9 and 25.8 days for Islamabad and Jhelum respectively. After Monsoon, this season has the highest number of TS days in a year. TS activity observed to be much higher at Islamabad, Murree and Jhelum as compared to the other regions of the province.

Monsoon Season:

Monsoon season observed to be the most active with respect to the occurrence of thunderstorms in Punjab also. TS frequency in this season varies from 4.7 (at Khanpur) to 45.3 (at Islamabad). The second and third highest values are 38.4 and 37.4 days for Jhelum and Murree respectively. Other significant values for the season are 27.2 days for Sialkot and 20.9 days for Lahore.

Post Monsoon Season:

Post Monsoon is the season least active with respect to TS frequency in Punjab. In this season, TS frequency varies from 0.2 (at Khanpur) to 6.0 days (at Murree). The second and third highest values are 5.9 and 4.5 days for Islamabad and Jhelum respectively (Fig.5).

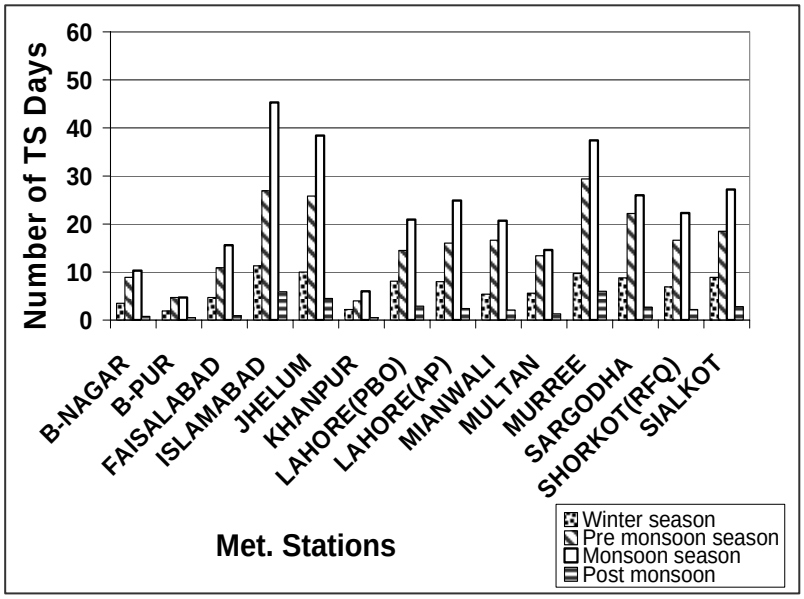


Fig.5: Punjab: Seasonal Normal (1961-1990) TS frequency

Annual:

The annual normal TS frequency varies from 11.8 (at Bahawalpur) to 89.4 days (at Islamabad) in Punjab. The second and third highest values are 82.5 and 78.7 days for Murree and Jhelum respectively. Other significant yearly normal values are 57.4 days for Sialkot, 46.4 days for Lahore and 34.9 days for Multan.

When the annual mean (1991-2000) TS frequency was compared with the respective

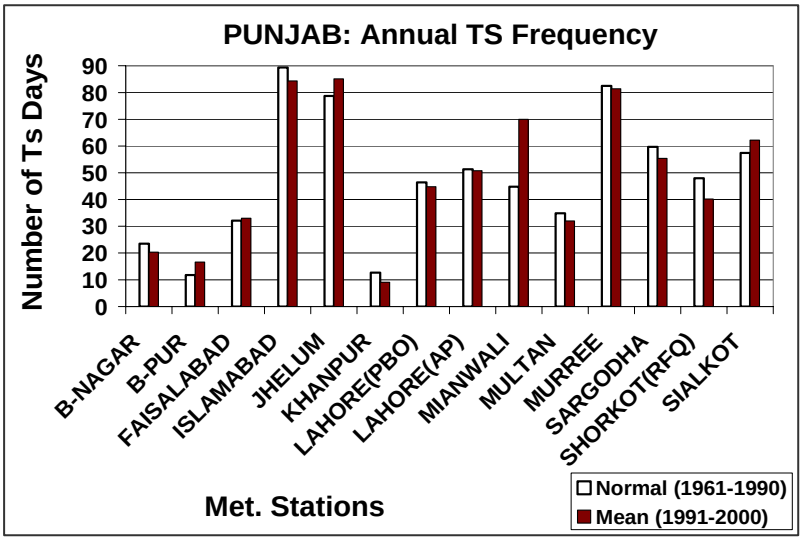


Fig.6: Punjab: Annual TS frequency Normal *versus* Mean

normal (1961-190) frequency, six stations of the province showed slight decreasing tendency, while the other four stations exhibited slight increasing tendency in TS frequency during 1991-2000. The highest drops were observed for Shorkot (RFQ) (-7.8 days), Islamabad (-5.1 days) Sargodha (-4.3 days) and Khanpur (-3.6 days).While the highest increases were +25.2 days (for Mianwali), +6.4 days (for Jhelum) and +4.8 days (for Bahawalpur & Sialkot) (Fig.6). The increase of +25.2 TS days at Mianwali observed to be the highest increase in whole Pakistan.

