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Research Article

Temporal-spatial Pattern of the Proportion of Grain-crop Sown Area in Henan in China from 1980 to 2012

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Abstract: In order to provide a scientific basis for the establishment of grain production policy, the temporal-spatial pattern of the proportion of grain-crop sown area at county level in Henan province is analyzed by the Kernel density method, ESDA method and spatial variogram method, using the softwares-such as GS+, ArcGIS and GeoDa. The following results are drawn based on the 126 county-scale data in 1980, 2004 and 2012. (1) The proportion of grain-crop sown area is decreased from 0.812 to 0.700 and the total disparities of the proportion of grain-crop sown area at county level in Henan province have enlarged. The distribution shapes of the proportion of grain-crop sown area typical "single peak" shape in 3 years, transforming from "spike peak" in 1980 to "broad peak" in 2004 and 2012. (2) The proportion of grain-crop sown area at county level shows a significantly trend of positive spatial correlation and similar areas cluster in space. And, the spatial continuity and constitutive property of the proportion of grain-crop sown area, as well as the mechanism of structural difference caused by spatial autocorrelation become more and more obvious and remarkable.

Keywords: Henan, kernel density method, proportion of grain-crop sown area, temporal-spatial pattern, variogram

INTRODUCTION

National security and social stability are based on food security (Liu *et al*., 2009, 2012; Sakschewski *et al*., 2014). Driven by the comparative benefit and the adjustment of agricultural planting structure, the proportion of grain farmers and the proportion of grain-crop sown area (grain-crop sown area accounts for the proportion of total sown area of crops) continuously decline and the negative effects of planting structure adjustment upon the total grain output are becoming more and more serious (Xiong *et al*., 2009; Van Ittersum and Cassman, 2013). Especially in areas with superior geo graphical or economic conditions, non-agricultural or non-food trends of farmland are obvious and rapid non-food trend in land circulation causes further decrease of the grain-crop sown area (Shi and Zhou, 2004; Wu *et al*., 2013). As a key method of reform in cultivated land use (Long, 2012), non-food trend in farmland use is based on certain economic rationality, however the over-heated non-food reform will pose a threat to regional and national food security. Based on data analysis in tracking study of farmers (Yi and Chen, 2010), most of the farmlands in hands of enterprises and cooperatives are used for the development of high-efficiency agriculture, that is to say, non-food agriculture. The negative effects caused by the declining proportion of grain-crop sown area upon the total grain output will be further developed. Up to now, the existing research is mainly based on survey data and research based on spatial and temporal variation pattern to reveal the importance of the proportion of grain-crop sown area in exosystem level is still under development. Moreover, it is difficult for us to understand the general distribution pattern and evolution trend hidden in the proportion of grain-crop sown area, based on cross-sectional data in a period (Yang *et al*., 2012).

Along with the expanding RS and GIS technologies and the development in the field of spatial analysis, the research methods have become increasingly diversified, providing a strong technical support for regional proportion variation study in different counties. Based on the counties in Henan Province as the basic unit and the proportion of grain-crop sown area as variable, the paper tries to analyze the proportion of grain-crop sown area since 1980 in temporal-spatial pattern, in terms of Kernel density estimation method, exponential model of spatial correlation, function model of spatial variables, in order to reveal regional grain production pattern changes from a new perspective.

RESEARCH METHODS AND DATA SOURCES

Research methods:

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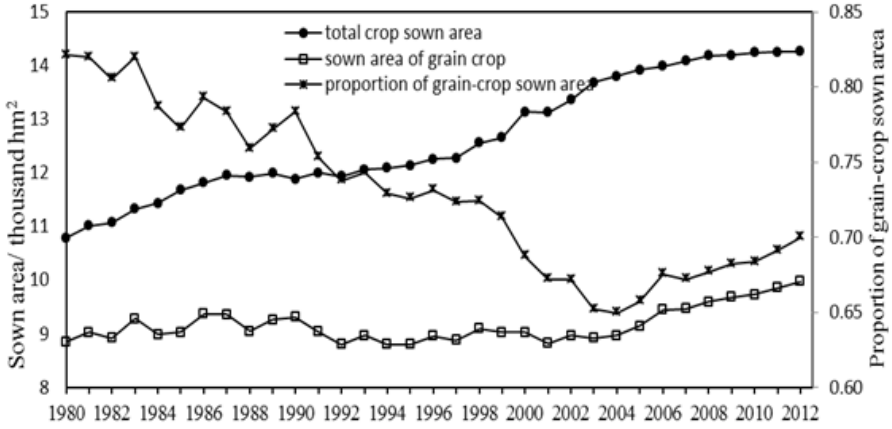


Fig. 1: Changes of proportion of grain-crop sown area in Henan province

Kernel density estimation method: Kernel density estimation method is a non-parametric estimation method, describing the distribution of random variables with continuous density curve, suitable for probability density estimation of random variables (Guo and Dong, 2012; Sun *et al*., 2012). Density function of random variable X is $f(x)$ and the probability density at the point x is:

$$f(x) = (\frac{1}{Nh}) \sum_{i=1}^{N} K[X_i - x)/h] \quad (1)$$

In the formula, h represents bandwidth, i = 1, 2, ..., N, K (,) is the kernel function of random kernel estimation.

