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A Decade of Thunderstorm Patterns: A Comparative Study of Iraq and Russia

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Abstract

This study analyzes thunderstorm activity based on archived data from daily meteorological observations over 10 years at three meteorological stations in Iraq (Khanaqin, Baghdad Airport, and Basra Airport) and at two meteorological stations in Russia (Rostov-on-Don and Taganrog). The analysis showed that the greatest frequency of thunderstorms occurred in March and April, 55% of them were in the northern mountainous part of Iraq. Analysis of the fronts for six months per year and for a 10-year period showed 75 baroclinic and 77 barotropic cases for Khanaqin station, 45 baroclinic and 36 barotropic cases for Baghdad Airport station, and 33 baroclinic and 22 barotropic cases for Basra Airport station. But in Russia (Rostov-on-Don and Taganrog), the results showed that the greatest frequency of thunderstorms occurred in June and July, 53.58% of them are in Taganrog due to the warming from the sea and the arrival of a cold mass from the north (from the polar). Analysis for six months per year and for a period of 10 years showed that there were 76 baroclinic and 60 barotropic cases in Rostov-on-Don and 80 baroclinic and 76 barotropic cases in Taganrog. The aim of the study is to analyze thunderstorms and the reasons for their recurrence in some stations more than others, and to predict the storm to reduce or avoid the damage caused by thunderstorms.

Keywords: Baroclinic; Barotropic; Cumulonimbus clouds; K-index; Thunderstorm activity.

1. Introduction

Thunderstorms are produced by the kind of cloud known as cumulonimbus and go through a cycle of growth from birth to maturity to decay, according to several studies [1],[2]. The initial stage is the cumulus stage, when cold, moist air rises and condenses to form a single cumulus cloud or a group of cumulus clouds. As in (Fig. 1), cumulus clouds have been seen and ascended briefly before dissipating. The combination of the surrounding, drier air with the cloud droplets causes them to evaporate, which causes this process to happen [1]. However, as soon as the water drops evaporate, the air becomes much more humid than before. A significant amount of latent heat is produced as water vapor transforms into liquid or solid cloud particles, which causes the cumulus cloud to grow taller and often resemble a tower or dome [3]. Rainfall and lightning are not present while the cloud is in the cumulus stage [1].

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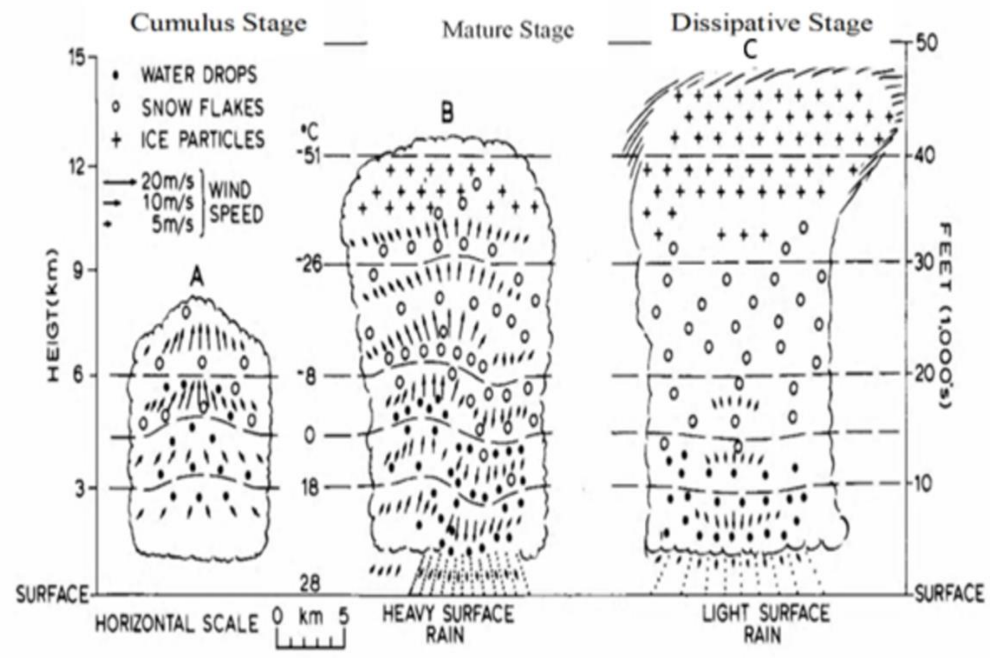

Figure 1: Stages of a thunderstorm [4].

