

Analysis of precipitation concentration degree changes and its spatial evolution in the western plain of Jilin Province

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सार – इस शोध पत्र में जिलिन के पश्चिमी मैदानों में फसल संवर्धन के मौसम के दौरान वर्षा की सांद्रता की डिग्री और अवधि के अस्थायी और स्थानिक विकास का अध्ययन सिंचाई की रणनीति को समायोजित करने के लिए किया गया है। परिणाम इस प्रकार हैं: लगभग 35 वर्षों में, शुरुआती मौसम के दौरान वर्षा की कमी ने अंतर-वर्षा में कमी लाने में अधिक योगदान दिया है। अधिकतम वर्षा और वर्षण की अवधि में मामूली गिरावट देखी गई है जबकि न्यूनतम वर्षा की स्थिति विपरीत रही है। वर्षा की अवधि का क्रम धीरे-धीरे पश्चिम से पूर्व की ओर बढ़ता गया है। पिछले 35 वर्षों में, वर्षा की सांद्रता डिग्री (PCD) “ $y = -0.0018x + 0.4655$ ” के रेखिक फलन से कम हो गई जो यह दर्शाता है कि वर्षा ने संतुलित वितरण की प्रवृत्ति दिखाई है। वर्षा की सांद्रता डिग्री (PCD) उत्तर-पश्चिम से दक्षिण पूर्व की ओर घटी है। वर्षा की सांद्रता अवधि (पीसीपी) से यह पता चलता है कि यह जुलाई की शुरुआत से जुलाई के अंत तक बदल गया है। संक्षेप में, इस क्षेत्र में सूखा-तैयारियों की आकस्मिकता की योजना को मजबूत करना महत्वपूर्ण था।

ABSTRACT. In order to study temporal and spatial evolution of the precipitation concentration degree and period in Western Plains of Jilin during the crop growing season and then adjust irrigation strategy, this paper studied the spatial and temporal characteristics of precipitation. Results are as follows: In the growing season from nearly 35 years, the decrease of precipitation during the growing season contributed more to the reduction of interannual precipitation. The maximum precipitation and precipitation duration showed a slight downward trend whereas the minimum precipitation was reversed. Precipitation duration gradually increased from west to east. In the past 35 years, the precipitation concentration degree (PCD) decreased by linear function of “ $y = -0.0018x + 0.4655$ ”, indicating that the precipitation exhibited a trend of balanced distribution. The PCD decreased from the northwest to the southeast. From the precipitation concentration period (PCP), it changed from early July to late July. In summary, it was important to strengthen the staged drought-preparedness contingency plans in the region.

Key words – Precipitation concentration degree, Precipitation concentration period, Trend analysis, Western plains of Jilin.

1. Introduction

Precipitation is an important indicator when studying the extent of floods in an area. When the precipitation per unit time is too heavy, it may cause flooding. The interannual precipitation in the western plain of Jilin Province is unevenly distributed in time and space, accounting for about 70% of the annual precipitation (Liu *et al.*, 2015). In general, scholars in China generally use the annual or monthly average precipitation to discuss the long-term trend of precipitation, analyze temporal and spatial distribution characteristics of precipitation (Feng *et al.*, 1998 and Wang *et al.*, 1997). In fact, the spatial and temporal distribution of precipitation is non-uniform each

year. Although these research methods can indicate basic state and change of precipitation in a certain extent, they cannot highlight the characteristics of maximum or minimum precipitation and precipitation concentration degree in a certain period. However, the latter is very important in studying climate disasters such as droughts or heavy rains and floods (Li and Qian, 2006). Taking the daily precipitation data of five sites from 1951 to 2003 in the west of Jilin Province (Changling, Baicheng, Qian Gorlos, Qian'an, Tongyu) as an example, average precipitation in the region for half a century was 301 mm, maximum variation was 292.22 mm. The ratio of maximum to minimum summer precipitation was 3.13-7.38. The longest continuous precipitation that occurs

