



Spatio-temporal Variation of Weather Systems and their Seasonal Variability in Iraq

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ABSTRACT

This study examines the spatio-temporal fluctuations in the occurrence of weather systems in Iraq by analyzing daily synoptic maps over 20 years (1999-2020). It calculates the frequency of the centers and extensions of weather systems at six meteorological stations (Erbil, Mosul, Baghdad, Rutbah, Nasiriya, and Basrah), which are spread across the country. The analysis was conducted on the temporal fluctuations, which reveal that five weather systems consistently traversed the area (Monsoon low, Siberian high, Red Sea depression, Subtropical high, and Mid-latitude depression), which are spatially distributed over the area of Iraq. Their monthly rates were computed and collected seasonally. Using ArcGIS, maps of the spatial distribution of weather system frequencies were generated. The results showed that monsoon lows significantly affect the climate over the majority of the year, namely for 126 days. The highest proportion of this influence is observed in the southern region, particularly during the summer. The occurrence of the Siberian high is more frequent during the winter season, particularly in the northern region, happening approximately 70.24 days per year. The occurrence of the Red Sea depression is more frequent in the spring, particularly in the central area, happening on around 59.76 days per year. The occurrence of subtropical highs in the autumn, particularly in the southern region, happens on around 17.66 days per year. Mid-latitude depressions are infrequent, transpiring approximately 7.68 days per year, predominantly in the central area of Iraq.

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التباين الزمني والمكاني للأنظمة الطقسية وتقلباتها الموسمية في العراق

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ملخص	معلومات الارشفة
تتناول هذه الدراسة التقلبات الزمانية والمكانية الحاصلة في الأنظمة الجوية في العراق من خلال تحليل الخرائط السايونيتيكية اليومية على مدى 20 عامًا للفترة (1999-2020) وحساب تردد مراكز وامتدادات الأنظمة الجوية في ست محطات أرصاد جوية (أربيل، الموصل، بغداد، الرطبة، الناصرية، البصرة)، الموزعة مكانيا في العراق. كشف التحليل على التقلبات الزمنية، عن أن خمسة أنظمة جوية عبرت المنطقة باستمرار (منخفض الهندي، مرتفع سيبيري، منخفض البحر الأحمر، مرتفع شبه استوائي، ومنخفض البحر المتوسط). تم حساب معدلاتها الشهرية وجمعها موسميًا. باستخدام ArcGIS، تم إنشاء خرائط للتوزيع المكاني لترددات الأنظمة الجوية. أظهرت النتائج أن منخفض الرياح الموسمية يؤثر بشكل كبير على المناخ على مدار غالبية العام، أي لمدة 126 يومًا. لوحظت أعلى نسبة من هذا التأثير في المنطقة الجنوبية، وخاصة خلال فصل الصيف. ويحدث المرتفع السيبيري بشكل متكرر خلال فصل الشتاء، وخاصة في المنطقة الشمالية، ويحدث حوالي 70.24 يومًا في السنة. ويحدث منخفض البحر الأحمر بشكل متكرر في فصل الربيع، وخاصة في المنطقة الوسطى، ويحدث حوالي 59.76 يومًا في السنة. ويحدث المرتفع شبه الاستوائي في الخريف، وخاصة في المنطقة الجنوبية، ويحدث حوالي 17.66 يومًا في السنة. أما المنخفضات في خطوط العرض المتوسطة فهي نادرة، وتستمر حوالي 7.68 يومًا في السنة، وخاصة في المنطقة الوسطى من العراق.	تاريخ الاستلام: 10-سبتمبر-2024 تاريخ المراجعة: 08-أكتوبر-2024 تاريخ القبول: 03-نوفمبر-2024 تاريخ النشر الإلكتروني: 01-أكتوبر-2025 الكلمات المفتاحية: المرتفع السيبيري منخفض الهندي منخفض البحر الاحمر منخفض البحر المتوسط المرتفع شبه مداري المراسلة: الاسم: سيف الجحيشي Email: saifaljuhaishi@uomustansiriyah.edu.iq

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Introduction

Atmospheric pressure systems are essential in determining a region's climate and weather patterns (Al-Hasani, 2018). In the center of the Middle East, in Iraq, atmospheric pressure systems affect the temperature, precipitation patterns, and the climate of several seasons (Al-Muhyi et al., 2024). The amount of rainfall in the area is influenced by atmospheric pressure systems, particularly those that move over the nation in the spring, autumn, and winter rainy seasons (Shaghati, 2011). From June to August, Iraq encounters hot and arid weather conditions during the summer months (Babausmail et al., 2021). Nevertheless, the southern regions, such as Basrah and its neighboring territories, can experience heightened levels of moisture and intermittent precipitation due to the effect of the Indian Ocean monsoon (Singh et al., 2020). The Siberian High is the prevailing atmospheric circulation system in the lowest part of the troposphere (Ali et al., 2024). During the winter season, it exerts significant dominance over the majority of continental Asia (Nicholson, 2015). The Siberian High exerts a considerable influence on the climate in the middle-to-high latitudes of Eurasia during the winter season (Hasanean et al., 2013). The Red Sea depression is a meteorological occurrence in the Middle East characterized by intense rainfall, sudden floods, and significant consequences for society (Delaunay et al., 2023). The source of this phenomenon is the interaction between a prolonged stationary wave in the tropical easterlies and an amplified Rossby wave. This interaction leads to the movement of moist air masses in a northward direction across the Red Sea (Vries et al., 2013; Parajuli et al., 2020). The subtropical high system is a prominent component of the

atmospheric circulation in the region (Qiu et al., 2023). Its geographical fluctuation and movement have a substantial influence on the atmospheric and climatic patterns in the surrounding area (Lashkari and Jafari, 2021).

