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Analysis of Variation Characteristics of Rainstorms in Jining City from 1981 to 2020

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Abstract Based on the data of daily precipitation in 11 national ground meteorological observation stations in Jining City from 1981 to 2020, the interdecadal variation, intensity, range and spatial distribution of rainstorms in Jining City were analyzed. The results show that the number of rainstorm days and the total amount of rainstorms in Jining City had significant changes among different decades. There was a continuous upward trend from the 1980s to the early 21st century and a decrease after the early 21st century. Rainstorms had distinct seasonal characteristics. They were mainly concentrated in summer, especially in July and August. In terms of spatial distribution, the frequency and intensity of rainstorms in the southeastern regions were significantly higher than those in the northwestern regions. The above results can provide a scientific basis for flood control and disaster reduction in Jining City.

Key words Rainstorm intensity; Rain range; Interdecadal variation; Jining

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Rainstorms and floods are one of the major natural disasters in China. Heavy rainstorms not only directly cause floods but also trigger secondary disasters such as landslides, rockfalls and mudslides[1 –4]. These disasters not only happen locally but also often affect a large area, causing serious harm to the national economy and people's lives and property. Yuan Wenhua *et al.*[5] proposed that under the background of global warming, the number of days with rainstorms and heavy rainstorms in Shandong Province increased, and drought and flood disasters had distinct regional characteristics.

Jining City is located in the southwest of Shandong Province, at the lower reaches of the Yellow River. It has a warm temperate monsoon climate, with concentrated precipitation and frequent rainstorms in summer. In this paper, based on the data of rainstorms in Jining City from 1981 to 2020, the interdecadal variation, intensity, range and spatial distribution characteristics of rainstorms were analyzed to provide a scientific basis for flood control and disaster reduction in Jining City.

1 Data sources and methods

Based on the data of daily precipitation in 11 national ground meteorological observation stations in Jining City from 1981 to 2020, the interdecadal variation, intensity, range and spatial distribution characteristics of rainstorms in Jining City were studied by means of data statistical analysis and other methods. According to the precipitation within 24 h, rainstorms can be classified into general rainstorms (50 –99.9 mm), heavy rainstorms (100 –249.9 mm), and extremely heavy rainstorms (>250 mm). In addition, rainstorms also can be classified into regional rainstorms and local rainstorms based on their influencing range. If rainstorms appear in three stations in a day at least, they are defined as regional rainstorms; otherwise, they are classified as local rainstorms.

2 General situation of rainstorms

According to statistics, the number of rainstorm days in Jining City reached 1 123 d from 1981 to 2020, and the annual average was 28 d. It can be seen from Table 1 that rainstorms in Jining City were mainly general rainstorms, and the number of general rainstorm days was 950 d, accounting for 84.6% of the total number of rainstorm days. However, the frequency of heavy rainstorms and extremely heavy rainstorms was relatively low, accounting for 15.2% of the total number of rainstorm days. The annual average number of general rainstorm days was about six times that of extremely heavy rainstorms, among which extremely heavy rainstorm only occurred in two days, appearing in August 1993 and 2018 in Weishan and Yutai, and the daily rainfall was 342.5 and 253.6 mm, respectively.

From the perspective of rainstorm range, the proportion of local rainstorms in Jining City in the past 40 years was relatively high, only 88.2%. The proportion of regional rainstorms was relatively small. The annual average number of local rainstorm days was also about three times that of regional rainstorm days, indicating that the influencing areas of rainstorms in Jining City were often relatively scattered.

3 Changing characteristics of rainstorms in Jining City

3.1 Interdecadal variation Fig. 1 shows the changing trends of the annual average number of rainstorm days and total amount of rainstorms in Jining City in different decades. It can be seen that

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the annual average number of rainstorm days and total amount of rainstorms in Jining City generally showed an upward trend from the 1980s to the early 21st century, but decreased after the early 21st century. That is, the frequency of rainstorms and total amount of rainstorms in Jining City fluctuated significantly in decades, namely increasing firstly and then declining.

Table 1 Intensity and range of rainstorms in Jining City from 1981 to 2020

Rainstorm	Numbder of rainstorm days // d	Proportion // %	Annual average number of rainstorm days // d
General rainstorm	950	84.6	23.8
Heavy rainstorm and above	173	15.2	4.3
Regenal rainstorm	133	11.8	3.3
Local rainstorm	990	88.2	24.8

Meanwhile, it is found that the proportion of total amount of rainstorms and the annual average number of rainstorm days in Jining City from 2001 to 2010 was the highest, both up to about 35%, followed by 2011 – 2020. Conversely, the proportion was the smallest from 1981 to 1990, approximately 17%. The maximum of the annual average number of rainstorm days reached 54 d, occurring in 2003. The minimum was only 8 d, appearing in 1988 and 2014. The annual average precipitation from 1981 to 2020 was 2 160.45 mm. The maximum appeared in 2003, reaching 4 280.4 mm. The minimum was only 474.7 mm, appearing in 2014. It can be seen that the number of rainstorm days was directly proportional to the total amount of rainstorms.