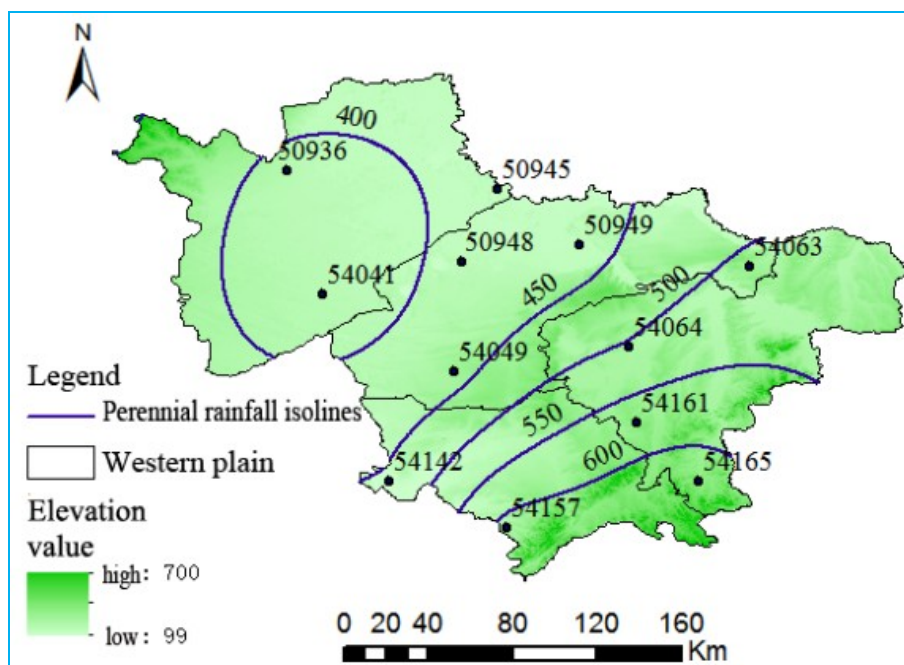


Fig. 1. Multi-year average precipitation and topography in the western plain of Jilin

in Changling lasted beyond 10 days meanwhile the longest continuous drought without precipitation lasted for 26 days that occurs in Baicheng (Wang and Wu, 2007). The focus of previous researches were on the analysis of average or extreme precipitation, but the concentration degree of precipitation is rarely studied, especially in the western plain of Jilin. Precipitation concentration degree (PCD) and concentration period (PCP) are two good parameters for quantitatively characterizing concentration and dispersion degree, which play an important role in study of floods. Therefore, PCD and PCP have a great significance for guiding irrigation and flood control in irrigation districts (Zhang and Qian, 2003; Zhang *et al.*, 2007). The research content mainly includes the following aspects: (i) analysis of the basic evolution characteristics of precipitation in the western plain of Jilin Province; (ii) analysis of PCD and PCP as well as their evolution trends in the growing season.

2. Data and methodology

2.1. General situation of Jilin Western plains

The western plain area of Jilin Province located in the southwest of Songnen Plain, including Baicheng, Songyuan, Changchun and Siping. The transportation is convenient, with a total area of 180,000 square kilometers. The western plain area is affected by a temperate continental monsoon climate, transitioning from a semi-

humid zone to a semi-arid zone from east to west, with evaporation greater than precipitation. From Fig. 1, precipitation was mainly concentrated in summer, accounting for 60%-80% of annual precipitation.

