Uses of the Geographical Detector Method to Analyse Spatiotemporal Changes and Impact Factors Related to Chinese Food Security

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***Abstract*—The issue of Chinese food security has attracted close attention from within China as well as from abroad. In this study, grain surplus was used to measure food security. The grain surplus of 340 cities in China was calculated. Cities were used as research units; and agricultural areas were used as regional units to study spatial distribution of Chinese food security. The geographical detector method was used to analyze 10 impact factors of food security in China, and the leading factors of each agricultural region were determined. According to the spatial pattern of Chinese food security and the influence of the 10 impact factors on each agricultural region, corresponding measures should be taken for each of China's different agricultural regions. According to the research result, the black soil should be protected to prevent loss of water and soil erosion in northeast China, the enthusiasm of agricultural production should be raised in south-eastern coast China.**

Keywords—Chinese food security, spatial-temporal changes, impact factors, agricultural regions, geographical detector

I. Introduction

The issue of Chinese food security has attracted close attention from within China as well as from abroad. Researchers have used methods such as Moran's I [1], gravity centers curve [2-4], and thematic map series to study the spatiotemporal patterns of per capita grain shares at the county level in China. Researchers of food security have investigated is the spatiotemporal pattern of grain supply–demand [5], grain production [6] and per capita grain possession in China and its influence factors [7-11].

In this study, using the per capita grain consumption data obtained by FAO and grain output data, the surplus grain of 340 cities in China was calculated to measure the food security of cities and agricultural regions. The geographical detector method was used to analyze the impact factors of food security in China, and the leading factors of each agricultural region were determined. According to the different leading impact factors of food security in different regions, policy recommendations are provided to help solve the food security issue.

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II. Data and Method

A. Sources of Data and Grain Surplus

The main data sources were the China County Statistical Yearbooks of different provinces.

Lu [12] determined that when it reached 400 kg, China's per capita grain consumption met the UN Food and Agriculture Organization requirement of nutrition security. Thus, per capita grain consumption of 400 kg can be regarded as the standard for Chinese food security. This standard was also applied to the current study and has been used in some correlation studies [13]. Grain surplus can be determined using the following formula:

$$C_p = C_r - P_r \times S_r \tag{1}$$

where C_p is grain surplus in region r, Cr is grain output in region r, P_r is resident population in region r, and S_r is residents' average food consumption per person. We assumed S_r = 400 kg in this study. If $C_p > 0$, the grain output of the region can not only meet its own demand but can also provide for other regions; thus, the region meets the standard for food security. If $C_p < 0$, the grain output of this region cannot meet its own demand and the region does not meet the food security standard. The value of grain output represents the degree to which the region's grain output is above or below the food security standard. We used the grain surplus of different regions to determine spatiotemporal changes in Chinese food security.

B. Selected Impact Factors

Generally, agriculturally related factors have been considered the main impact factors of food security. The most popular impact factors include per capita GDP, grain sown area, arable acreage, total power of agricultural machinery, meteorological conditions, agricultural consumption of chemical fertilizer, and permanent resident population. This study uses comparison and interaction to determine and examine the impact factors of food security. Because this study seeks to compare the influence of impact factors to determine the leading impact factors in different regions, this report focuses on the factors that have been explored the most by researchers. Accordingly, this study uses ten impact factors of food security to determine the leading impact factors and corresponding policy recommendations in different regions. The ten impact factors included per capita GDP (X1), proportion of the permanent resident population with a bachelor's degree or above (X2), grain sown area (X3), arable acreage (X4), total power of agricultural machinery (X5), area of mechanized harvest (X6), agricultural consumption of chemical fertilizer (X7), annual precipitation (X8), mean annual temperature (X9), and annual sunshine duration (X10).

