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NATURAL VEGETATION DISTRIBUTION AND CLIMATE ECOLOGY PREDICTION BASED ON GEOGRAPHIC INFORMATION SYSTEM

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Abstract

The global climate change, especially global warming, has seriously affected our living environment and the terrestrial biosphere. The typical consequences include biosystem destruction, crop failure and the rise of sea level. Therefore, a growing attention has been paid to quantify the relationship and mutual influence between vegetation and climate in the recent decade. In this paper, the vegetation distribution across China is digitized using the geographic information system (GIS) software. The raster data on the distribution of geographical spaces were obtained for 198 species of plants, including 92 species of arbor, 48 species of herbaceous plants and 46 species of shrubs. Besides, the Kriging interpolation was adopted to disclose the relationships between the geographical distribution of plants and different climate factors. The research results show that the selected climate factors can be widely applied to plant and climate prediction models, and used to forecast the response of vegetation to global climate change. The research findings provide reference and theoretical support to the research on natural vegetation distribution and climate ecology prediction.

Keywords: climate ecology, geographic information system (GIS), natural vegetation

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1. Introduction

21st century is a period of geological history closely related to human activities and the most intense period of global change (Accad and Neil, 2006). The study of the Quaternary global change process is an important basis for predicting future environmental changes (He et al., 2007). For the mechanisms of the global change process, a comprehensive and multidisciplinary study is needed (Dittrich et al., 2013; Košir et al., 2018; Wimberly and Spies, 2001). Many studies have shown that ecosystems and climate change have a great relationship with human activities, vegetation distribution and growth. The interaction between climate and natural vegetation has become one of the constant concerns by scholars at home and abroad (Jabro et al., 2010; Lundberg, 2011).

Global warming is one of the most prominent features in global changes (Carranza et al., 2003; Taramelli et al., 2010; Xiao et al., 2002). According to the outcomes of Intergovernmental Panel on Climate Change, China's temperature will increase by 4.1-6.2 degrees Celsius in the next 2,100 years (Lebeau et al., 2015), the annual average rainfall will increase by 11-17%, and the monsoon intensity will continue to rise (Ohno, 1991; Witte et al., 2015). Given the enormous impact of climate change on vegetation growth, this outcome will likely have a significant impact on the entire ecosystem of the planet.

Therefore, a growing attention has been paid by the scientists to the accurate prediction of future

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global climate changes and the possible impacts of climate change on ecological vegetation systems (Török et al., 2017; Zou et al., 2009). To this end, a model of the relationship between climate-influencing factors and natural vegetation should be established (Schumacher et al., 2006; Yao et al., 2015). Due to China's vast territory, complex climate types and species diversity, it's important to understand the relationship between the geographical distribution of key plant species and climate factors when applying various vegetation to simulate the vegetation distribution under future climate conditions. The comparative study between the main pollen species on the continental scale and the geographical distribution of vegetation is only found in the arbour pollen species and the geographical distribution of plants in China. However, currently there is no similar research on their climatic characteristics based on the digitization of plant geographic distribution and the spatial distribution of pollens. On this basis, the paper uses the Geographic Information System (GIS) software to digitize the main plant species in China's vegetation maps (Devin and Harrington, 2007), and obtains the raster data on the geographical distribution of these plant species (Bokhorst et al., 2009). Then, it discloses the relationship between plant geographical distribution and climate by Kriging interpolation. The results show that the Chinese plant flora can be re-classified according to the geographical distribution data and climate parameters of the main vegetation groups in China. Meanwhile, the research findings can also provide a reliable data reference for studying the quantitative relationship between Quaternary pollen and vegetation.

2. Material and Methods

The accuracy of climatological data on the surface pollen sample points is theoretically based on the observation data from weather stations. But due to the uneven spatial distribution (taking county stations as the sampling point) and insuffcient density (the field sampling points are often at a certain distance from the location of the weather station, e.g., at least dozens of kilometers) of the weather stations, the climate data of the pollen sampling points need to be obtained by spatial interpolation based on the observation data of nearby weather stations.

Spatial data interpolation is a mathematical process of deriving other unknown points or area data according to a certain mathematical relationship by a set of known discrete data or partitioned data. Generally, using the local fitting methods such as nearest proximity method (Schwartz and Zeger, 1990), inverse distance weighted interpolation method (Davis, 1922), spline method (Villalobos and Wahba, 1987), and Kriging method, etc. (Tager et al., 2005), the characteristic values of a few known sample points adjacent to the unknown point are adopted to estimate those of the unknown point, while only considering that the local characteristics of the interpolation area are not affected by other areas. In addition to Kriging interpolation, other methods also don't consider the other factors such as the landform etc.

