IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received March 20, 2022, accepted April 2, 2022, date of publication April 6, 2022, date of current version April 28, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3165189

Analysis on Mechanism of China's Grain Production Development and Evolution From 1985 to 2019

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This work was supported by the Project of National Special Program of Scientific Basic Working under Grant 2013FY112800.

ABSTRACT China's grain production has been on a pathway paralleled with urbanization in recent 40 years, from lower efficiency and productivity to the higher ones, and has met complex impact factors and contradiction between sustainable development of farming and urbanization. Spatial-temporal pattern of grain production in China, by total and per capita output, was analyzed through Local Moran'I from 1985 to 2019. Until 2019, the high-output countries were mainly aggregated in the main plains and basins on the third step of China's terrain and the low-output areas increased in the southeastern coastal regions; the countries with high per capita output almost disappeared and the low areas increased a lot in the central and southern regions Then the impact factors, by total output in the whole country and in grain surplus-shortage regions, were detected and found out through Geodetector. In the whole country, cultivated land areas, agricultural machinery, total meat output and value-added of primary industry not only played important role independently, but also had mutual coupling effect in grain total output. And in the grain surplus regions, major factors were cultivated land areas and value-added of primary industry, while in the grain shortage regions, were labors and market as well as economic factors. Thirdly, factor mechanism of China's grain production for four types of development orientations, i.e., orientation on production scale, production efficiency and benefit, product quality and economic coordination, were concluded, and the way of grain production in different regions with unique suitability and advantage were expounded.

INDEX TERMS Grain production, spatial-temporal pattern, geodetector, factor mechanism, regional advantage.

I. INTRODUCTION

China's grain production is not only closely related to the daily lives of residents, but also plays a vital role in the country's sustainable development and the stability of the world's food market [1]. The current researches on China's grain production mainly focused on the evolution of spatial-temporal patterns [2]–[4], the impact factors [5]–[7], the balance of supply and demand [8]–[12], and grain production potential [13]–[16].

As to the impact factors, firstly, cultivated land was the basic factor for grain production, the transformation of the spatial-temporal pattern of grain production was generally consistent with that of cultivated land [17], [18]. With the rapid development of urbanization in China, on the one hand, the conflicts between the growth of urban construction land and agricultural land have become increasingly significant [19], on the other hand, cultivated land abandonment brought about the degradation of ecological environment in grain production and the reduction of cultivated land production capacity [20]. Hence, holding fast to the "1.8 billion mu" red line of cultivated land has become a major national goal. Secondly, a shift of agricultural labor from country to city or from agricultural industry to non-agricultural industry caused the aging of rural labor and the rise of agricultural labor price [21], [22]. However, such changes have provided great potential for growth for the agricultural machinery investment, and then promoted the development of agricultural modernization [23], [24]. Thirdly, the adjustment of residents' dietary structure has brought about a significant

The associate editor coordinating the review of this manuscript and approving it for publication was Geng-Ming Jiang.

increase in the demand for livestock products, i.e., meat, eggs and dairy products, which affected the direct and indirect consumption of grain [11]. In addition, researchers mainly paid attention on changes of farmers' production behavior and agricultural technologies [25] as well as climate factors [26], [27]. The previous studies on the impact factors for grain production were mostly focused on the impact intensity of single factor and few interactive impact analyses of multi factors, and few analyses on the impact factors for grain production in grain surplus-shortage regions. Moreover, we also know that China's grain problem is that the overall amount contradiction has already transformed to the structural one, appearing the spatial unbalance supply and demand among various regions. And then we are also thinking about what changes have taken place in the spatial pattern of grain production, and what kinds of impact factors have driven such spatial pattern during the pattern evolution as well as what the regional advantage of grain production for each region has when grain production faces with sustainable development. Therefore, we aim to obtain knowledge and reach conclusions helpful in supplementing the current scheme of regional development advantage of China's grain production by the analysis of the spatial pattern of grain production evolution by total and per capita output and the main factors affecting such pattern evolution.

Overall, in this paper, we identified the spatial agglomerations of grain total and per capita output based on the spatial autocorrelation and investigated the spatial pattern evolution from 1985 to 2019. Then, we used Geodetector to analyze the impact intensity of single factor and interactive impact intensity of multi factors for grain total output in the entire country and grain surplus-shortage regions from 1985 to 2015. Furthermore, based on the impact factors analysis, the qualified regions with different grain production advantages were compiled via spatial overlap analysis.

The remainder of the paper is organized as follows. In Section 2, we describe the data and methods. After analyzing the spatial-temporal pattern of grain total and per capita output in Section 3.1, we further investigated the impact intensity of single factor and multi factors for grain total output in the entire country and grain surplus-shortage regions in Section 3.2, then we assess factor mechanism of China's grain production for four types of development orientations in Section 3.3. Discussion is presented in Section 4. Finally, conclusion area drawn in Section 5.

II. MATERIALS AND METHODS

A. DATA COLLECTION

1) SPATIAL BASIC GEOGRAPHICAL DATA

As shown in TABLE 1, digital elevation model (DEM) data of China from Shuttle Radar Topography Mission (SRTM). Meteorological datasets of China contained the annual average precipitation, the annual average temperature and accumulated temperature above 0°C. Cultivated land datasets were extracted by China's land use datasets. The above datasets and the spatial data of soil subclasses

TABLE 1. The data collection.

Data Name	Data type	Spatial-temporal resolution
DEM	Raster data	1km
Geomorphic type	Raster data	1km
Annual average precipitation	Raster data	1km, 1985/1990/1995/2000/2005/2010 /2015
Annual average temperature	Raster data	1km, 1985/1990/1995/2000/2005/2010 /2015
Accumulated temperature above 0 ℃	Raster data	1km, 1985/1990/1995/2000/2005/2010 /2015
Soil subclasses	Raster data	1km
Cultivated land	Raster data	1km, 1985/1990/1995/2000/2005/2010 /2015
China's county administrative divisions	Vector data	2013
China's agricultural regionalization	Vector data	2013
Statistical data	—	County level (1985–2016)

and geomorphic type in China were provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC). GIS vector data of China's county administrative divisions and agricultural regionalization were in 2013. China's agricultural regionalization includes Northern arid and semiarid region, Northeast China Plain, Huang-Huai-Hai Plain, Loess Plateau, Middle-lower Yangtze Plain, Sichuan Basin and surrounding regions, Qinghai Tibet Plateau, Yunnan Guizhou Plateau and Southern China.

2) STATISTICAL DATA

The statistical data at county level during 1985–2016, including total grain output, rural population, the number of primary industry employees in rural population, total power of agricultural machinery, total meat output, GDP and the value-added of primary industry, was obtained from China statistical yearbook (county-level), which did not include data for the Hong Kong Special Administrative Region, the Macao Special Administrative Region, and Taiwan Province. Herein the grain output data for the period of 2017–2019 could not be matched with the former because of different statistical indices used. We managed to derive the data for the entire period from 1985 to 2019 using substituted indices and data. In addition, due to the change in the scopes or names of county-level administrative divisions in different years, we used the scopes and codes of China's county-level administrative divisions in 2013 as the benchmark to revise the administrative units that only change names in other years.

B. METHODS

1) LOCAL MORAN'S I

Spatial autocorrelation is a measure of the degree of numerical clustering in a global or local spatial region, which can be measured by Global Moran's I or Local Moran's I. Local spatial autocorrelation is used to evaluate the local heterogeneity of spatial autocorrelation (non-stationarity). By using local spatial autocorrelation, the spatial clustering of elements with high or low values within the region of interest can be identified as well as spatial outliers.

The Local Moran's I statistic of spatial association is calculated by Equation (1):

$$I_i = \frac{n\left(x_i - \bar{x}\right)\sum_{j=1}^{n} w_{ij}\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)} \tag{1}$$

where x_i represents an attribute for feature i, $\bar{x}$ represents the mean of the corresponding attribute, n represents the total number of features, and w_{ij} represents the spatial weight matrix ($n \times n$) between features i and j.

We chose grain output and per capita grain output at the county level as the local indicators of spatial association index cluster patterns.

2) GEODETECTOR

Geodetector is a method to detect spatial stratified heterogeneity and reveal its driving factors that cause the stratified heterogeneity. Because of this characteristic, the collinearity between the independent variables has no influence on the model calculation results, which is also one of the advantages of Geodetector [28]. The spatial stratified heterogeneity detection, factor detection and interaction detection in Geodetector are measured by the q value.