Molecules in the cloud expand above the freezing point, they eventually lose their ability to stay suspended in the rising air, and they start to fall. This occurrence is caused by a mechanism called entrainment, which pulls drier air from the area around the cloud into it as it happens. Some of the rain evaporates as a result of the entrainment of drier air cooling the surroundings; the air begins to descend as a downdraft. The downdraft may intensify because part of the atmosphere is drawn along by the rain as it falls [1],[2],[5].

Storm intensity is highest when fully developed (mature stage). Strong upper-level winds disseminate the cloud's ice crystals horizontally as the cloud top attains a stable zone of the environment (perhaps the stratosphere) and starts to resemble the recognizable anvil form (see Fig. 1B). The cloud itself may reach heights of over 12 km and have a near-base diameter of several kilometers. In the center of the cloud, updrafts and downdrafts are strongest and cause extreme turbulence. Overshooting is the term used when updrafts from some storms enter the stable atmosphere above the cloud top. In the mature stage, lightning and thunder are also present [1],[6]. At this stage, downburst winds, huge hailstones, and flash flooding brought on by significant precipitation are the major causes of thunderstorm damage [7].

The clouds release a lot of rain (and perhaps tiny hail). With the beginning of precipitation above the ground, there is frequently a downrush of chilly air that can be perceived as a powerful wind gust. Nevertheless, depending on the relative humidity beneath the storm, the rain may or may not reach the surface [1],[3].

Within 15 to 30 minutes after the storm reaches its mature stage (see Fig. 1B), it starts to fade. When the updrafts begin to fade and the downdrafts begin to dominate most of the cloud, the dispersal phase occurs. Cloud droplets no longer form when the abundant supply of warm, humid air is removed. The cloud now emits light precipitation with no stronger downdrafts. Lower-level cloud particles quickly dissipate as the storm fades (see Fig. 1C) [1],[8].
Given that it accounts for over 70% of flight delays and cancellations, weather is one of the most significant elements impacting aviation operations. O. F. Khayoon examined the

meteorological conditions that impact civil aviation flights at international airports in Iraq. Specifically, the impact of fog, thunderstorms, snowfall, and dust storms was examined, along with the influence of wind and air temperature for the year 2020 [6].
Another study analyzed storms' distribution throughout the 1998–2011 period in Iraq and identified the area between latitudes (35–36°N) and longitudes (45–46°E), it is the area most affected by lightning-accompanied thunderstorms, and April was the most common month when the Mediterranean depression was combined. There were more thunderstorms and lightning strikes when there was a Red Sea depression or a Sudanese depression [9].
Robinson PJ Studied the effect of fog and thunderstorms on flights, as this effect was measured on the basis of the difference between delays in clear conditions and in different types of stormy weather. The study showed that fog and thunderstorms caused delays at different stages of each flight [10]. Ground-based 3D Lidar monitoring of low-level wind shear was used to increase flight safety and protection of human lives and health, the major goal was to compare weather events recorded throughout a year to the occurrences of low-level wind shear scenarios including vertical wind field discontinuities, frontal passes, and gust fronts in order to improve flight safety and safeguard human lives and health [11]. But the difference between our study and other researchers is the use of data for all months of the year except for the summer months in Iraq and the winter months in Russia for the period 2010–2019 to analyze thunderstorms and their frequency and classification by type of thunderstorm (barotropic or baroclinic). The reason for choosing the fall and winter months (in Iraq) is to show the difference between the seasons spring and fall, and distinguish this study from other researchers. This work aims to identify the features of the spatial distribution of trends in variability between years (months) of thunderstorm activity in Iraq and Russia.

