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Spatial analysis and districting of the livestock and poultry breeding in China

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Abstract: The capacity of livestock breeding in China has increased rapidly since 1949, and the total output of meat, poultry and eggs maintains the world's top first in recent 20 years. Livestock emissions and pollution is closely associated with its population and spatial distribution. This paper aims to investigate the spatial patterns of livestock and poultry breeding in China. Using statistical yearbook and agricultural survey in 2007, the county-level populations of livestock and poultry are estimated as equivalent standardized pig index (ESP), per cultivated land pig index (PCLP) and per capita pig index (PCP). With the help of spatial data analysis (ESDA) tools in Geoda and ArcGIS software, especially the Moran's I and LISA statistics, the nationwide global and local clustering trends of the three indicators are examined respectively. The Moran's I and LISA analysis shows that ESP and PCP are significantly clustering both globally and locally. However, PCLP is clustering locally but not significant globally. Furthermore, the thematic map series (TMS) and related gravity centers curve (GCC) are introduced to explore the spatial patterns of livestock and poultry in China. The indicators are classified into 16 levels, and the GCCs for the three indicators from level 1 to 16 are discussed in detail. For districting purpose, each interval between gravity centers of near levels for all the three indicators is calculated, and the districting types of each indicator are obtained by merging adjacent levels. The districting analysis for the three indicators shows that there exists a potential uniform districting scheme for China's livestock and poultry breeding. As a result, the China's livestock and poultry breeding would be classified into eight types: extremely sparse region, sparse region, relatively sparse region, normally sparse region, normal region, relatively concentrated region, concentrated region and highly concentrated region. It is also found that there exists a clear demarcation line between the concentrated and the sparse regions. The line starts from the county boundary between Xin Barag Left Banner and Xin Barag Right Banner, Inner Mongolia Autonomous Region to the west coast of Dongfang County, Hainan Province.

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Keywords: livestock; spatial autocorrelation; gravity centers curve; spatial patterns; demarcation; the thematic map series; sparse region; concentrated region

1 Introduction

Livestock breeding is an important industry for regional agricultural development. The output values of livestock industry account for more than 50% of the total agricultural output in many developed countries (Jefferson *et al*., 2001; Ohkuma *et al*., 1994). The livestock breeding capacity of China has increased rapidly since 1949, and the total output of meat, poultry and eggs maintains the world's first in recent 20 years (Cheng, 2008). The proportion of animal output value in agricultural production in China has increased from 18% in 1980 to 30% in 2010, and increased rapidly in recent years. With the growth of livestock industry, the environmental problems have been becoming serious in China. For example, the excess excrement from livestock and poultry causes evident pollution in water, soil and atmosphere (Ding, 2000; Kong *et al*., 2002; Li *et al*., 2000; Gao *et al*., 2006; Cheng, 2008).

The China's first national pollution sources census bulletin published in 2010 shows that the agricultural non-point source pollution (AGNPS) is becoming the major source for surface water pollution. The livestock pollution is more prominent in AGNPS, and the COD, total nitrogen and total phosphorus, account for 96%, 38% and 56% of AGNPS in China (Wu, 2011). It is also claimed that, such hazards have exceeded the industrial pollution, and solving the environmental problem from the livestock industry is an urgent task at current stage of environmental protection and sustainable development in China (Wang *et al*., 2006; Gan *et al*., 2006; Liu, 2009; Gao *et al*., 2006).

Spatial distribution of livestock is critical to China's regional environmental protection. However, there are few studies on the spatial distribution of livestock industry, especially at regional level of China. Several related researches are: Elk distribution and spatial overlap with livestock during the brucellosis transmission risk period (Proffitt *et al*., 2011), the spatial distribution of livestock concentration areas and soil nutrients in pastures in US (Sanderson *et al*., 2010), the spatiotemporal changes in livestock distribution in Mongolia (Saizen *et al*., 2010), spatial distribution modelling of livestock in Europe at the landscape level (Neumann *et al*., 2009), spatial distribution of blackfly challenge for livestock farmers in South Africa (Hobololo, 2009), risk for intra-specific and badger-livestock disease transmission (Bohm *et al*., 2008), and changes in the spatial distribution of livestock in China (Verburg *et al*., 1999).

Searching "livestock distribution" by title in SCI abstract databases, there are more than 50 literatures, including the aforementioned literatures. Among these literatures, five focused on grazing and pasture (Cicero, 1997; Eccard *et al*., 2000; Orr, 1980; Pringle *et al*., 2004; Rinella *et al*., 2011), three focused on livestock spatial distribution (Cecchi *et al*., 2010; Orhan *et al*., 2009; White *et al*., 2001). More than twenty literatures since 2000 mostly focused on biology and disease (Estrada-Pena *et al*., 2005; Gondwe *et al*., 2009; Kabeya *et al*., 2003; Malele *et al*., 2011; Sumption *et al*., 2008; Vo *et al*., 2006), and excrement and pollutants (Bolan *et al*., 2004; Costanza *et al*., 2008; Hutchison *et al*., 2008; Kim *et al*., 2004; Norwood *et al*., 2005; Sim *et al*., 2011). The study regions are located in Europe (Neumann *et al*., 2009), Africa (Cecchi *et al*., 2010; Hobololo, 2009), America (Sanderson *et al*., 2010), Mongolia (Saizen *et al*., 2010), Turkey (Orhan *et al*., 2009), and Global (White *et al*., 2001).

For domestic livestock distribution research in China, a few literatures investigate the nationwide distribution, utilization and environmental load of livestock excrement, phosphorus and nitrogen nutrient resources (Liu *et al*., 2010; Liu *et al*., 2005; Xu *et al*., 2005). Most researches focused on sub-national regions', such as Beijing (Li *et al*., 2010), Northeast China (Li *et al*., 2007), Jilin (Xie *et al*., 2011), Hebei (Ma *et al*., 2006), Jiangsu (Wang *et al*., 2007), Qinghai (Cai *et al*., 2010), Chongqing (Peng *et al*., 2006; Peng, 2009).

In recent years, scholars have paid more attention to the issues of AGNPS in China, but there are several difficulties in researches, such as the availability of basic data, the lack of thematic site survey, the weakness of quantitative modelling for watershed scale AGNPS analysis, and the lack of experiences in AGNPS control and management (Zhu, 2011). Consequently, the nationwide pollution distribution of livestock industry is still unknown (Peng, 2009).

