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Research Article

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The spatial variation characteristics of water requirements for main crops in Sichuan Province, P. R. China

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ABSTRACT

Through the website of International Water Management Institute, the referenced evapotranspiration (ET_0) was found which was calculated by the meteorological data during 1961-1999 from 147 stations in Sichuan Province. Further, according to the crop coefficients of rice, maize, wheat, rape, the water requirements (ET) of main crops were estimated by using Food and Agriculture Organization (FAO) Penman-Monteith equation. The spatial distribution characteristics of ET_0 were drawn by Spatial Interpolation method by means of Geographic Information System (GIS). Results showed that: (1) the maximum and minimum of ET_0 were at summer and winter respectively, and the maximum of ET_0 in three climatic sub-zones occurred at different times; (2) the crop growth stage was different, so ET of different crop was significantly different, and ET of crops at the same region from high to low were: rice> maize> wheat> rape; (3) spatial distribution of crop water requirements changed largely, and the high-value zone of crop water requirement was mainly distributed in the southwest mountain areas, and the most areas of Aba belonged to low-value zone.

Keywords: crop; water requirement; spatial distribution; ET_0

INTRODUCTION

Using the historical climatic data to analyze the variation characteristics of water requirement will contribute to have a deep and good understanding of water requirement to the drought and flood regularity of occurrence under the circumstances of Global Warming. In terms of the variation of water requirements for main crops, Tang *et al*[1]calculated the potential evapotranspiration (ET_0) in every month by using the Penman-Monteith equation, according to the monitoring data of 10 meteorological stations during the years 1951-2009 in the Ning Xia hui Autonomous region, and Kriging interpolation showed that ET_0 decreased from north to south in the study area. Gao *et al* [2] analyzed the temporal and spatial distribution characteristics and the variation tendency of the potential ET_0 in the main ten watersheds of China, and discussed the main climatic factors which causing the variation of potential ET_0. Yang *et al* [3] analyzed the temporal and spatial variation of water requirements for main corns in growth period and irrigation period at spring and summer in the Yellow-Huaihe-Haihe region, and discussed the correlation between the water requirements for crops and climatic factors. Wang *et al* [4] probed into the spatial distribution characteristics of water requirement for wheat in Middle Reaches of the Heihe River by using the method of GIS, and the results showed that the water requirements of wheat presented an increasing tendency from south to north. Li *et al* [5] analyzed the information of water requirements for single-cropping and double-cropping rice in the Middle and Lower Reaches of the Yangtze River, and the water requirements of single-cropping rice decreased in growth period.

Nowadays, there is a lot of researches about the water requirement of crops in Sichuan Province.

For example, Zhang *et al* [6] analyzed the relationship between the variation of field water budget and climate change for three crops in the growth period in Sichuan different climatic zones over nearly 40 years. Zhou *et al* [7] analyzed the variation and the period characteristics of the atmospheric precipitation in Sichuan. Chen *et al* [8] investigated the variation characteristics of ET_0 for main crops and the principal climatic factors in 5 basin stations and 5 plateau stations in Sichuan Province from 1961 to 2009. But the studies by using the method of GIS for allocating the water requirement of crops do not have been much applied in Sichuan Province. So this article was based on historical climatic data and data of crop in the growth period, through the analysis and calculation of the water requirement to the four main crops: rice, maize, wheat and rape for 147 meteorological stations on the ground. According to the climatic and geographical differences of different areas, a detailed study was made on the main crops water requirements in Sichuan, which can provide a scientific basis for monitoring the soil moisture, evaluating regional water resources, planing and designing the farmland and water conservancy engineering, making the field irrigation plan and adjusting the planting of crops.