2.1. Interpolation method of climate data

Kriging interpolation is similar to inverse distance weighting interpolation. Both methods obtain the value of the unknown sample point by assigning weights to known points, which can be expressed in Eq. (1):

$$Z(x_0)=\sum_{i=1}^{n}\chi_i\cdot Z(x_i) \tag{1}$$

where, $Z(x_0)$ is the value of the unknown sample point; $Z(x_i)$ is the value of the known point around the unknown point; χ_i is the warrant of the i-th known point to the unknown point; n is the number of known sample points.

Fig. 1 shows the "shielding effect" in Kriging interpolation, indicating that this method can eliminate the error caused by uneven sampling (Sarma, 1969).

The calculation process of the Kriging interpolation is divided into two steps:

(1) Calculate the experimental variance function according to the data distribution characteristics, that is, select the appropriate variogram model under the premise of spatial structure analysis of the data;

(2) Based on this, the Kriging interpolation calculation is performed.

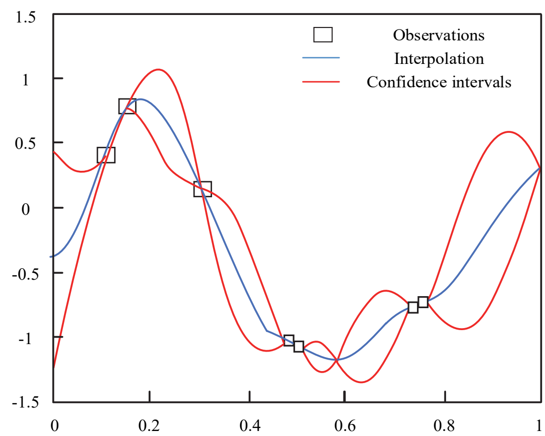

Fig. 1. Kriging interpolation method

2.2. Climatic factors affecting the geographical distribution of plant species

The vegetation distribution is mainly affected by heat and moisture in climatic factors. In this study, the monthly average temperature and rainfall were used as the minimum temperature and rainfall among the climatic factors affecting the geographical distribution of plants in China, while the average temperature and rainfall in July were the maximum temperature and rainfall. Besides, 10 other climate parameters were selected, including annual average temperature, warmness/coldness index, annual rainfall, growing degree days at the temperature above 5°C (*GDD5*), and annual relative humidity.

The specific calculation method is as follows:

(1) Add the average monthly temperature from January to December together to obtain the annual average temperature; take the average temperature in January as the annual average temperature of the coldest month in the year, and the average temperature in July as the average temperature of the hottest month in the year;

(2) The average rainfall in January and July; total rainfall in January-December is regarded as the annual rainfall;

(3) When the annual GDD is greater than 5°C, it's calculated according to the Eq. (2):

$$GDD5 = \sum(T_d) \quad (2)$$

Among them, T_d is the daily average temperature of the days at the temperature over 5°C during the year.

(4) Annual relative humidity is the average value of the total relative humidity from January to December;

(5) Calculation method of coldness and warmness index is shown in Eqs. (3-4):

$$WI = \sum(T_m - 5) \quad (3)$$

$$CI = \Sigma(5 - T_m) \quad (4)$$

T_m is the average monthly temperature of the months at the temperature over 5°C.

2.3. Simulation of biota distribution

A biota refers to the dominant species within a geographic region that have the same life cycle, acclimatization, and natural structure in the face of the same climatic conditions. Biota are closely related to vegetation types. The Carbon Assimilation in the Biosphere model (CARAIB) can be used to simulate the carbon cycle, vegetation spatial distribution, and net/primary productivity of the terrestrial biosphere (Warnant et al., 1994). The most important output of the CARAIB model is the primary productivity of vegetation and the net productivity of ecosystems. It is based on the coupling of three sub-models, as shown in Fig. 2. It can also calculate the sum of vegetation carbon storage and organic carbon pools of soil, as well as the carbon flux between the atmosphere and the terrestrial biosphere (François et al., 2006).