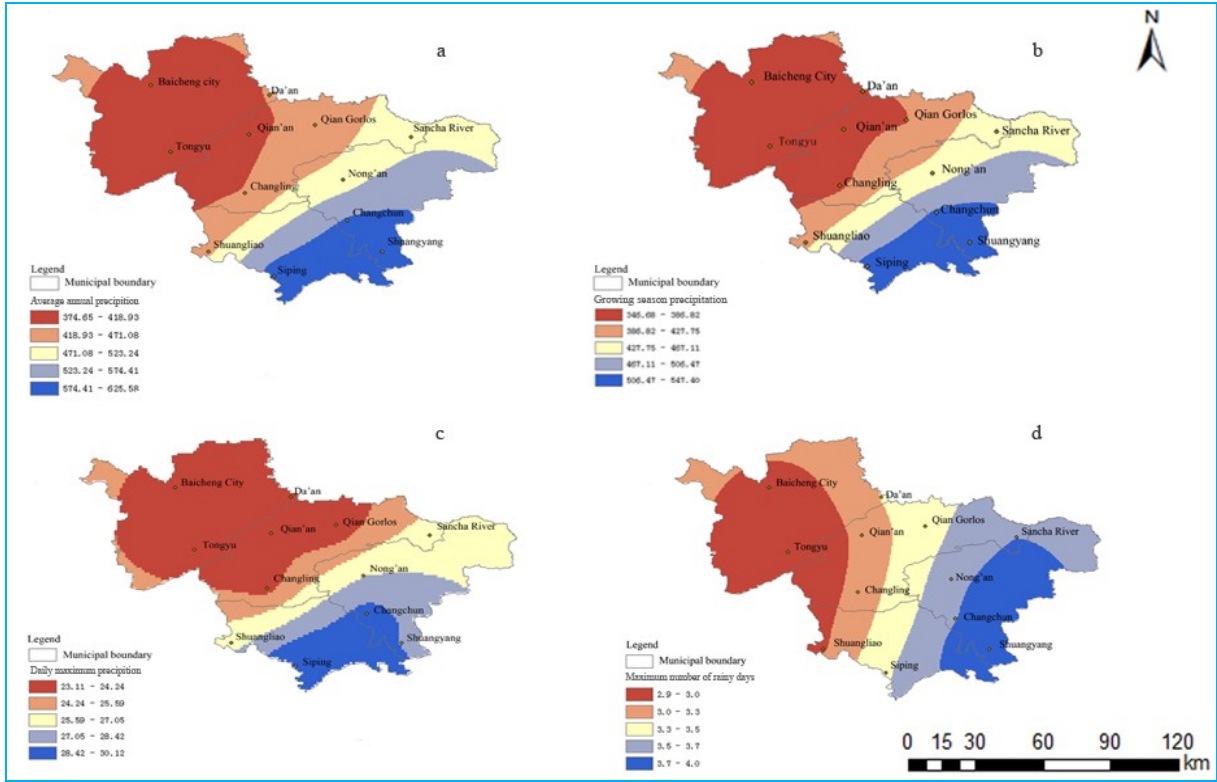
2.2. Precipitation concentration degree and period

PCD reflects the concentration degree of total precipitation during the study period. During the study period, PCD is the ratio of the modulus of composite vector to the total amount of precipitation within a certain time. If annual total precipitation totally concentrates on a specific month, the maximum one of yearly PCD can be obtained.

If the amount of precipitation is equal for each time, their components are accumulated and the value of PCD is zero. PCP is the azimuth of composite vector reflects the concentration time of precipitation during the study period.

Calculating PCD and PCP are based on the vector of monthly total precipitation. The assumptions can be made that monthly total precipitation is a vector quantity with both magnitude and direction for a year can be seen as a circle (360°). Then the yearly PCP and PCD for a location can be defined as follows:

$$PCD_i = \sqrt{R_{xi}^2 + R_{yi}^2} / R_i \quad (1)$$



Figs. 2(a-d). Variations of precipitation

$$PCP_i = \arctan(R_{xi} / R_{yi}) \quad (2)$$

In the formula:

$$R_{xi} = \sum_{j=1}^N r_{ij} \times \sin \theta_j; R_{yi} = \sum_{j=1}^N r_{ij} \times \cos \theta_j;$$

R_i is the annual precipitation during the study period of a station; r_{ij} is the amount of monthly precipitation in a study period; θ_j is the azimuth corresponding to each moment in the study period; i is the year ($i = 1961, 1962, \dots, 2014$); j is the month ($j = 1, 2, \dots, 12$) in a year. PCP represents the period (month) in which the annual precipitation of the i th year concentrates and PCD represents the degree that the annual precipitation of the i th year concentrates in 12 months. Based on Equations, yearly PCP, as the azimuth of composite vector, implies the population effect of each monthly precipitation after being composited. Therefore, yearly PCP can reflect which month the maximum monthly precipitation. Yearly PCD can reflect the degree to how annual total precipitation is distributed in 12 months. The range of yearly PCD is from 0 to 1. In this article, the precipitation concentration period at $0-60^\circ$ belongs to April, the same as $60^\circ-120^\circ$ is May;

$120^\circ-180^\circ$ is June; $180^\circ-240^\circ$ is July; $240^\circ-300^\circ$ is August; $300^\circ-360^\circ$ is September. The maximum precipitation is the maximum rainfall during the crop growing season. In the same way, the minimum one is minimum rainfall. The maximum precipitation duration means the longest time that a rainfall can last. Extreme value ratio is the ratio between annual maximum precipitation and annual minimum precipitation in the statistical period to represent the inter-annual change of precipitation.