EXPERIMENTAL SECTION

Study Area: Sichuan is located in the Upper Reaches of the Yangtze River in the southwest of China. The longitude is between 97°21'E and 108°31' E and the latitude is between 26°03'N and 34°19'N. It is over 1075 km from east to west, 921 km from north to south with an area of 485,000 km^2, including 181 counties (city, district). Sichuan is the fifth largest province in China. The landscape of Sichuan is complicated, which is mainly mountain land. As a whole, the east is the Sichuan basin and the western part is plateau and mountain region. Thus, Sichuan includes four types of landscape: mountain, hill, plain and plateau which have the proportion of 74.2%, 10.3%, 8.2%, 7.3% respectively. According to the geographical climatic characteristics and the national standard of the Chinese Meteorological Geographic Distribution, Sichuan Province can be divided into three climatic zones: (1) the Eastern Basin, including Guangyuan, Mianyang, Deyang, Chengdu, Bazhong, Dazhou, Nanchong, Guang'an, Sui'ning, Ziyang, Neijiang, Zigong, Meishan, Leshan, Ybin, Luzhou and the Yingjing, Tianquan, Lushan, Baoxing, Mingshan of Ya'an City. This area belongs to the subtropical moist climatic region，and it is warm and humid with hot rainy season throughout the year. The annual average temperature ranges from 14℃ to 19℃, the annual average precipitation ranges from 900 mm to 1200 mm, and annual sunlight time throughout is about 1000 h to 1600 h which is one of the less sunshine area in China. (2) the Western Plateau, including Ganzi and Aba. This area belongs to the alpine climate zone without summer season throughout the year and with a long winter. It has an obvious dry and rainy season. The annual average temperature is greater than 8℃, the annual average precipitation mostly ranges from 600 mm to 700 mm, and the annual sunlight time is about 1200 h to 2700 h. (3) the Southwest Mountains Area, including Panzhihua, Liangshan and the Hanyuan, Shimian in Ya'an City. This area belongs to the subtropical semi-humid climate zones, and it is not distinct in the four seasons. The annual average temperature is about 15℃ to 20℃ in the valley and 5℃to 15℃ in the mountains. It has great difference of precipitation in every region and is clear by drought and wet season .The annual average precipitation ranges from 800 mm to 1200 mm, but precipitation of the valley of the Jinsha River is less than 400 mm. The annual sunlight time is about 2000 h to 2500h, which is twice the eastern basin.

Data of ET_0: The values of ET_0 were taken from the website of International Water Management Institute(IWMI) which based on the data from meteorological stations on the ground of the 147 counties in Sichuan Province and were calculated by the method of Penman-Monteith equation that was recommended by Food and Agriculture Organization (FAO). The distribution of meteorological stations is shown in **Fig.1**.

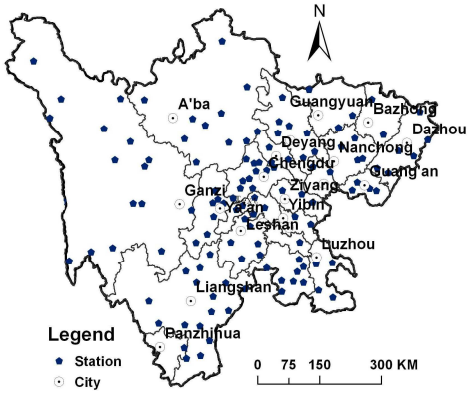

Fig.1 Distribution of meteorological stations in the study area, Sichuan Province

Water Requirements: Crop water requirement (ET) refer to the amount of water required to compensate for ET_0 losses from a cropped field, on the condition that the crops have a high yield in the specified period which have a proper soil moisture and fertility without injurious insects. Crop water requirement includes ET_0 and the water requirement of photosynthesis which is negligible small[9]. So, in the production practice, the ET_0 is similar to the crop water requirement under normal growth conditions[10]. In the whole growth period，crop water requirement will vary with the growth stage, especially the vigorous growth stage needs the maximum water.

Thus, theoretical crop water requirement can be replaced by ET_0. By using the method of crop coefficients to calculate the crop water requirement in some period, the calculation of the water requirement ET in this article is as following:

$ET=Kc\times ET_0$

In the formula, ET: water requirement in the calculating period, ET_0: evapotranspiration in the corresponding time, Kc: the crop coefficient which reflects the crops characteristics of itself that have an effect on water requirement, for example, the type and variety of crop, growth period and the population of leaf areas, and others.

Crop Coefficient: The main crops in Sichuan province are wheat, maize, rice and rape throughout the year. According to the data of *Agricultural meteorological Resources* in China，the value of Kc was not the same for different crops in different growth stages. FAO confirmed a lot of crops' Kc on the basis of the many experiments all over the world. In terms of the practical situation in Sichuan Province, crop coefficients in the article were gained from the FAO-56[11]and *The Main Crop Coefficient Kc Table in Sichuan Province*, **Table 1** are listed for the main crops. The values of Kc in the initial, mid-stage as well as the late stage were corresponding with tillering, blooming and ripe stage. At first, Kc would be very low in the germinating stage, but gradually with the growth of crops, the Kc would increase to the maximum when the crops were in the vigorous growth period. And with the maturity of crops, Kc would decrease slowly.