On the whole, a meager increase of 1.8% in TS frequency was observed in Punjab during 1991-2000. On seasonal basis, however, TS frequency was observed to be decreased in winters (6.5 %) & Monsoon (3.2 %) seasons and increased in pre monsoon (8.8 %) and post monsoon (23.1 %) seasons. On regional basis, significant increases of 56.3 % & 40.1 % in TS days were observed over Mianwali & Bahawalpur respectively and significant decrease of 28.3 % was observed over Khanpur, while the increase or decrease in TS frequency over the other stations ranged from 1% to 8%.

N/AREAS & AJK:

Winter Season:

During winter season, normal TS frequency varies from zero (at Astore, Chilas, and Gupis & Skardu) to 10.7 days (at Ghari Dupatta). The second and third highest values are 9.9 and 7.6 days for Kotli and Muzaffarabad.

Pre Monsoon Season:

In pre monsoon season, TS frequency varies from 0.8 (at Gilgit) to 36.0 days (at Ghari Dupatta) in N/Areas & AJK. The second and third highest values are 35.0 and

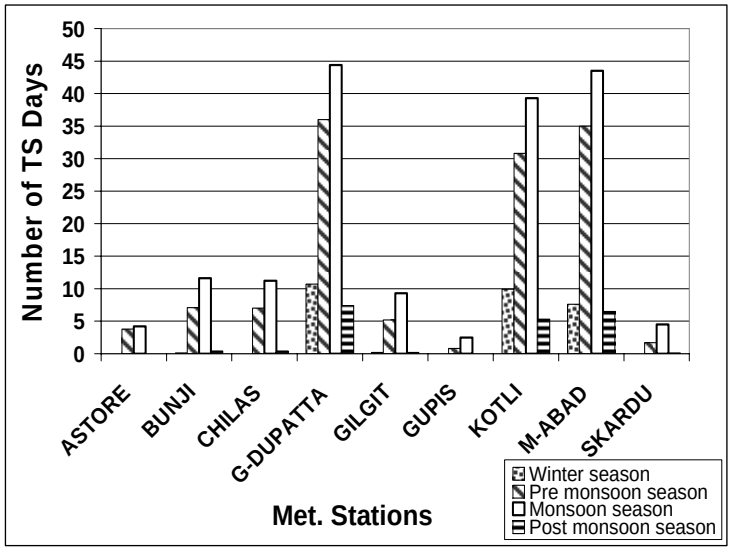


Fig7: N/Areas &AJK: Seasonal Normal (1961-1990) TS frequency

30.8 days for Muzaffarabad and Kotli respectively. After Monsoon, this season has the highest number of TS days in a year in N/Areas & AJK too.

Monsoon Season:

Monsoon season observed to be the most active of all the seasons with respect to the occurrence of thunderstorms in N/Areas & AJK. Seasonal normal TS frequency varies from 2.5 (at Gilgit) to 44.4 days (at Ghari Dupatta). The second and third highest values are 43.5 & 39.3 days for Muzaffarabad and Kotli respectively.

Post Monsoon Season:

TS frequency in post monsoon season observed to be the lowest of all seasons in N/Area & AJK. It varies from zero (at Astore & Gupis) to 7.4 (Ghari Dupatta). The second and third highest values for the season are 6.5 & 5.3 days for Muzaffarabad and Kotli respectively (Fig.7).

Annual:

Normal annual TS frequency varies from 8.0 (at Astore) to 98.5 days (at Ghari Dupatta) in Northern Areas & AJK. The second and third highest normal values are 92.6 & 85.3 days for Muzaffarabad and Kotli respectively, with no station having zero normal.