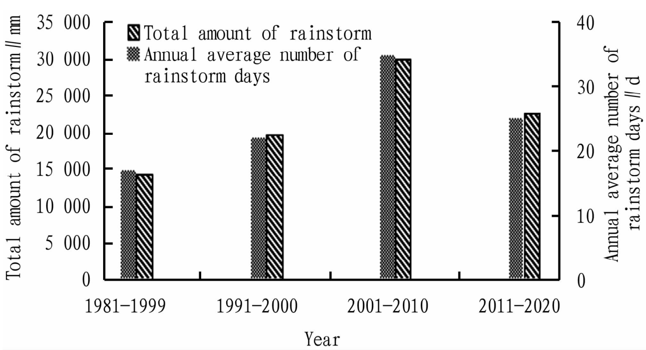

Fig. 1 Interdecadal variation in the annual average number of rainstorm days and total amount of rainstorms in Jining City during 1981 – 2020

3.2 Monthly variation Fig. 2 presents the monthly variation of the total number of rainstorm days in Jining City from 1981 to 2020. As shown in Fig. 2, the total number of rainstorm days in Jining City generally remained stable from January to March, continuously rose from April to July, reached a peak in July, dropped sharply from August to October, and then remained stable again.

It is also found that rainstorms in Jining City had distinct seasonal characteristics, mainly concentrated in summer. Particularly, the number of rainstorm days in July and August was significantly higher than that in other months, accounting for approximately 33.1% and 30.0% of the total number of rainstorm days throughout the year, respectively. The number of rainstorm days was 372 and 336 d, respectively. The number of rainstorm days in June and September was relatively smaller, and they respectively accounted for approximately 13.3% and 9.3% of the total number of rainstorm days throughout the year. Relatively speaking, the occurrence of rainstorms in winter was relatively rare. The number of rainstorm days in December was the smallest, only 6 d, accounting for 0.5% of the total number of rainstorm days. It was also small in February, only 8 d. The number of rainstorm days in spring and autumn was relatively even.

This strong seasonal characteristics were closely related to the climatic features of Jining City. Jining City has a warm temperate monsoon climate. In summer, due to the influence of the southwest airflow and the subtropical high, abundant warm and humid air currents are prone to meet cold air to cause rainstorms. In addition, the strong solar radiation, high ground temperature and vigorous atmospheric convection in summer also provide favorable conditions for the formation of rainstorms.

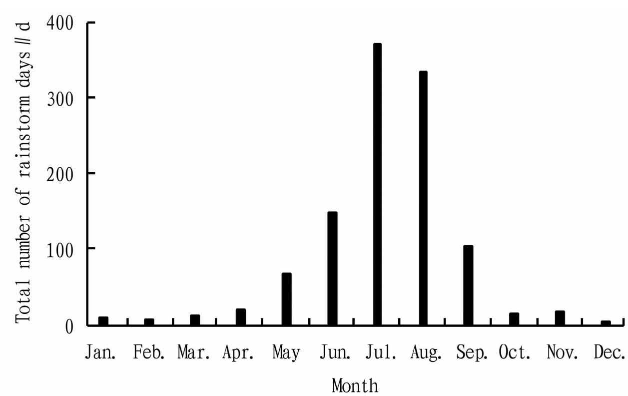

Fig. 2 Monthly variation in the total number of rainstorm days in Jining City from 1981 to 2020

3.3 Variation characteristics of rainstorm range Fig. 3 shows the changing trends of regional rainstorms and local rainstorms in Jining City from 1981 to 2020. The temporal distribution of regional rainstorms and local rainstorms had certain regularity. Overall, in the past 40 years, the rainstorms in Jining City were mainly local rainstorms, with the total number of 990 d and proportion of 88.2%. A total of 133 days of regional rainstorms occurred, accounting for 11.8%.

During 1981 – 2020, the frequency of regional rainstorms showed a slightly increasing trend, rising by 0.414 every 10 a. Among them, the number of regional rainstorm days was the highest in 2009, but the maximum was only 8 d. However, no regional rainstorms occurred in 1988, 2002, and from 2013 to 2014, and local rainstorms were predominant. On the whole, the frequency of regional rainstorms may not show a significant upward or downward trend, but there was a certain interannual fluctuation.