However, livestock pollution is closely associated with its population and spatial distribution. This paper aims to investigate the spatial patterns of livestock and poultry breeding in China using regional data published in official statistical yearbooks and agricultural surveys. The authors believe that the investigation of the spatial patterns of livestock and poultry breeding will benefit to AGNPS control and management in China.

2 Data and methodology

2.1 Data sources

The main datasets used in this paper include the county-level livestock census (pig, cattle, sheep, chicken, duck and goose), cultivated land and demographics from the national agricultural statistics, provincial statistical yearbooks and national agricultural survey. Since the First National Survey on Pollution Sources was conducted in 2007, the statistical data at year 2007 are selected. Outlier data are rejected or modified by comparing the relevant data in 2006 and 2008. As a result, the livestock population data for 2426 counties are prepared. For the purposes of mapping and spatial analysis, a GIS layer of the county-level administrative division of China is collected from the Data Sharing Infrastructure of Earth System Science (www.geodata.cn).

2.2 Indicators

In order to simplify the processes of environmental impact assessment, the equivalent standardized pig (ESP) index is introduced to estimate the total regional livestock population. The ESP is calculated according to statistical relationships between pig and other livestock and poultry (Wu, 2005). The estimation method and parameters are cited from the national standard "Discharge Standard of Pollutants for Livestock and Poultry Breeding" (GB18596-2001) published in 2001, and the related conversion standards drafted in 2011. According to these standards, one pig equivalent to 30 laying hens, 60 broilers, 30 ducks, 15 geese or 3 sheep, and one dairy equals to 10 pigs, and one beef cattle to 5 pigs. The statistic populations of cows, laying hens in stock and pigs, cattle, chickens slaughtering in 2007 are used, and the estimated pig population data are consistent with the data from the pollution sources survey.

Per cultivated land pig (PCLP) index and per capita pig (PCP) index are introduced to estimate the density of livestock population. The PCLP, the ESP in per acre cultivated land, is an important density index for environmental assessment of livestock. For county i, PCLPi= ESPi/SAi, where ESPi is the ESP in pigs and SAi is the cultivated land area in acres. Wu (2005) suggests that the PCLP in China should be no more than 1.0. Accordingly, for PCP, the ESP per capita, PCPi= ESPi/SPi, where SPi is the population of county i.

2.3 Methodology

In this paper, many technologies are introduced to analyze characteristics of ESP, PCLP and PCP of China. The exploring spatial data analysis (ESDA) technologies help to make basic characteristics analysis. The spatial data clustering analysis (SDCA) technology is used for clustering characteristics detecting. The choropleth map classification (CMC) and thematic map series (TMS) methods are used for spatial patterns analysis. The gravity centers curve (GCC) method assists in for classification analysis.

2.3.1 Exploring spatial data analysis (ESDA)

The exploring spatial data analysis (ESDA) is used to analyze the spatial patterns of livestock industry. The ESDA originated in the late 20th century (Hampson *et al*., 1999; Hoaglin *et al*., 1983), and gradually accepted and introduced into GIS research by geographers since the 1990s (Haining, 1990; Wang *et al*., 2010). It includes a series of techniques and tools such as histograms, scatter plots, trend surface analysis, semivariogram model, spatial autocorrelation coefficient and spatial statistics (Brus and de Gruijter, 2000). ESDA is often used as the basis of spatial analysis and modelling for data cleaning, hypotheses testing, variable selection, rule discovery and model selection (Wang *et al*., 2010).

Spatial clustering analysis aims to detect the clustering characteristics of a spatial dataset (Deng, 2011). The analysis for two-dimensional spatial points can take advantage of point pattern analysis techniques (Shekhar *et al*., 2008), such as quadrat, kernel density estimation, nearest neighbor index, K-function and G-function (Wang *et al*., 2007). For spatial data with thematic attributes, the spatial autocorrelation analysis techniques are frequently used (Aldstadt, 2010), such as Moran's I (Moran, 1948; 1950), Geary's C (Geary, 1954), Getis's G (Getis *et al*., 1992) and LISA (Anselin, 1995). The global and local spatial autocorrelation analysis tools provided in GeoDa and ArcGIS are used in this paper.

2.3.2 Choropleth map classification (CMC), thematic map series (TMS) and gravity centers curve (GCC)

CMC is a hierarchical structure of a thematic map in which areas are shaded or patterned in proportion to the measurement of the statistical variable being displayed on the map. Appropriate class interval is beneficial to clearly express the spatial patterns of thematic attributes, and show its geographical clustering characteristics (Ge *et al*., 2009). By use of appropriate CMC and TMS, the spatial patterns of ESP, PCLP and PCP can be identified.

TMS, a series of defragmentation maps at multiple classification levels, provides more information. For the purpose of representing the implied clustering information, ESP, PCLP and PCP levels are merged by adjacent geographic location and clustering characteristics. According to the GCC method of population by Ge *et al*. (2009), the GCC of ESP, PCLP and PCP are proposed and moderately merged by the adjacency of gravity centers. As a result, the districting types are obtained by merging corresponding levels. It should be noted that

TMS is based on quantile method (Guan *et al*., 2010) and gravity centers of each level generated by Mean Center Tools in ArcGIS.

3 Analysis and results

3.1 General analysis of livestock and poultry breeding in China

As shown in Figure 1, the spatial distribution of ESP, PCLP and PCP indicators present us different spatial patterns. For ESP index, the highest value regions are mainly distributed in Northeast China, eastern part of Inner Mongolia, North China, southern parts of South China, and the higher value regions are mainly distributed in eastern part of Northeast China, eastern part of Sichuan, Chongqing, East China, eastern part of South China, and lower value mainly distributed in the regions of West China, Yunnan and Guizhou. For PCLP index, the value of East China is higher than that of West China, especially in regions of North China, South China and East China, and the higher value regions mainly include Hebei, Henan, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hubei, Liaoning and Sichuan, while relatively low value regions mostly distributed in West China, Jilin and Heilongjiang. For PCP index, higher value regions are distributed in Northeast China, North China, Inner Mongolia, northern part of Xinjiang, and high value regions are distributed in East China and South China, and low value ones distributed in Southwest China.