The annual mean (1991-2000) DS frequency was compared with the respective

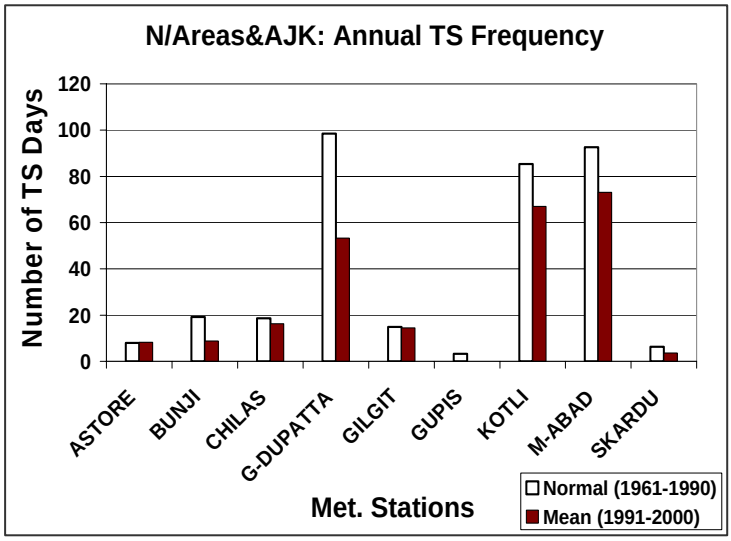


Fig.8: N/Areas &AJK: Annual TS frequency Normal *versus* Mean

normal (1961-1990). All the met. stations (except Astore) showed decreasing tendency in TS frequency during 1991-2000. The highest decrease observed to be –45.2 days (46 %) at Ghari Dupatta (which was also the highest decrease in TS days in whole Pakistan) Other significant drops were -19.5, -18.3 and -10.4 for Muzaffarabad, Kotli and Bunji. Astore is the only met. station which showed a meager increase of +0.2 day in TS frequency(Fig.8).

A net decrease of 29.4 % in TS frequency was observed in the region during 1991-2000, which was also the highest decrease in TS frequency in Pakistan. On seasonal basis, TS frequency also observed to be decreased in all four seasons i.e. winters (24.2 %), pre monsoon (27.2%), monsoon (32.1 %) and post monsoon (27.6 %) seasons.

Balochistan:

Winter season:

In Baloch-istan, normal TS frequency varies from 0.8 (at Pasni) to 6.0 days (at Quetta) during winters. The second and third highest values are 4.1 and 3.1 days at Barkhan and Zhob respectively.

Pre Monsoon Season:

In pre monsoon season, normal TS frequency varies from 0.2 (at Pasni) to 14.4 days (at Barkhan). The second and third highest values are 10.9 and 7.8 days at Zhob and Khuzdar respectively.

Monsoon Season:

During this season, normal TS frequency varies from 0.3 (at Nokkundi) to 25.3 days (at Barkhan) in Balochistan. The second and third highest values are 19.0 and 11.8 days for Zhob and Khuzdar respectively.

Monsoon season observed to be the most active of all the seasons with respect to the

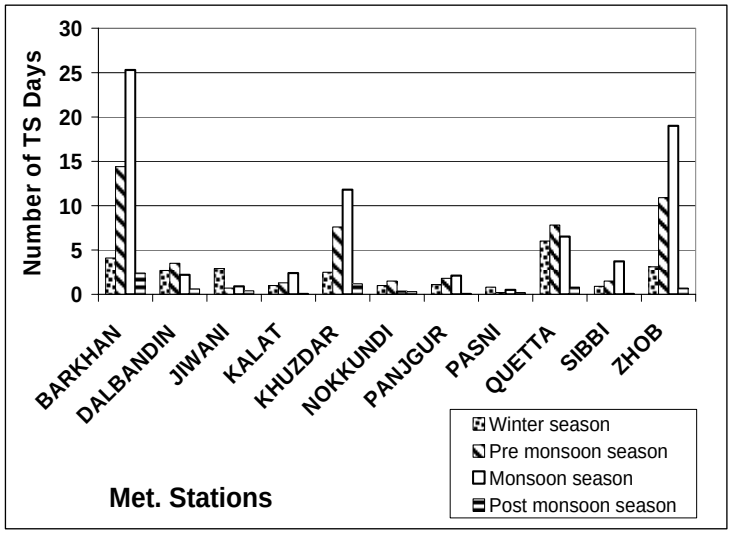


Fig.9: Balochistan: Seasonal Normal (1961-1990) TS frequency

occurrence of thunderstorms in Balochistan also, but still TS activity is less than half that of N/Areas & AJK, one third that of Punjab and about one fourth that of NWFP in the same season.