Table1 Crop Coefficient in different growth stages

crop	Kc initial	Kc mid	Kc late
rice	0.6	1.2	0.6
maize	0.5	1.15	0.6
wheat	0.3	1.15	0.25
rape	0.4	1.15	0.35

The Distribution of Water Requirement Based on GIS: The limited number of climatic monitoring stations caused restricted data of the crop water requirement by calculating from the Penman-Monteith equation. Because the different crop water requirements were changing in space, water requirement can be regarded as the spatial analysis object, which has the characteristics of presenting geographic position in GIS. Thus, data of the entire study area can be obtained by using the Spatial Interpolation method. That is to say, making full use of the crop water requirement in the known climatic stations can inquire by means of GIS into the data in undiscovered climatic stations in the study area. In order to reveal the spatial distribution rules of main crops in Sichuan Province, specialized data base was established by using the coordinates of 147 climatic stations on the ground and the four main crops water requirements. Next, the data were led into ArcGIS processed through the Inverse Distance-weighed Interpolation (IDW), and then spatial diagrams of the crop water requirements were produced.

RESULTS AND ANALYSIS

Dynamic changes of ET0 characteristics: Fig.2 displays the annual average ET_0 in dynamic changing curves, month by month in different regions and shows that ET_0 firstly increased, then decreased on the whole. The maximum and minimum of ET_0 were at summer and winter respectively, and it gradually rose in spring and declined rapidly in autumn. Furthermore, the period from December to January in next year was at the minimum level of ET_0 in the whole year. On the other hand, the maximum of ET_0 occurred at different times. The maxima of ET_0 in the southwest mountains area, the eastern basin and the western plateau were at April-May, July-August, and May-July respectively. Seeing from the different areas, the average ET_0 in the southwest mountains area was mainly higher than in the eastern basin and in the western plateau, and the average ET_0 in the eastern basin was slightly lower than the western plateau, except in the April-September period.

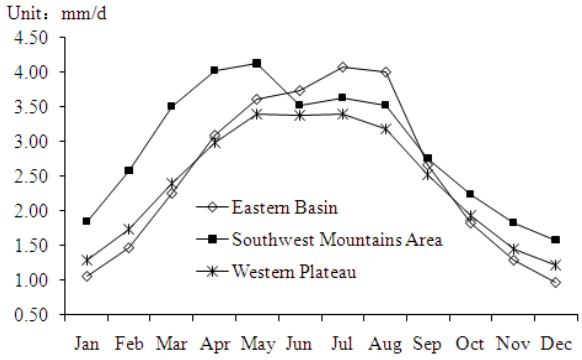

Fig.2 The changing curves of annual average ET_0

The Spatial Distribution Characteristics of Crop Water Requirement: Fig. 3 shows the spatial distributions of water requirements for four main crops during the growth period in Sichuan Province.

Rice: Rice is one of the main crops in Sichuan Province which is mostly planted in the eastern basin and the southwest mountain area, and it has a little part in the western plateau. Fig. 3a shows that the rice average annual water requirement was between 471.15 mm and 644.55 mm in the whole province, but it had a great diversity in different space. The high-value zone of rice water requirement is mainly distributed in the southwest mountain areas and the eastern basin's Chengdu, Deyang and part of Mianyang and the value ranged there from 590 mm to 644.55mm. Most area of the western plateau belongs to the lower-value zone for rice average annual water requirement, which was between 471.15 mm and 530mm. Moreover, the value of the eastern and southern part in the eastern basin was in the middle level, which ranged from 530 mm to590 mm.

Maize: Maize is mainly planted in the eastern basin and the southwest mountain areas. From Fig. 3b, the maize average annual water requirement was between 392.57 mm and 551.61mm in the whole province, but it had a great diversity in different space. The high-value zone of the maize water requirement is mainly distributed over most of the southwest mountain area. The value ranged from 499 mm to551.61 mm. The southeast of the western plateau, the north of Ya'an, the south of Leshan and the south of Luzhou belong to the lower-value zone, which was between 292.57 mm and 443.36mm. Moreover, the value of Ya'an, Leshan, Luzhou and the central, south of the Ganzi in the eastern basin were in the middle level, which ranged from 443.36mm to 499mm.

Wheat: Wheat is one of the main crops which all have been planted in Sichuan Province. From Fig. 3c, the wheat average annual water requirement was between 266.46mm and 521.15mm in the whole province, but it had a great diversity in different space. The water requirement in the study area decreased from south to north, that was, the southwest mountain area was the high-value zone of wheat water requirement which was between 400.72 mm and 521.15mm. The east and north of the basin, the northwestern part of Ganzi and the most area of Aba all belong to the low-value zone, which was between 266.46 mm and 319.19mm.

Rape: Rape is one of the main crops in Sichuan Province which has a great cultivated areas in the plain and the hill area, and in some southwest mountain areas and the western plateau. From Fig. 3d, the rape average water requirement over the years was between 248.19 mm and 492.34mm, and it also had a great diversity in different space. The rape water requirement decreased from south to north, but it had an increasing trend towards the northeast. The southwest mountain area and the most part areas of the Leshan, Luzhou are the high-value zone which was between 400.6 mm and 492.34mm. The low-value zone was mainly distributed in the most part areas of Aba, Chengdu, Deyang, Mianyang and the northwest of Ganzi. The value ranged from 248.19 mm to 293.33mm. The most area of the Ganzi, some part of the Ziyang, Neijiang, Guangyuan, Dazhou and Bazhong in the eastern basin were in the middle level, which ranged from 293.33 mm to 400.6mm.