Exponential model of spatial correlation: The ESDA method provides an effective way to study the spatial distribution model and spatial relative deviation of attribute values in different regions (Verburg *et al*., 2000; Wang *et al*., 2009; Kim and Dall'erba, 2014). Spatial autocorrelation analysis, consisting of global spatial autocorrelation analysis and local spatial autocorrelation analysis, is a commonly used index to analyze whether there is significantly association between the observed value of certain spatial location and the observed value of neighboring spatial point. In this research, Moran's I statistics and Getis-Ord General G index are used for spatial correlation analysis of the proportion of grain-crop sown area. Getis and Ord developed the index G_i^*, used for measurement of local spatial correlation and deviation between region and its surrounding area. High G_i^* index shows areas of high proportion of grain-crop sown area (hot spots) and low G_i^* index shows areas of low proportion of grain-crop sown area (cold spots). For detailed calculation method, (Wang *et al*., 2009).

Function model of spatial variables: Spatial variation function is also known as the variogram, serves as a fundamental method to study the randomness and structure of regionalized variables through quantitative description, reflecting the spatial characteristics of variables: correlation and randomness and showing the structure of regionalized variables by randomness. If it meets second-order stationary conditions and intrinsic hypothesis, calculation formula of variation function is as follow (Saikia and Sarkar, 2005; Masoud, 2014):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)\right]^2 \quad (2)$$

In the formula: $r(h)$ is the semi variogram value; h is spatial distance of samples, i.e., the step; $Z(x_i)$ and $Z(x_i+h)$, respectively represent the actual values of regionalized variable $Z(x_i)$ at the spatial points of x_i and x_i+h; $N(h)$ shows the number of samples with the interval distance of h. Usually, the experimental variogram value is made based on sampling points and formula of variation function. The curve after fitting is called experimental variogram. The distribution of the experimental variogram is observed, to fit linear combination with a theoretical model or several theoretical models of geo-statistics. The main parameters include nugget variance, structure variance, sill, nugget coefficient, etc.

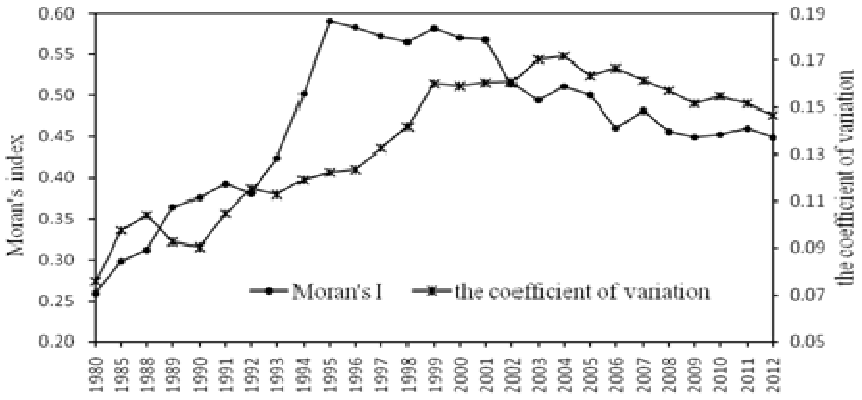
Survey of research areas: Since 1980, crop sown area and grain-crop sown area in Henan province have been showing a rising trend, but the proportion of grain-crop sown area is in decline with fluctuation (Fig. 1). In 1980, the total crops own area in Henan province is 10.79 million hm^2, the sown area of grain crops swon 8.86 million hm^2 and the proportion of grain-crop sown area is 0.812, slightly higher than the national average level (0.801); in 2012, the total crop sown area in Henan province and the sown area of grain crops were respectively increased to 14.26 million hm^2 and 9.99 million hm^2, but the proportion of grain-crop sown area dropped to 0.700, still higher than the national average

level (0.681). In general, it can be roughly divided into three stages: decline with fluctuation from 1980 to 1997, rapid decline from 1998 to 2003 and restorative rise from 2004 to 2012. Given changing characteristics of the proportion of grain-crop sown area in Henan province, the research periods are selected as year 1980, 2004 and 2012, to study the temporal and spatial variations of the proportion of grain-crop sown area at county level.

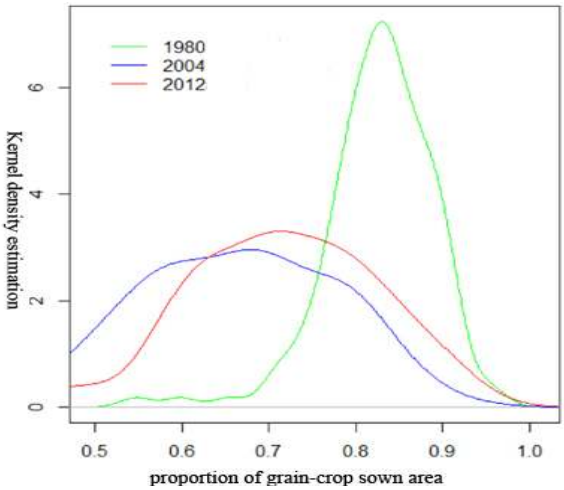
Data sources: Since the administrative division of the city changes fast and their grain sown areas are small, in order to ensure consistency of data evaluation unit, the division of 2012 is used as a basic principle to modify the administrative division unit. That is to say, the administrative districts in prefecture-level cities merge in to prefecture-level cities. And eventually there are 18 prefecture-level cities and 108 counties (including county-level city), a total of 126 research units, in periods of year 1980, 2004 and 2012. The data of total crop sown area, sown area of grain crops and grain yield in this research is based on Henan Thirty Years of Reform and Opening-up, Henan Statistical Yearbook and Henan Rural Statistical Yearbook in the corresponding year. In addition, field researches are conducted in Xinxiang City, Zhoukou City, and Luoyang City, offering a large amount of survey data and providing materials for spatial differentiation mechanism of the proportion of grain-crop sown area.