Post Monsoon Season:

In post monsoon season, normal TS frequency varies from 0.1 (at Kalat, Panjgur & Sibbi) to 2.4 days (at Barkhan). The second and third values are 1.2 and 0.8 days for Khuzdar and Quetta respectively. The season is the least active with respect to the formation of thunderstorms in Balochistan (Fig.9).

Annual:

Normal annual TS frequency varies from 1.7 (at Pasni) to 46.2 days (at Barkhan) in Balochistan. The second and third highest normal values are 33.7 & 23.1 days for Zhob and Khuzdar respectively.

When the annual mean (1991-2000) TS frequency was compared with the respective normal (1961-1990) frequency, seven (out of eleven) met. stations showed a decreasing tendency in the TS frequency and the remaining four showed an increasing trend during 1991-2000. The highest decrease observed to be –7.9 days (88 %) at Dalbandin. The other drops range from -3.3 (at Khuzdar) to -1.1 days (at Jiwani). While the highest increase of +10.1 days (163 %) in TS frequency is observed at Sibbi. The increases for other three stations are: +6.4 days (133 %) for Kalat, +5.5 days (26 %) for Quetta and +5.3 days (11 %) for Barkhan (Fig.10).

On the whole a net increase of about 4.3 % in TS frequency was observed in the province during 1991-2000. On seasonal basis, however, TS frequency was

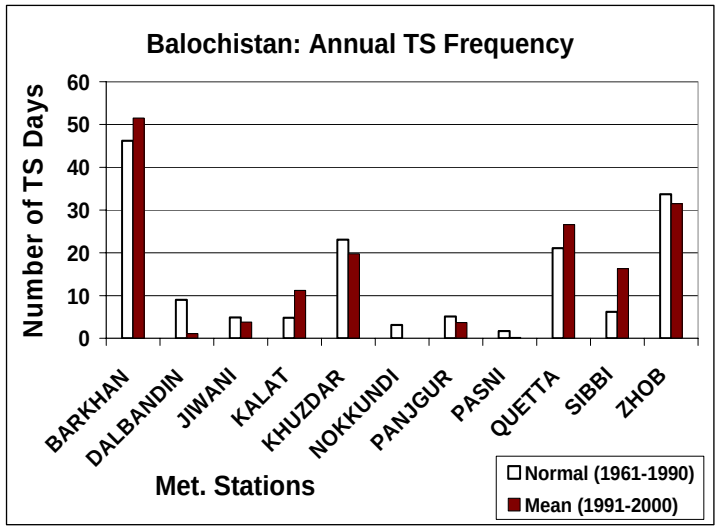


Fig.10: Balochistan: Annual TS frequency Normal versus Mean.

observed to be decreased in winter (14.2 %) & Monsoon (2.7 %) seasons and increased in pre monsoon (21.1 %) and post monsoon (26.1 %) seasons.

Sindh:

Winter Season:

The normal seasonal TS frequency in winter season varies from 0.4 (Badin) to 2.1 days (at Jacobabad). The second and third highest values are 1.7 & 1.3 days for Karachi (Masroor) and Larkana respectively.

Pre Monsoon Season:

In pre monsoon season, TS frequency varies from 0.7 (at Karachi (Faisal)) to 3.1 days (Chhor). The second and third highest values are 2.7 & 2.3 days for Larkana and Hyderabad respectively.

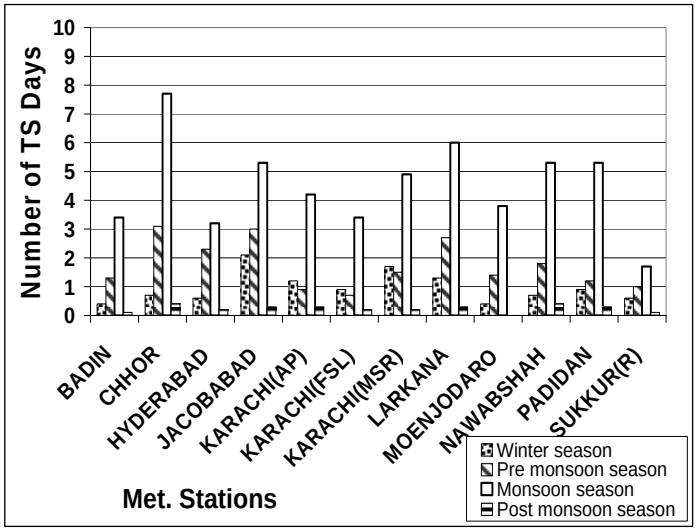


Fig.11: Sindh: Seasonal Normal (1961-1990) TS frequency

Monsoon Season:

In monsoon season, TS frequency varies from 1.7 (at Sukkur (Rohri)) to 7.7 days (Chhor). The second and third highest values are 5.3 days (for each of Jacobabad, Nawabshah & Padidan) and 4.9 days for Karachi (Masroor). Likewise other regions of Pakistan, in Sindh too, monsoon season observed to be the most active of all the seasons with respect to the occurrence of thunderstorms. But still TS activity in Sindh is lesser of all.

Post monsoon Season:

In this season, TS frequency varies from 0.1 (at Moenjodaro, Nawabshah & Sukkur (Rohri)) to 1.2 days (at Chhor). The second and third highest values are 0.8 & 0.7 days for Hyderabad and Karachi (Masroor) respectively (Fig.11).

Annual:

Normal annual TS frequency in Sindh varies from 3.4 (at Sukkur (Rohri)) to 11.9 (at Chhor).The second and third highest normal values are 10.7 & 10.3 days for Jacobabad and Larkana respectively.

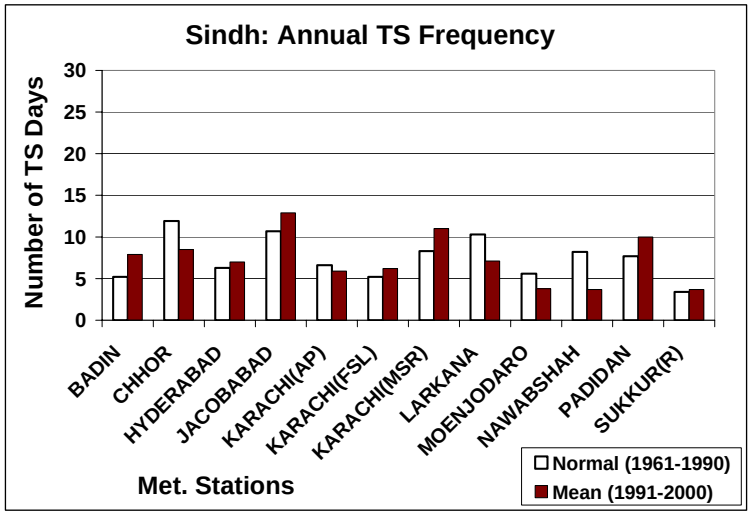


Fig.12: Sindh: Annual TS frequency Normal versus Mean.

The annual mean (1991-2000) TS frequency was compared with the respective normal (1961-1990). Five out of twelve met. stations of Sindh showed a decreasing tendency, while the other seven exhibited increasing tendency in TS frequency during 1991-2000. The highest drops are observed to be -4.5 days for Nawabshah, -3.4 days for Chhor and -3.2 days for Larkana while the highest increases are +2.7 days (for each of Badin & Karachi (Masroor)), +2.3 days for Padidan and +2.2 days for Jacobabad (Fig.12). On the whole a net decrease of 1.9 % in TS frequency was observed in Sindh during 1991-2000. On seasonal basis, however, TS frequency was observed to be decreased in winters (6.1 %), pre monsoon (2.4 %) & monsoon (3.5 %) seasons and increased in post monsoon season (89.3%).