In the literature, many studies focus on analyzing the effect of atmospheric pressure systems on the climate of Iraq, especially their impact on precipitation and temperature. Still, they focus on one type of these systems or a case study of a specific kind of them. Al-Qadi et al. (2021) conducted a comprehensive examination of the relationship between El Niño Southern Oscillation and dust storms in Iraq spanning the years 1971 to 2016. In the summer, the Indian monsoon-low pressure system is responsible for around 50.4% of the dust storms in Iraq, while the Red Sea depression contributes about 24.8%. Siberian high pressure contributes 7.3% of aerosols, while Mediterranean cyclones contribute 5.1%. Yousif and Kadhum (2020) examined the assessment of atmospheric blocking effects on weather events, specifically in Iraq. The results showed that omega blockage, such as the one witnessed in February 2006, can result in significant precipitation occurrences, such as the 120 mm of rainfall documented during that time. The primary source of moisture for rainstorms is primarily derived from the Mediterranean Sea and the Red Sea. Zeki et al. (2023) conducted a study on the categorization of different forms of aerosols in Iraq, utilizing MODIS data. The findings indicate that the Indian monsoon-low-pressure system significantly contributes to the occurrence of dust storms in Iraq, particularly during the summer season.

Most studies focus on studying the temporal variation of weather system frequencies only, or they investigate the frequency of a single atmospheric pressure system or case studies for limited periods.

This study examines the analysis of the spatio-temporal variation of the frequencies of the atmospheric pressure systems that dominate Iraq's weather. The study is carried out by calculating the frequencies of the atmospheric pressure systems of six stations distributed over the area of Iraq by analyzing the daily synoptic maps of the observation (1200). Spatial covariance analysis is performed on maps created using ArcGIS to calculate the seasonal sum of average atmospheric pressure system frequencies for selected stations.

Study area

Iraq is situated in the northern hemisphere of the Earth, with a coordinate system of latitudes (29° 05' to 37° 23') north and longitudes (38° 45' to 48° 45') east (Adeeb and Al-Timimi, 2019). Iraq has a land area of 438,320 km² (Al-Knani et al., 2021). The mountains in the north, northeast, and east characterize the surrounding region (Mutar et al., 2023). The eastern area of Iraq consists of a plateau, which is separated from the mountains by a sedimentary plain (Al-Bayati et al., 2020; Zangana et al., 2021). Figure 1 shows the study area marked with meteorological station locations. The climate of Iraq is classified as a transitional zone between the continental and subtropical regions (Kadhum et al., 2022). Winter is usually marked by cool to cold temperatures with daytime highs reaching up to 16 °C and nighttime lows dropping to 2 °C. The summers are sweltering and arid, with temperatures reaching above 43 °C in July and August and dropping to 26 °C at night (Al-Obaidi and Al-Timimi, 2022). The prevailing winds come from the northwest (Awadh, 2023). Iraq's rainfall is categorized as seasonal, with the majority of the country's rainy season falling from November to April in the north and northeast. The average annual rainfall in all of Iraq's regions is 192.03 mm (Al-Jbouri and Al-Timimi, 2021). Springtime dust storms in Iraq are produced by two distinct wind patterns: the north wind, which has historically produced dust storms in this area, and the Al-Khamsian (Halos and Mahdi, 2021).

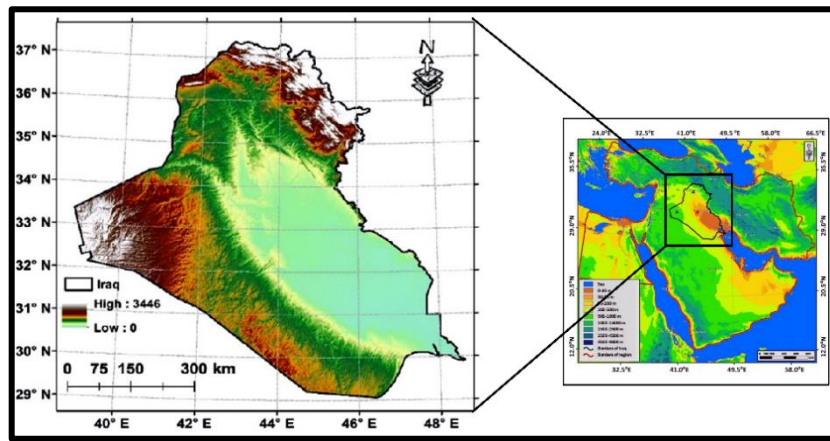


Fig. 1. Location of the study area.