- The spatial stratified heterogeneity detection and factor detection

The spatial stratified heterogeneity detection and factor detection are given by Equations (2) and (3):

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{2}$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2, SST = N\sigma^2 \tag{3}$$

where $h = 1, \ldots \ldots, L$ is the strata of dependent variable Y or the strata of independent variable X, namely classification or division; N_h and N are the number of units in strata h and the whole area, respectively; σ_h^2 and σ^2 are the variances of Y value of strata h and the whole area, respectively. SSW (Within Sum of Squares) and SST (Total Sum of Squares) are the sum of variance within the strata and the total variance of the whole area, respectively.$q \in [0, 1]$, the larger the value of q, the more obvious the spatial stratified heterogeneity; if the strata are generated by X, then the larger the value of q, the higher interpretation of X to Y, else the lower interpretation of X to Y. In extreme conditions, when $q = 1$, it indicates that X completely controls the spatial distribution of Y, when $q = 0$, it indicates that X has no spatial relationship with Y.

- Interaction detection

Interaction detection can evaluate whether the combined effect of independent variable $X_1$and X_2will enhance or weaken the interpretation for dependent variable Y. Firstly, the q value of X_1 and X_2 to$Y$are calculated, respectively, namely $q(X_1)$and $q(X_2)$; secondly, the q value of the new layer $X_1 \cap X_2$ resulting from the overlay of $X_1$and X_2 to $Y$is calculated, namely $q(X_1 \cap X_2)$. $q(X_1)$, $q(X_2)$ and $q(X_1 \cap X_2)$ were compared, if $q(X_1 \cap X_2) < Min(q(X_1), q(X_2))$, then the interaction is nonlinear weakening; if $Min(q(X_1), q(X_2)) < q(X_1 \cap X_2) < Max(q(X_1), q(X_2))$, then the interaction is single-factor nonlinear weakening; if $q(X_1 \cap X_2) > Max(q(X_1), q(X_2))$, then the interaction is dual factor enhancing; if $q(X_1 \cap X_2) = q(X_1) + q(X_2)$, then the interaction is independent; if $q(X_1 \cap X_2) > q(X_1) + q(X_2)$, then the interaction is nonlinear enhancing.

3) IMPACT FACTORS SELECTION

Grain production is the organic combination of social and natural reproduction. China's grain production was historically based on elevation, climate and soil types. However, rapid development in agricultural technologies and market supply and demand chains as well as urbanization and industrialization have significantly broken through the historical boundaries of the main producing regions of China's grain in recent years [29]. Therefore, combined with the impact factors selected in the existing related researches, the impact factors we selected from the following five categories: physical factors, cultivated land resources, agricultural production factors, market factors and economic factors. Because the spatial scale of basic geographical data and statistical data is different, basic geographical data needs to be matched with statistical data by the spatial calculation in ArcGIS 10.5.

- Physical factors

Physical factors are the most fundamental in the suitability for agricultural production, which support and maintain farming activities, of which climate and soil resources determine the pattern, structure, output, and quality of agricultural production to a great extent [30]. Thus, we selected topographic factors (elevation and geomorphic type) and meteorological factors (the annual average precipitation, the annual average temperature and accumulated temperature of 0°C) therein. Using Zonal Statistics tools, the modes of elevation, geomorphic type and accumulated temperature above 0°C, and the averages of the annual average precipitation and temperature were calculated within a county. The reason for choosing the mode was that the mode represents the uniformity of a group of data, which can effectively avoid the influence of extreme values in the data.

- Land resources

Land resources is the basic input factor of agricultural production, and its quantity and quality have a direct influence on the variety and output of crops [31]. We focused on the quantity and quality of cultivated land in land resources, of which topography and soil type are the main factors affecting the quality of cultivated land. Thus, we selected cultivated land area, cultivated land area with slope category and soil subclasses as land factors at county level. Cultivated land area with slope category at county level was calculated by the following steps: (1) to calculate angle of slope by DEM using Slope tools; (2) to reclass the slope as 0–3°, 3–8°, 8–15°, 15–25° and above 25° using Reclass tools [32]; (3) to class the cultivated land using Raster Calculator into cultivated land with 5 slope categories; (4) to calculate the sum of each category of cultivated land area within a county using Tabulate Area tools. The sum of cultivated land area was calculated between cultivated land data and China's county administrative divisions and outputted a table of cultivated land area at county level using Tabulate Area tools. In addition, the modes of soil subclasses were calculated within a county using Zonal Statistics tools.

- Production factors

Besides physical and land resources, the input factors of agricultural production also include labor and agricultural science and technology. Historically, China's grain production is labor-intensive. Although many agricultural labors have transferred to cities or non-agricultural industries in recent years, grain production still depends on a quantity of labor in most regions without extensive application of agricultural machinery. The agricultural production technology can expand the capacity for labor. For example, the input of agricultural machinery not only improves the agricultural production efficiency but also saves in labor, which makes the agricultural labor transfer to other industries so as to increasing income [19]. Thus, we selected labor factors (rural population, the number of primary industry employees in rural population and non-agricultural employment opportunities) and agricultural technology factors (total power of agricultural machinery) as production factors at county level. Among them, non-agricultural employment opportunity was identified by the proportion of the number of non-agricultural employees in rural population.

- Market factors

The improvement of residents' living standards and the transfer of rural residents to urban have promoted the change of residents' dietary structure, which the demand for livestock products has a markedly increase trend such as meat, eggs and milk. Thus, the rapid development of animal husbandry has promoted the feed grain demand, so as to the difference in the feed grain demand in different regions leads to the difference in grain production [33]. Hence, we selected the total meat output as a market factor at county level.

- Economic factors

The development of industrialization and urbanization in China has brought about the transfer of rural labor to urban and non-agricultural industries, on the one hand, the government's support and public welfare services for agriculture production could be enhanced by the improvement of regional economy, on the other hand, the reduction of agricultural labor and land has also had a negative impact on grain production [34], [35]. Therefore, we selected the value-added of primary industry, per capita GDP and urbanization rate as economic factors at county level. Among them, urbanization rate was identified by the proportion of urban population in total population at county level.

Overall, we selected 20 impact factors to analyze the mechanism of China's grain development and evolution during 1985–2015 (TABLE 2).

III. RESULTS

A. SPATIAL-TEMPORAL PATTERN OF GRAIN OUTPUT

1) BY TOTAL GRAIN OUTPUT

The Moran's I and z-value for grain output at county level increased from 0.67 to 0.73 and from 50.56 to 54.23, respectively, which indicated an increasingly high global clustered pattern for the grain total output from 1985 to 2019.

Then the spatial pattern map of grain total output (FIGURE 1) from 1985 to 2019, were made, reflecting four patterns of high-high, low-low, high-low, low-high in the country.

The high-high pattern represents the core counties and their surrounding counties with relatively high grain total output in a high-land shape model, and the spatial differentiation among them is small, which were aggregated, in 1985, in the main plains and basins with superior thermal and moisture conditions, located on the second and third steps of China's terrain. The high-high counties have markedly increased in Northeast China Plain and decreased in Middle-lower Yangtze Plain and Sichuan Basin and surrounding regions from 1985 to 2019. And by 2019, the similar geomorphologic units with similar conditions mainly were aggregated on the third step of China's terrain. And there was an increase trend from 37.62% in 1985 to 40.62% in 2019 in the percentage of grain total output.

The low-low pattern represents the core counties and their surrounding counties with relatively low grain total output in a low plain shape model, and the spatial differentiation among them is small, which were aggregated, in 1985, in the first and second steps of China's terrain. The low-low counties have only increased in the southeastern coastal areas and decreased in the second step of China's terrain from 1985 to 2019. And by 2019, the low-low counties were mainly in the first step of China's terrain, Northern arid and semi-arid region, Loess Plateau, Yunnan-Guizhou Plateau and the southeastern coastal areas.

The high-low pattern represents the core counties with high output and surrounding counties with low total output of grain in an island shape model, meaning the spatial differentiation among them is large, which were discretely distributed around low-low counties. High-low counties were mainly in the oasis agriculture areas and the basins between hills, and there was a decline trend from 0.62% in 1985 to 0.21% in 2019 in the percentage of grain total output.