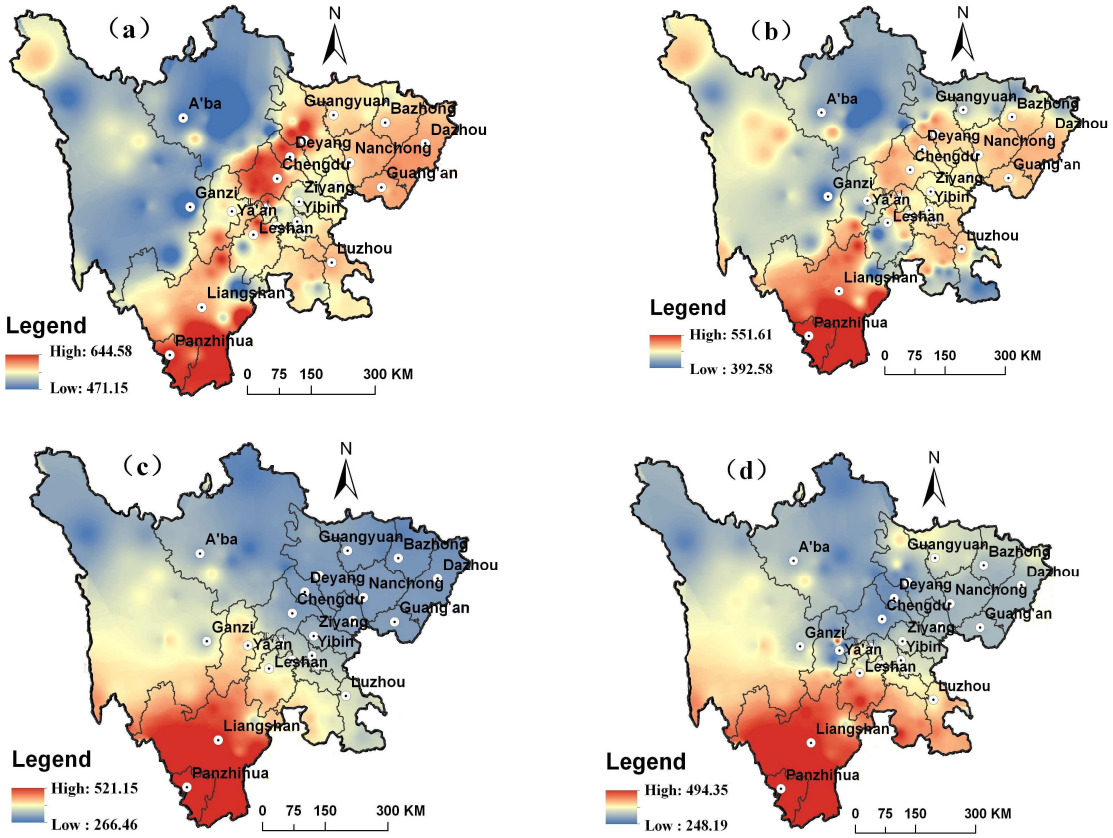

Fig.3 Spatial distribution of water requirements for main crops (a. rice, b. maize, c. wheat, d. rape)

In generally: (1) at space, the spatial distribution of water requirement had a great diversity for rice, wheat, maize and rape. Maybe the largely different climate would cause the spatial distribution in the eastern basin, the southwest mountain area and the western plateau; (2) for rice, wheat, maize and rape, there were different crop water requirement, because the difference of the crop growth period and the crop coefficients would contribute to the different crop water requirement; (3) the different crops in growth period were at different seasons, moreover, the water requirement of different crops in the same region were different. The relation was: rice > maize > wheat > rape, and it was the same as the research result of Liu [12].

CONCLUSION

By analyzing retrospectively the main crops water requirements for rice, maize, wheat and rape during 1961-1999 (40 a) in Sichuan Province, the conclusions are as follows:

(1)The maximum and minimum of ET_0 were in summer and winter respectively，and December-January of next year were the lower-value of ET_0. Moreover, the maxima of ET_0 in different areas occurred at different times.
(2)The spatial distribution of the water requirements for four main crops presented a great difference. The water requirement in the southwest mountain area was higher than that of the eastern basin and the western plateau. At the same time, the most part of Aba belongs to the low-value zone.

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