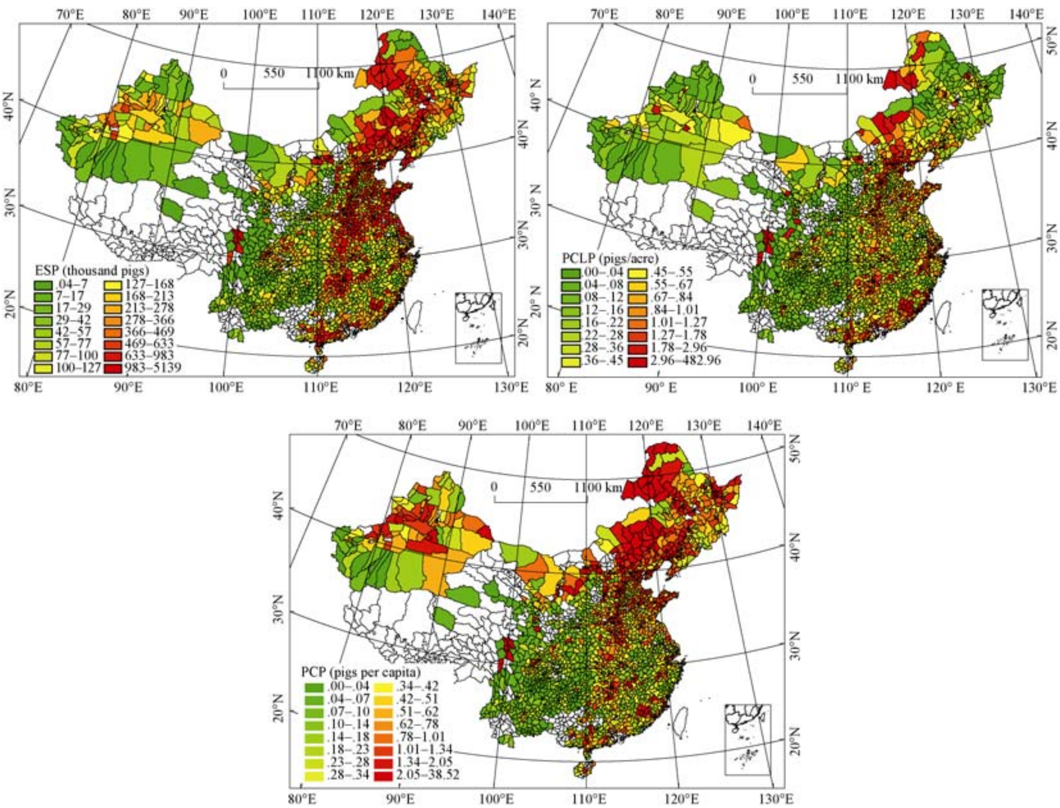

Figure 1 The CMC of ESP, PCLP and PCP in 2007 at county level (16 levels)

For the global perspective, there exist similar distribution characteristics of ESP, PCLP and PCP in China. Most of the three indicators' value of eastern China is higher than that of western China, and densely populated areas is high also. Since the differences of cultivated land and population, the clustering characteristics in spatial distribution of PCLP and PCP are quite different from that of ESP index. Even though, there exists a potential demarcation on all the three maps.

3.2 Spatial clustering analysis of livestock and poultry breeding in China

3.2.1 Global spatial autocorrelation analysis of the three indicators

In order to analyze the spatial patterns of the three indicators, global spatial autocorrelation analysis is used, by a common Moran's I tools supported by ArcGIS and GeoDa respectively. And the spatial weight matrix uses the adjacency method.

For ESP index, the Moran I value is 0.39, Z value is 35.5, and p value is 0, passing the 1% significance level test. That value in Geoda is 0.33, it also passed the 1% significance level test. Therefore, ESP index is spatial clustered in a global level.

For PCLP index, the Moran I value is 0.01, Z value is 0.94, p value is 0.35, and it did not pass the significance level test. That value in Geoda is 0.006, it also did not pass the 1% significance level test. Therefore, spatial clustering characteristics of PCLP index are not obvious in a global level.

For PCP index, the Moran I value is 0.18, Z value is 16.8, p value is 0, and it passed the 1% significance level test. The value in Geoda is 0.19, and also passed the 1% significance level test. Therefore, PCP index is spatial clustered in a global level.

Figure 2 shows the Moran's I scatter map of ESP, PCLP and PCP. The first and third quadrants in the figure show positive spatial relationship, the other two quadrants show negative spatial relationship. In the first quadrant, high value regions are surrounded by other high value regions (High-High). In the second quadrant, low value regions are surrounded by high value regions (Low-High). In the third quadrant, low value regions are surrounded by low value regions (Low-Low). And in the fourth quadrant, high value regions are surrounded by low value regions (High-Low). The scatter map in Figure 2 also shows that the ESP and PCP indicators have more obvious spatial clustering characteristics, while PCLP has not.

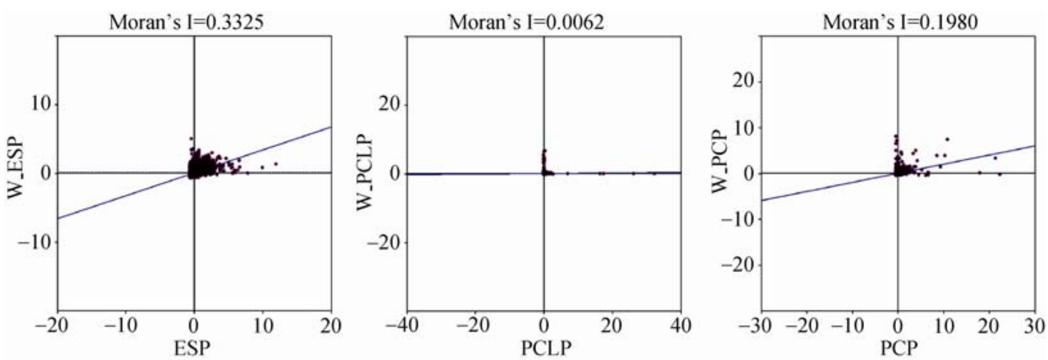

Figure 2 Moran's I scatter map of ESP, PCLP and PCP

3.2.2 Local spatial autocorrelation analysis of the three indicators

The global spatial autocorrelation analysis can detect whether there exist the spatial clustered region and spatial isolated region, then detect the spatial clustering trend. However, the local spatial autocorrelation analysis can reveal the specific spatial patterns, and find the location of the spatial clustered and isolated regions. By using a common LISA tools supported by GeoDa, the local spatial autocorrelation analysis is held and the results are shown in Figures 3–5.