TABLE 2. **Independent variables selection for Geodetector.**

Factors	Variable selection	Variable type	Variable name
Physical factors	Elevation	numerical	X_1
	Geomorphic type	categorical	X_2
	Annual average temperature	numerical	X_3
	Accumulated temperature≥0°C	numerical	X_4
	Annual average precipitation	numerical	X_5
	Soil subclasses	categorical	X_6
Land resources	Cultivated land area	numerical	X_7
	0−3° cultivated land area	numerical	X_8
	3−8° cultivated land area	numerical	X_9
	8−15° cultivated land area	numerical	X_{10}
	15−25° cultivated land area	numerical	X_{11}
	≥25° cultivated land area	numerical	X_{12}
Production factors	Rural population	numerical	X_{13}
	the number of primary industry employees in rural population	numerical	X_{14}
	Non-agricultural employment opportunities	numerical	X_{15}
	Total power of agricultural machinery	numerical	X_{16}
Market factors	Total meat output	numerical	X_{17}
	Value-added of primary industry	numerical	X_{18}
Economic Factors	Per capita GDP	numerical	X_{19}
	Urbanization rate	numerical	X_{20}

The low-high pattern this represents the core counties with low output and surrounding counties with high total output of grain in a hollow-land shape model, meaning the spatial differentiation among them is large, which were discretely distributed around the high-high counties. Low-high counties were mainly in the regions with both development of forestry and animal husbandry, the mountain areas and the poverty counties, where the percentage of grain total output has decreased from 0.79% in 1985 to 0.40% in 2019.

2) BY PER CAPITA GRAIN OUTPUT

The Moran's I and z-value for per capita grain output at county level increased from 0.45 to 0.67 and from 34.44 to 49.93, respectively, which indicated an increasingly high global clustered pattern for per capita grain output from 1985 to 2019.

Then the spatial pattern map of per capita grain output (FIGURE 2) from 1985 to 2019, is similar to FIGURE 1, also reflecting four patterns of high-high, low-low, high-low, low-high. The difference is that, from 1985 to 2019, the high-high counties almost disappear and the low-low counties increased a lot in the central and southern regions, indicating that there is much more amount and much higher density of population, which accounts much lower share of grain output per capita in these areas than in others. Before 2005, the evolution of the spatial agglomeration of grain output per capita was mainly represented in the increase of high-high counites in Northeast China Plain and Northern arid and semi-arid region and the decrease of high-high counites in Middle-lower Yangtze Plain and low-low counties in the second step of China's terrain. After 2005, the evolution was mainly shown in the increase of high-high counites in Northeast China Plain and Northern arid and semi-arid region and low-low counties in Yunnan-Guizhou Plateau and the southeastern coastal areas.

B. IMPACT FACTORS ANALYSIS ON CHINA's GRAIN OUTPUT

The spatial stratified heterogeneity of impact factors, single and interaction, on grain total output, was detected using Geodetector, thus investigating the contributions of 20 factors to China's grain production in the whole country and grain surplus–shortage regions.

1) THE SPATIAL STRATIFIED HETEROGENEITY DETECTION FOR IMPACT FACTORS

When using Geodetector, the value of q is uniquely determined for categorical independent variables. For numerical independent variables, it needs to be discretized into categorical variables. On the one hand, different discretization granularities will have a significant impact on the model results, and usually choose discretization scheme with the largest value of q statistic, on the other hand, the number of spatial strata should be within a reasonable range to ensure the interpretability of the results [28]. In the related

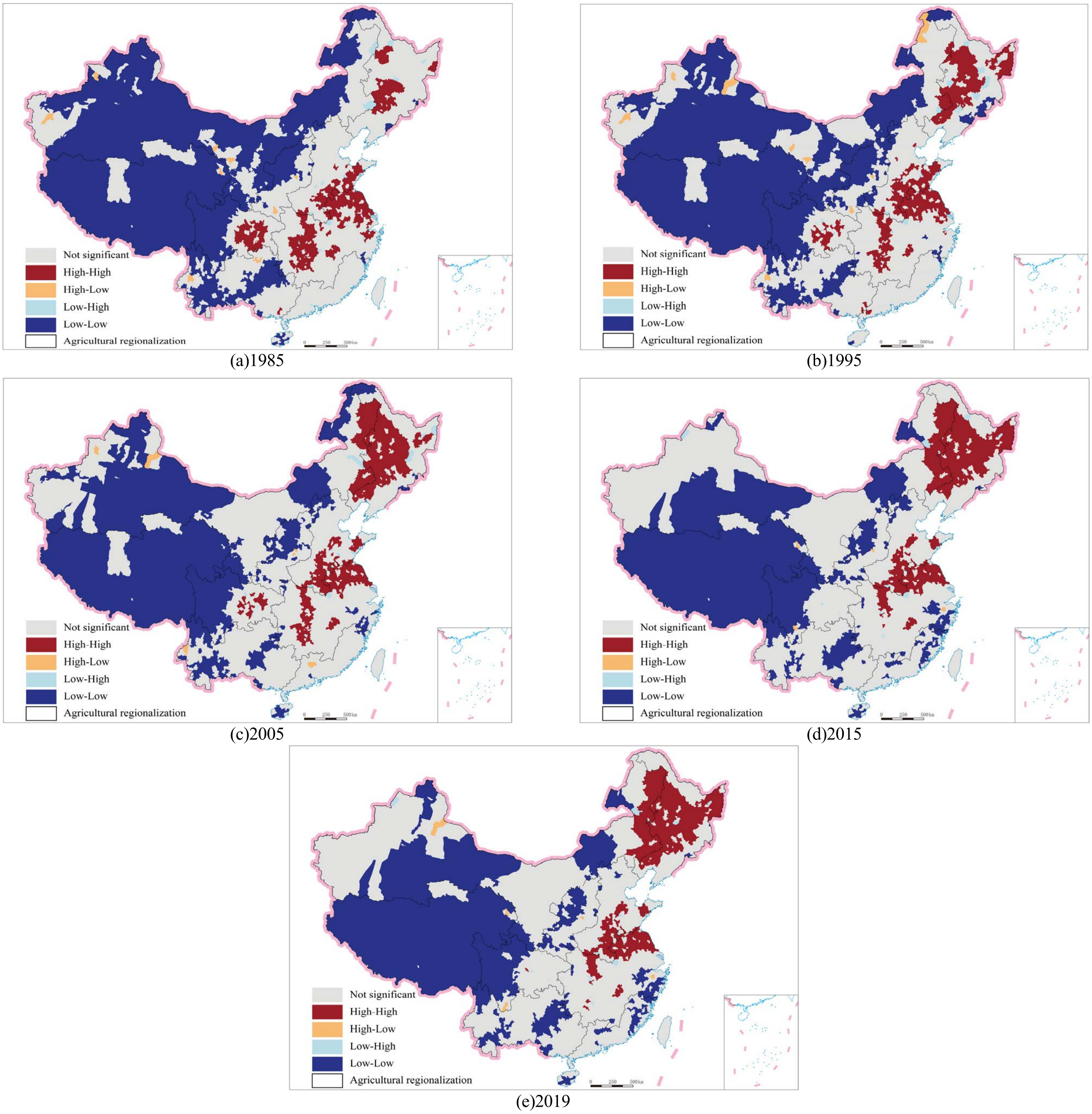

FIGURE 1. **Spatial agglomeration of grain total output at the county level from 1985 to 2019.**

researches, the spatial strata of independent variables were divided uniformly by researchers' experience. Although it can ensure the interpretability of the results, the difference of spatial distribution among the independent variables will be ignored. Therefore, we firstly applied K-means method to divide each numerical independent variable into 3–10 clusters. Then the q value of each cluster was calculated using the spatial stratified heterogeneity detection of Geodetector, and the q value of the classification results of numerical independent variables were obtained. The results of the spatial stratified heterogeneity detection for the numerical independent variables were featured in FIGURE 3, taking the results in 2015 as an example. Finally, the spatial strata result of the numerical independent variable was selected by the cluster value corresponding to the q value at the inflection point and the interpretability of independent variable. As shown in TABLE 3, the cluster values representing the spatial strata of numerical independent variables were determined by the above steps from 1985 to 2015, indicating that numerical independent variables were