In addition, through the CARAIB model we obtained the leaf and stem respiration, heterotrophic soil respiration and leaf area index (LAL), as well as the distribution of vegetation types simulated by climatic values of vegetation primary productivity and plant function types. Originally, the CARAIB model divided the global ecosystem into 12 planting types. In actual application, the vegetation types can be appropriately increased or deleted according to the actual situation of vegetation distribution in the study area to ensure that all vegetation types are covered in the research range. In addition, the relationship between the geographical distribution of plants and the annual rainfall threshold can be calculated using the quantile function according to the mesh points of the plant geographical distribution.

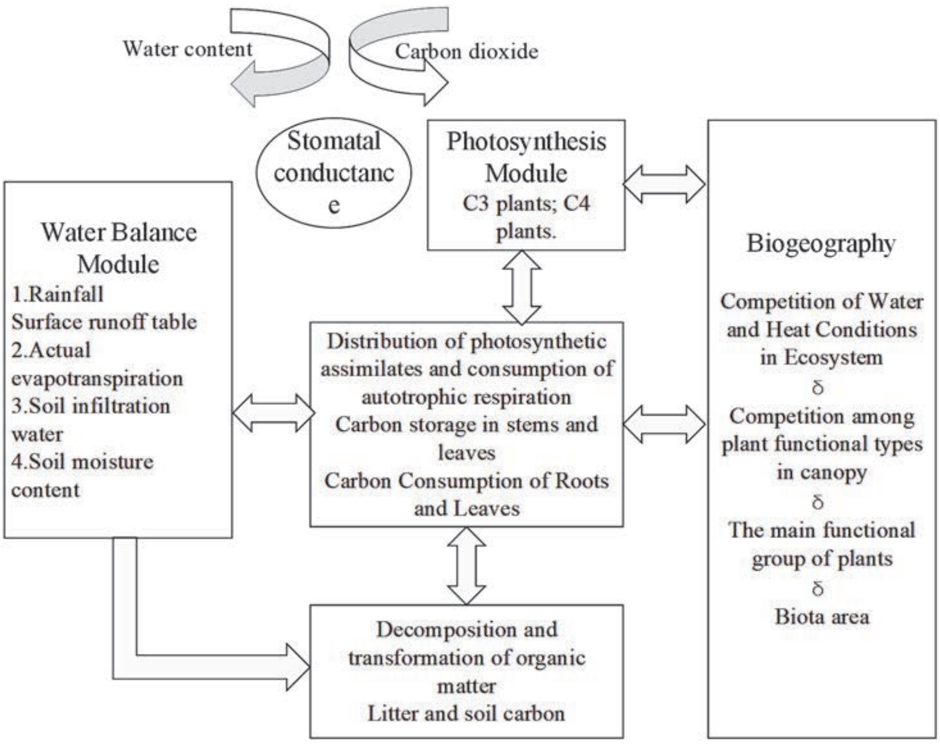

Fig. 2. Schematic diagram of the CARAIB vegetation model

In order to better compare the percentage of pollen species with the geographical distribution of plants in climatic space in this paper, only 1,652 surface pollen data in mainland China were used as samples. The main part of the data were from the analysis results of the laboratory in the past decade; some were the samples and analysis results provided by domestic and foreign collaborators, and the former China Quaternary Pollen Database; a small number of sample data were digitized from published literature.

3. Results

3.1. Zonal characteristics of vegetation geographical distribution

The south-eastern half of China is the monsoon region, suitable for growing various types of Mesozoic forests; the north-western half is a weak monsoon region with dry grasslands and deserts. Therefore, in the southeast part of the forest area, with the heat increasing from northwest to south, different vegetation belts are obviously replaced in turn, as shown in Fig. 3.

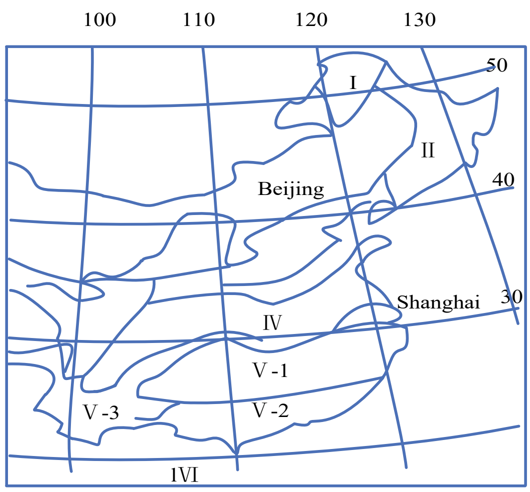

Fig. 3. Division of forest vegetation zone (Fang and Yoda, 1990)

3.2. Geographical distribution and climate thresholds

In this study, one of the important findings is the relationship between plant geographical distribution and climate thresholds. Table 1 lists the relationship between the geographical distribution of 6 species of Abies and annual rainfall.