Materials and Methods

The frequency of prevailing atmospheric pressure systems in Iraq (monsoon low, Siberian high, Red Sea low, subtropical high, and mid-latitude low) is calculated from the analysis of daily synoptic maps from the National Oceanic and Atmospheric Administration NOAA Physical Sciences Laboratory (PSL) website (Team, 2023). Observations (1200) and level (1000) millibars are selected for the years 1999-2020 for six stations (Erbil, Mosul, Baghdad, Rutbah, Nasiriyah, Basrah) distributed over the study area. Table 1 lists the locations and elevations of the stations in the study area. Figure 2 shows a sample of the synoptic maps downloaded from the PSL website. Figure 3 shows the flow chart of the research methodology. The synoptic maps are analyzed after being downloaded from the website, and the type of atmospheric pressure system present at each meteorological station is determined. The frequency of each atmospheric pressure system is recorded at each station throughout the study period. The frequencies are recorded in Excel. The frequency rate of the atmospheric pressure system was calculated for each month for the period (1999-2020). The rate is calculated for each season, and then the annual average of the frequencies is calculated for 20 years. Timelines of the frequency rate of the monthly, seasonal, and yearly atmospheric pressure systems are then drawn using Microsoft Excel. From the seasonal average data of the frequencies of the atmospheric pressure systems of the meteorological stations, spatial distribution maps of the frequencies for each system in the four seasons are created using ArcGIS v10.8. The frequency data are imported from Excel to ArcGIS and converted to a shapefile. Then, a raster of the frequencies is created using the IDW interpolation tool. Then, the study area is cut using the Extract by Mask tool. Then, a spatial classification of the frequencies is made using the classification tool. Then, contour lines are added using the Surface tool. Finally, the final output of the maps is prepared, and the legend, grid, north indicator, and scale are added.

Table 1: Location of meteorological stations in the study area and their altitude

Station	Latitude	Longitude	Altitude (m)
Erbil	36.09	44	420
Mosul	36.19	43.09	223
Baghdad	33.18	44.24	34
Rutbah	33.02	40.17	615
Nasiriya	31.01	46.14	3
Basrah	30.31	47.47	2