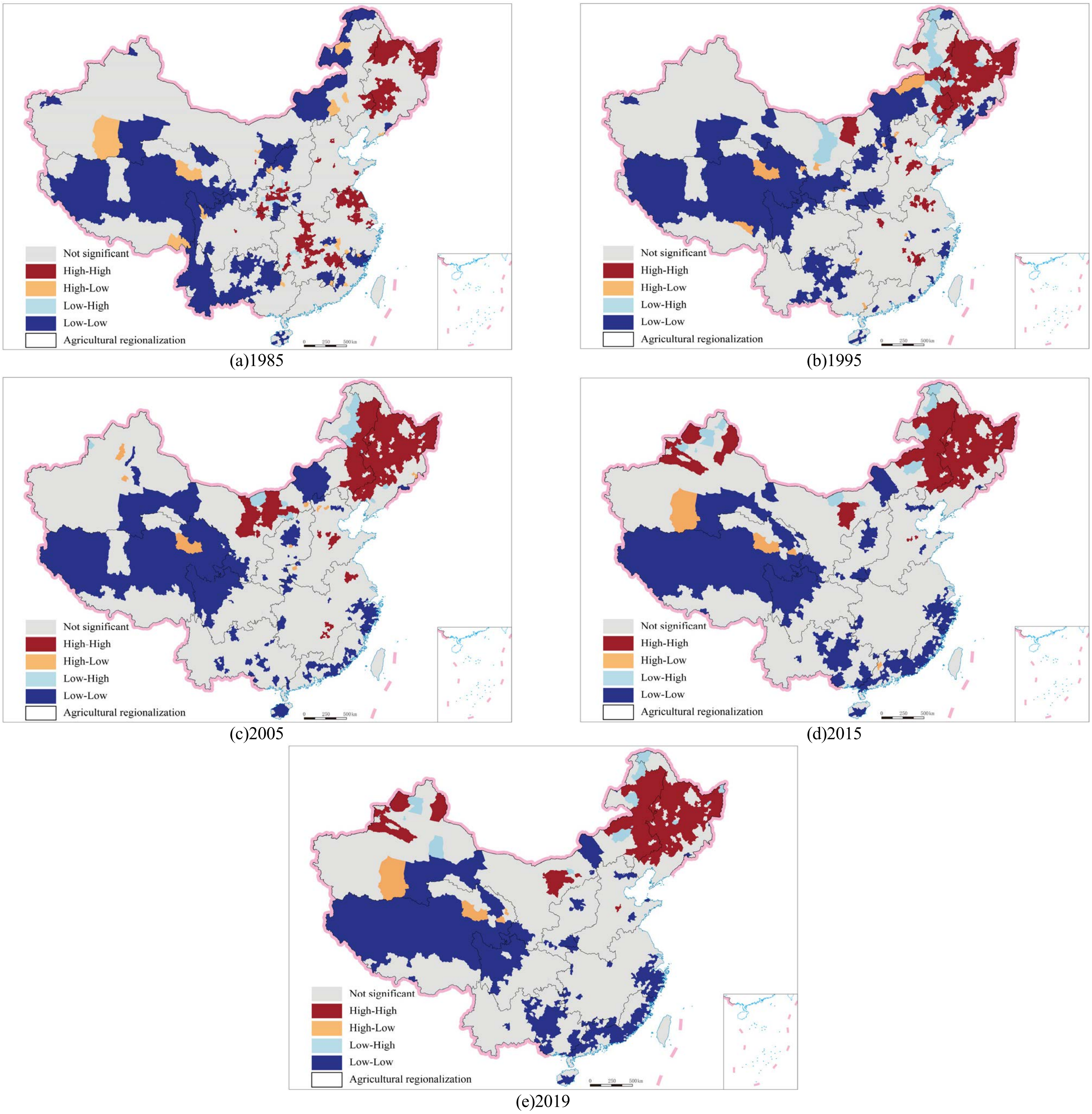

FIGURE 2. Spatial agglomeration of grain output per capita at the county level from 1985 to 2019.

discretized into categorical ones with corresponding cluster value.

2) BY TOTAL OUTPUT IN THE WHOLE COUNTRY

First of all, let's see the result of factor detection.

As shown in FIGURE 4, in general, the main impact factors on grain output were topographic factors (X_1, X_2), soil subclasses (X_6), cultivated land area (X_7), 0–3° cultivated land area (X_8), rural population (X_{13}), the number of primary industry employees in rural population (X_{14}), total power of agricultural machinery (X_{16}), total meat output (X_{17}) and value-added of primary industry (X_{18}). Among them, soil subclasses (ranged from 0.40 to 0.46), cultivated land area (ranged from 0.33 to 0.56), 0–3° cultivated land area (ranged from 0.38 to 0.60) and total power of agricultural machinery (ranged from 0.36 to 0.45) were featured by marked increase trend during the study period. Note that the impact intensity of the cultivated land area above 25° (X_{12}) was higher than that of cultivated land area at 3–25 ° (X_9–X_{11}), and had an increase trend.

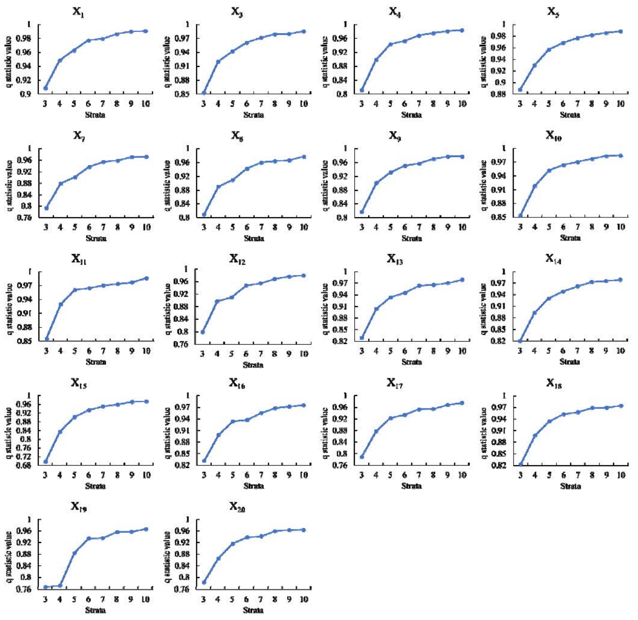

FIGURE 3. The spatial stratified heterogeneity detection for the strata of the numerical independent variables in 2015.

TABLE 3. The results of the spatial strata of independent variable *X*.

Variable	1985	1990	1995	2000	2005	2010	2015
X_1	6	6	6	6	6	6	6
X_3	6	6	6	6	6	6	8
X_4	5	5	5	6	5	5	5
X_5	6	7	5	7	5	7	5
X_7	6	8	7	7	7	6	7
X_8	6	6	7	7	7	6	7
X_9	8	6	6	6	6	6	6
X_{10}	6	6	6	5	6	5	5
X_{11}	5	7	6	6	6	6	5
X_{12}	6	6	6	6	6	6	6
X_{13}	8	5	7	5	6	7	7
X_{14}	—	7	7	6	6	7	5
X_{15}	—	6	6	6	6	7	6
X_{16}	6	5	7	5	6	6	5
X_{17}	6	6	6	6	5	7	5
X_{18}	7	7	6	6	6	6	6
X_{19}	6	6	6	6	7	6	6

From the perspective of each time point, major factors affecting regional differences in grain output before 2000, are mainly production and market as well as economic ones, such as labors, meat output, and value-added of primary industry, while after 2000, changed to land resource factors, meaning that the land resource is increasingly important with the urbanization courses in various regions.

Secondly, the results of interaction detection (FIGURE 5) show that, the interaction between any two independent variables on grain output was dual factor enhancing or nonlinear enhancing during 1985–2015. Herein the interaction intensity between land resources (X_6, X_7 and X_8) and production factors as well as social-economic factors ($X_{13}, X_{14}, X_{16}, X_{17}$ and X_{18}) are much higher than the interaction among others, and such trend increased after 2000, meaning there is increasingly positive enhancement between land resources and production as well as social-economic features for the spatial difference of grain production. Thus, these factors not only play important role independently, but also have mutual coupling effect in China's grain production and security.