In Table 1, according to the geographical distribution of abies, the annual rainfall of 452mm was the one corresponding to 10% grid points, representing the lowest rainfall of plant geographical distribution. Studies also show that 10% of mixed abies were distributed in a climate zone with annual rainfall between 452 and 558mm. Therefore, an annual rainfall of 558mm means that 10% of the grass abies appear at the rainfall threshold.

To sum up, it’s concluded that:

(1) The climatic factors such as temperature in January and July, rainfall in January and July, annual average temperature, annual average rainfall, annual *GDD5*, annual average relative humidity etc. are widely applied to the vegetation model, and can be used to predict the response of vegetation to global changes.

(2) Different pollen species have different climatic characteristics. Meanwhile, sampling points with a lower percentage of pollen species have a wider climatic threshold, while those with a higher percentage have a narrower climatic threshold.

(3) The kriging climate interpolation method can be used to establish the relationship between the plant geographical distribution and climatic factors, and derive the climatic threshold range of each plant's geographical distribution, which can provide important parameters for assessing terrestrial ecosystems.

4. Discussion

4.1. Relationship between vegetation and threshold values of climatic factor under different quantiles

Considering the climate thresholds of the geographical distribution for various plants, the quarantine function was adopted to calculate the confidence interval of climates. The results are shown in Table 2.

Table 2 shows that after several attempts, the clustering results of 10% and 90% climate values are ideal, which further indicates that the climatic parameters in Table 2 can be widely applied to vegetation models for predicting the impact of global changes on vegetation.

4.2. Comparison of climates and gymnosperm distribution/pollen content

In gymnosperms, the dominant species of the Pinus plant community had an average annual temperature ranging from -4 to 25 degrees Celsius, and annual rainfall from 500 to 2500millimeters according to the raster data. The raster data of distribution space of Pinus plants shows that the distribution area of Pinus massoniana was the largest, followed by pinus yunnanensis (in Yunnan only). Thus, the climate with the grid point greater than 1% was 9-12 degrees Celsius, and that with the grid point greater than 10% was concentrated in the subtropical zone (15-20 degrees Celsius). However, the correlation between pollen content and climate shows that although the grid number of average annual temperature corresponding to the distribution of Pinus plants was less than 1%, the relevant pollen content can reach 65%-85%. It can be seen from the comparison chart that there is no obvious linear relationship between climate values and Pinus pollen, as shown in Fig. 4 in detail.

Table 1. Relationship between geographical distribution of 6 species of Abies and annual rainfall threshold

Taxa	*Quantile*						
	0%	10%	25%	50%	75%	90%	100%
Abies delavayi var. motuoensis	450	573	8	717	847	971	1366
Abies fabri	493	621	670	704	754	799	1316
Abies georgei	609	670	716	788	891	946	1214
Abies kawakamii	2171	2238	2311	2360	2477	2504	2520
Abies nephrolepis	450	500	570	642	676	716	803
Abies spectabilis	373	486	618	670	905	1123	1385

Table 2. Relationship between vegetation and the thresholds of climatic factors under different conditions

Quantile	*Climate parameters*							
	Temperature /℃		*Annual average humidity /mm*	*Rainfall /mm*			*GDD5*	*Relative humidity of air*
	January	July		January	July /mm	Annual		
0%	-30.95	14.65	-6.95	3.35	99.55	447.45	815.75	69.4%
5%	-29.85	15.15	-6.05	3.45	107.45	470.15	892.15	69.5%
10%	-29.65	15.45	-5.75	3.45	113.55	497.45	943.05	69.6%
25%	-24.65	16.75	-1.25	3.85	128.15	566.95	1227.15	70.2%
50%	-21.65	18.15	-0.35	4.35	144.15	638.85	1483.25	72.0%
75%	-17.65	19.45	2.25	6.75	168.45	673.05	1586.75	73.4%
90%	-16.15	19.95	2.75	7.65	176.35	712.75	1720.35	74.6%
95%	-15.55	20.25	3.25	82.65	179.95	741.85	1803.65	74.9%
100%	-13.75	21.45	4.15	9.75	186.25	799.65	1966.85	75.5%