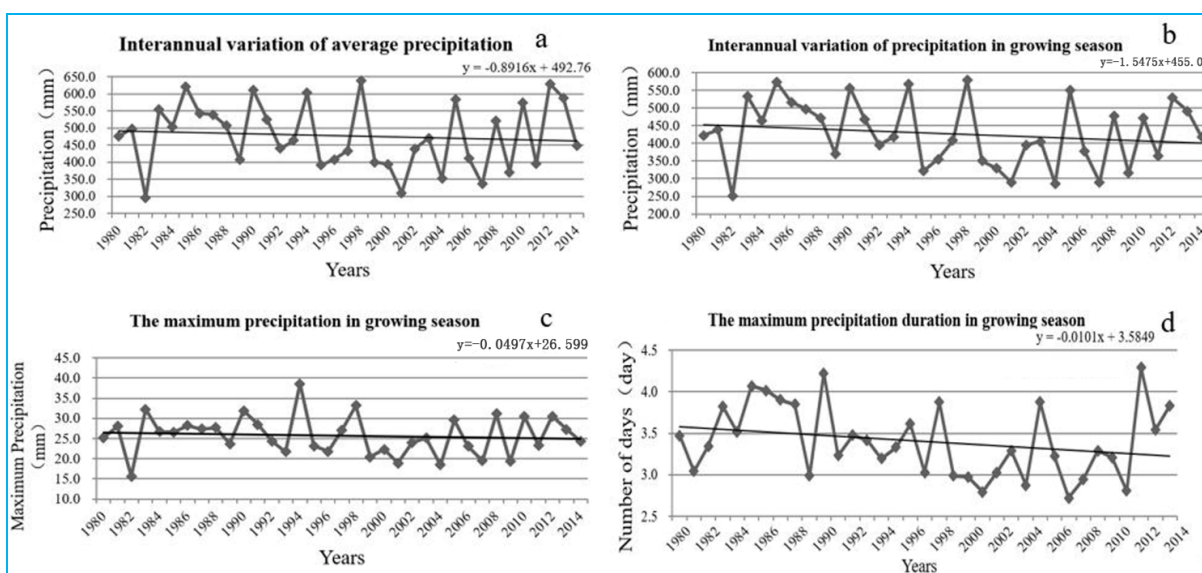
2.3. Analysis method

Rstudio software based on R language was used to conduct trend analysis by Mann-Kendal detection to comprehensively reflect the evolution trend of PCD and PCP in the western plain of Jilin. ArcGIS-10.4 software was used to analyze temporal and spatial evolution of precipitation including PCD, PCP and the trend of above items.

3. Results and discussion

3.1. Interannual precipitation

From Fig. 2(a), it shows that the year with maximum precipitation was 1998; the maximum precipitation was



Figs. 3(a-d). Spatial variation of precipitation in the western plain of Jilin Province

638.1 mm. The year with the minimum precipitation (296.5 mm) was 1982. The extremum ratio was 2.15. It can be seen from the table that overall precipitation showed a slight downward trend.

From the spatial analysis in Fig. 3(a), we can see that the maximum precipitation was 625.5mm occurring in Shuangyang. The minimum precipitation was 374.7mm that occurring in Tongyu. At the same time, it shows that the annual precipitation from the west to east of the western plain was increasing. The annual precipitation distribution was uneven. Considering the precipitation in Siping and Shuangyang, more attentions should be paid to flood prevention during the rainy season to prevent the loss of people's economic assets.