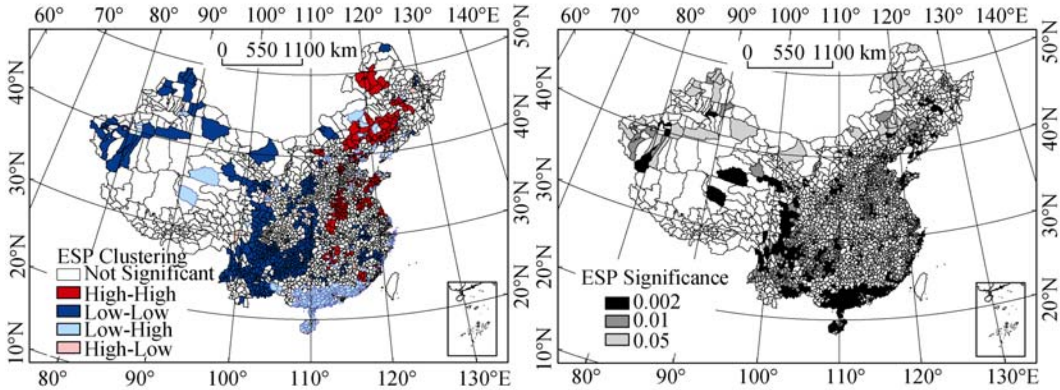

Figure 3 The clustering and significance map of ESP using LISA method

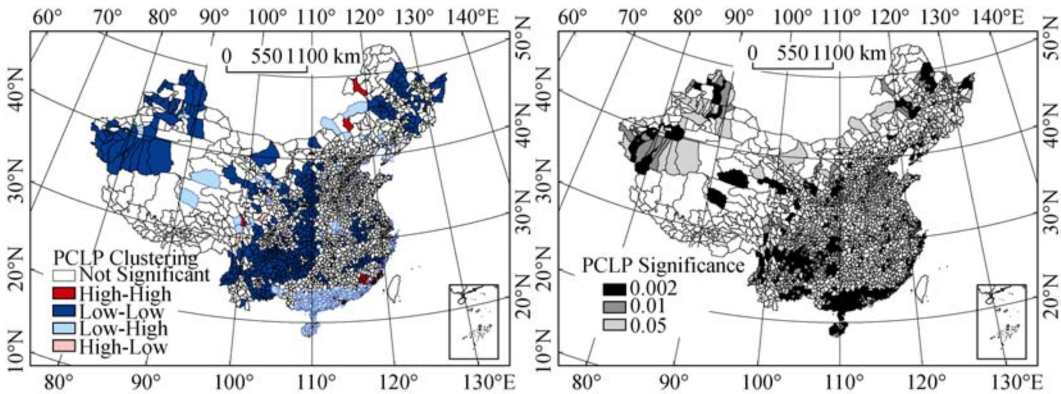

Figure 4 The clustering and significance map of PCLP using LISA

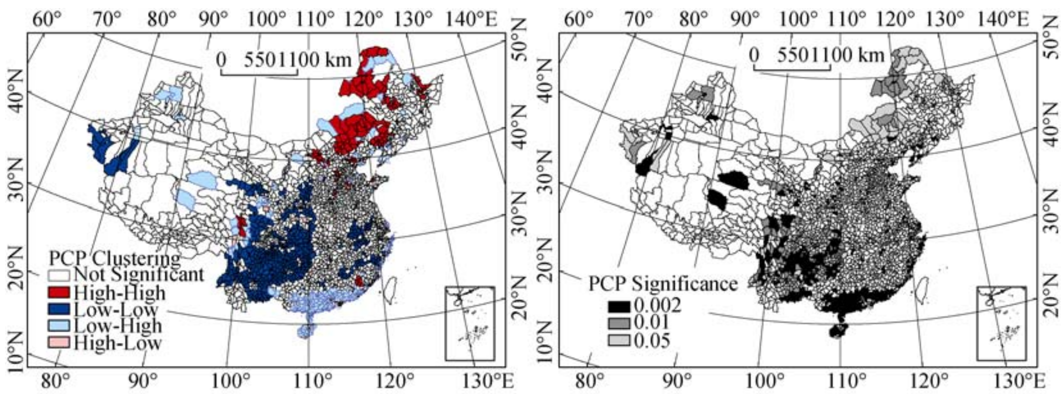

Figure 5 The clustering and significance map of PCP using LISA

As shown in Figure 3, obviously spatial clustering characteristics exist in the analysis result of ESP. “High-High” clustered regions are mainly distributed in the adjacent regions between Northeast China and Inner Mongolia, eastern Henan, northern Hubei, eastern Shandong, the interlaced regions of Shandong, Jiangsu, Anhui, and the adjacent regions between Hunan and Jiangxi, eastern Fujian, and most of these regions’ significance levels are 1%–5%. “Low-Low” clustered regions are mainly distributed in most parts of Yunnan and Guizhou, center of Sichuan, northeastern Ningxia, most parts of Shaanxi, the interlaced regions of Hunan and Sichuan, the interlaced regions of Hubei and Sichuan, and part of Xinjiang, most of these regions’ significance levels are 0.2%–1%. “Low-High” isolated regions are mainly accompanied with “High-High” clustered regions, most parts of Guangdong, Guangxi and Hainan belong to this type, and most of these regions’ significance levels are 0.2%. “High-Low” isolated regions are relatively few and always sporadically along with “Low-Low” clustered regions.

As shown in Figure 4, some spatial clustering characteristics exist in the analysis result of PCLP. There are few “High-High” clustered regions and “High-Low” isolated regions. However, “Low-Low” clustered regions and “Low-High” isolated regions are consistent with that of ESP index, and these regions’ significance levels are 0.2%–1%.

As shown in Figure 5, obviously spatial clustering characteristics also exist in the analysis result of PCP. “High-High” clustered regions are mainly distributed in the northeast of Inner Mongolia, the interlaced regions of Liaoning and Hebei, southwestern part of northern Heilongjiang, western Sichuan, part of western Fujian, and these regions’ significance levels are 1%–5%. “Low-Low” clustered regions are mainly distributed in Yunnan, Guizhou, Sichuan, Shaanxi, Chongqing, western Qinghai, part of western regions of Xinjiang, part of Anhui, Jiangxi, Zhejiang and Fujian, its distribution is consistent with that of ESP, and most of these regions’ significance levels are 0.2%–1%. The isolated regions distribution is more consistent with ESP, and most of these regions’ significance levels are 0.2%–1%.

Overall, the result of ESP has an obvious spatial clustering trend and the clustered regions also concentrated. Meanwhile, PCP result is affected by unevenly distributed regional population. However, the clustered regions are consistent with that of ESP at a nationwide scale. And PCLP result is also affected by unevenly distributed regional cultivated land area, and it is not obvious in a global level but shows clustering tendency in a local level.