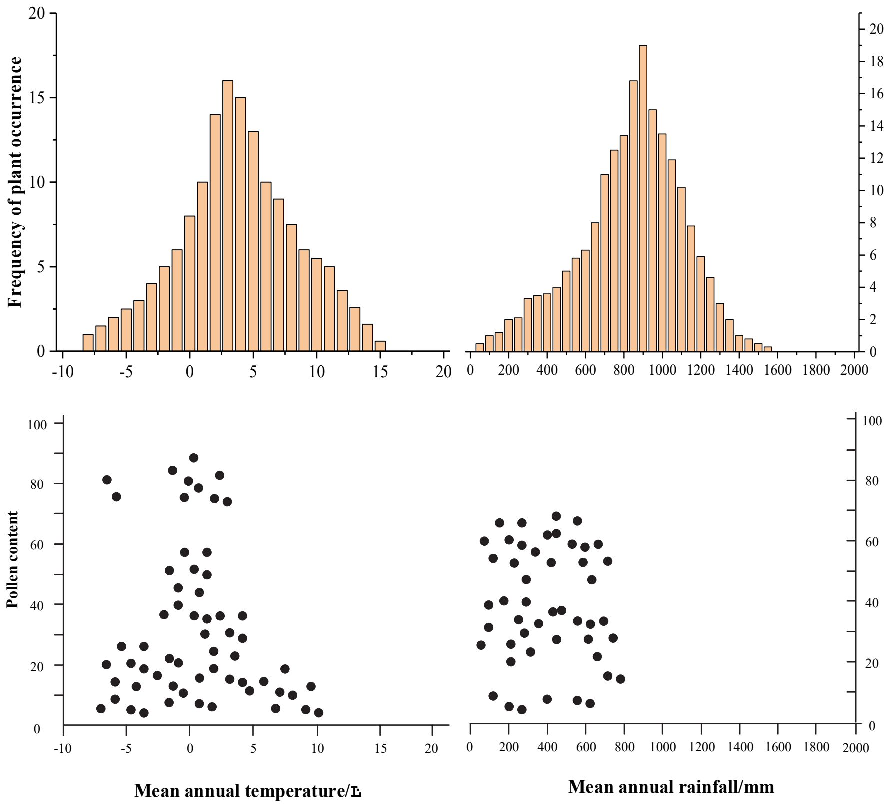

Fig. 4. Comparison of climates and gymnosperm distribution/pollen content

4.3. Comparison of climates and herb/shrub plant distribution

Artemisia plants are distributed throughout the country, but mainly in temperate grasslands and desert areas. According to the raster data analysis of Artemisia's seven geographical distribution points, the annual average temperature range of Artemisia was -8-12 degrees Celsius, and the annual rainfall range was 35-500 mm; while the pollen is distributed throughout the country, and the pollen content gradually decrease from north to south on the whole, and according to its geographical distribution, the annual average temperature ranged from -8 to 17 degrees Celsius, and the annual rainfall range was 25-1900 mm. In view of the strong representativeness of Artemisia pollen, the climatic conditions for the higher percentage of pollen should be considered, when studying the relationship between pollen content and plant distribution. When the percentage of Artemisia was greater than 12%, the annual average temperature in the quantile interval ranged from -3 to 10 degrees Celsius, and the annual rainfall was 70 to 700 mm. Therefore, the climatic range of the Artemisia pollen distribution has a good corresponding relationship with plant distribution, as shown in Fig. 5.

Poaceae plants are widely distributed throughout the country, and grassland is the main vegetation type of gramineous plants. China's grasslands are mainly distributed in the temperate and grassland areas of the Qinghai-Tibet Plateau. According to the quantile statistical analysis of plant distribution points, the annual average temperature of Poaceae plants was -4-10 degrees Celsius, and the annual rainfall range was 80-640 mm. Surface pollens of Poaceae are also widely distributed across the country. Contrary to the changes of Artemisia, the overall trend of its distribution is gradually increasing from north to south: the annual average temperature for the quantile interval of Poaceae plants with a ratio of more than 10% ranged from -2 to 19 degrees Celsius, and its annual rainfall was 60-1800 mm. Therefore, the percentage of pollen content is slightly different from the distribution of plants in the climatic space, as shown in Fig. 6.