C. Geographical Detector

In order to explore the comparison and interaction of the ten impact factors, the appropriate method must be chosen. The research method for analyzing the influence of several factors on one geographic phenomenon include a questionnaire, principal components analysis, multiple linear regression, and the geographical detector method. Principal components analysis and the multiple linear regression method are mathematical statistics methods that analyze the comparison and interaction of impact factors' influence. However, because the influence of several factors and their interaction must be analyzed using different scales per region, this study employs the geographical detector method.

The geographical detector method was developed in 2010 by Wang et al. and has been used for geographical health risk assessment [14]. One study examined the spatial pattern and influencing factors of grain output using the geographical detector method [15]. However, the focus was on grain output and the research area was provincial administrative units. Using geographical divisions, the geographical detector method can analyze the impact factors of geographical phenomena. The other methods used for studying the impact factors of geographical phenomena, such as principal component analysis, cannot consider geographical division.

Factors that influence the spatiotemporal change in Chinese food security were analyzed at the city level using the geographical detector method. The geographical detector model is as follows:

$$P_{D,U} = 1 - \frac{1}{n\sigma^2_U} \sum_{i=1}^{m} n_{D,i} \sigma^2_{U_{D,i}} \qquad (2)$$

where $P_{D,U}$ is the power determinant of each impact factor of the Chinese food security distribution, $n_{D,i}$ is the number of sub regional samples, n is the number of samples in the entire region, and m is the number of sub regions. σ^2 is the variance of food security of the entire region, and $\sigma^2_{U_{D,i}}$ is the variance of food security of each sub region. If $\sigma^2_{U_{D,i}} \neq 0$, the model is tenable, and the interval of $P_{D,U}$ can be set to [0, 1]. When $P_{D,U}$=0, the spatial distribution of regional food security is random. The larger the value of $P_{D,U}$, the stronger the influence of the area division factor on regional food security.

III. Results

There are nine terrestrial agricultural regions in China: the North China region; Inner Mongolia and the region along the Great Wall, the Huang–Huai–Hai Region, the Loess Plateau region, the middle and lower reaches of the Yangtze River, the southwest China region, the South China region, the Gansu–Xinjiang region, and the Qinghai–Tibet region. This study used cities as research units and nine agricultural areas as regional units to study the spatiotemporal changes in Chinese food security [16].

A. Spatial Distribution of Chinese Food Security

We calculated the grain surplus of the 340 cities (the upper-level administrative unit of counties in China, including urban and rural areas) in 2014. Maps of Chinese food security in each of these years were drawn using ArcGIS software in Fig. 1.

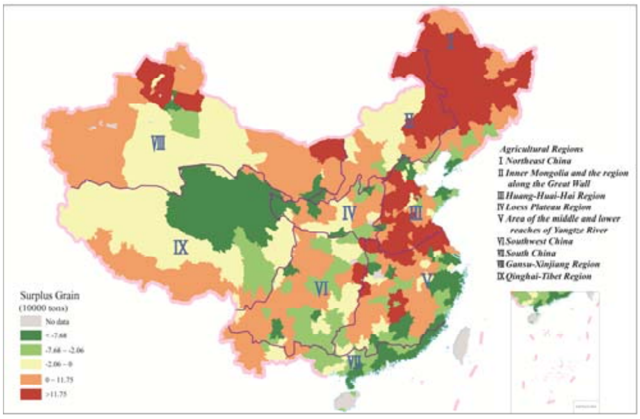

Fig.1. The spatial distribution of surplus grain of China in 2014.

Spatial distribution map of grain surplus of China in 2014 was showed in Fig. 1. The spatial distribution map showed that the northeast region and middle and lower reaches of the Yangtze River were the main grain output areas; the Huang–Huai–Hai region became a major grain production area. The South China region was an area in which grain production could not meet the demand of its resident population. Owing to rapid economic development in the region, farmers have become reluctant to engage in grain production, leading to the abandonment of large areas of cultivated land. With no efforts to encourage agricultural production, the food security issue in South China will become more severe and long-lasting.