3) BY TOTAL OUTPUT IN GRAIN SURPLUS–SHORTAGE REGIONS

The spatial agglomeration of grain output per capita (FIGURE 2) reminded us that the population amount and density impacted not only on grain supply, but also on its demand in each region. Thus, the mechanism of grain surplus and shortage by county-level units in 2015 was analyzed further, applying the standard grain consumption line of 400 kg grain output per capita, which generated the impact density for factors grain surplus and shortage regions of in China. The result of factor detection (FIGURE 6) shows that in the grain surplus regions, the major factors were land resources (X_6, X_7 and X_8) and value-added of primary industry (X_{18}), while in the grain shortage regions, were production and social-economic factors (X_{13}, X_{14}, X_{17} and X_{18}), and there were great differences in the impact intensity of main factors between two types of regions. Another contrast shows that, in terms of production factors, regional differences depended mainly on labors input in grain shortage regions, while in grain surplus regions, mainly on machinery input.

The result of interaction detection on factors shows that in the grain surplus regions (FIGURE 7(a)), the interaction intensity among land resource factors (X_6, X_7 and X_8) and economic factors (X_{18}) were much higher than the interaction among others, meaning that grain surplus mainly determined by land resources and economic benefit, while in shortage regions (FIGURE 8(b)), the interaction intensity among land resources (X_7, X_8) and production (X_{13}–X_{16}) as well as social-economic factors (X_{17}, X_{18}) were much higher than others, meaning that limitation of cultivated land area, sufficient input of production factors, especially labors input, plus market demand and benefit were the major reasons of grain shortage.

C. FACTOR MECHANISM OF CHINA's GRAIN PRODUCTION FOR FOUR TYPES OF DEVELOPMENT ORIENTATIONS

Grain production is an organic combination of social and natural reproduction. China's grain production has been on a pathway in recent 40 years, from relatively extensive sowing and less grain output per unit area as well as total output, to sown areas decreasing and grain output per unit area as well as total output increasing, driven by several factors of natural resources and social-economic features. The above results lead us to think: what should be China's regional advantage or orientation in grain production? Here we presenting four types of development orientations for China's grain production according to the regional production advantage, including production scale orientation, production

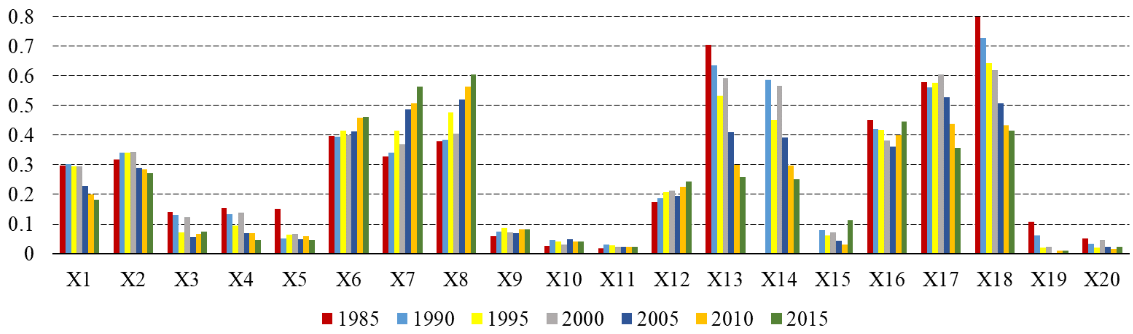

FIGURE 4. **Variation of *q* statistic value of impact factors on grain total output from 1985-2015.**

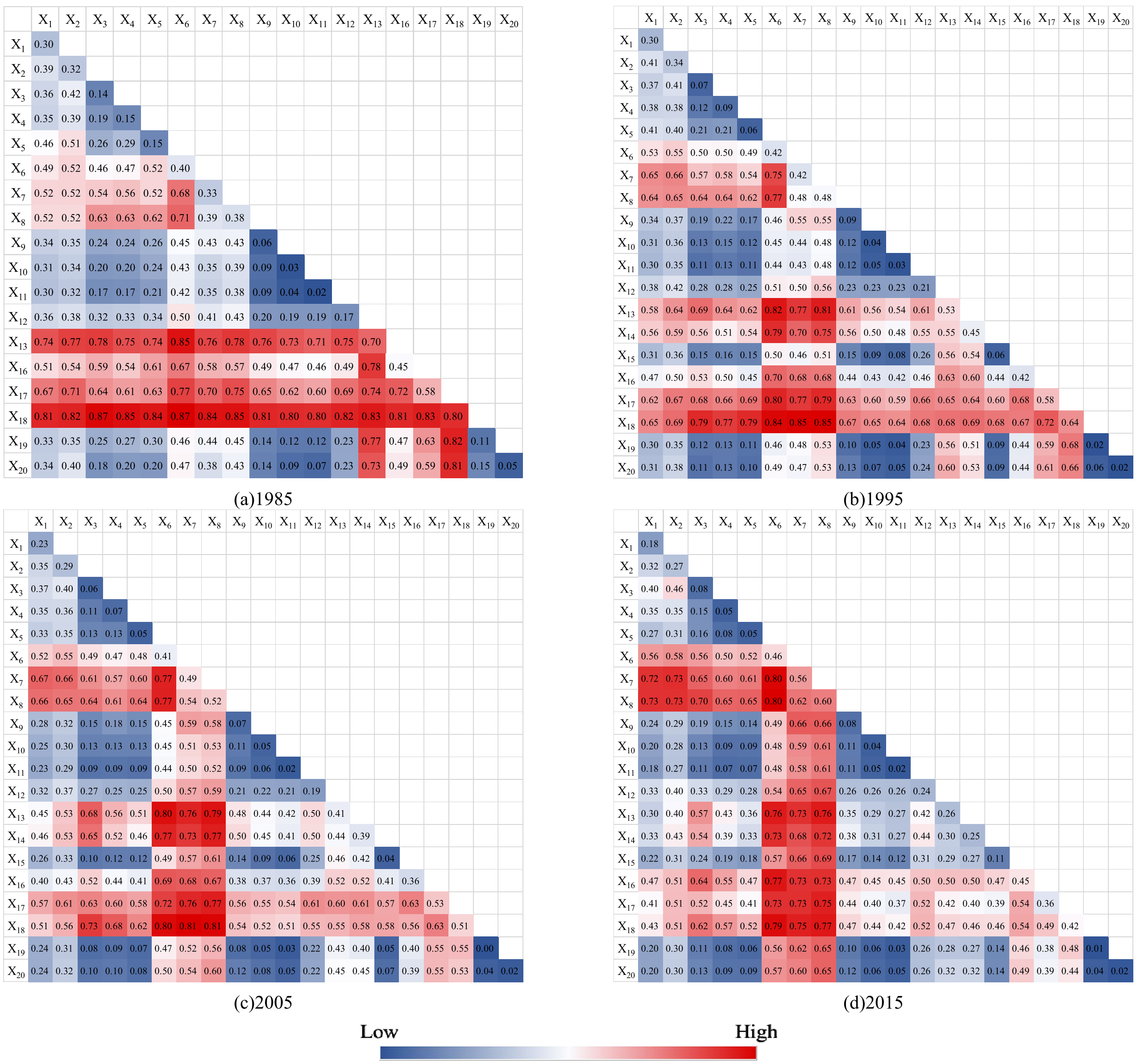

FIGURE 5. **The interaction detection of impact factors on grain total output from 1985 to 2015: (a) the interaction detection in 1985 without X_{14} and X_{15}; (b) the interaction detection in 1995; (c) the interaction detection in 2005; (d) the interaction detection in 2015.**

efficiency and benefit orientation, product quality orientation and economic coordination orientation. Furthermore, the regions with single factor advantage were firstly selected by the factor value higher than the national average, and then the

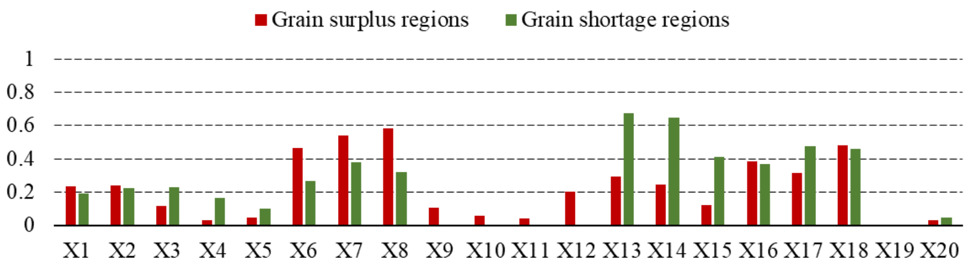

FIGURE 6. The q statistic value of impact factors on grain total output in grain surplus–shortage regions.