2. Materials and methods

Iraq has a peculiar climate due to its position at the meeting point of the Mediterranean and continental air masses and the barrier effect of its mountains, which create conditions for the formation of convective clouds throughout the year [12]. The climate in Russia (in the Rostov region) is humid continental, with chilly and long winters, and warm summers with bright sunshine [13][14].

The study was conducted based on the analysis of daily (archived) meteorological data on thunderstorms over 10 years for the period 2010-2019 at three meteorological stations in Iraq, as shown in (Fig. 2), Khanaqin (34°.21 N; 45°.23 E), Baghdad Airport (33°.18 N; 44°.24 E), and Basra Airport (30°.31 N; 47°.47 E) (http://meteologix.com/iq) [15]. While for Russia, data on thunderstorms for the same period at two meteorological stations, as shown in (Fig. 3), Rostov-on-Don (47°.13 N; 39°.42 E) and Taganrog (47°.13 N; 38°.55 E) were taken from (http://rp5/ПогодавРоссии), (http://en.tutiempo.net/climate/turkey.html), and (http://meteologix.com/ru) [16][17].

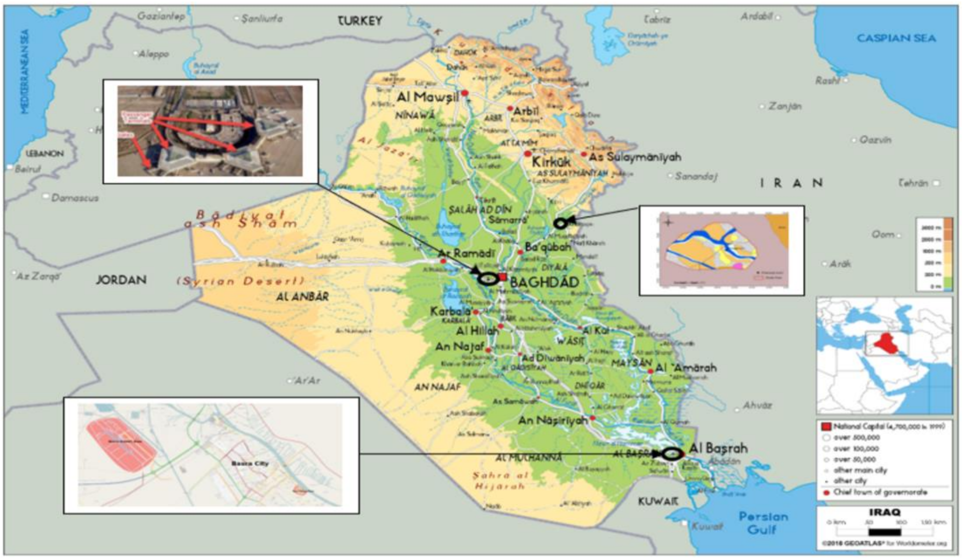

Figure 2: Map of Iraq [18].

Figure 3: Map of Russia [19].

Thunderstorms (Barotropic or baroclinic) were analyzed at all five meteorological stations. The data obtained were statistically processed, formed into tables, and included the daily, monthly, and annual number of days with thunderstorms at each station. In the study, only the main times were used (00:00, 06:00, 12:00, and 18:00) hour's local time of the day on which a thunderstorm was recorded (in the station area or remotely).

A brief statistical analysis was applied to assess the variability and possible differences in the average number of days with at least one thunderstorm event in the data series. The statistical significance of their changes was calculated by the Mann-Kendall test for the period 1972-2011 [20].

2.2 . K-Index

The stability of the atmosphere is frequently assessed using several measures. One of these measures is the K-index in (°C). It is a helpful tool for determining the likelihood of thunderstorms and forecasting convection. It can be calculated as follows:

K = T (850 mb) + Td (850 mb) – T (500mb) – DD (700 mb)

Where T is the temperature, Td is the dew point temperature and DD is the dewpoint temperature depression. A potential thunderstorm can be determined by the value of the K-index, as shown in Table 1 [21].

Table 1: Atmospheric stability is based on the K-index value (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-pressure-levels?tab=form) [22][23].