B. Impact Factors of Chinese Food Security

The factors that have an impact on different agricultural areas were analyzed according to the spatial variability of Chinese food security. Using the geographical detector method, we calculated the q statistic and p-value between surplus grain in 2014 and the ten impact factors in the nine agricultural regions and nationwide were shown in table 1 to 4.

TABLE I. The q Statistic Between Suplus Grain and Different Impact Factors in China and I to IV Regions Using the Geographical Detector Method

Impact Factor	Agricultural Region				
	China	*I*	*II*	*III*	*IV*
X1	0.29	0.08	0.55	0.35	0.42
X2	0.35	0.63	0.36	0.38	0.46
X3	0.58	0.90	0.87	0.65	0.43

Impact Factor	Agricultural Region				
	China	*I*	*II*	*III*	*IV*
X4	0.52	0.84	0.58	0.33	0.36
X5	0.50	0.71	0.67	0.40	0.60
X6	0.50	0.27	0.66	0.76	0.65
X7	0.49	0.76	0.92	0.43	0.50
X8	0.35	0.54	0.27	0.31	0.29
X9	0.36	0.77	0.53	0.30	0.55
X10	0.33	0.56	0.23	0.03	0.45

[a] X1 means per capita GDP, X2 means proportion of the permanent resident population with a bachelor's degree or above, X3 means grain sown area, arable acreage, X4 means total power of agricultural machinery, X5 means area of mechanized harvest, X6 means agricultural consumption of chemical fertilizer, X7 means annual precipitation, X8 means mean annual temperature, X9 means annual temperature and X10 means annual sunshine duration.

[b] I means Northeast China, II means Inner Mongolia and the region along the Great Wall, III means Huang-Huai-Hai Region, IV means Loess Plateau Region.

TABLE II. THE P-VALUE BETWEEN SUPLUS GRAIN AND DIFFERENT IMPACT FACTORS IN CHINA AND I TO IV REGIONS USING THE GEOGRAPHICAL DETECTOR METHOD

Impact Factor	Agricultural Region				
	China	*I*	*II*	*III*	*IV*
X1	0.00	0.97	0.82	0.29	0.54
X2	0.00	0.02	0.98	0.58	0.46
X3	0.00	0.00	0.57	0.00	0.51
X4	0.00	0.00	0.55	0.90	0.63
X5	0.00	0.00	0.88	0.41	0.27
X6	0.00	0.86	0.58	0.00	0.22
X7	0.00	0.01	0.34	0.36	0.68
X8	0.00	0.29	1.00	0.32	0.76
X9	0.00	0.00	1.00	0.96	0.25
X10	0.00	0.23	1.00	1.00	0.30

[c] X1 means per capita GDP, X2 means proportion of the permanent resident population with a bachelor's degree or above, X3 means grain sown area, arable acreage, X4 means total power of agricultural machinery, X5 means area of mechanized harvest, X6 means agricultural consumption of chemical fertilizer, X7 means annual precipitation, X8 means mean annual temperature, X9 means annual temperature and X10 means annual sunshine duration.

[d] I means Northeast China, II means Inner Mongolia and the region along the Great Wall, III means Huang-Huai-Hai Region, IV means Loess Plateau Region.

TABLE III. THE Q STATISTIC BETWEEN SUPLUS GRAIN AND DIFFERENT IMPACT FACTORS IN V TO IX REGIONS USING THE GEOGRAPHICAL DETECTOR METHOD

Impact Factor	Agricultural Region				
	V	*VI*	*VII*	*VIII*	*IX*
X1	0.36	0.10	0.61	0.51	0.16
X2	0.42	0.23	0.48	0.82	0.53
X3	0.58	0.41	0.70	0.70	0.29
X4	0.44	0.18	0.69	0.77	0.32
X5	0.48	0.18	0.66	0.68	0.42
X6	0.63	0.42	0.79	0.60	0.80
X7	0.46	0.17	0.65	0.65	0.24
X8	0.55	0.24	0.58	0.68	0.39
X9	0.54	0.08	0.58	0.75	0.90