3.2. Precipitation in growing seasons

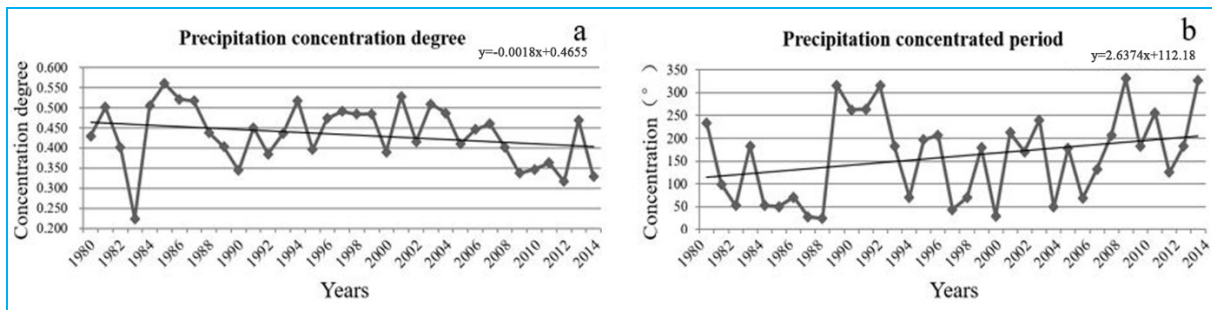
Figs. 2(b) and 3(b) show temporal and spatial distribution characteristics of precipitation during the crop growing season respectively. It can be seen from Fig. 2(b) that the maximum precipitation in the growing season was 580.2 mm in 1998; the year with the smallest precipitation (250.2 mm) in the growing season was 1982. And the extreme ratio was 2.31. At the same time, the annual precipitation in the growing season from 1980 to 2014 showed a slight downward trend and the precipitation in the growing season decreased faster than the interannual precipitation, indicating that the reduced precipitation during the growing season contributes more to the reduction in interannual precipitation. The study was consistent with the results by Liu *et al.* (2017) and Sun & Gao (2000). They found that the precipitation in Jilin

Province in Northeast China showed a decline trend for many years, which was closely related to the lack of rainfall in the growing season. At the same time, it shows that the annual precipitation in the growing season from west to east was increasing.

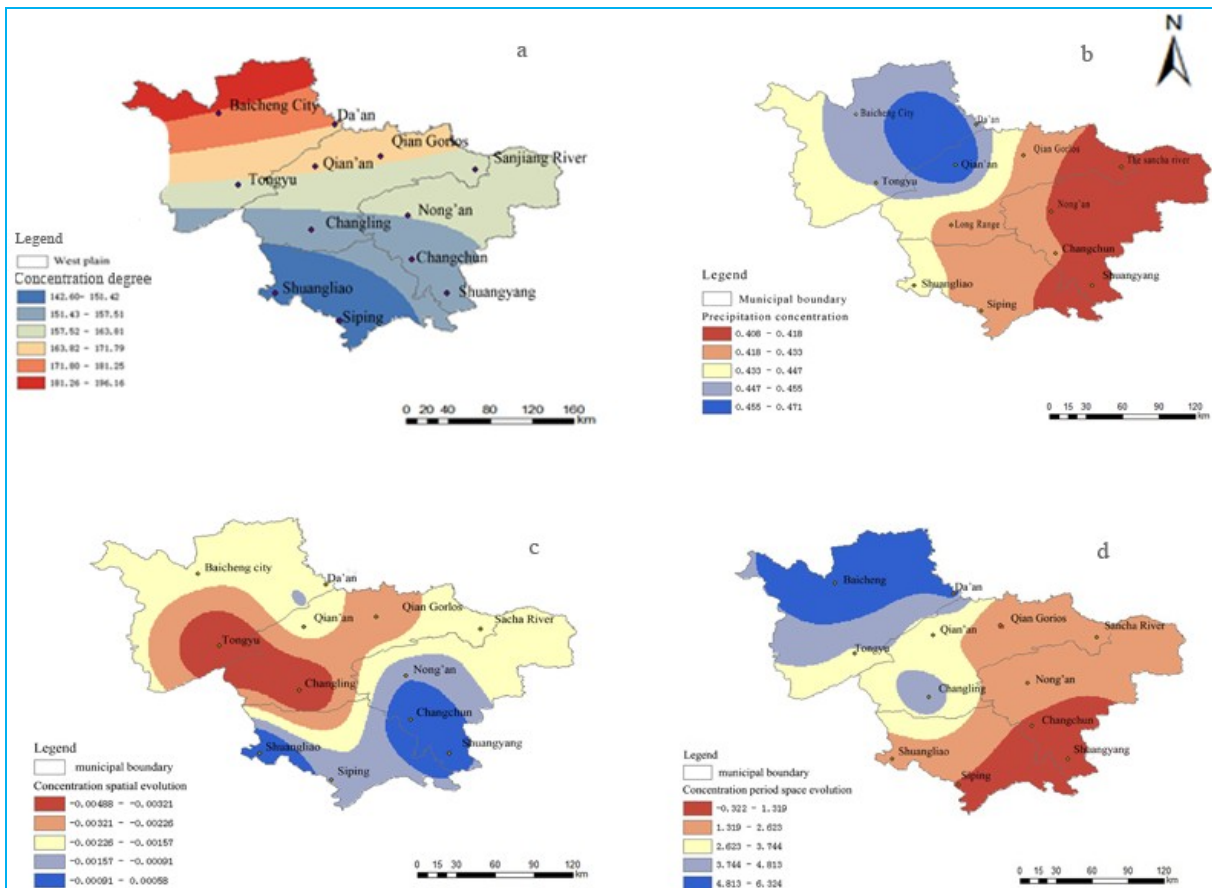
3.3. Spatio-temporal distribution of the maximum precipitation