TEMPORAL-SPATIAL PATTERN OF THE PROPORTION OF GRAIN-CROP SOWN AREA

General characteristics of variation in the proportion of grain-crop sown area: Variation in the proportion of grain-crop sown area in counties is basically consistent with the proportion of grain-crop sown area in Henan province, showing the trend of 'rising after decline':



(a)



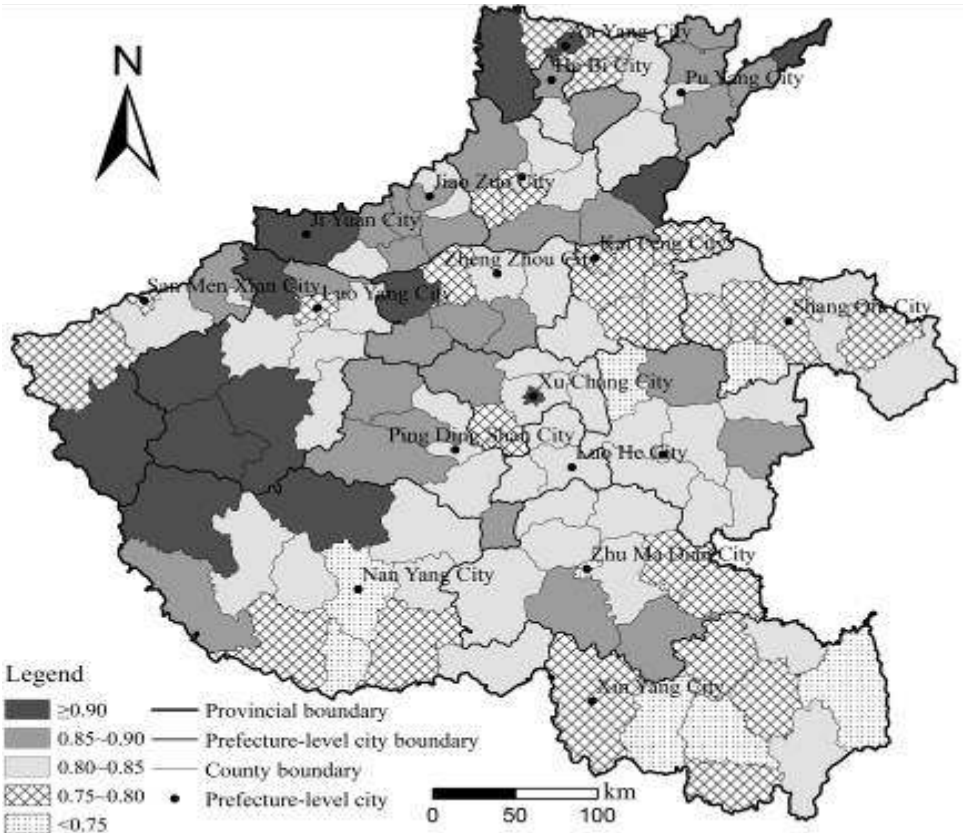
(b)

Fig. 2: Statistics figures for proportion of grain-crop sown area in Henan province, (a) global Moran's I and variation coefficient, (b) kernel density estimation map of proportion of grain-crop sown area

- The variation coefficient of the proportion of grain-crop sown area in counties shows the trend of 'decline after rising'. In 2004, the coefficient of variation reached the highest value 0.172, indicating that when the proportion of grain-crop sown area in counties dropped, the variation in counties gradually increased; a decline with fluctuation shows that during restorative rising of the proportion of grain-crop sown area in counties from 2004 to 2012 years, the variation between counties reduces to some extent.
- GeoDa software is used to calculate Global Moran's I of the annual proportion of grain-crop sown area at county level in 27 years (Fig. 2). Global Moran's I of the proportion of grain-crop sown area at county level are all positive and pass 5% of the significance tests, indicating that the higher (or lower) proportion of grain-crop sown area at county level tends to be close to the proportion of the neighboring counties, that is to say, the proportion of grain-crop sown area of neighboring counties of the county with higher proportion is higher (Type HH), the proportion of grain-crop sown area of neighboring counties of the county with lower proportion is lower (Type LL). The values of Global Moran's I show a trend of 'decline after rising'. From 1995 to 2001, spatial autocorrelation of the proportion of grain-crop sown area in counties is quite obvious. The range of Global Moran's I is 0.55~0.60; since 2002, the value of Global Moran's I has been dropping, but basically above 0.45, which indicates that there is an obvious positive correlation in spatial distribution of the proportion of grain-crop sown area, the areas of similar proportion (HH or LL) are in spatial distribution concentration.
- Ratio data is collected based on the proportion of grain-crop sown area at county level in 3 years and Kernel density curve of proportional distribution for the proportion of grain-crop sown area at county level is made according to Gaussian density function models. Kernel density curve of the proportion at county level shows the typical unimodal distribution. Curve peaks basically are in average level, showing approximate normal distribution based on average level of most proportions of counties. In terms of positions, from 1980 to 2012, density distribution curve shows an overall trend of left shift, directly show in grapid decline of the proportion of grain-crop sown area in different counties. There is an obvious trend that the 'sharp peak' in density curve of the proportion turns into 'broad peak'. In 1980, the proportion of grain-crop sown area forms a typical sharp peak. With the passage of time, kurtosis gradually becomes lower, indicating that when the proportion of grain-crop sown area at county level declines, the variation between different counties becomes gradually shaper. Compared with 1980, peak in Kernel density distribution of 2004 relatively declines and move toward slow value of the proportion of grain-crop sown area. The distribution is more disperse than in 1980, indicating that during this period there is a deepening gap in the variation of the proportion in Henan. In 2012, the peak height increases and moves towards high value of the proportion of grain-crop sown area, indicating from 2004 to 2012 there is a narrowing gap in the variation of the proportion in counties to a certain extent.