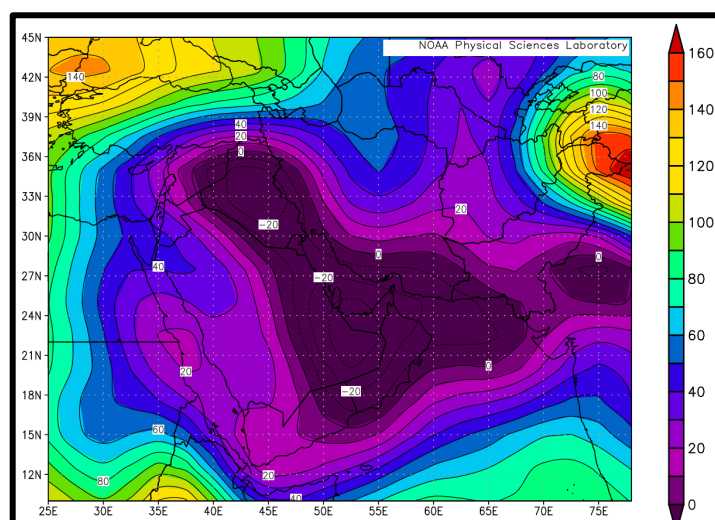


Fig. 2. Geopotential height synoptic map for Middle East

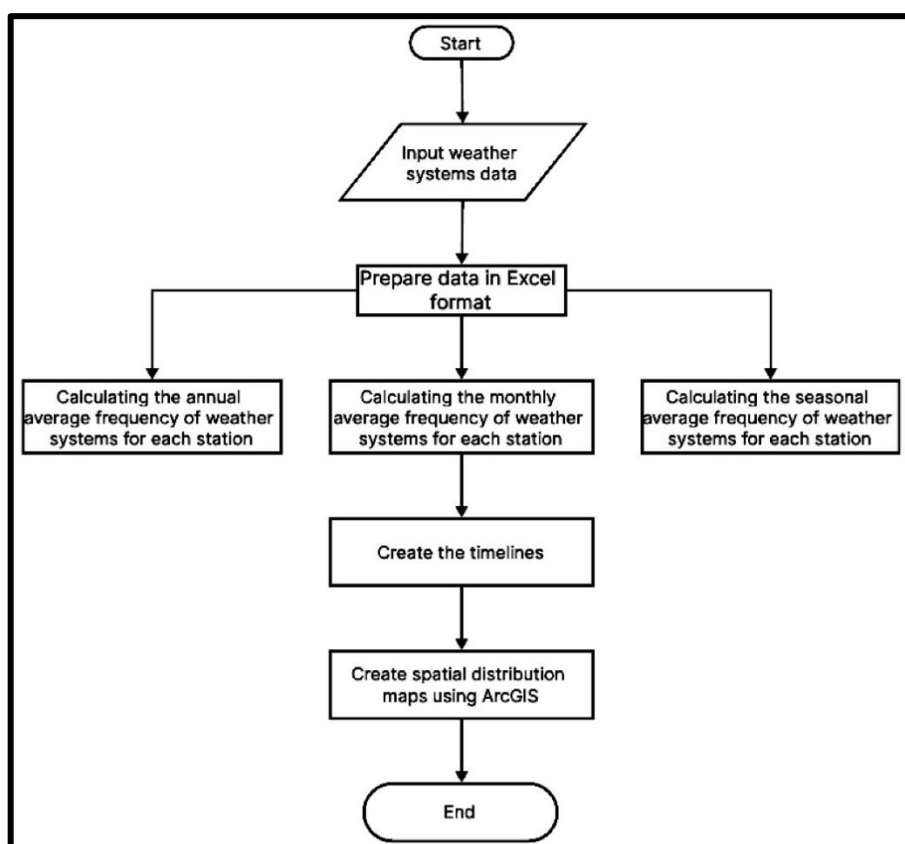


Fig. 3. Research methodology

Results and discussion

Figure 4 represents the annual total average days of frequency for the centers or extensions of the atmospheric pressure systems that control the climate of Iraq for the period (1999-2020). The values were calculated as an average for the six stations in the study area. It is observed that the low monsoon extensions occur for the majority of days in a year, with a frequency of 126.55 days per year. Additionally, the combined frequency of the low monsoon extension and the center of the low, which is 28.25 days per year, totals 154.8 days per year. This indicates that it has had the most significant impact on the climate of Iraq for an extended period. The highest frequency in second place is the Siberian Ridge, as the number of days of frequency of the center of the Siberian Ridge reached 22,825 days per year, and the number of days of frequency of its extensions 47.41 days per year, totaling 70,235 days per year. It has a

significant impact on the climate of Iraq, especially in the cold months. The average days of frequency of the Red Sea depression were 59.76 days per year, while the average days of frequency of Red Sea depression centers were 20.27 days per year, and the average days of frequency of its extensions were 39.49 days per year, which is ranked third. In fourth place was Subtropical High, with an average day frequency of 17.66 days per year, divided into an average day frequency of the center of the high of 6.63 days per year and an average day frequency of extensions of 11.03 days per year. In fifth place, mid-latitude depression was the least frequent during the year, with a rate of 7.68 days per year, divided into the average days of low frequency of 2.48 days per year and the average frequency of extensions of 5.2 days per year.

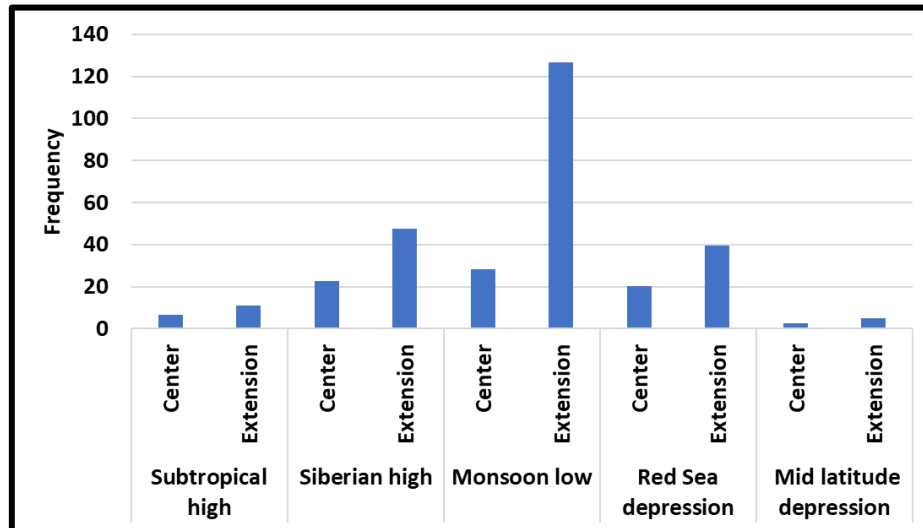


Fig. 4. Annual total frequency of atmospheric pressure systems in Iraq for the period (1999-2020)

Figures (5 and 6) show the monthly total of the frequency rate of atmospheric pressure systems in Iraq for the period 1999-2020 and the seasonal total of the frequency rate of atmospheric pressure systems in Iraq for the period 1999-2020, respectively. The values represent the average of the sum of the center and extension frequencies of the atmospheric pressure systems of the stations in the study area. Notice the total monsoon low control over the climate of Iraq in the summer and the partial control in the spring and autumn seasons, especially in the months (May, June, July, August, and September), with a frequency rate of 30.98 days in the summer months and 27.64 days in the five months. This explains the high temperatures in most areas of Iraq. Siberian high dominates the climate of Iraq in the winter, and its frequency is high in the spring and autumn seasons, especially in the months (November, December, January, and February), with a frequency rate of 14.42 days in the winter months and 11.9 days in the four months, which explains the low temperatures and low humidity on most days of these months. Red Sea depression dominates the climate in Iraq on most days of the spring months (March and April) and October of the autumn season, and its frequency increases in large proportions in the winter and autumn months (November, December, January, and February), reaching 10.14. One day in October, and an average of 7.9 days during the seven months. Subtropical high frequency occurs during the months of winter, spring, and autumn (January, February, March, April, May, October, and December) in varying proportions, with its average frequency reached 2.2 days in the eight months. Mid-latitude depression recurs at different rates in the months of winter, spring, and autumn (January, February, March, April, May, October, and December), with an average frequency of 0.95 days in the eight months.