For LISA result of the three indicators, the spatial patterns are more obvious. Most of the “High-High” clustered regions are distributed in Northeast China, Inner Mongolia and the central regions of China, and mainly are traditional agricultural regions. “Low-Low” clustered regions are mainly distributed in Yunnan, Guizhou, Sichuan, Shaanxi, Chongqing, part of Xinjiang. The unevenly distributed population and cultivated land area have a certain influence on these regions, but have little effect in a global level. “Low-High” isolated regions are mainly distributed in South China, sporadically distributed in other regions and always accompanied with “High-High” clustered regions. There are relatively few “High-Low” isolated regions sporadically distributed throughout the country.

3.3 TMS and GCC of livestock and poultry breeding in China

3.3.1 TMS of ESP, PCLP and PCP

Livestock distribution is influenced by variety factors. For further analysis purpose, this study uses TMS method to analyze ESP, PCLP and PCP spatial distribution. The method cites the research ideas of Ge *et al*. (2009), and explores livestock spatial patterns by livestock population, per unit cultivated land and per capita perspectives. Figures 6–8 show the TMS of ESP, PCLP and PCP, the values in each map is gradually increased from level 1 to level 16.

TMS shows spatial patterns of ESP, PCLP and PCP in each level, and also shows spatial variation of each index from low value to high value. All the three TMS shows gradual transition from the western to the eastern in nationwide perspectives. As Figure 6 shows, regions of ESP are finally clustered into North China and Northeast China, and Figure 7 shows that regions of PCLP are transited to the east but relatively scattered. However, Figure 8 shows regions of PCP are mainly clustered in Northeast China and Inner Mongolia.