Spatial characteristics of the proportion of grain-crop sown area at county level: In 1980, the proportion of grain-crop sown area at county level in Henan is between 0.65~0.96, with the highest value (0.96) in Luanchuan county, the lowest (0.65) in Xinyecounty and the average value is 0.83. In spatial distribution, the proportion at county level in Henan shows gradual rising trend from east to west and the variation pattern of 'high in East and low in West' is obvious. In 2004, the proportion at county level in Henan is between 0.37~0.93, with the highest value (0.93) in Qi county, the lowest (0.37) in Xinye County and average value 0.67. Compared with 1980, the proportion declines sharply and the variation becomes sharper; in terms of the spatial distribution, quite different from the pattern in 1980, the distribution pattern of the proportion in 2004 is 'high in the middle and low in both sides'. In 2012, the proportion of grain-crop sown area at county level in Henan is between 0.46~0.95, with the highest value (0.95) in Qixian county, the lowest (0.46) in Zhongmou county and average value 0.72. Compared with 2004, the proportion in 2012 rises to a certain degree, but in terms of spatial distribution, the proportion in 2012 remains consistent with the pattern in 2004 (Fig. 3).

Generally speaking, in the early stage of reform and opening up, the agricultural production adhered to the principle of 'grain crop as the key'. Therefore, the production of planting industry mainly consisted in grain and cotton production. The grain planting mainly consisted of grain, wheat and corn. There was little adjustment in planting industry and the proportion of grain-crop sown area was at a higher level; however, facing the boost of grain yield and the changes in food consumption demand, with the continuous effort in food production, Henan province increased the multiple cropping index, expanded the area of economic crops and other crops and implemented a series of measures to promote the adjustment in agricultural structure. With a relatively low grain production efficiency and a rising sown area of economic crops, the proportion of grain-crop sown area dropped. Since 2004, the central government has issued 11CPCCC Document No. 1, the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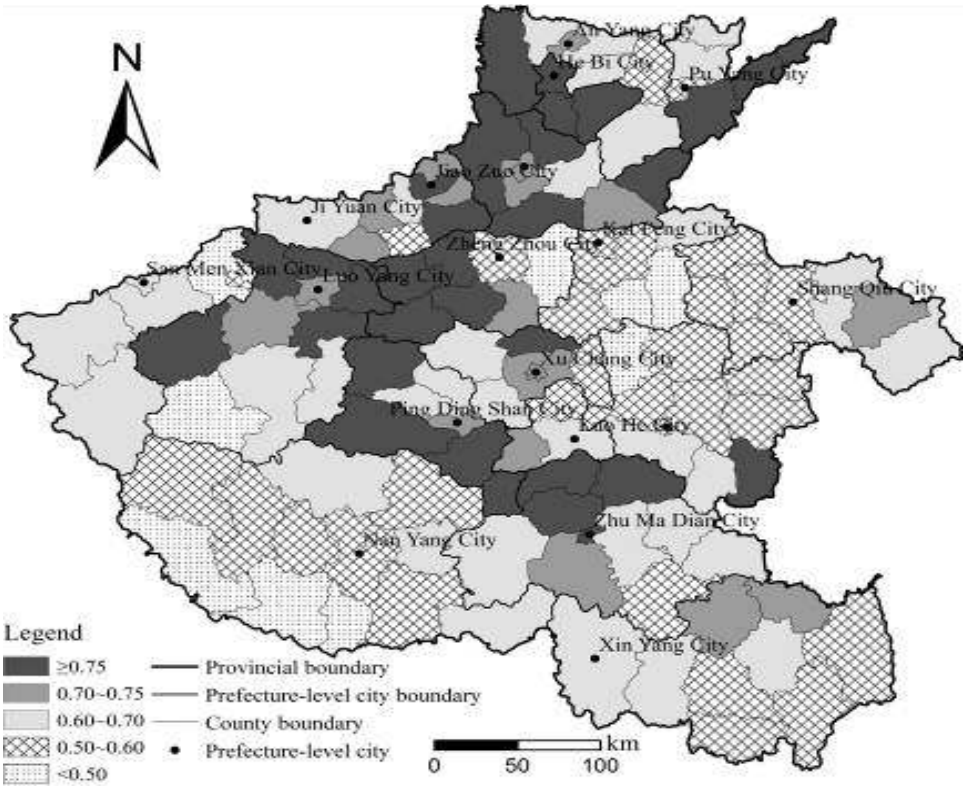
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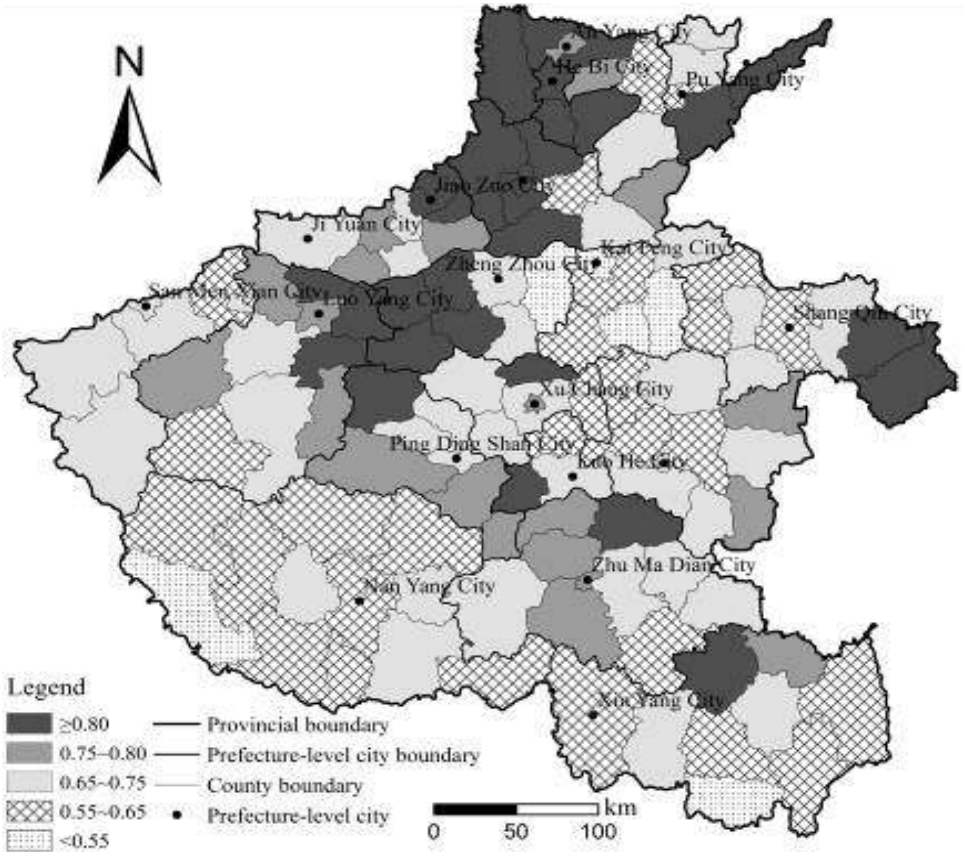
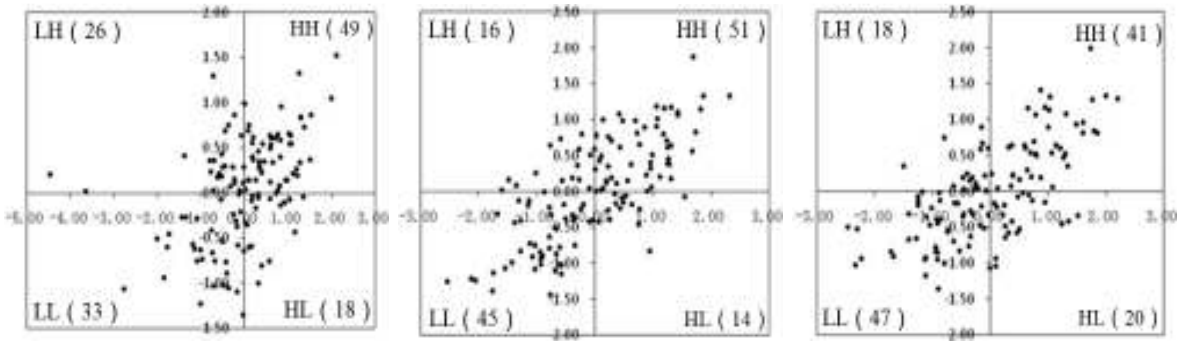


(c)

Fig. 3: Distribution pattern for the proportion of grain-crop sown area at county level in (a) 1980, (b) 2004, (c) 2012