Impact Factor	Agricultural Region				
	V	*VI*	*VII*	*VIII*	*IX*
X10	0.48	0.14	0.61	0.68	0.36

[e] X1 means per capita GDP, X2 means proportion of the permanent resident population with a bachelor's degree or above, X3 means grain sown area, arable acreage, X4 means total power of agricultural machinery, X5 means area of mechanized harvest, X6 means agricultural consumption of chemical fertilizer, X7 means annual precipitation, X8 means mean annual temperature, X9 means annual temperature and X10 means annual sunshine duration.

[f] V means Middle and lower reaches of Yangtze River, VI means Southwest China, VII means South China, VIII means Gansu-Xinjiang region, IX means Qinghai-Tibet Region.

TABLE IV. THE P-VALUE BETWEEN SUPLUS GRAIN AND DIFFERENT IMPACT FACTORS IN V TO IX REGIONS USING THE GEOGRAPHICAL DETECTOR METHOD

Impact Factor	Agricultural Region				
	V	*VI*	*VII*	*VIII*	*IX*
X1	0.01	0.97	0.00	0.33	1.00
X2	0.00	1.00	0.17	0	0.59
X3	0.06	1.00	0.23	0.01	0.98
X4	0.88	1.00	0.25	0.01	0.99
X5	0.18	1.00	0.04	0.06	0.98
X6	0.00	0.82	0.00	0.19	0.31
X7	0.14	1.00	0.23	0.39	1.00
X8	0.00	1.00	0.23	0.01	0.95
X9	0.31	1.00	0.46	0.01	0.02
X10	0.01	1.00	0.33	0.10	0.97

[g] X1 means per capita GDP, X2 means proportion of the permanent resident population with a bachelor's degree or above, X3 means grain sown area, arable acreage, X4 means total power of agricultural machinery, X5 means area of mechanized harvest, X6 means agricultural consumption of chemical fertilizer, X7 means annual precipitation, X8 means mean annual temperature, X9 means annual temperature and X10 means annual sunshine duration.

[h] V means Middle and lower reaches of Yangtze River, VI means Southwest China, VII means South China, VIII means Gansu-Xinjiang region, IX means Qinghai-Tibet Region.

The results of this calculation showed that the p-value of surplus grain and the ten impact factors nationwide was zero, which indicates that all ten factors had an appreciable impact on food security nationwide. The influence these ten impact factors had on nationwide food security, from greatest to least, was as follows: grain sown area (0.58), arable acreage (0.52), area of mechanized harvest (0.50), total power of agricultural machinery (0.50), agricultural consumption of chemical fertilizer (0.49), mean annual temperature (0.36), proportion of permanent resident population with a bachelor's degree or above (0.35), annual precipitation (0.35), annual sunshine duration (0.33), and per capita GDP (0.29).

Agriculturally related impact factors such as grain sown area, arable acreage, area of mechanized harvest, total power of agricultural machinery, and agricultural consumption of chemical fertilizer made a greater difference to nationwide food security than the remaining factors. According to the results, the grain sown area should be appropriately increased, arable land should be protected, the agricultural mechanization level improved, and adequate fertilization should be instated to increase grain production and reduce environmental pressure. However, the unbalanced spatial distribution caused differences in the effects of impact factors in different areas. The leading factors of each of the nine agricultural regions were analyzed to clarify their impacts on food security.