The changing trend of local rainstorms was different from that of regional rainstorms. The occurrence frequency of local predominant rose first, decreased, and slightly increased, rising by 3.996 every 10 a. As can be seen from the figure, the frequency of local rainstorms increased most rapidly from 2003 to 2007, up to the maximum in 2007 (48 d). The number of rainstorm days was also the largest in 2007.

Overall, there were certain interannual fluctuations in the occurrence frequency of regional and local rainstorms in Jining City from 1981 to 2020. The occurrence frequency of regional rainstorms was relatively stable, while that of local rainstorms generally showed an upward trend.

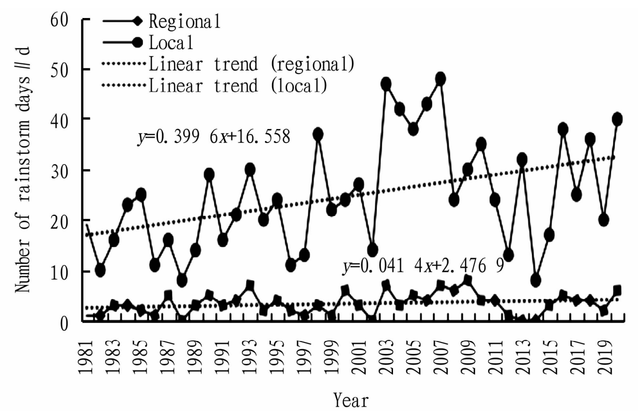

Fig. 3 Changing trend of the number of regional and local rainstorm days in Jining City from 1981 to 2020

4 Spatial distribution of the total number of rainstorm days and total amount of rainstorms

From Fig. 4, it can be seen that the total number of rainstorm days in Jining City varied significantly among different regions. The total number of rainstorm days in the southeast was significantly higher than that in the northwest. Among them, the total number of rainstorm days in Sishui County in the southeast was the largest in the past 40 years, reaching 123 d, accounting for approximately 11.0% of the total number of rainstorm days. It was 114 d in Weishan County and 110 d in Qufu City. On the contrary, the minimum appeared in Liangshan County in the northwest, only 69 d, accounting for approximately 6.1% of the total number of rainstorm days. It was only 89 d in Wenshang County and 99 d in Jiaxiang County.

Fig. 5 shows the spatial distribution characteristics of total amount of rainstorms in Jining City. It can be seen that the spatial distribution of total amount of rainstorms was basically consistent with that of the total number of rainstorm days, and the total amount of rainstorms in the southeast was significantly higher than that in the northwest. This reveals that the frequency and intensity of rainstorms in the southeast were high. The total amount of rainstorms in Sishui County in the past 40 years was 9 138.2 mm, while that in Liangshan County was only 5 316.8 mm.

It can be seen that the frequency of rainstorms in areas close to mountains and lakes was higher, which may be related to the terrain and climatic conditions.

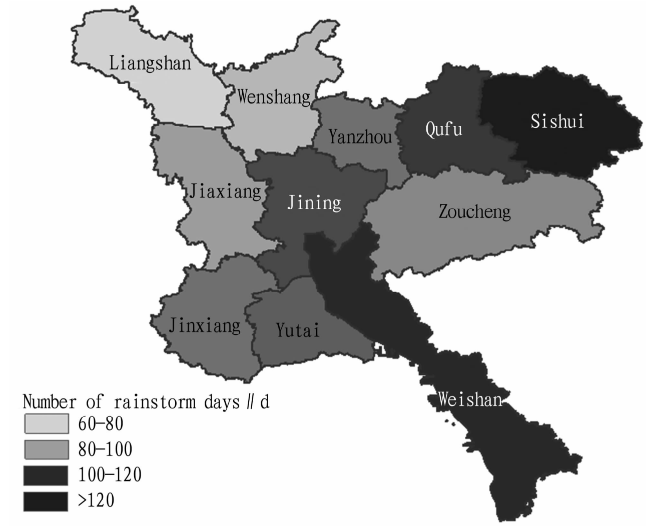

Fig. 4 Spatial variation of the number of rainstorm days in Jining City from 1981 to 2020