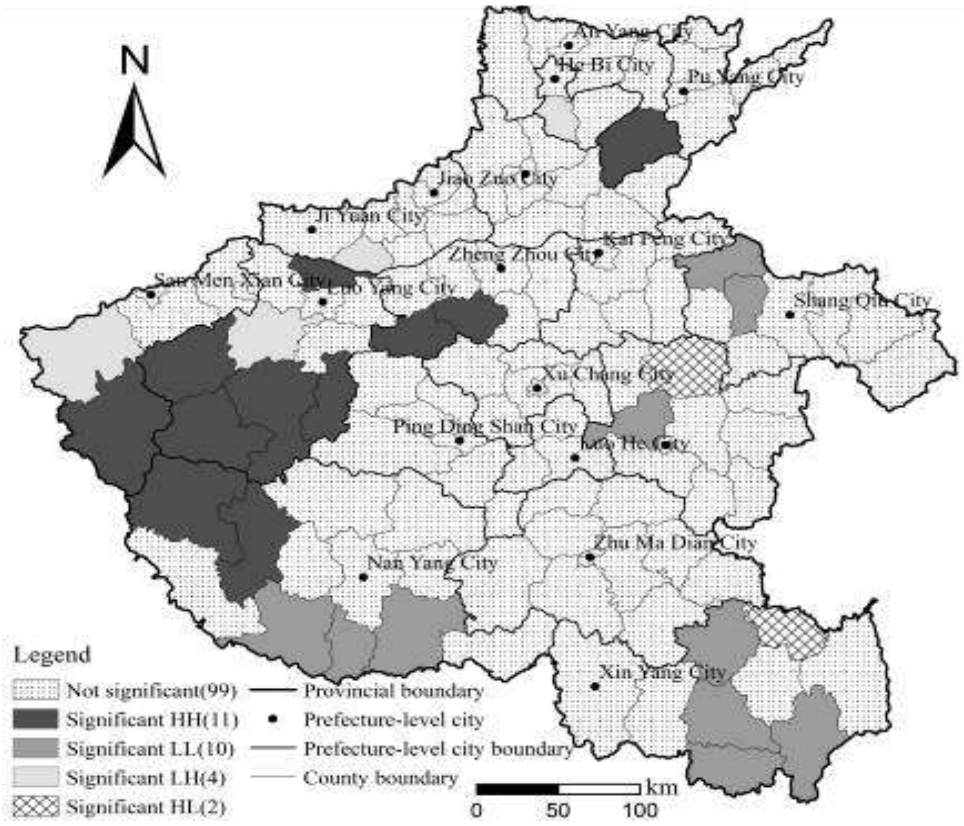


(a) (b) (c)

Fig. 4: Moran scatter plot for the proportion of grain-crop sown area at county level in (a) 1980, (b) 2004, (c) 2012
The number in parentheses is the number of county associated with each type

State Council and governments of different levels in Henan implemented a series of policies and measures to support agriculture, such as the abolition of agricultural taxes, food subsidies, seed subsidies and subsidies of large and medium-sized agricultural machinery, to courage the enthusiasm of farmers in grain planting; at the same time, the construction projects, such as farmland water conservancy, comprehensive agricultural development, high-standard basic farmland construction, improved agricultural production conditions and the rising level of agricultural mechanization promoted the cultivation of food crops, increasing the proportion of grain-crop sown area.

According to the grain yield data of Henan province, Moran scatter plot of the proportion of grain-crop sown area in 3 years is made (Fig. 4). In 1980,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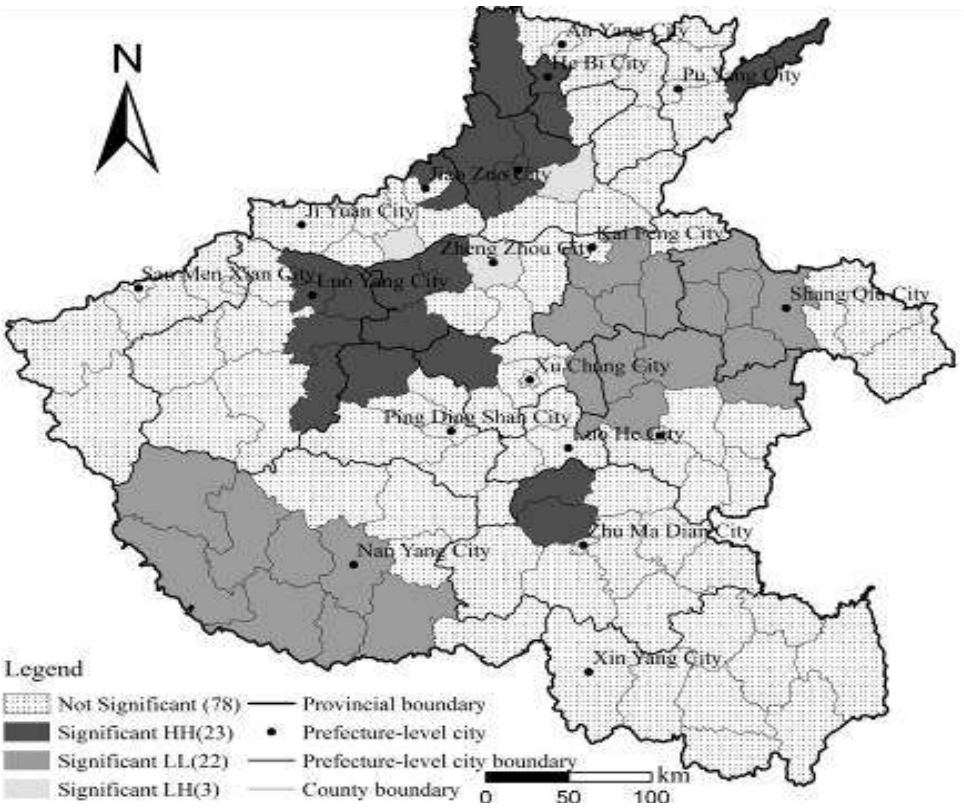
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Not Significant (78)
Significant HH(23)
Significant LL(22)
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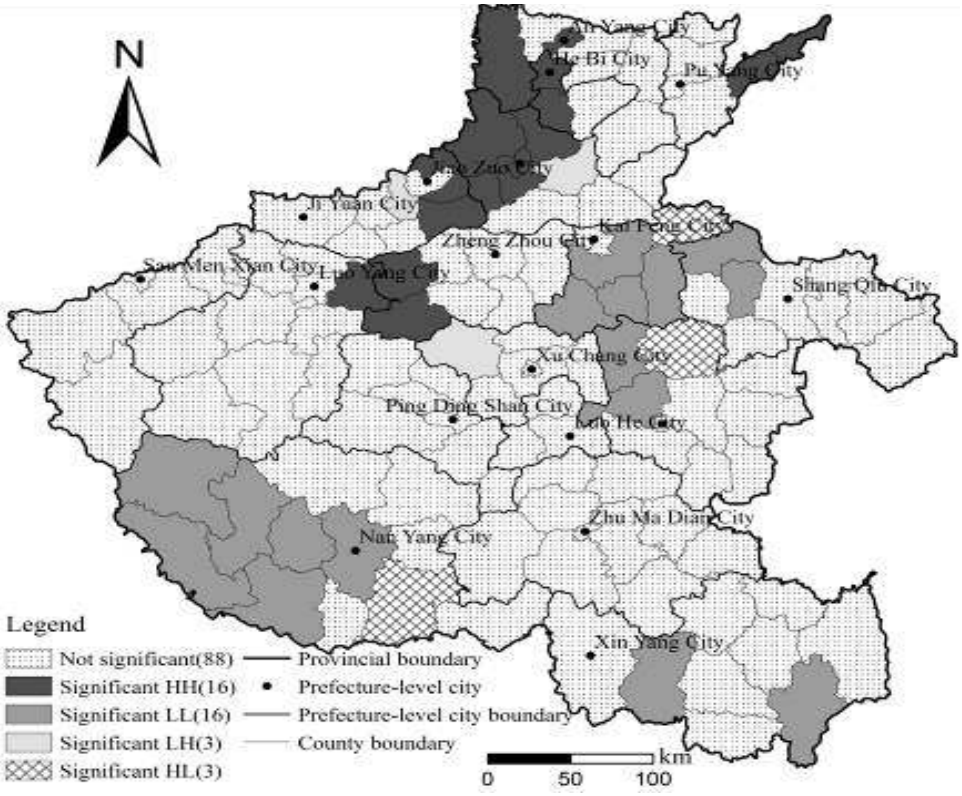