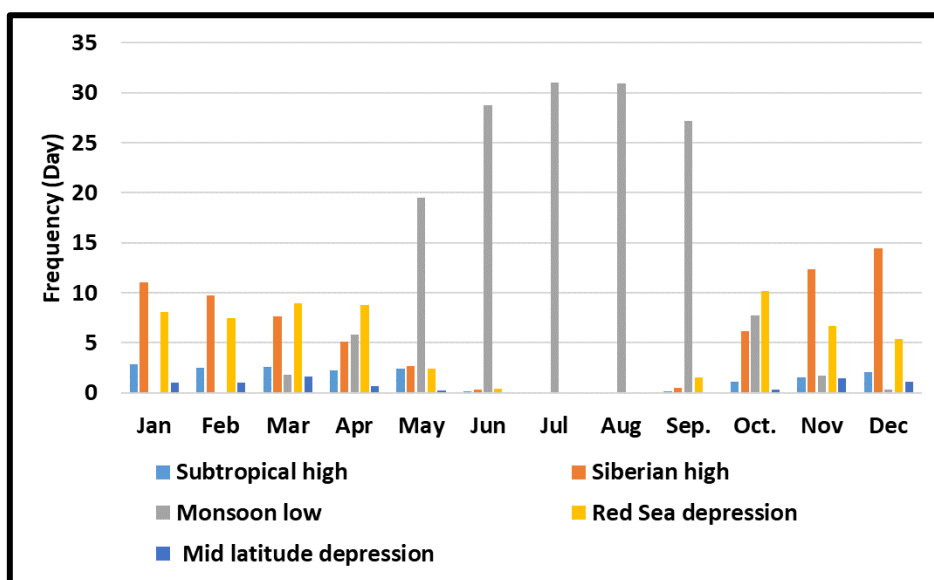


Fig. 5. Monthly total rate of atmospheric pressure systems frequency in Iraq

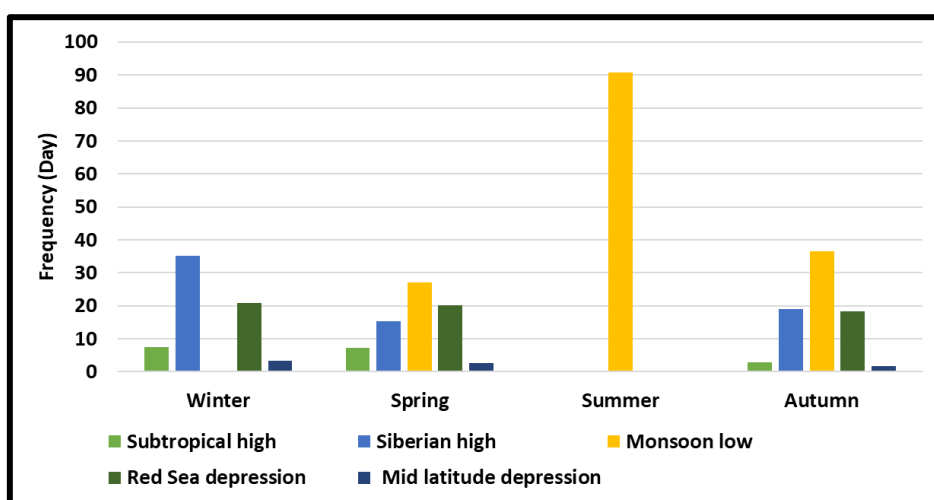


Fig. 6. Seasonal sum of atmospheric pressure systems frequency in Iraq

Figure 7 shows the spatial distribution of the average frequencies of the centers and extensions of the low monsoon in Iraq for the period (1999-2020) for the meteorological stations (Erbil, Mosul, Baghdad, Rutbah, Nasiriyah, and Basrah), divided by seasons. In general, there has been a rise in the occurrence of frequencies in the southeastern region of Iraq, and the frequencies decrease towards the north. This indicates that the region entering the monsoon low is the southeast region of the country. Results show a significant increase in the frequency rate as well as in the area covered by the low frequencies in the summer, as it reaches 91.38 days as the highest value. There is a significant decrease in the frequency rate, which is almost nonexistent as it reaches 0.2 days as the lowest value, and the area it covers in the winter. The results clearly show a relatively high rate of frequencies in the autumn season compared to the spring and winter seasons.