The impact factors with the greatest influence on food security in the northeast region were grain sown area, arable acreage, mean annual temperature and fertilizer. The impact factors with the greatest influence on grain security in the Gansu–Xinjiang region were a proportion of the permanent resident population with a bachelor's degree or above, arable acreage, mean annual temperature, grain sown area and number of employees in the tertiary sector of the economy. The top three impact factors with the greatest influence on grain security in the Huang–Huai–Hai region were area of mechanized harvest, grain sown area, and agricultural consumption of chemical fertilizer. The impact factors with the greatest influence on grain security in the Loess Plateau region were area of mechanized harvest, total power of agricultural machinery and mean annual temperature. The leading impact factor of grain security with the greatest influence in Inner Mongolia and the area along the Great Wall was agricultural consumption of chemical fertilizer. The impact factors of grain security with greatest influence in the Qinghai–Tibet region were mean annual temperature, area of mechanized harvest, and proportion of residents with a bachelor's degree or above. The impact factor with the greatest influence on grain security of the southwest region was proportion of residents with a bachelor's degree or above. The main impact factors of grain security in the middle and lower reaches of the Yangtze River region were area of mechanized harvest, grain sown area and annual precipitation. The impact factors of grain security with the greatest influence in the South China region were area of mechanized harvest, grain-sown area, and arable acreage.

IV. DISCUSSION

According to the spatial distribution of surplus grain and the influence of ten impact factors on different agricultural regions of China, the corresponding measures should be taken in each of these regions to help to stabilize food security in the country.

First, a guarantee of sustainable agricultural development should be in place for the major grain output regions (northeast China and the Huang–Huai–Hai region). To this end, adequate fertilization, water-efficient irrigation, and increased funding for agricultural technology should be implemented.

Second, famers should be encouraged to engage in grain production and reduce the abandonment of cultivated land in economically developed areas (South China and the middle and lower reaches of the Yangtze River). The primary measures to emphasize include promoting farmers' income, developing preferential policies of agricultural development in these regions, and transforming traditional agricultural business operations.

Third, characteristic agriculture should be developed in areas with special climate conditions (Qinghai–Tibet region). The main measures to implement include marketization of agricultural products and increasing investment in science and technology as well as government policy support.

Fourth, measures to develop grain production in other regions of the country should be implemented. These measures include increasing the cultivated area of major grain crops and enhancing the level of agricultural modernization.

V. CONCLUSIONS

This study analyzed the spatiotemporal distribution of Chinese food security across the nine agricultural regions of China. The main grain production areas were the northeast and Huang–Huai–Hai regions. Most of the food supply of other regions came mainly from these two regions or from imports. The lack of grain self-sufficiency was most serious in the South China region. The spatial pattern of Chinese surplus grain represented a conspicuous spatial imbalance that paralleled that of food security in China.

Using the geographical detector method, the influence of ten impact factors on Chinese food security and the leading factors in each agricultural region were determined. Grain sown area, arable acreage, area of mechanized harvest, total power of agricultural machinery, and agricultural consumption of chemical fertilizer had the greatest effects on food security of the country. The leading impact factors in each agricultural region varied: in the northeast, the main factors were grain sown area, arable acreage, and mean annual temperature; in the Gansu–Xinjiang region, the main factors were proportion of permanent residents with a bachelor's degree or above, arable acreage, and mean annual temperature; in the Huang–Huai–Hai region, the main factors were area of mechanized harvest and grain sown area; in the Loess Plateau region, the main factors were area of mechanized harvest, total power of agricultural machinery, and mean annual temperature; in Inner Mongolia and the region along the Great Wall, the main factors were agricultural consumption of chemical fertilizer and grain sown area; in the Qinghai–Tibet region, the main factors were mean annual temperature and area of mechanized harvest; in the southwest region, the main factors were area of mechanized harvest and grain sown area; in the middle and lower reaches of the Yangtze River, the main factors were area of mechanized harvest, grain sown area, and annual precipitation; and in South China, the main factor was area of mechanized harvest.

According to the spatial pattern of Chinese food security and the differing impact of various factors on different agricultural regions, appropriate measures are needed in each of the country's main agricultural regions. Such measures include guaranteeing sustainable agricultural development in major grain output regions, encouraging famers to engage in grain production, reducing the area of abandoned cultivated land in economically developed regions, developing characteristic agriculture in areas with unique climate conditions, and implementing measures to develop grain production in other agricultural regions of China.

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