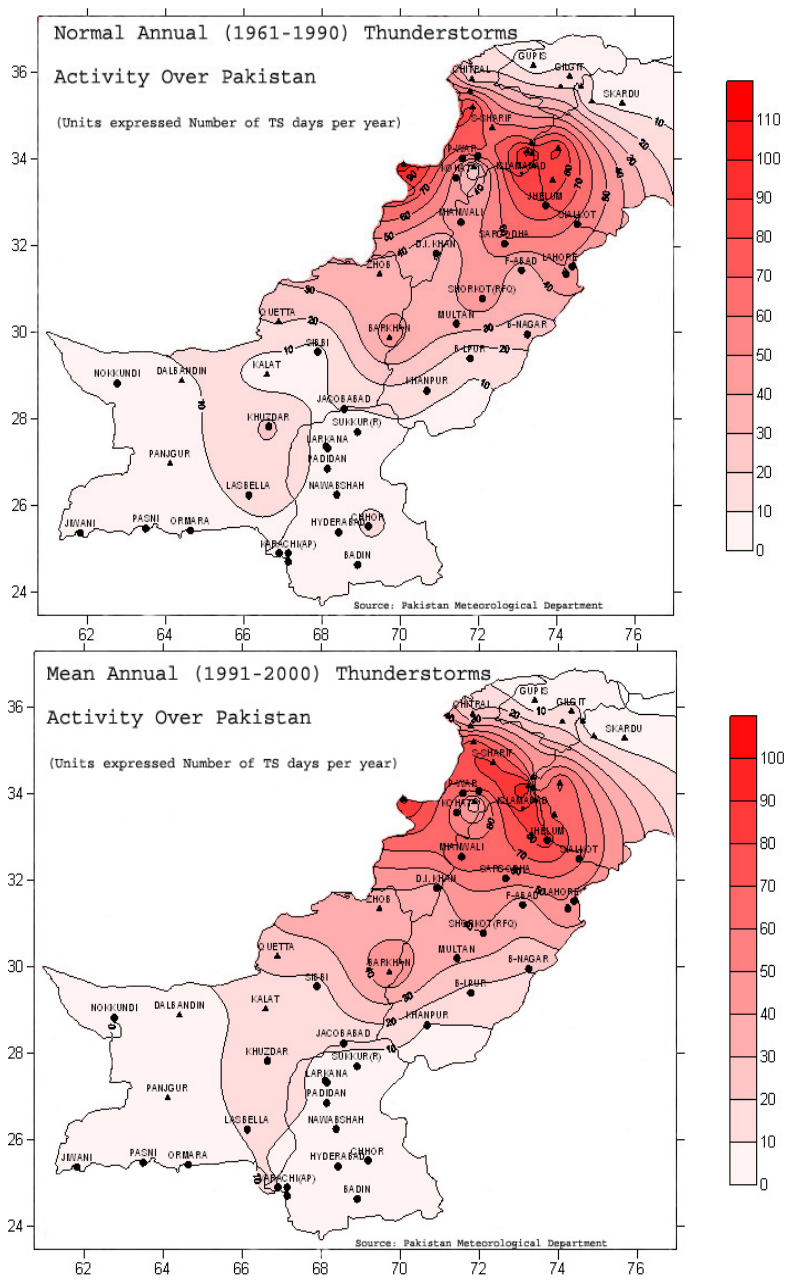


Figure 13: Distribution of normal (1961 – 1990) annual thunderstorms frequency over Pakistan.

Table 1: RANKING OF MET. STATIONS WITH RESPECT TO THE OBSERVED NUMBER OF THUNDER STORMS DAYS

RANKING	NORMAL (1961-1990)	MEAN (1991-2000)
Very High Frequency (TS days > 90.0)	NWFP: Parachinar & Kakul.	NWFP: Kakul & Parachinar.
	Punjab: NIL	Punjab: NIL
	N. Areas & AJK: Muzaffarabad, Ghari Dupatta.	N. Areas & AJK: NIL
	Balochistan: NIL	Balochistan: NIL
	Sindh: NIL	Sindh: NIL
High Frequency (TS days 60.1 to 90.0)	NWFP: Dir, Balakot, Risalpur & Saidu Sharif.	NWFP: Saidu Sharif, Dir, Risalpur & Peshawar.
	Punjab: Islamabad, Murree & Jhelum.	Punjab: Jhelum, Islamabad, Murree, Mianwali & Sialkot.
	N. Areas & AJK: Kotli.	N. Areas & AJK: Muzaffarabad & Kotli.
	Balochistan: NIL	Balochistan: NIL
	Sindh: NIL	Sindh: NIL
Moderate Frequency (TS days 30.1 to 60.0)	NWFP: Peshawar & Drosh.	NWFP: Balakot, Drosh & D.I. Khan.
	Punjab: Sialkot, Sargodha, Lahore(AP), Shorkot(RFQ), Lahore(PBO), Mianwali, Multan & Faisalabad.	Punjab: Sargodha, Lahore(AP), Lahore(PBO), Shorkot(RFQ), Faisalabad & Multan.
	N. Areas & AJK: NIL.	N. Areas & AJK: Ghari Dupatta.
	Balochistan: Barkhan & Zhob.	Balochistan: Barkhan & Zhob.
	Sindh: NIL	Sindh: NIL
Low Frequency (TS days 10.1 to 30.0)	NWFP: D.I. Khan, Chitral & Cherat.	NWFP: Cherat & Chitral.
	Punjab: Bahawalnagar, Khanpur & Bahawalpur.	Punjab: Bahawalnagar & Bahawalpur.
	N. Areas & AJK: Bunji, Chilas & Gilgit.	N. Areas & AJK: Chilas & Gilgit.
	Balochistan: Khuzdar & Quetta.	Balochistan: Quetta, Khuzdar, Sibbi & Kalat.
	Sindh: Chhor, Jacobabad & Larkana.	Sindh: Jacobabad & Karachi (Masroor).
Very Low Frequency (TS days ≤10.0)	NWFP: NIL	NWFP: NIL
	Punjab: NIL	Punjab: Khanpur.
	N. Areas & AJK: Astore, Skardu & Gupis.	N. Areas & AJK: Bunji, Astore, Skardu & Gupis*. * No TS during 1991-2000 at Gupis
	Balochistan: Dalbandin, Sibbi, Panjgur, Jiwani, Kalat, Nokkundi & Pasni.	Balochistan:, Panjgur, Jiwani, Dalbandin & Pasni & Nokkundi*. * No TS during 1991-2000 at Nokkundi.
	Sindh: Karachi (MSR), Nawabshah, Padidan, Karachi (AP), Hyderabad, Moenjodaro, Karachi (FSL), Badin & Sukkur (Rohri).	Sindh: Padidan, Chhor, Badin, Larkana, Hyderabad, Karachi (FSL), Karachi (AP), Moenjodaro, Nawabshah, Sukkur (Rohri).