Figs. 2(c) and 3(c) show temporal and spatial distribution characteristics of maximum precipitation during the crop growing season respectively. As shown in Fig. 2(b), the maximum value of annual precipitation occurred in 1994 at 38.6 mm; the minimum value of the annual maximum precipitation occurred in 1982 at 15.7 mm in Fig. 3(c). It can be seen from the trend line that the maximum annual precipitation showed a slight downward trend. And the fluctuations were more intense in the 80s and 90s, but smaller after 00 years. The Nong'an, Shuangliao and Shuangyang areas were still with severe changes in maximum precipitation.

As shown in Fig. 3(c), the maximum precipitation location occurred in Siping. The maximum precipitation value was 30.1mm. The minimum precipitation location occurred in Qian Gorlos. The minimum value was 23.1mm. Distribution of maximum precipitation during the growing season was consistent with that of annual average precipitation. The maximum precipitation is an important indicator of compensatory irrigation for drought (Kong and Tong, 2008; Wu *et al.*, 2016). Therefore, we studied this indicator and found that the maximum precipitation and average precipitation in the region were very little,



Figs. 4(a&b). Precipitation concentration



Figs. 5(a-d). Spatial variation of precipitation concentration, period and their evolution trends in the western plain of Jilin Province

which would result in reduced production of many crops under rain-fed cultivation mode.

3.4. Temporal and spatial distribution of precipitation duration

Figs. 2(d) and 3(d) show temporal and spatial distribution characteristics of precipitation duration during the crop growing season respectively. The maximum value of maximum precipitation duration was 4.3 days in

2012; the minimum value of maximum precipitation duration was 2.7 days in 2007. The extremum ratio was 1.59. The trend line that the maximum precipitation duration showed a slight downward trend, indicating that the number of days of maximum precipitation duration was getting smaller.

As shown in Fig. 3(d), the site where the maximum value of maximum precipitation duration lasts (4.0 days) was Shuangyang. The site where the minimum value of

TABLE 1
Precipitation concentration degree in the western plain of Jilin Province

Site	Baicheng	Da'an	Qian'an	Qian Gorlos	Tongyu	Changling
K	-0.0018	-0.0019	-0.0018	-0.0030	-0.0049	-0.0045
Tau	-0.0487	-0.1025	-0.1025	-0.1866	-0.2336	-0.1933
P	0.69	0.39	0.39	0.12	0.05	0.11
Site	Sancha River	Nong'an	Shuangliao	Siping	Changchun	Shuangyang
K	-0.0018	-0.0010	0.0006	-0.0011	-0.0003	-0.0002
Tau	-0.0521	0.0050	0.0151	-0.0689	-0.0958	0.0353
P	0.67	0.98	0.91	0.57	0.43	0.78

Note : K is the slope of the trend equation; TAU is the trend value detected by M-K