(c)

Fig. 5: LISA cluster map for the proportion of grain-crop sown area at county level, (a) 1980, (b) 2004, (c) 2012

2004 and 2012, the numbers of the counties located in the HH and LL quadrant are respectively 82, 96 and 88, occupying 65.08, 76.19 and 69.84%, respectively of the total number of county units, indicating that there is a strong spatial correlation of the proportion in local scopes and there exists a significant pattern of local accumulation.

Combining the Moran scatter plot and LISA significance level graph, the paper made Local Moran's I with the support of ArcGIS (Test p = 0.05, Fig. 4 and 5), in order to dig into the differentiation of local accumulation and to collect visual information of the proportion evolution:

- High-High concentration area (type HH) changes during research period. In 1980, concentration distribution takes place with Luanchuan county as the center; in 2004 and 2012, the original hot spots of the proportion of grain-crop sown area disappear and there emerge two hot spot areas in the north central region of Henan, with Dengfeng city and Huixian city as the centers and other hot areas in small size. The new hot spot areas that located in plain are Henan's traditional agricultural areas with perfect production conditions and solid agricultural infrastructure.
- Low-Low concentration area (type LL), the local low concentration type, is the main type and there is little change in the number of the counties. In 1980, distribution of LL area in counties is scattered, without concentrated distribution; in 2004 and 2012, there emerge two concentrated distribution areas: in the southwest of Henan (Nanyang city) and northeast of Henan (boundary of Shangqiu City, Kaifeng city and Zhoukou City).
- Low-High concentration area (type LH region) and (HL region), the distribution area in counties is little, without regularity.

Changes in the proportion in areas of farming system level II are basically consistent with the proportion of grain-crop sown area of Henan province, but there exists obvious difference among areas of farming system level II (Fig. 5). In 1980, difference of the proportion among areas of farming system level II remains little, between 0.77~0.87. With the passage of time, difference of the proportion among areas of farming system level II becomes obvious and the proportion of grain-crop sown area in hilly areas at the boundary of Hubei, Henan and Anhui and hilly areas of western Henan drops significantly; the changes of the proportion in plain areas of Yanshan-Taihang Mountains remain little, basically with the fluctuations around 0.80; in 2012, the proportion in plain areas of Yanshan-Taihang Mountains goes higher than the

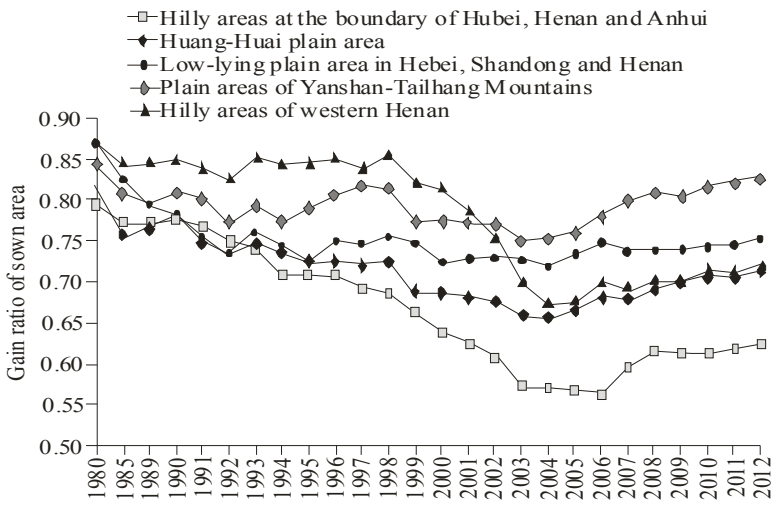

Fig. 6: Evolvement pattern of the proportion of grain-crop sown area

Table 1: Parameters of variogram model on the spatial pattern of the proportion of grain-crop sown area in Henan