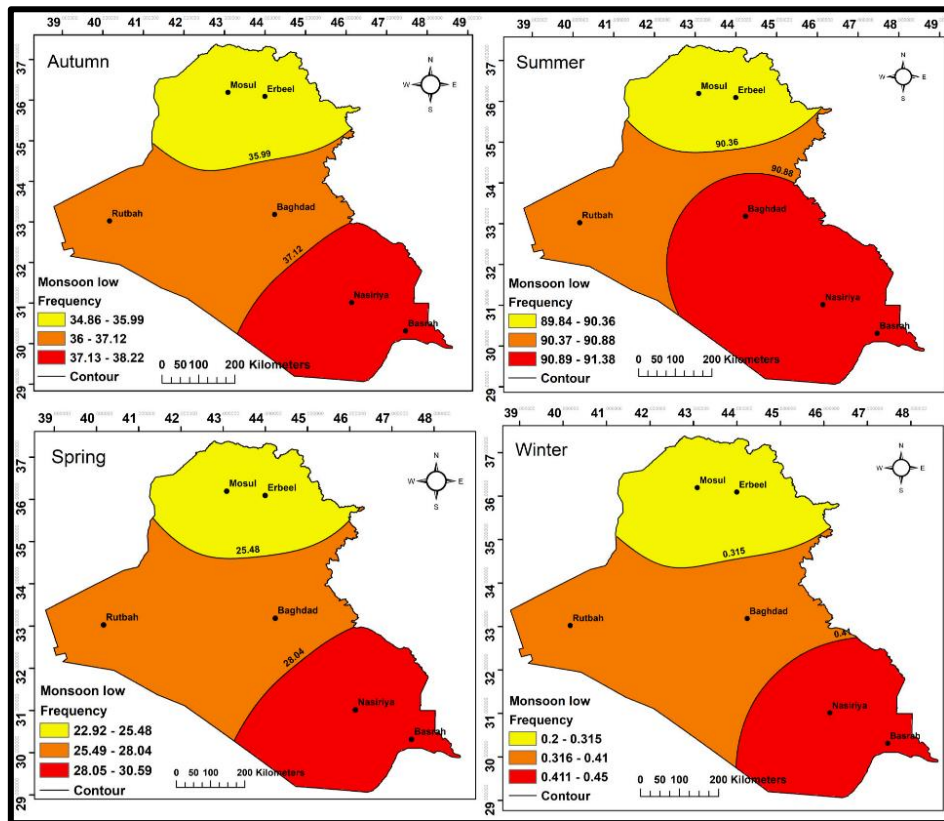


Fig. 7. Spatial distribution of the average frequencies of monsoon lows in Iraq

Figure 8 displays the arrangement of the average frequency of the centers and extensions of the Siberian High in Iraq from 1999 to 2020, categorized by seasons. Typically, there is a rise in frequencies observed in the northern part of Iraq, while there is a decline towards the south. The frequencies experience a substantial increase during the winter season, particularly in the northern region, where they reach a peak value of 38.45 days. The frequencies diminish and become nearly negligible throughout the summer, with the lowest value reaching 0.4 days. The frequency values reach a convergence throughout the spring and autumn seasons, ranging between 22.6 and 13.31 days. There is a significant increase in the northern region and a steady decline in the south.

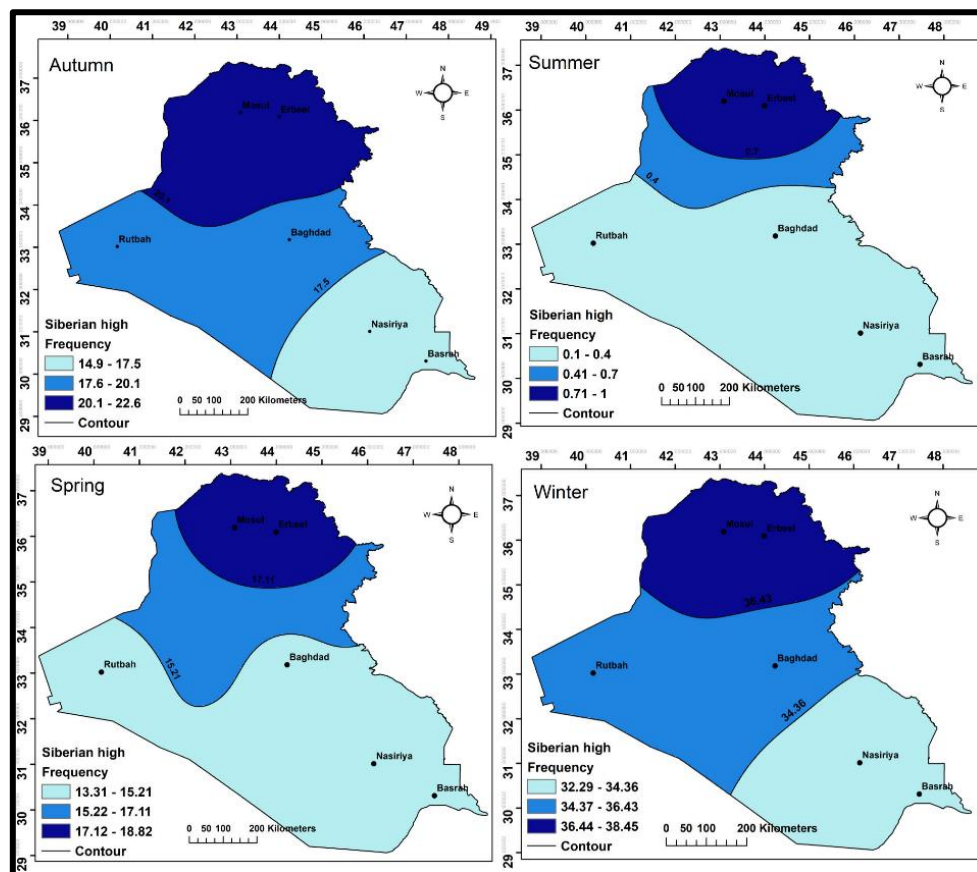


Fig. 8. Spatial distribution of the average frequencies of the Siberian High in Iraq