TABLE 2
Precipitationconcentrationperiod in the western plain of Jilin Province

Site	Baicheng	Da'an	Qian'an	Qian Gorlos	Tongyu	Changling
K	6.4324	5.2586	2.4468	1.0469	3.4857	4.8069
Tau	0.2202	0.2235	0.1664	0.1462	0.1462	0.2403
P	0.05	0.05	0.16	0.22	0.22	0.04
Site	Sancha River	Nong'an	Shuangliao	Siping	Changchun	Shuangyang
K	2.2987	2.5287	1.6113	1.2361	0.9148	-0.4187
Tau	0.2403	0.2034	0.1933	0.0185	0.1597	-0.1261
P	0.04	0.09	0.11	0.89	0.18	0.29

maximum precipitation duration lasted was Tongyu and the minimum value was 3. Their extremum ratio was 1.33. At the same time, it shows that the short duration of precipitation in the west was an important factor leading to drought or crop yield reduction in this region. Sun and Gao (2000) and Wu *et al.* (2019) always believed that a longer drought cycle and duration of rainfall resulted in regional droughts.

3.5. Precipitation concentration degree

Figs. 4(a) and 5(a) show temporal and spatial distribution characteristics of precipitation concentration degree during the crop growing season respectively. The maximum PCD was 0.560 in 1985; the minimum PCD was 0.224 in 1983 and the extremum ratio was 2.5. It can be seen from the trend line that the overall PCD has declined slightly over the past 35 years, indicating that precipitation became more uniform.

As shown in Fig. 5(a), it shows that the PCD from the northwest to the southeast was decreasing. However, since the maximum and minimum values were not much

different, the change was not very drastic. A higher PCD (close to 0.5) of the western part of the Plain indicated that the irregular precipitation in this area was likely to lead to sudden drought in some years. In most of studies, the researches on PCD were mainly concentrated on the time scale. For the western plain of Jilin Province, the research on the spatial scale was very rare. In our results, it shows that the probability of concentrated precipitation or uniform precipitation in the future was very low, which was consist with the research on precipitation concentration degree in Songyuan city of Jilin province by Chi *et al.* (2015).

3.6. Precipitation concentration period

Figs. 4(b) and 5(b) show temporal and spatial distribution characteristics of PCP during the crop growing season respectively. On an interannual scale, PCP was in April for eight years, accounting for 22% of the total number of concentration periods; in May for 5 years, accounting for 14% of the total number of concentration period; in June for 5 years, accounting for 14%; in July for 9 years, accounting for 25%; in August for 4 years,

accounting for 11%; in September for 4 years, accounting for 11%. It shows that the precipitation was likely to be concentrated in July. At the same time, we can see from the trend analysis that the precipitation had a tendency ($k = 2.64$) to change towards August.

However, as shown in Fig. 5(b), the precipitation only in Baicheng was concentrated in July, the precipitations in other 11 sites were concentrated in June. Precipitation in Shuangliao and Siping were concentrated in the early June whereas precipitations in Changling, Changchun, Shuangyang and Nong'an were concentrated around mid-June. And precipitations in the rest sites were concentrated around the end of June. The PCP is an important indicator for judging when precipitation is concentrated (Javier *et al.*, 2004; Li *et al.*, 2011).

3.7. Evolution tendency of precipitation concentration degree and period

In Table 1, the evolution tendency of PCD was analyzed using Mann–Kendall trend detection. Only in Tongyu site, the downtrend of the PCD reached a significant level ($P \leq 0.05$). At the same time, PCD in Nong'an, Shuangyang exhibited a steady trend; while PCD in Shuangliao showed an upward trend, indicating that precipitation in Shuangliao was more and more concentrated. Fig. 5(c) shows that the decline rate of PCD in the west was considerable, while the decline trend of PCD in the east was very small.

In Table 2 and Fig. 5(d), in Baicheng, Da'an, Changling, Sancha River, PCP presented an almost significant upward trend. The PCPs in most regions showed upward trends, explaining that the concentration period in these areas might move to the next growth period in the future. From the spatial scale, the PCP in the western part with the least precipitation changed very significantly. The decline of PCP in this area was relatively large, indicating that the concentration period might shift from June to July in the western part, while the changes in PCP in the east were not obvious.

The above data shows that in the western plain of Jilin Province, the change in concentration period is greater than the concentration degree, indicating that changes in PCD were relatively stable, but PCP would shift from June to July. Therefore, in the future, it is necessary to prevent drought in the early stage of crop growth especially in June.