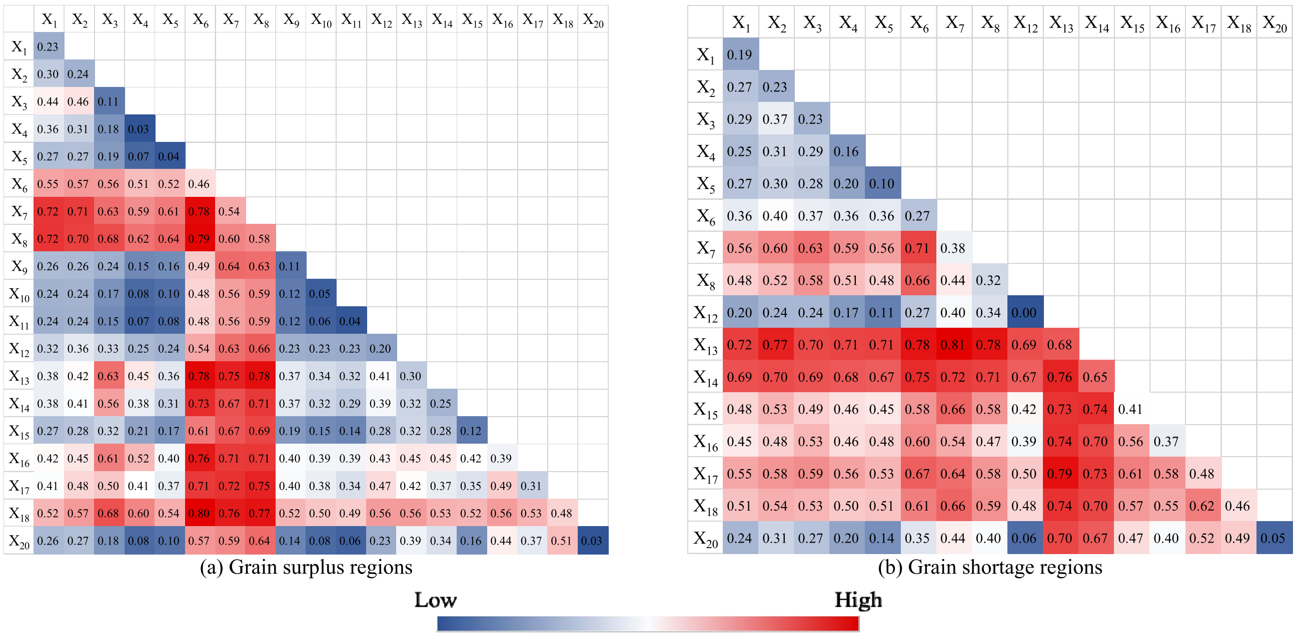

FIGURE 7. The interaction detection of impact factors on grain output in grain surplus and shortage regions in 2015: (a) the interaction detection in grain surplus regions, excluding X_{19} (non-significant); (b) the interaction detection in grain shortage regions, excluding X_9, X_{10}, X_{11} and X_{19} (non-significant).

qualified regions were compiled through overlay analysis of the regions with single factor advantage.

1) PRODUCTION SCALE ORIENTATION

It's our primary objective to increase the production scale and raise the quantity of grain to the maximum extent. In 70 years since the founding of the People Republic of China (PRC), China's farming has been mainly on the way of scale orientation, by fully utilizing suitable farming conditions and natural, social, economic and technological resources, expanding sowing area, and increasing grain output per unit areas at the same time. China's cultivated land was mainly concentrated in Northeast Plain, Northern arid and semi-arid region, Huang-Huai-Hai Plain and Middle-lower Yangtze Plain, with accounting for 66.84% of the total area in 1985 and 70.16% in 2015. Among them, the cultivated land area had an increase in Northeast Plain, Northern arid and semi-arid region by 0.91% and 3.34%, respectively, which has driven the transformation of the spatial pattern of grain output.

Therefore, the advantage regions for this orientation should have large-scale cultivated land area and high cultivated land connectivity. And the realization of this orientation relies on following factors: physical factors (geomorphic type) and land resources (cultivated land area). As shown in FIGURE 8, the qualified regions for this orientation have the cultivated land area greater than a national average of 764 km^2, and plains and basin as well as platform, and they are mostly in Northeast China Plain, Northern arid and semi-arid region, Huang-Huai-Hai Plain, Middle-lower Yangtze Plain and Sichuan Basin and surrounding regions.

2) PRODUCTION EFFICIENCY AND BENEFIT ORIENTATION

This orientation is the second objective of grain production, with increasing yield per unit areas and feature of market demand as well as economic benefit. The grain production could be integrated with extremely utilizing the capacity of physical features such as climatic elements, and machinery power, animal husbandry as well as primary industry. Before

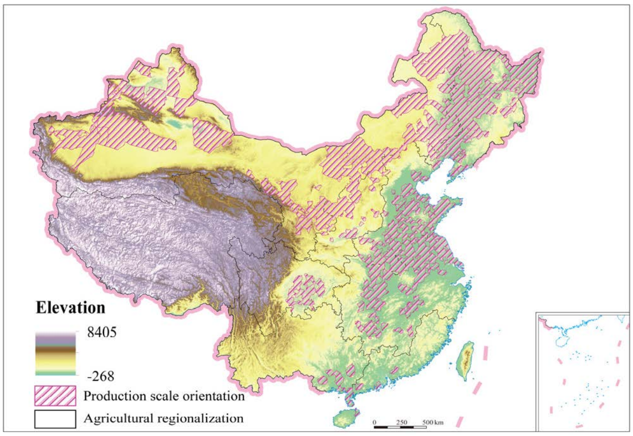

FIGURE 8. **The spatial distribution of the suitable regions for production scale orientation.**

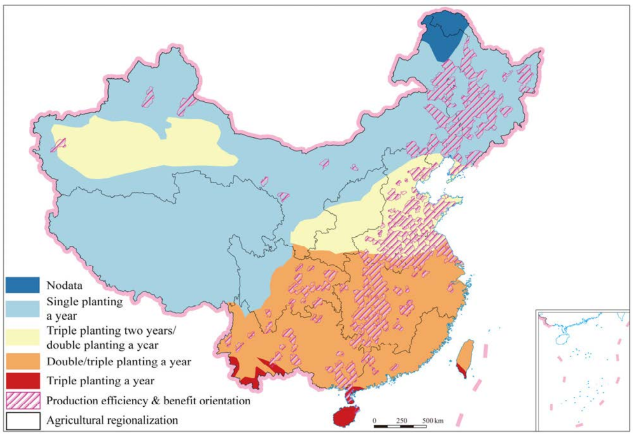

FIGURE 9. **The spatial distribution of the suitable regions for production efficiency and benefit orientation.**

2005, there was a complementary relationship between machinery and labor in grain production. And the transfer of rural labors caused cultivated land abandonment, which brought about the decline of the level of agricultural mechanization. After 2005, the implementation of the subsidy policy for the purchase of agricultural machinery and tools, the integration of cultivated land and the establishment of new agricultural business entities have improved the level of agricultural mechanization. The relationship between agricultural machinery and labor has been changed from complementarity to substitution in the northern China [23]. By 2015, Middle-lower Yangtze Plain (25.93%), Huang-Huai-Hai Plain (21.66%), Northeast Plain (14.25%) and Yunnan Guizhou Plateau (13.17%) were concentrated distribution regions of meat output. Value-added of primary industry had a relatively high level of influence on grain output, although there was a decrease trend after 2000, indicating that the benefits of the primary industry promoted farmers' willingness to produce.