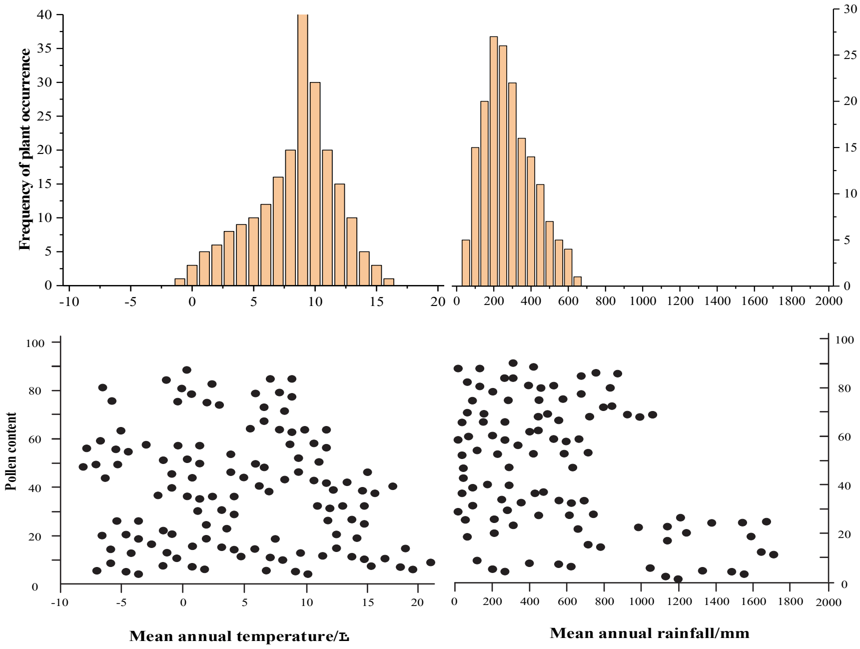

Fig. 5. Comparison between the herb plant distrition and pollent content

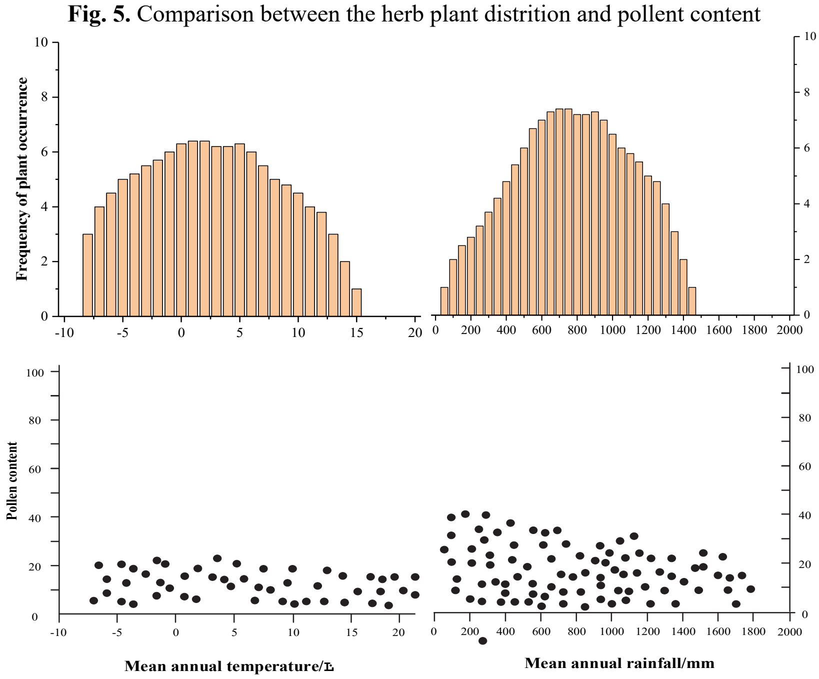

Fig. 6. Comparison between the shrub plant distrition and pollent content

5. Conclusions

At present, global changes, especially global warming, bring serious consequences such as deglaciation, sea level rise, desertification, ecosystem damage, and agricultural output reduction to the climate, ecology, and environment, thus directly affecting human survival.

This has increasingly attracted much attention from the international community. So, it has become the focus of research in the science circle to understand the relationship between natural vegetation distribution and its climatic factors, and accurately predict the possible effects of future climate change on ecosystems.

However, previous research on their relationship was basically carried out on a local scale, rather than across China mainland. In view of the above, this paper attempts to study the natural vegetation distribution and climate ecology prediction based on the GIS.

The main conclusions are as follows:

(1) Based on GIS software, the vegetation distribution across China is digitized to obtain the raster data on the geographical distribution of spaces of these plant species;

(2) The Kriging interpolation method was used to calculate the climate threshold of geographical distribution for each plant, and analyse the relationship between vegetation and climatic threshold;

(3) The climate prediction models established in this study can be used to forecast the response of vegetation to global climate change.

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