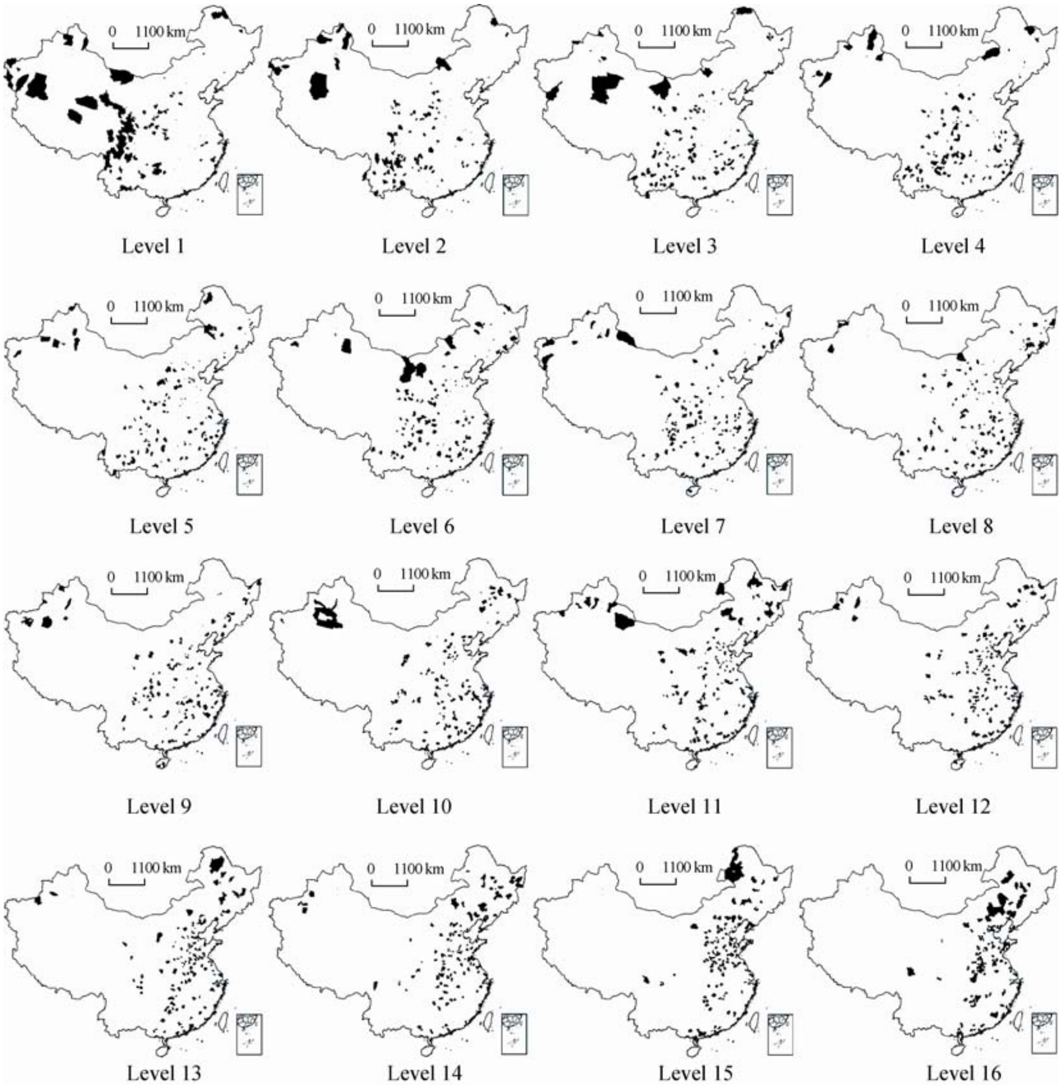

Figure 6 The TMS of ESP in 2007

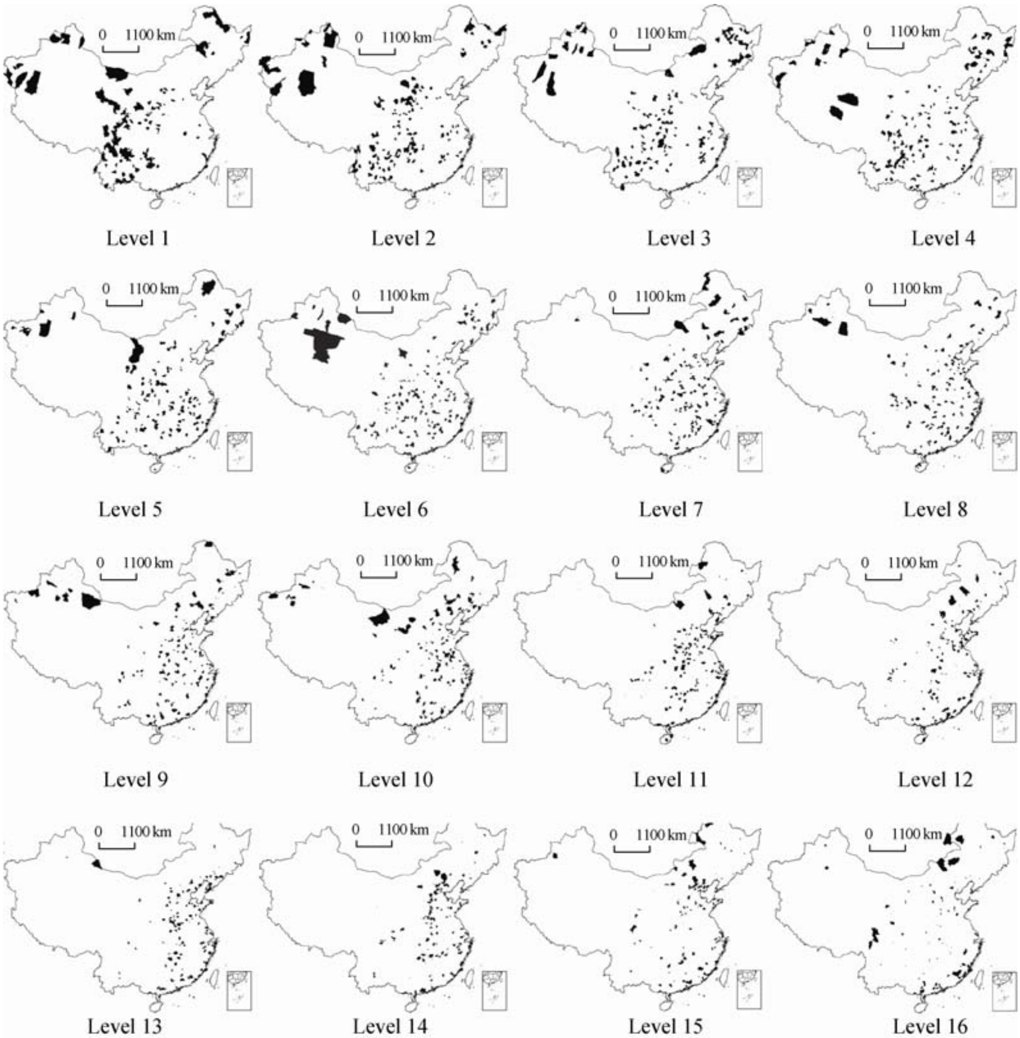

Figure 7 The TMS of PCLP in 2007

3.3.2 GCC of ESP, PCLP and PCP

From the clustering trend analysis result, distributions of the three indicators are in line with the description of the Tobler geographical first law, that is, the adjacent spatial unit has similar characteristics. Therefore, under the premise of classification continuity, levels with nearby location and similar livestock population are merged by their contiguity.

Accordingly, this study introduced gravity centers curve of ESP, PCLP and PCP, the method cites of Ge *et al*. (2009). Gravity centers of every level of ESP, PCLP and PCP are computed by Mean Center tools of ArcMap. For each indicator, connecting every gravity center by level order (1–16), it can form the GCC of that indicator. It should be noted that respective weights are used by corresponding values of ESP, PCLP and PCP in the calculation process.

Obviously, the gravity center's location depends on each level's regional distribution of ESP, PCLP and PCP. If it is evenly distributed, the gravity center should be the geometric

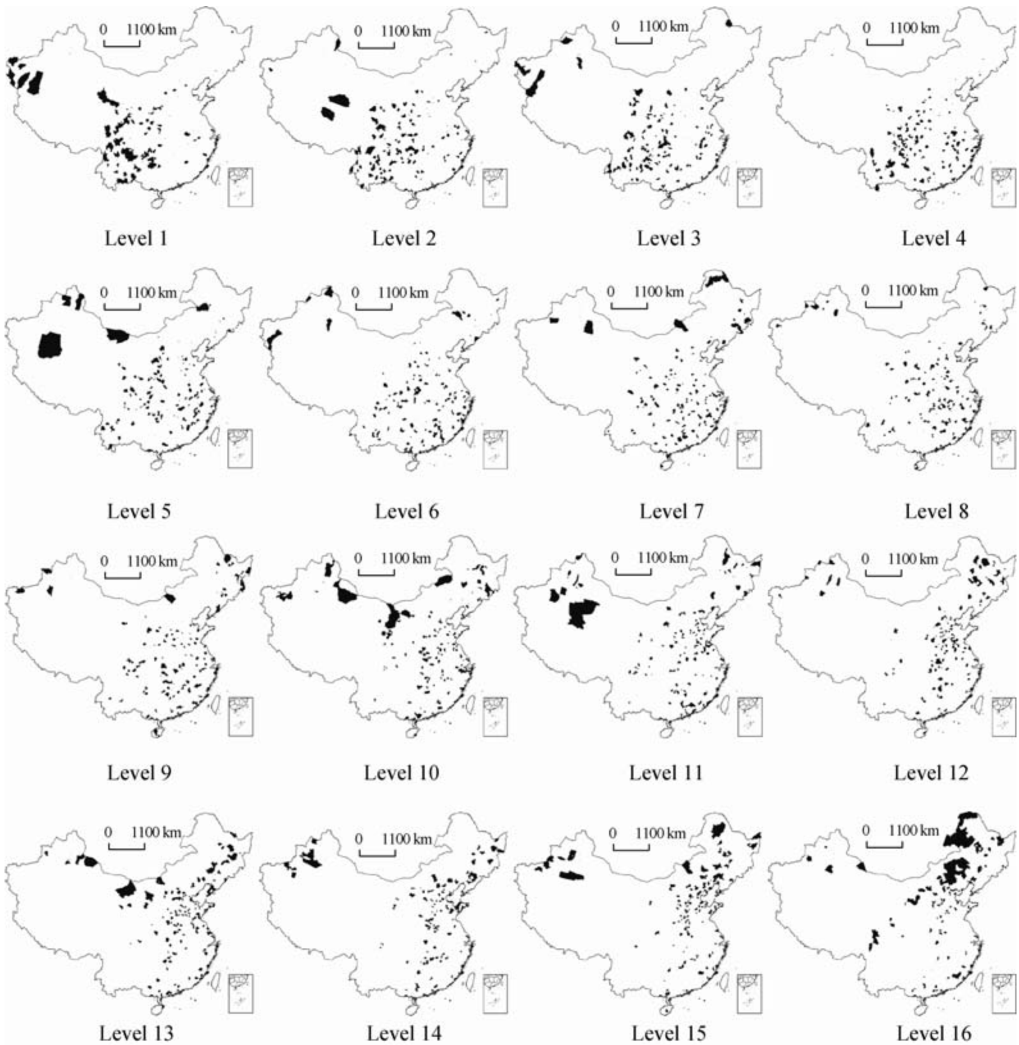

Figure 8 The TMS of PCP in 2007

center of the region. Otherwise, if it is not evenly distributed, location of the gravity center will be offset.