Number	K-Index Value (°C)	Thunderstorm Probability (Types)
1	K below 20	None
2	K between 20 to 30	Isolated thunderstorms
3	K below 30	Widely scattered thunderstorms
4	K over 30	Scattered thunderstorms
5	K = 40	Numerous thunderstorms

3. Results and discussion

In this study, thunderstorms were analyzed graphically for the period (2010-2019) for three stations in Iraq (Khanaqin, Baghdad Airport, and Basra Airport) for 9 months of the year and for two stations in Russia (Rostov-on-Don, Taganrog) for 7 months of the year, and for the following times (00:00, 06:00, 12:00, and 18:00). The reason for choosing these months is because of the frequency of thunderstorms in them. The temporal variability of the total number of days with thunderstorms on the territory of Iraq for three weather stations is shown in Fig. 4 for a 10-year period. The results of the analysis show that the largest number (frequency)of thunderstorms during the 10-year period fell on the mountainous areas in Khanaqin station with 281cases (197 days), and the lowest frequency was observed in the Persian Gulf region at the Basra airport weather station with 65 cases (62 days), but the frequency of the Baghdad airport station was 113 cases (99 days).

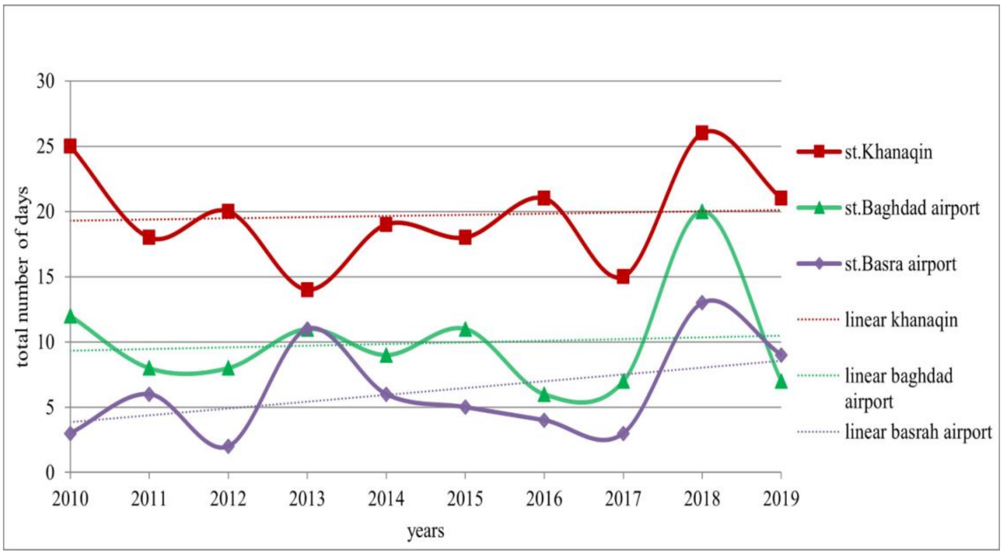

Figure 4: Distribution of the total number of thunderstorms by year over a 10-year period in Iraq.

During the study period, a trend of increase in the number of days with thunderstorms was observed in the area of Khanaqin station and the rest of the region (the flat part) of Iraq. In 2018, there was a significant increase in the number of thunderstorms at all stations.

At the same time, (Fig. 5) shows the dynamics behaviour of the total number of days with thunderstorms over the territory of Russia for two weather stations over a period of 10 years. The results of the analysis show that the largest number (frequency) of thunderstorms during the study period fell on the weather station Taganrog with 187 cases (157 days), and the lowest frequency was observed at the weather station Rostov-on-Don with 154 cases (136 days).