Figure 9 shows the spatial distribution of the average frequencies of the centers and extensions of the Red Sea depression in Iraq for the period (1999-2020), divided by seasons. There is a noticeable variation in the regions with the highest occurrence rate in the study area. During the spring and autumn seasons, the central region experiences the highest frequency, while in the winter season, it is the southern region, and in the summer season, it is the northern region. This variation is attributed to the disparity in the areas with low entry between the different seasons of the year. The Red Sea depression experiences its highest average frequency during the winter season, with the southern region of Iraq recording the highest number of 23.3 days. The frequency of depression increases in the northern areas. The summer season exhibits the lowest frequency rate, which is nearly negligible, with a minimum value of 0.27 days. Toward the northern regions, the frequency gradually increases. The depression originates in the western region during the spring and autumn seasons. Thus, the center region experienced the highest frequencies over these two seasons.

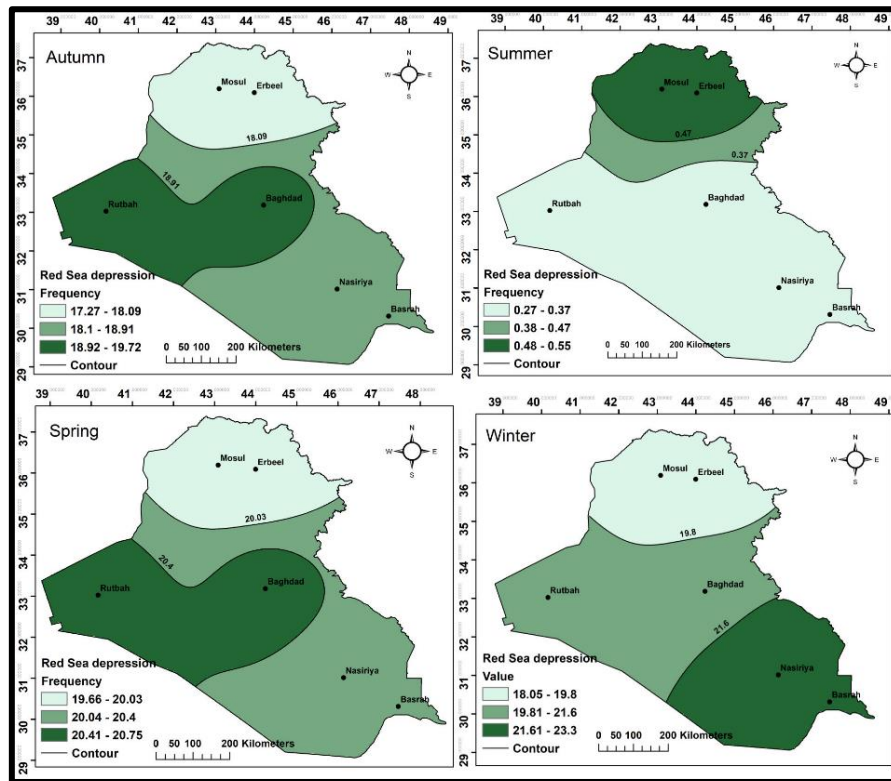


Fig. 9. Spatial distribution of the average frequencies of the Red Sea depression in Iraq

Figure 10 shows the spatial distribution of the average frequencies of Subtropical High centers and extensions in Iraq for the period (1999-2020), divided by seasons. In general, the highest frequencies occurred in the southeastern region of Iraq and gradually decreased towards the north. The highest frequency occurred in the spring season and reached 13.1 days in southern Iraq, followed by the winter season and then the autumn season. The lowest frequency of the high occurred in the summer season and is almost nonexistent, as it reached 0.09 days as the lowest value.