Findings:

A net decrease of 5.3 % in TS frequency was observed over Pakistan during 1991-2000 when compared with the normal (1961-1990).

TS frequency is comparatively much higher over the mountains and sub mountain regions which are exposed to the monsoonal currents coming from Bay of Bengal or Arabian Sea.

TS frequency is much higher in the pre monsoon and monsoon seasons (especially in monsoon) as compared to the winter and post monsoon seasons over Pakistan. The reasons obviously are; the penetration of monsoonal currents in to the region during monsoon season and existence of thermal conditions during both pre monsoon and monsoon seasons (which are actually the sub divisions of the summer months over the country).

Extreme eastern & western parts of NWFP, whole AJK and north/northeastern parts of Punjab share about 65% of the total TS frequency (over Pakistan) for the period 1961-2000. The same is also in confirmation with the following subcontinent lightning map prepared by GHCC (Global Hydrology and Climate Center) Lightening Team (http://thunder.msfc.nasa.gov/primer)of National Atmospheric & Space Administration (NASA), USA with the help of the data received from two space-based optical

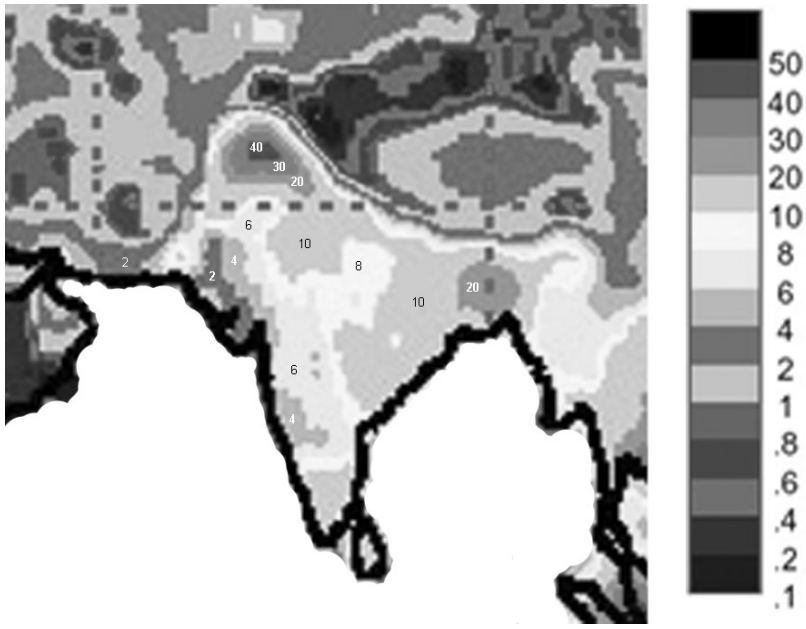


Figure 14: Subcontinent lightning map: units are flashes/square kilometer/year

detectors; Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS) (Christian, et al (1989) & (1992)), that have been giving researchers their first complete picture of planet-wide lightning activity. The infrared sensors of these lightning detectors can spot brief lightning flashes even under daytime conditions. Colors as

shown in the map above correlate to the frequency of lightning strikes, and the units listed are flashes/square kilometer/year. Among Florida, Argentina and central Africa, northern Pakistan and India experience some of the most intense lightning on the planet due to the local orography and regional airflow patterns.