4. Conclusions

In order to provide irrigation planning for the western plains of Jilin, this paper studied the spatial and

temporal distribution characteristics of precipitation concentration degree and concentration period in the western plain of Jilin Province. The findings and conclusions are as follows:

In the past 35 years, the precipitation in the western plain of Jilin showed a trend of balanced distribution and the degree of uniform distribution tended to be stable. From the concentration period, the precipitation concentration period showed an increasing trend, indicating that the precipitation in the area had the tendency to concentrate from July to late July. From the perspective of space scale, the precipitation concentration period in the four regions of Baicheng, Da'an, Changling and Sancha He had a significant tendency to delay. As the precipitation concentration period tended to delay, so it was important to strengthen the staged drought-preparedness contingency plans in the region.

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References

- Chi, D., Wang, Z., Chen, T., Xu, X. and Zhang, R., 2015, "Application of Monte Carlo and ARIMA Models for Precipitation Forecast", *Journal of Shenyang Agricultural University*, **46**, 2, 187-191.
- Feng, Q., Wang, G. and Li, S., 1998, "Temporal and spatial changes of precipitation in China and storms and floods", *Journal of Natural Disasters*, **7**, 1, 87-93.
- Kong, Y. F. and Tong, W. W., 2008, "Spatial exploration and interpolation of the surface precipitation data", *Geographical Research*, **27**, 5, 1097-1108.
- Li, S. and Qian, Y., 2006, "A New Method for Studying temporal and Spatial Evolution Characteristics of Precipitation in China during the Year", *Journal of Nanjing Institute of Meteorology*, **29**, 3, 314-321 (Chinese with English Abstract).
- Li, X., Jiang, F., Li, L. and Wang, G., 2011, "Spatial and temporal variability of precipitation concentration index, concentration degree and concentration period in Xinjiang", *China. International journal of climatology*, **31**, 1679-1693.
- Liu, B., Xiao, C. and Liang, X., 2015, "Evaluation of spatial and temporal characteristics of precipitation variations in Jilin Province Northeast China", *Theoretical and applied climatology*, **122**, 1-2, 129-142.

- Liu, J., Shan, L., Han, C. and Zheng, H., 2017, "Spatial-temporal Pattern Analysis of Rainfall Nearly 50 Years in Western Jilin Province", *Journal of Jilin Normal University*, **238**, 1, 131-133.
- Martin, V. J., 2004, "Spatial distribution of a daily precipitation concentration index in peninsular Spain", *International Journal of Climatology*, **24**, 8, 959-971.
- Sun, A. J. and Gao, B. A., 2000, "A diagnostic Analyses of Serious Flood/drought During Summer Season in the North China Plane", *Chinese Journal of Atmospheric Sciences*, **24**, 3, 393-402 (Chinese with English Abstract).
- Wang, J., Gu, W. and Yao, H., 1997, "Seasonal Changes of Precipitation and Heavy Rain in China", *Advances in Water Science*, **8**, 2, 108-116.
- Wang, Y. and Wu, Z., 2007, "Study on temporal and Spatial Regularity of Summer Precipitation and Rainstorm in the Semi-arid Region of Western Jilin Province", *Journal of Arid Land Resources and Environment*, **5**, 21-5.
- Wu, Q., Chi, D., Xia, G., Chen, T., Sun, Y. and Song, Y., 2019, "Effects of Zeolite on Drought Resistance and Water-Nitrogen Use Efficiency in Paddy Rice", *Journal of Irrigation and Drainage Engineering*, DOI:10.1061/(ASCE)IR.1943-4774.0001420.
- Wu, Q., Xia, G., Chen, T., Zheng, J., Bu, F. and Chi, D., 2016, "Effects of Nitrogen and Zeolite on Rice Grain Yield, Water and Nitrogen Use and Soil Total Nitrogen in Coastal Region of Northeast China", *Communications in Soil Science and Plant Analysis*, **47**, 18, 2103-2114.
- Zhang, L. and Qian, Y., 2003, "Annual distribution features of precipitation in China and their inter annual variation", *Acta Meteorologica Sinica*, **17**, 2, 146-163 (Chinese with English Abstract).
- Zhang, T., Cheng, B., Wang, J., Zhang, Y. and Liu, X., 2007, "Temporal and Spatial Variation Characteristics of Precipitation Concentration and Concentration Period in North China Rainy Season", *Plateau Meteorology*, **26**, 4, 843-853 (Chinese with English Abstract).
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