Therefore, the advantage regions for this orientation should have high agricultural mechanization level and economic benefit. Moreover, due to the natural distribution law of heat and moisture conditions, China's agricultural planting system (natural production efficiency) increases from north to south. Here is the factor list for this orientation: physical factors (temperature and precipitation), production factors (total power of agricultural machinery), market factors (total meat output) and economic factors (value-added of primary industry). As shown in FIGURE 9, Concerning the temperature and precipitation, the qualified regions are Middle-lower Yangtze Plain, Southern China, Sichuan Basin and surrounding regions and Yunnan Guizhou Plateau, where the best conditions of heat and water can supply double or triple planting of farming a year [30]. Concerning agricultural mechanization level and market demand as well as economic benefit, the qualified regions are mostly in Northeast China Plain, Huang-Huai-Hai Plain and Middle-lower Yangtze Plain, with exceeding national averages of the total power of agricultural machinery (0.46 million kw) and total meat output (43.6 thousand tons) as well as value-added of primary industry (249.7 million CNY).

3) PRODUCT QUALITY ORIENTATION

With the improvement of residents' living standards, residents' requirements for the quality of agricultural products are also increasing. The quality orientation is the new demand of modern agriculture, by utilizing the special feature of physical conditions, producing grains with high quality such as Basmati rice, Waxy corn, grains products with rare trace elements, and grain products with geographical indication, etc. The quality of agricultural products is closely related to natural resource conditions and production technology characteristics, especially soil types.

Therefore, this orientation could be realized in any region of China. For instance, in Northeast China Plain, the typical product of Basmati rice has long been produced, and in the large parts of northern China, Waxy corn is also popularly produced, and in southern, southwestern and northwestern parts of China where there are rare trace elements, may produce high quality grain with geographic indications. The agricultural product with geographical indication is one of the important brands of high-quality agricultural products in China, which have evident characteristics in terms of terrain, humanities and quality. Here is the factor list for this orientation: land resources (soil types) and grain products with geographical indication. As shown in FIGURE 10, there are 324 grain products with geographical indication until 2021, which are mostly in Middle-lower Yangtze Plain (59 products), Loess Plateau (53 products) and Huang-Huai-Hai Plain (51 products).

4) ECONOMIC COORDINATION ORIENTATION

There is a two-way relationship between grain production and regional economic development. On the one hand, grain production is an important part of the primary industry and has a certain direct contribution to regional economic benefits. On the other hand, regional economic development has a

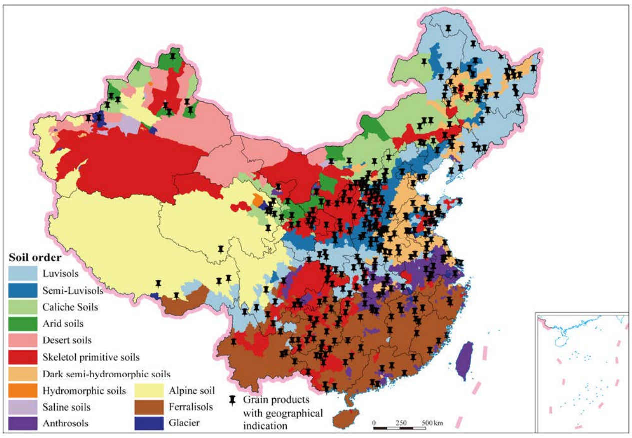

FIGURE 10. **The location of grain products with geographical indication until 2021.**

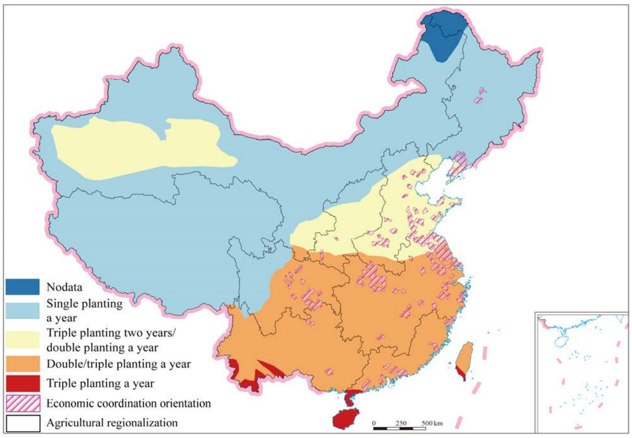

FIGURE 11. **The spatial distribution of suitable regions for economic coordination orientation.**

negative influence on grain production, i.e., cultivated land occupation, or a positive influence, i.e., capital subsidies. Thus, the economic coordination orientation is the demand of advanced economy, with feature of recycling economy and industrial coordinated development. The grain production could be integrated with ecosystem protection, and secondary & tertiary industries. The advantage regions for this orientation should have high the number of labors as well as regional economic development level. Here is the factor list for this orientation: production factors (rural population and non-agricultural employment opportunities) and economic factors (value-added of primary industry, per capita GDP and urbanization rate).

As shown in FIGURE 11, the qualified regions are mostly in Huang-Huai-Hai Plain and Middle-lower Yangtze Plain, with exceeding national averages of rural population (393 thousand) and non-agricultural employment opportunities (42.0%) as well as value-added of primary industry, per capita GDP (38.3 thousand CNY), urbanization rate (21.1%), especially in Yangtze Delta where there is high level of economy and urbanization, could develop a new kind of farming coordinated with other industries, and rural vitalization, as well as tourism.

IV. DISCUSSION

A. PREREQUISITE AND SUFFICIENT FACTORS FOR CHINA's GRAIN PRODUCTION

The qualification of grain producing areas is the combination of multiple factors, among which the physical features and natural resources are prerequisite and necessary conditions of farming, and the social and economic factors are supplementary conditions. Integration of the two types of factors may compose a sufficient one, under which adequate grains could be produced, and could feed large quantity of local people as well as supply to animal husbandry and secondary as well as tertiary industries. The grain surplus, if there are any, could supply to the outside areas.

Therefore, the grain surplus regions are those areas where there are both prerequisite and sufficient factors for producing adequate grain to support not only to local people and economy, but also to the outside ones, While the shortage regions are those areas where there are not necessary farming factors, or the necessary factors couldn't supply sufficient grain for local people, let alone for local economy, or to the outside areas.

B. DIFFERENT SUITABILITY IS THE BEST REGIONAL CHOICE FOR FOUR TYPES OF GRAIN ORIENTATION

The four types of grain developing orientations are not unified criteria for various regions, but should be carried out according to their own advantages and suitability, instead. For example, Northeast China Plain is the special region which is suitable for three orientations, i.e., the ones for production scale, production efficiency and benefit, and product quality. The areas in the Yangtze Delta are suitable, to some extent, for production scale and efficiency as well as benefit mode, but mostly suitable for economic coordination orientation. So different suitability is the best regional choice for the grain orientation of themselves.

V. CONCLUSION

Spatial-temporal pattern of grain output in China, by total and per capita output, was analyzed. We found out the number of the regions with high grain total output had increased in northern China and decreased in southern China while the number of the regions with low grain total output had increased in the southeast coastal areas and decreased in central and western China from 1985 to 2019. There was a similar transformation in per capita grain output. Until 2019, the regions with high per capita output were concentrated in Northeast China Plain and Northern arid and semiarid region while the regions with low per capita output were concentrated in Qinghai Tibet Plateau, Loess Plateau, Yunnan Guizhou Plateau and Southern China. Then the impact factors, by total output in the whole country and grain surplus–shortage regions, were detected and found out. The results showed that the main impact factors for the regional differences in grain total output in the whole country changed from labor, market and economic factors to land resources, machinery power, market and economic factors during the study period, and these factors not only played important role independently, but also had mutual coupling effect in China's grain production and security. In the grain surplus regions, the major factors were land resources and value-added of primary industry, while in the grain shortage regions, were labor and market as well as economic factors. And in terms of production factors, regional differences depended mainly on labor input in grain shortage regions, while in grain surplus regions, mainly on machinery input. Thirdly, factor mechanism of China's grain production for four types of development orientations, i.e., orientation on production scale, production efficiency and benefit, product quality and economic coordination, were concluded, and the way of grain production in different region with unique advantage and suitability were expounded. This paper still leaves a large space for additional research, which needs further exploration and application. For example, China's grain production is also affected by policies. Hence, the impact factors on grain output need to further include the policy factors and their interaction with other factors.

ACKNOWLEDGMENT
The authors would like to thank the reviewers and editors for valuable comments and suggestions.