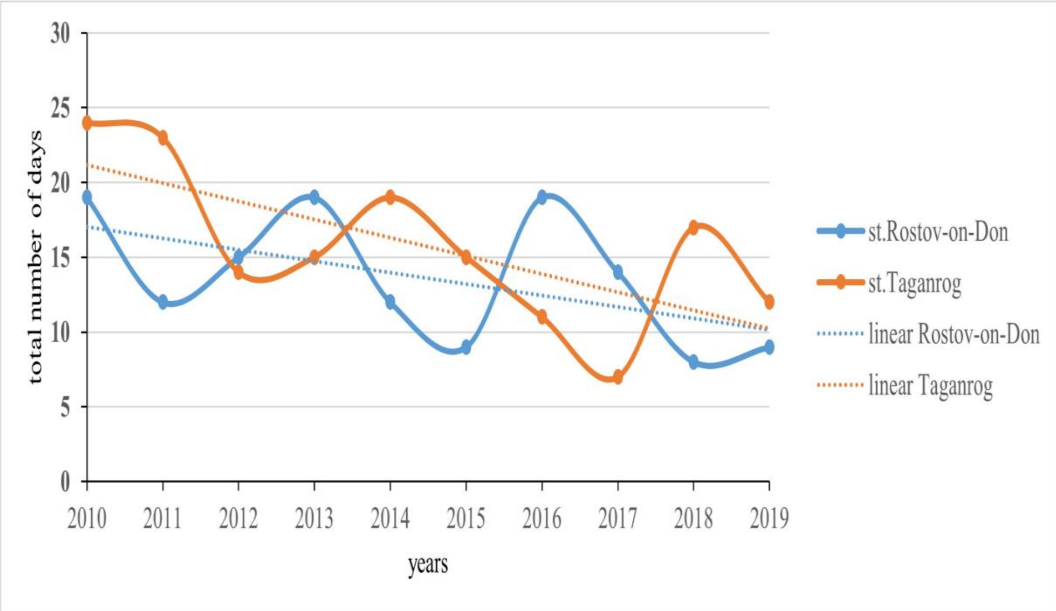

Figure 5: Distribution of the total number of thunderstorms by year over a 10-year period in Russia.

An analysis of the average monthly number of days with thunderstorms over a 10-year period (2010 to 2019) for three weather stations in Iraq showed that there were typically about 52.8% of all thunderstorms during March-May, but 26.8% during October-November (Fig. 6).

The maximum thunderstorm activity was observed in April (maximum 8 days at the Khanaqin station). The number of days increased in the northern and northwestern parts of the country, in mountainous areas, due to the prevailing orographic conditions for convective initiation.

An analysis of the average monthly number of days with thunderstorms over a 10-year period (2010 to 2019) for two weather stations in Russia showed that typically about 71% of all thunderstorms occurred during the months of May-July (Fig. 7).

The maximum thunderstorm activity was observed in June (maximum 11 days at the Taganrog station). The number of days increased due to heating from the sea and the arrival of a cold mass from the north (from the polar) for convective initiation.

The number of days increased due to the rise in sea temperature and the arrival of a cold mass from the north (from the polar region) to move convection. No thunderstorms were observed throughout Iraq during the summer months, and they were extremely rare in September, occurring 1-2 times every five years at the Khanaqin station. They were never recorded at Baghdad and Basra airport terminals in September due to the high air temperatures and evaporation prevailing throughout the country. In October, the average monthly number of

days with thunderstorms for the stations Khanaqin, Baghdad Airport, and Basra Airport respectively was (2, 2, 1), and for November it was (2, 1, 2).
From December to February, thunderstorms were very rare; their frequency in January–February did not exceed 1-2 cases in five years for the Baghdad Airport station, but for the Basra Airport station, it was 1-2 cases in six years and more. While in December, thunderstorms were extremely rare-three cases in 10 years at the Basra Airport station.
During the summer period, thunderstorms were observed abundantly in Russia. In August, the average monthly number of days with thunderstorms for the two stations was 2.
In September, October, and April, thunderstorms were rare (1-2) cases for Rostov-on-Don station, Taganrog station in September (2-3) cases, and October only two cases for 10 years. The month of May for the two stations had an average monthly number of days with thunderstorms of 3.