Figures 9–11 show the three indicators' GCC. For each GCC, it is easy to find that the proximities (spatial distance) in adjacent levels are changing from low value level center to the higher ones (from level 1 to level 16). The curve shape shows that the changing tendency of ESP is relatively balanced, but PCLP and PCP's are more dramatic.

3.4 Classification maps based on GCC of ESP, PCLP and PCP

There are three steps in this part. The first step is to calculate the distance of every two adjacent gravity centers in each GCC. The next step is to select the demarcations by proximities, which reflected by distances. And the last step is to merge levels moderately in TMS of ESP, PCLP and PCP by the proximities of every GCC. Table 1 lists the demarcation and intervals between gravity centers of ESP, PCLP and PCP.

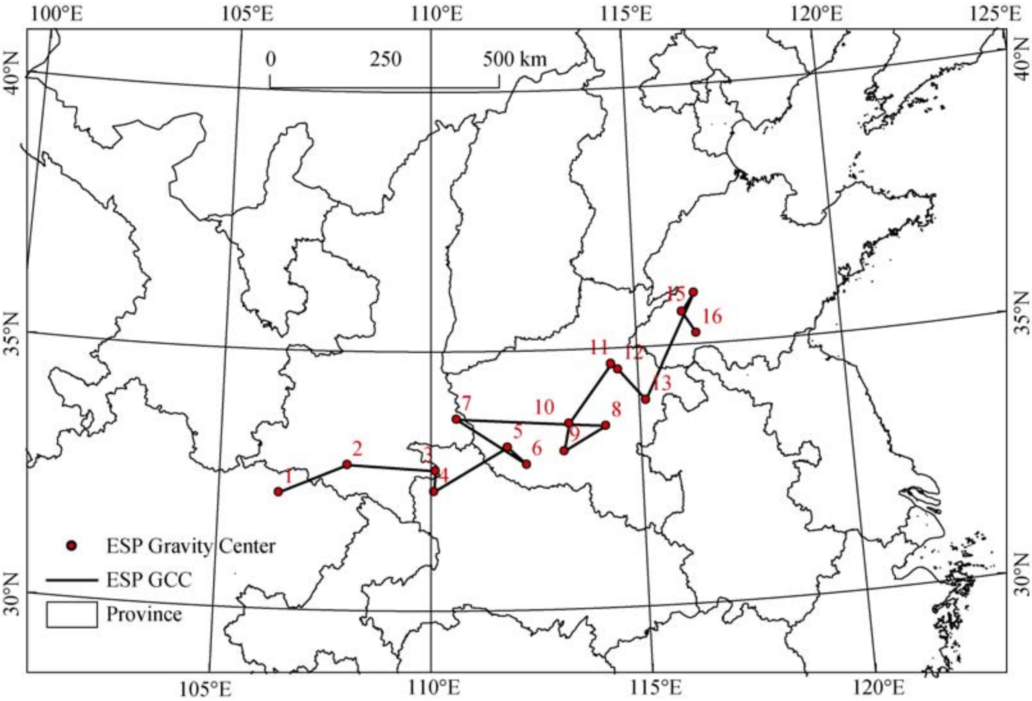

Figure 9 The GCC of ESP in 2007

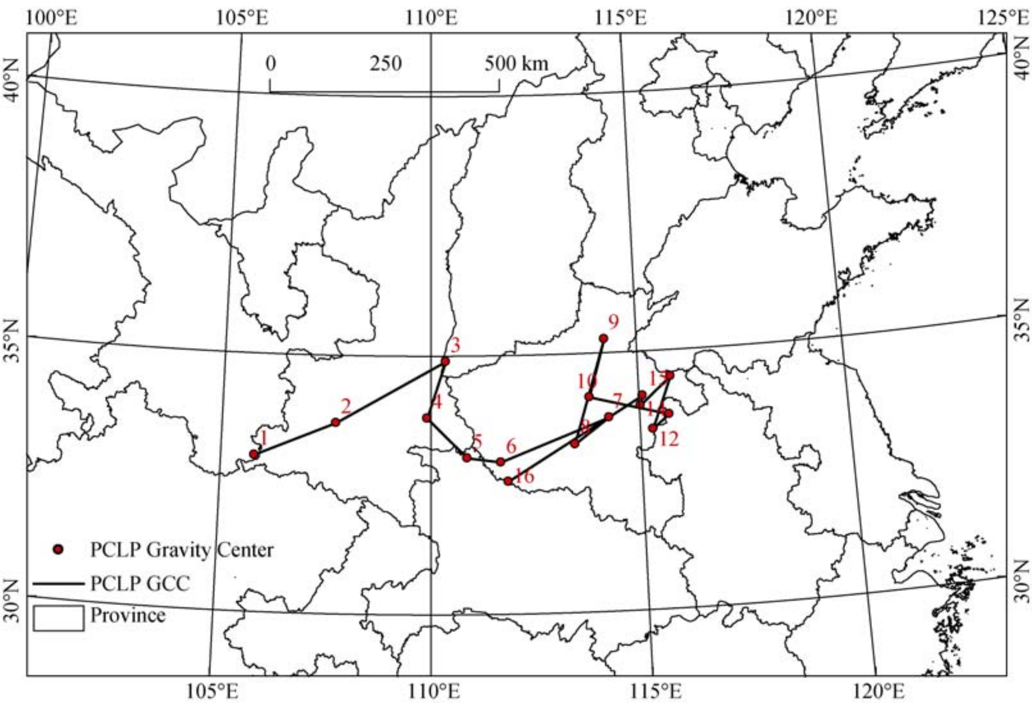

Figure 10 The GCC of PCLP in 2007

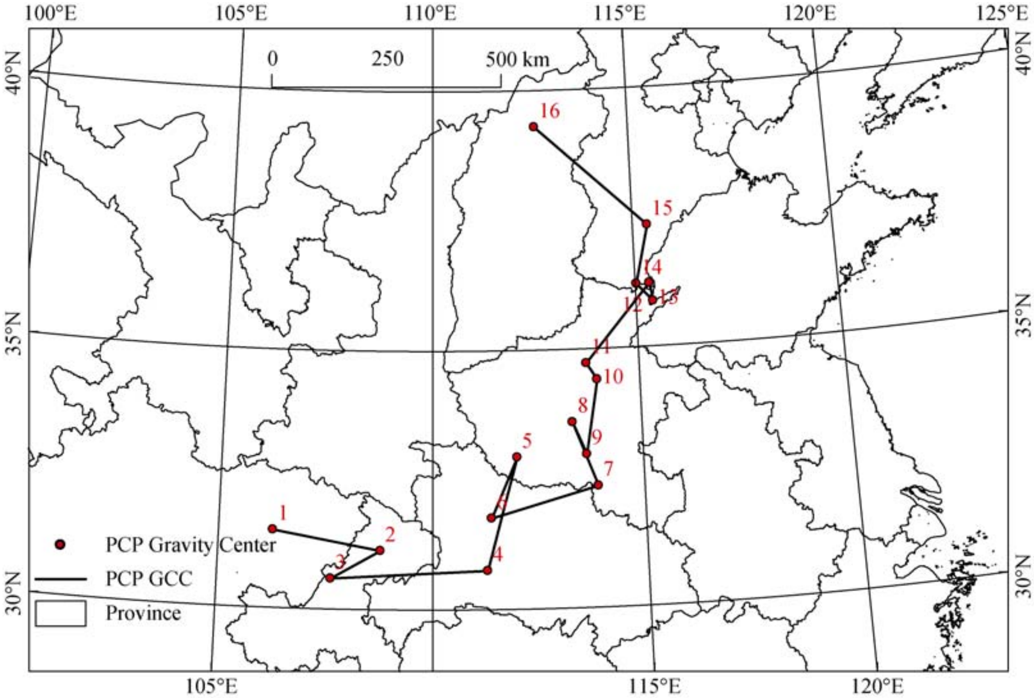

Figure 11 The GCC of PCP in 2007

Table 1 The demarcation and intervals between gravity centers of ESP, PCLP and PCP

Inter level	Interval of gravity center of ESP	Demarcation of moderately merging	Interval of gravity center of PCLP	Demarcation of moderately merging	Interval of gravity center of PCP	Demarcation of moderately merging
1–2	**161.2**	I-II demarcation	**192.1**	I-IIdemarcation	**239.1**	I-IIdemarcation
2–3	**193.3**	II-III demarcation	**273.7**	II-III demarcation	124.3	
3–4	45.2		126.7		**344.3**	II-III demarcation
4–5	**188**	III-IV demarcation	**128.6**	III-IV demarcation	**255.4**	III-IV demarcation
5–6	46.9		74.1		144	
6–7	**181.7**	IV-V demarcation	**255.3**	IV-V demarcation	**243.7**	IV-V demarcation
7–8	**318.9**	V-VI demarcation	94.5		149.3	
8–9	106.1		**237.5**	V-VI demarcation	76.3	
9–10	59.2		131		**164.7**	V-VI demarcation
10–11	**157.9**	VI-VII demarcation	**177.4**	VI-VII demarcation	42.2	
11–12	18.6		47.6		**223**	VI-VII demarcation
12–13	90.3		120.9		40.3	
13–14	**254**	VII-VIII demarcation	91.3		51.7	
14–15	48.6		22		130.9	
15–16	56		**348.2**	VII-VIII demarcation	**325**	VII-VIII demarcation

According to the demarcations in Table 1, there exist eight Chinese livestock districting types for each indicator. Table 2 lists the adjusted districting types of ESP, PCLP and PCP. The eight districting types are extremely sparse region, sparse region, relatively sparse region, normally sparse region, normal region, relatively concentrated region, concentrated region and highly concentrated region.

Meanwhile, the adjusted classification maps show that there exists a clear demarcation line between the concentrated and the sparse regions of livestock and poultry breeding in