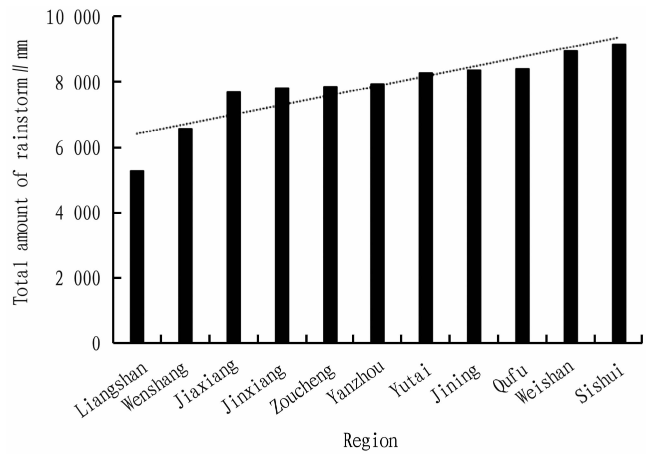

Fig. 5 Total amount of rainstorm in various regions of Jining City from 1981 to 2020

5 Conclusions

(1) In the past 40 years, most of the rainstorms in Jining City were general rainstorms, accounting for 84.6% of the total number of rainstorm days, while the frequency of heavy rainstorms and extremely heavy rainstorms was relatively low. In terms of rainstorm range, local rainstorms occurred more frequently than regional rainstorms.

(2) From 1981 to 2020, the average number of rainstorm days and the total amount of rainstorms in Jining City significantly changed in different decades, both showing a continuous upward trend from the 1980s to the early 21st century, but decreasing after the early 21st century. It also indicates that the number of rainstorm days was directly proportional to the total amount of rainstorms.

(3) The rainstorms in Jining City also had distinct monthly variation characteristics, that is, there was a strong seasonal feature of rainstorms. Rainstorms happened frequently in summer

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strike disaster. The China General Nuclear Power Corporation's wind farm received full compensation from the insurance company.

3 Development trends of meteorological services

3.1 Enhancing the capacity of energy meteorological services It is needed to carefully study the *Implementation Plan for Energy Meteorological Services in Inner Mongolia* issued by the Meteorological Bureau of Inner Mongolia Autonomous Region, clarify important tasks, and accelerate the improvement of energy meteorological service capabilities. Firstly, efforts should be made to enhance the capacity for resource assessment, meteorological conditions and climate change should be studied and analyzed for the further development of wind and solar energy resources and site selection. Secondly, it is needed to give full play to professional advantages, strengthen meteorological guarantee services for the normal operation and maintenance of wind and solar power stations, and provide services for disaster prevention and mitigation during the operation of stations under extreme weather conditions. Finally, to meet the diversified demands for energy meteorological services, it is necessary to explore precise forecasting technologies for wind and solar power generation, establish an integrated meteorological service platform, enhance the capacity for diversified service support, achieve full coverage of meteorological disaster early warning services for energy supply security, and promote the sustainable development of energy industry.

3.2 Promoting and applying digital information technology Based on the big data sample library of historical weather in Ulanqab City, superalgorithms are used to refine longitude and latitude coordinates as much as possible in space and narrow the grid of prediction data. Meanwhile, it can continuously increase the prediction frequency of meteorological elements in time, and update the data every hour in case of various extreme weather. When sand and dust weather occurs, for the prediction of photovoltaic power generation output, the influence of sand cover thickness on power generation can be obtained by using the supercomputer operation model. Algorithms can be used to establish precise prediction models for wind power output under various extreme weather conditions such as high temperatures, and cold waves, thereby achieving detailed classification and accurate forecasting. Information technologies such as big data and artificial intelligence are promoted and applied to enhance the ability to predict weather changes, making the development of wind and solar power generation energy industry more stable and more efficient[4].

4 Conclusion

The installed capacity of new energy sources such as wind power and photovoltaic power in Ulanqab City is getting larger and larger, and it has become an important energy base in China. Meanwhile, the development of wind and solar power industry must rely on accurate weather forecasts and meticulous services. In the face of the accelerated transformation of energy industry, meteorological departments should fully grasp the ability of weather and climate change, give full play to the role of "meteorology + energy", strengthen the research and development of numerical model forecast products for wind and solar energy, carry out short-term revised forecasts, continuously optimize algorithm models, produce multi-element prediction products at different time and space scales, continuously improve the level of energy meteorological services, and establish an energy meteorological service system that meets market demands to ensure the sustainable development of wind and solar power generation.

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(especially July and August). They were relatively rare in winter (December, January and February).

(4) The temporal distribution of regional and local rainstorms in Jining City also had certain regularity. The frequency of regional rainstorms was relatively stable, while the frequency of local rainstorms generally showed an upward trend.

(5) There were significant differences in the spatial distribution of the number of rainstorm days and the total amount of rainstorms in Jining City. The frequency and intensity of rainstorms in the southeast were significantly higher than those in the northwest.

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