In Pakistan, the areas of higher lightning or TS activity (as discussed above) lay above 30º N. There is no region beyond 30º North or South in the world having such a higher TS activity. On the average, possibly, every 2nd or 3rd day and every 3rd or 4th day could be a TS day over there during monsoon and pre monsoon seasons respectively.

On monthly basis, TS frequency observed to be the highest in the months of July & August during 1961-2000, while November, December & January are the least active months with respect to the formation of thunderstorms over Pakistan.

In NWFP, normal TS frequency varies from low to very high. It is low in the extreme north and northwestern parts (Cherat, Chitral etc.) and very high in extreme eastern (Kakul) and western parts (Parachinar). The province shares 34.7% & 35.6% of the total TS frequency (over Pakistan) for the periods 1961-1990 and 1991-2000 respectively.

In Punjab, normal TS frequency found to be low in south and southeastern parts, high in the north and northeastern parts and moderate in the rest of the province. The province shares 34.7% & 37.3% of the total TS frequency (over Pakistan) for the periods 1961-1990 and 1991-2000 respectively.

N/Areas & AJK share 17.8% & 13.3% of the total TS frequency (over Pakistan) for the periods 1961-1990 and 1991-2000 respectively. TS frequency is very low to low in the Northern areas while it is high to very high in AJK. The reasons, obviously, are the exposure of AJK stations to the monsoon currents during monsoon season, orography and orientation of the hilly terrain.

In Balochistan, TS frequency observed to be moderate in the northeastern parts (Barkhan, Zhob etc.) and very low to low in the rest of the province. It shares about 8.2% & 9.0% of the total TS frequency over Pakistan during 1961-1990 and 1991-2000 respectively. The reasons of comparatively higher TS activity over northeastern parts are orography and the fact that more monsoonal currents and systems reach over this part as compared to the other areas of the province (which generally receive little monsoon rainfall)

In Sindh, TS frequency is found to be very low or low. Its share to the total TS frequency (over Pakistan) observed to be 4.6% & 4.8% for the periods 1961-1990 and 1991-2000 respectively.

Increasing or decreasing tendency (in TS days) at 46 (out of 57) met. Stations fall within ± 10 days. Out of remaining eleven stations, seven showed decreasing tendency in TS days which ranged from -10.4 to -45.2 (all these stations belong to N/Areas & AJK and NWFP), while the other four stations exhibited increasing tendency with range +10.1 to +25.2 (these are; Mianwali(Punjab), Saidu Sharif, Cherat (NWFP) and Sibbi (Balochistan).

Normal TS frequency is observed to be (approximately) ten times the frequency of dust storms over Pakistan (Hussain A. et al, 2005) but each of the phenomena has its own

distribution pattern over the region depending upon the favorable conditions for its formation.

Conclusion:

As the Thunderstorm activity is found to be much higher in the pre monsoon and monsoon seasons and especially over those hilly areas which are exposed to the monsoonal currents & systems, so it can be concluded that most of the thunderstorms activities over Pakistan are due to the air mass thunderstorms (i.e. local heat, orographic and advection thunderstorms). Frontal thunderstorms are observed mostly during winter season and occasionally during pre monsoon and post monsoon seasons due to the passage of western disturbance or westerly waves across the country.

A net decrease of 5.3% in the Thunderstorm frequency observed over Pakistan during 1991-2000 is mainly due to the noteworthy decrease (29.4 %) in TS frequency over N/Areas & AJK, otherwise the decrease or increase in TS frequency over the four provinces is within ±5%. Although decrease of 29.4 % in TS activity over N/Areas & AJK is quite significant, yet it can not simply be attributed to climate change over the region, if the formation mechanism, duration and atmospheric/dynamic scale of a thunderstorm are kept in view (often the phenomenon is of micro scale). For the trend of such type of phenomenon, the time span of ten years (1991-2000) to compare with that of normal period (1961-1990) also seems to be too short. However, this decrease can partially be accredited to local climate variability over certain parts of the region.

Suggestions:

On the basis of this study it is suggested that lightening detectors may be installed at stations where the thunderstorms frequency is high or very high in order to fulfill the modern observational needs and possibly in depth research in future.

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