REFERENCES
[1] The National Food and Strategic Reserves Administration, China. *Food Security in China*. Accessed: Oct. 14, 2019. [Online]. Available: http://www.lswz.gov.cn/html/xinwen/2019-10/14/content_247014.shtml
[2] J. Wang and Y. Liu, "The changes of grain output center of gravity and its driving forces in China since 1990," *Resour. Sci.*, vol. 31, no. 7, pp. 1188–1194, 2009.
[3] Y. Liu, G. Wang, B. Gao, and Y. Zhou, "Spatio-temporal analysis of grain production at different levels in China-based on statistical data from 1998 to 2010," *Res. Agricult. Modernization*, vol. 33, no. 6, pp. 673–677, 2012.
[4] Y. Li, S. Pan, and C. Miao, "The spatial-temporal patterns of per capita share of grain at the county level in China: A comparation between registered population and resident population," *Acta Geograph. Sinica*, vol. 69, no. 12, pp. 1753–1766, 2014.
[5] J. Pan and J. Zhang, "Spatial-temporal pattern and its driving forces of per capital grain possession in China," *Resour. Environ. Yangtze Basin*, vol. 26, pp. 410–418, 2017.
[6] F. Wang, Y. Liu, X. Kong, Y. Chen, and J. Pan, "Spatial and temporal variation of grain production and its influencing factors at the county level in China," *Econ. Geogr.*, vol. 38, no. 5, pp. 142–151, 2018.
[7] Z. Xu, Z. Song, A. Deng, W. Chen, F. Chen, and W. Zhang, "Regional changes of production layout of main grain crops and their actuation factors during 1981–2008 in China," *J. Nanjing Agricult. Univ.*, vol. 36, no. 1, pp. 79–86, 2013.
[8] Z. Liu, H. Zhong, Y. Li, Q. Wen, X. Liu, and J. Jian, "Change in grain production in China and its impacts on spatial supply and demand distributions in recent two decades," *J. Natural Resour.*, vol. 36, no. 6, pp. 1413–1425, 2021.
[9] P. Yin, X. Fang, Y. Ma, and Q. Tian, "New regional pattern of grain supply-demand in China in the early 21st century," *J. Natural Resour.*, vol. 21, no. 4, pp. 625–631, 2006.
[10] P. Yin, X. Fang, Y. Ma, and Q. Tian, "Distribution and regional difference of food shortage in China in 21st century," *Acta Geographcia Sinica*, vol. 27, no. 4, pp. 463–472, 2007.
[11] G. Xie, S. Cheng, Y. Xiao, C. Lu, X. Liu, and J. Xu, "The balance between grain supply and demand and the reconstruction of China's food security strategy in the new period," *J. Natural Resour.*, vol. 32, no. 6, pp. 895–903, 2017.
[12] Z. Feng and X. Li, "The stratagem of cultivated land and food supplies security: Storing food in land-raising the comprehensive productivity of land resource of China," *Geography Territo Rial Res.*, vol. 16, no. 3, pp. 1–5, 2000.
[13] L. Liu, X. Xu, J. Liu, X. Chen, and J. Ning, "Impact of farmland changes on production potential in China during 1990–2010," *J. Geograph. Sci.*, vol. 25, no. 1, pp. 19–34, Feb. 2015.
[14] L. Fei, L. Ya, and M. Shuang, "Regional difference of grain production potential change and its influencing factors: A case-study of Shaanxi Province, China," *J. Agricult. Sci.*, vol. 157, no. 1, pp. 1–11, Jan. 2019, doi: 10.1017/S0021859619000145.
[15] X. Tian, X. Yu, and X. Zhang, "Grain output potential in China: A perspective from club convergence," *J. Zhejiang Univ., Humanities Social Sci.*, vol. 46, no. 5, pp. 112–128, 2016.
[16] Q. Lu and M. Lv, "Trends and basic causes of the regional pattern changes in China's grain production since 1950's," *Prog. Geogr.*, vol. 16, no. 1, pp. 31–36, 1997.
[17] Y. Liu, J. Wang, and L. Guo, "The spatial-temporal changes of grain production and arable land in China," *Scientia Agricultura Sinica*, vol. 42, no. 12, pp. 4269–4274, 2009.
[18] T. Hu, Z. Ju, and W. Zhou, "Regional pattern of grain supply and demand in China," *Acta Geograph. Sinica*, vol. 71, no. 8, pp. 1372–1383, 2016.
[19] S. Wang, X. Bai, X. Zhang, S. Reis, D. Chen, J. Xu, and B. Gu, "Urbanization can benefit agricultural production with large-scale farming in China," *Nature Food*, vol. 2, no. 3, pp. 183–191, Mar. 2021.
[20] Y. Li, W. Ma, G. Jiang, G. Li, and D. Zhou, "The degree of cultivated land abandonment and its influence on grain yield in main grain producing areas of China," *J. Natural Resour.*, vol. 36, no. 6, pp. 1439–1454, 2021.
[21] X. Yi and Y. Yan, "The impact of rural labor price fluctuation on grain production and its regional differences," *J. South China Agricult. Univ., Social Sci. Ed.*, vol. 6, no. 6, pp. 70–83, 2019.
[22] N. Xu and L. Zhang, "Impact of aging labor force on agricultural production efficiency in China," *J. China Agricult. Univ.*, vol. 19, no. 4, pp. 227–233, 2014.
[23] M. Huang, X. Li, and L. You, "Impact of agricultural machinery and agricultural labor investment on grain production and its elasticity of substitution," *J. Huazhong Agricult. Univ., Social Sci. Ed.*, no. 134, pp. 37–45, 2018.
[24] S. Yu, T. Liu, and B. Cao, "Effects of agricultural mechanization service on the cost efficiency of grain production—-Evidence from wheat-producing areas in China," *J. Huazhong Agricult. Univ., Social Sci. Ed.*, no. 142, pp. 81–89, 2019, doi: 10.13300/j.cnki.hnwkxb.2019.04.009.
[25] Y. Ye, Q. Qi, L. Jiang, and A. Zhang, "Impact factors of grain output from farms in Heilongjiang reclamation area based on geographical detector," *Geograph. Res.*, vol. 37, no. 1, pp. 171–182, 2018.
[26] G. Du, J. Ma, L. Zhang, X. Sun, Z. Zhang, and Z. Liu, "Spatiotemporal characteristics of grain potential productivity change under the background of climate change over the past 50 years in the Sanjiang Plain," *Res. Soil Water Conservation*, vol. 25, no. 2, pp. 361–366, 2018.
[27] R. Zhao, H. Wang, and Y. Dong, "Impact of climate change on grain yield and its trend across Guanzhong region," *Chin. J. Eco-Agricult.*, vol. 28, no. 4, pp. 467–479, 2020.
[28] J. Wang and C. Xu, "Geodetector: Principle and prospective," *Acta Geographica Sinica*, vol. 72, pp. 116–134, Jan. 2017.
[29] G. Veeck, "Delineating historical and contemporary agricultural production regions for China," *Int. J. Cartogr.*, pp. 1–23, Aug. 2021, doi: 10.1080/23729333.2021.1925495.
[30] C. Lei, Q. Qi, L. Jiang, Y. Fu, and Q. Liang, "Analysis of current and qualified major grain producing areas in China in the last 30 years," *Sustainability*, vol. 14, no. 5, p. 2909, 2022, doi: 10.3390/su14052909.
[31] L. Wang, A. Liu, and L. Xin, *Research on Strategy of China's Grain Security and Cultivated Land Safeguard*. Beijing, China: China Agriculture Press, 2019, pp. 15–20.
[32] J. Fan, *Assessment Guidelines for Resources and Environmental Carrying Capacity and Territorial Development Suitability*. Beijing, China: Science Press, 2018, p. 8.
[33] C. F. E. Society, *China's Grain Reform and Open in Recent 40 Years*. Beijing, China: Economy & Management Publishing House, 2019, pp. 5–10.
[34] T. Zhang, *Grain Security and Agricultural Structure Adjustment*. Beijing, China: China Agriculture Press, 2019, pp. 20–23.
[35] F. Wang and X. Yu, *Food Economy and Culture*. Beijing, China: China Book Publishing House, 2019, pp. 1–5.

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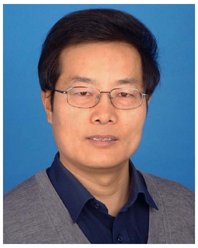

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