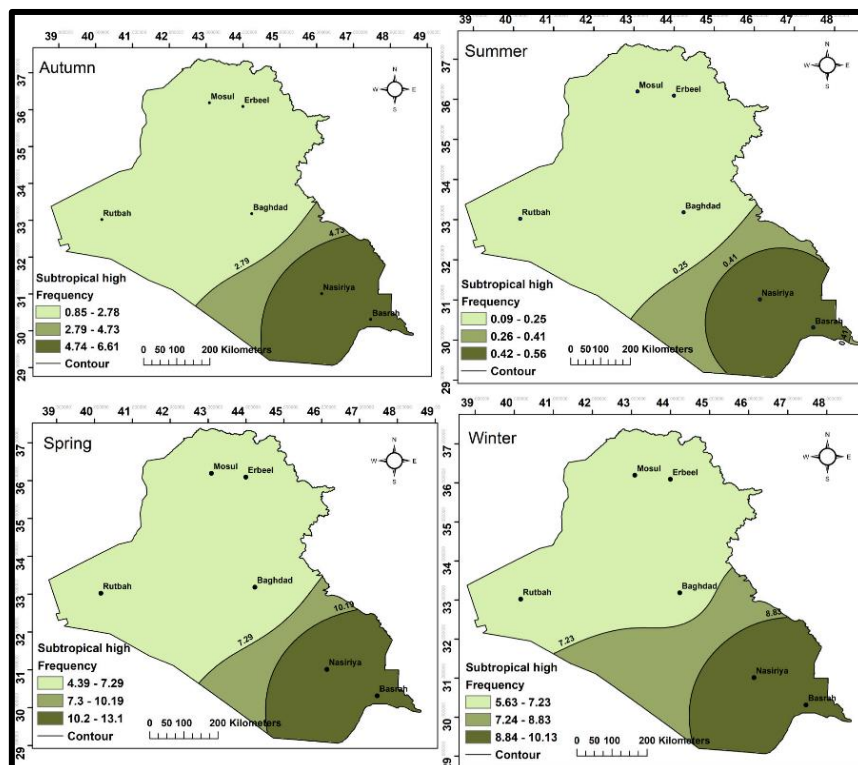


Fig. 10. Spatial distribution of average frequencies of the Subtropical High in Iraq

Figure 11 shows the spatial distribution of the average frequencies of the centers and extensions of the Mid-latitude depression in Iraq for the period (1999-2020), divided by seasons. The highest frequency was recorded in the winter and spring seasons, followed by the autumn season, reaching 3.35 days as the highest value in the winter season. No depression was recorded in the summer at all stations.

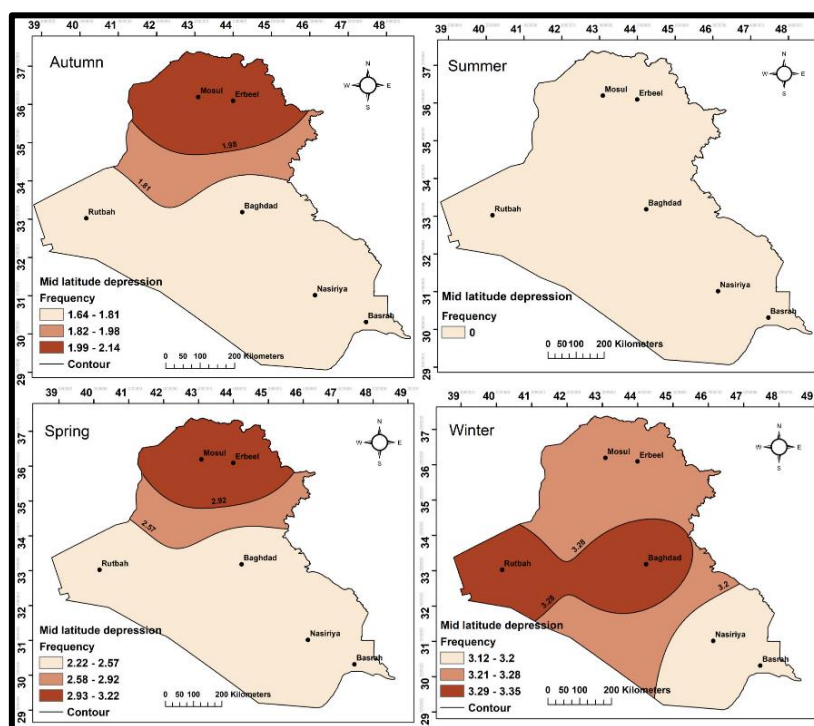


Fig. 11. Spatial distribution of average frequencies of Mid-latitude depressions in Iraq

Conclusions

The atmospheric pressure systems that dominate Iraq's climate include the Monsoon low, Siberian high, Red Sea depression, Subtropical high, and Mid-latitude depression. The monsoon low exerts the most significant influence on the climate throughout the majority of the year, with a duration of 91.38 days in the summer and an annual sum of 126.55 days. The frequency of the monsoon low intensifies in southern Iraq due to its role as the point of entry for the cyclone. The frequency decreases towards the northwest. The occurrence of the Siberian High increases significantly in winter, especially in northern Iraq, where its frequency reaches 38.45 days during the winter and 70.24 days annually. It also occurs during the spring and autumn seasons, but is almost absent during the summer. Red Sea depression increases in frequency in spring and winter, and it also has an impact during autumn, with 20.9 days in winter and 59.76 days per year. The frequencies of weather phenomena rise in the western and central parts of Iraq during the spring and autumn seasons, as these areas serve as the entry point for a low-pressure system. These three systems have the highest occurrence and exert the most significant impact on the climate of Iraq. Subtropical high frequencies are present during the winter, spring, and autumn seasons but are rare in the summer. They occur for 10.14 days in October and 17.66 days throughout the year. High frequency is increasing in the southern region. Mid-latitude depression is infrequent during the winter, spring, and autumn seasons and absent in the summer. The peak frequencies occur during the winter season, with a maximum of 3.35 days. The most elevated frequencies are seen in the center and northern region of Iraq.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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