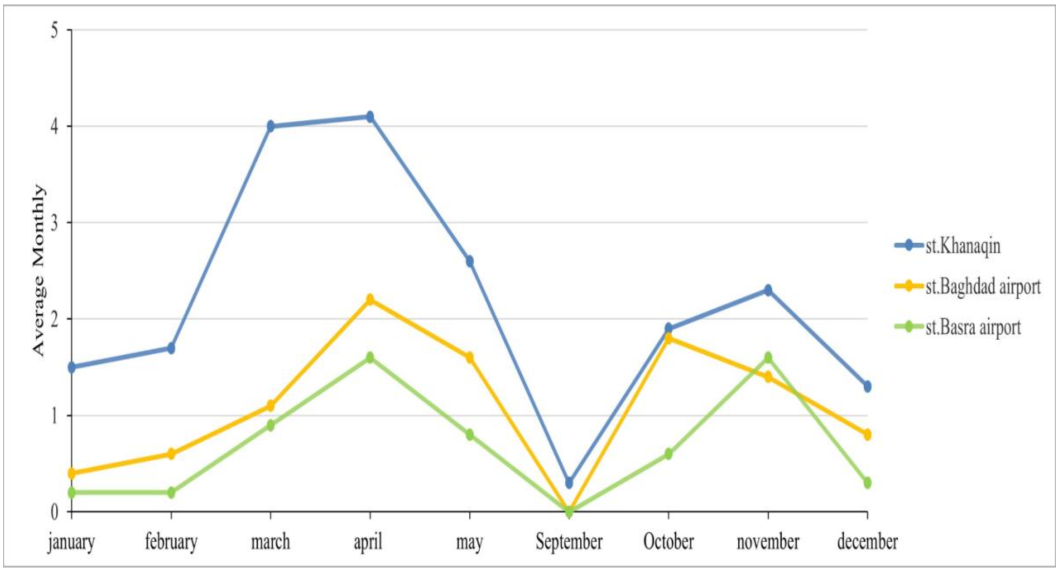

Figure 6: Average monthly number of days with thunderstorms for the period from 2010 to 2019 in Iraq.

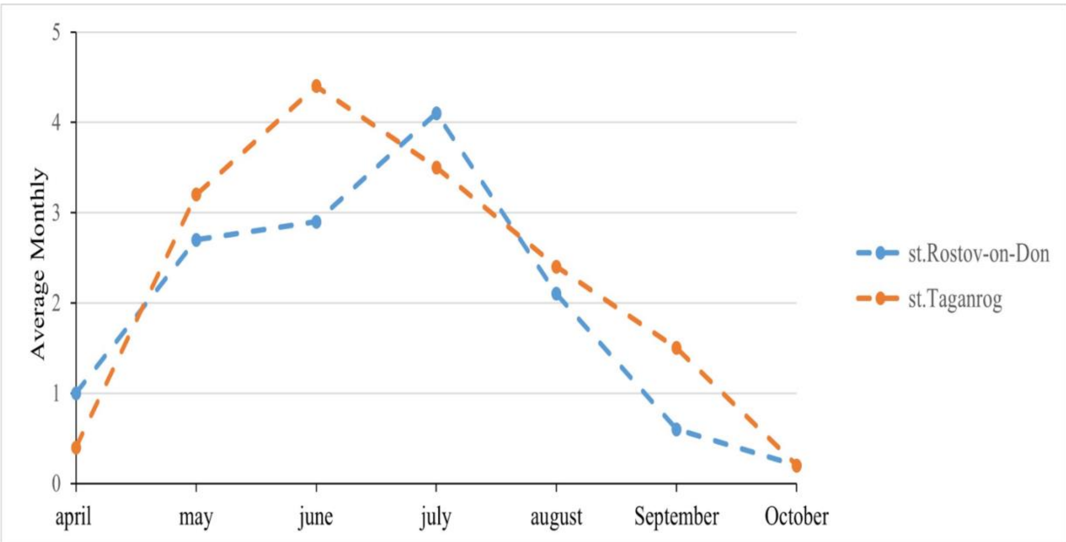

Figure 7: Average monthly number of days with thunderstorms for the period from 2010 to 2019 in Russia.
Table (2) represents the analysis of fronts for six months a year (March, April, May, September, October, and November) for the period (2010-2019) for the study areas in Iraq, while Table (3)

presents the analysis of fronts for seven months a year (April, May, June, July, August, September, and October) for the period (2010-2019) for the study areas in Russia.