Year	Fitting model	Nugget variance C_0	Structure variance C	Sill C_0+C	Nugget coefficient C_0/ (C_0+C)	Variable spacing a/km	Determination coefficient R^2	Residual S.S. RSS
1980	Gaussian	0.0024	0.0016	0.004	0.6102	97.111	0.9753	1.29E-10
2004	Gaussian	0.0033	0.0103	0.014	0.2447	56.382	0.9569	5.95E-09
2012	Gaussian	0.0021	0.0090	0.011	0.1910	40.336	0.9591	3.16E-09

C_0: The nugget variance, showing spatial heterogeneity caused by local randomness of variables; C: Structure variance, showing spatial heterogeneity caused by spatial autocorrelation of variables; C_0+C: As sill, showing the stable value of semi variogram when spacing increases to C; C_0/ (C_0+C): Serves as nugget coefficient, showing the proportion of spatial hetserogeneity caused by randomness compared to spatial heterogeneity of the total; a: Variable spacing, showing the spacing which makes semi variogram become a stable value; S.S.: Sum of square

proportion in the hilly areas of western Henan and the plain areas of Yanshan-Taihang Mountains become the areas with the highest proportion in Henan; the changes in low-lying plains at the boundary of Hubei, Henan and Shandong also remain little, especially since 1990, basically between 0.70~0.75; from 1980 to 2004, the proportion of grain-crop sown area of Huang-Huai plain declines, from 0.81 in 1980 to 0.67 in 2004 and since 2004, the rising trend of the proportion in Huang Huai plainis obvious, to 0.71 in 2012. Generally speaking, concentrated distribution trend of the grain production in the plain areas of Henan is clear (Fig. 6).

Temporal-spatial characteristics of the proportion of grain-crop sown area at county level: The proportion of grain-crop sown area forms geometric center in each county spatial unit and the spatial characteristics of the proportion at county level in Henan are studied by variation function. In the analysis of geo statistics, interpolation effect works better when data is in the normal distribution and usually data in skew distribution is changed with logarithmic transformation, more close to the data in the normal distribution. Therefore, the data in 3 years is processed with logarithmic transformation, in order to basically in accordance with normal distribution standards. Experimental variograms of data sources are calculated respectively and the model of the highest fitting degree will be found and chosen.

In terms of structural factors, nugget coefficient can show the extent of spatial correlation of system variables. When the ratio is less than 25%, it indicates that there is a strong spatial correlation; when the ratio is between 25~75%, it indicates that there is a moderate spatial correlation; more than 75%, it indicates that there is a weak spatial correlation (Combardella *et al*., 1994). As Table 1 shows, since 1980, the spatial difference of the proportion of grain-crop sown area in counties has been rising. The sill in 2012 is 2.75 times as high as in 1980; nugget coefficient shows a significant declining trend, from 61.02% in 1980 to 24.47% in 2004, then to 19.10% in 2012. The change from moderate correlation to strong correlation shows that the proportion of spatial heterogeneity caused by randomness compared to spatial heterogeneity of the total is dropping; the ratio of deterministic and structural factors is increasing; spatial autocorrelation of variables is enhanced; and differentiation mechanism of the proportion of grain-crop sown area is significantly improving.

By all the chosen spatial variation models after fitting in 3 years by least square method are Gauss models, we can conclude that from the year 1980, the structural characteristics of the proportion of grain-crop sown area in counties of Henan province in different periods are similar and the coefficients of determination are all above 0.95 (the closer to 1 for the coefficient of determination, the higher fitting degree), indicating that

in the early period of reform and opening up, the randomness of spatial distribution is higher and the structural distribution is not obvious; with the passage of time, spatial self-organization of proportion of grain-crop sown area at county level in Henan gets higher and difference in the spatial distribution gets more obvious. At the same time, the effective variable spacing reduces, indicating that the spatial correlation effect caused by structured spatial gradient of the proportion of grain-crop sown area in counties becomes weaker.

DISCUSSION AND CONCLUSION

Through statistical analysis and spatial correlation analysis, this thesis depicts the temporal-spatial characteristics of the proportion of grain-crop sown area in Henan since 1980 by Kernel density estimation method, spatial variation function and so on:

- The proportion of grain-crop sown area in Henan decreases from 0.812 in 1980 to 0.700 in 2012; distribution pattern of the proportion of grain-crop sown area in counties is typical unimodal and 'sharp peak' in density curve of the proportion turns into 'broad peak'; the overall pattern of the proportion of grain-crop sown area in counties maintains relatively stable.
- In terms of the overall space pattern, the proportion of grain-crop sown area in counties shows a strong spatial autocorrelation. The cold spot area of the proportion is expanding with Kaifeng city, Xinyang city, Nanyang city as centers; spatial structure of proportion of grain-crop sown area at county level is stable, the ratio of deterministic and structural factors compared to the total variation is rising.
- This study is a preliminary research for temporal-spatial dynamic study of the proportion of grain-crop sown area in Henan and ecological influence of the pattern changes in environment needs further analysis and evaluation. At the same time, the survey on the planting desire of the famer is insufficient and the impacts of the natural factors on planting structure, such as climate change, are not discussed, due to the limited sample data and article length. In terms of typical area selection, planting desire promotion of farmers, the impacts of the natural factors on the proportion of grain-crop sown area, incentive policy of grain production in different regions, there needs further discussion and research.

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