Table 2: The frequency of thunderstorms (baroclinic and barotropic) in Iraq for the period (2010-2019).

Years	Stations					
	Khanaqin		Baghdad airport		Basra airport	
	Baroclinic	Barotropic	Baroclinic	Barotropic	Baroclinic	Barotropic
2010	5	8	5	4	3	0
2011	9	8	5	1	3	2
2012	7	10	3	4	2	0
2013	4	6	4	5	6	5
2014	12	6	5	4	4	2
2015	9	6	5	6	0	4
2016	9	5	3	2	2	1
2017	6	8	3	4	2	1
2018	8	10	8	5	7	5
2019	6	10	4	1	4	2
sum/day	75	77	45	36	33	22

Table 3: The frequency of thunderstorms (baroclinic and barotropic) in Russia for the period (2010-2019).

Years	Stations			
	Rostov-on-Don		Taganrog	
	Baroclinic	Barotropic	Baroclinic	Barotropic
2010	13	6	16	8
2011	7	5	12	11
2012	7	8	5	9
2013	13	6	7	8
2014	4	8	8	10
2015	7	2	10	5
2016	8	11	5	6
2017	8	6	1	6
2018	6	2	12	5
2019	3	6	4	8
sum/day	76	60	80	76

During the study period of nine months (January, February, March, April, May, September, October, November, and December) in Iraq and seven months (April, May, June, July, August, September, October) in Russia, the best time for thunderstorms to recur was (18:00), the lowest time was (00:00) for Khanaqin and Basra Airport stations, the lowest time was (06:00) for Baghdad Airport and Rostov-on-Don stations, and finally, the lowest time was (12:00) for Taganrog station, as described in Table (4).

Table4: The frequency of thunderstorms during the four main times (2010-2019)

Stations	Time 00:00(UTC)	Time 06:00(UTC)	Time 12:00(UTC)	Time 18:00(UTC)
Khanaqin	61	63	74	83
Baghdad	37	10	22	44
Basra	12	15	17	21
Rostov-on-Don	31	18	26	79
Taganrog	34	47	31	75

Table (5) shows the values of the air stability index and is classified into five categories, and the most repeatable value is (k between 26 to 30) for two stations (Khanaqin, Rostov-on-Don), while the most repeatable value is (k between 31 to 35) for the stations (Baghdad airport, Basra Airport and Taganrog) in the same period in Table (4).

Table 5: Frequency of air stability index (2010-2019)

Stations	K below 20	K between 20 to 25	K between 26 to 30	K between 31 to 35	K = 40 or Above 35	Total frequency
Khanaqin	10	46	112	98	15	281
Baghdad AirPort	5	16	40	45	7	113
Basra Airport	6	6	20	28	5	65
Rostov-on-Don	7	19	62	55	11	154
Taganrog	10	27	64	72	14	187

4. Conclusions

Based on the analysis of the frequency of thunderstorms in the study area, it can be concluded that:

1- A high level of thunderstorm activity was observed in the northern and northeastern parts of Iraq.

2- The highest incidence of thunderstorms in the annual cycle occurred between March-April.

3- During the study period, the number of days with thunderstorms increased to 26 days at Khanaqin meteorological station, 20 days at Baghdad airport station, and 13 days at Basra airport station in 2018. Dry thunderstorms occurring during the warm season often resulted in dust and sand storms.

4- Most of the thunderstorms in Russia occurred in the annual cycle of June-July.

5- In 2010, a rise in the number of days with thunderstorms by 19 days was recorded at the Rostov-on-Don meteorological station, while 24 days were recorded at the Taganrog meteorological station.

6- Areas in Russia were more frequently affected by thunderstorms than Iraq due to their distance from the equator as well as the arrival of cold fronts from the pole. Thunderstorms were more noticeable in Russia, especially in summer, due to the humid masses from the Black Sea towards Rostov-on-Don.

7- During the summer, numerous thunderstorms were observed in Russia, while no cases were recorded in Iraq.

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