China. It starts from the county boundary between Xin Barag Left Banner and Xin Barag Right Banner, Inner Mongolia Autonomous Region to the west coast of Dongfang County, Hainan Province. For easier representation purpose, the demarcation line is hereinafter referred to Chinese livestock line (CL line).

Table 2 The adjusted districting types of ESP, PCLP and PCP

Type num.	Districting types	Gravity center of ESP	Gravity center of PCLP	Gravity center of PCP
I	Extremely sparse region	1	1	1
II	Sparse region	2	2	2,3
III	Relatively sparse region	3,4	3,4	4
IV	Normally sparse region	5,6	5,6	5,6
V	Normal region	7	7,8	7,8,9
VI	Relatively concentrated region	8,9,10	9,10	10,11
VII	Concentrated region	11,12,13	11,12,13,14,15	12,13,14,15
VIII	Highly concentrated region	14,15,16	16	16

For counties with sparse and extremely sparse districting types (type I and II), there are 236 counties distributed in the west of CL line for ESP and PCLP, and 74 counties in the east. And there are 320 counties distributed in the west of CL line for ESP and PCLP, and 142 counties in the east. These statistics show that counties with sparse types are mainly distributed in the west of CL line.

For counties with concentrated and highly concentrated districting types (types VII and VIII), there are 272 counties distributed in the west of CL line for ESP and PCLP, and 1088 counties in the east. And there are 175 counties distributed in the west of CL line for ESP and PCLP, and 883 counties in the east. These statistics show that counties with concentrated types are mainly distributed in the west of CL line.

Table 3 shows the counties in both west and east sides of CL line. The obvious contrast of the statistical characteristics verified the spatial characteristics reflected by CMC and TMS of the three indicators.

Table 3 The county numbers in both west and east sides of CL line

Districting types	West of CL line (ESP)	East of CL line (ESP)	West of CL line (PCLP)	East of CL line (PCLP)	West of CL line (PCP)	East of CL line (PCP)
Extremely sparse region	131	29	131	29	131	29
Sparse region	105	46	105	46	189	113
Relatively sparse region	170	132	170	132	86	65
Normally sparse region	142	160	142	160	142	160
Normal region	76	75	125	177	173	280
Relatively concentrated region	140	313	91	211	80	222
Concentrated region	88	365	122	633	85	519
Highly concentrated region	44	410	10	142	10	142

The adjusted classification maps of ESP, PCLP and PCP are shown in Figures 12–14. Compared with Figure 1, the adjusted classification maps reduce the fragmentation degree, thus better expressing the spatial patterns of livestock population in China.

Due to the impact of population and cultivated land area, part of the eight types of ESP, PCLP and PCP is slightly different, the detailed analysis as follows:

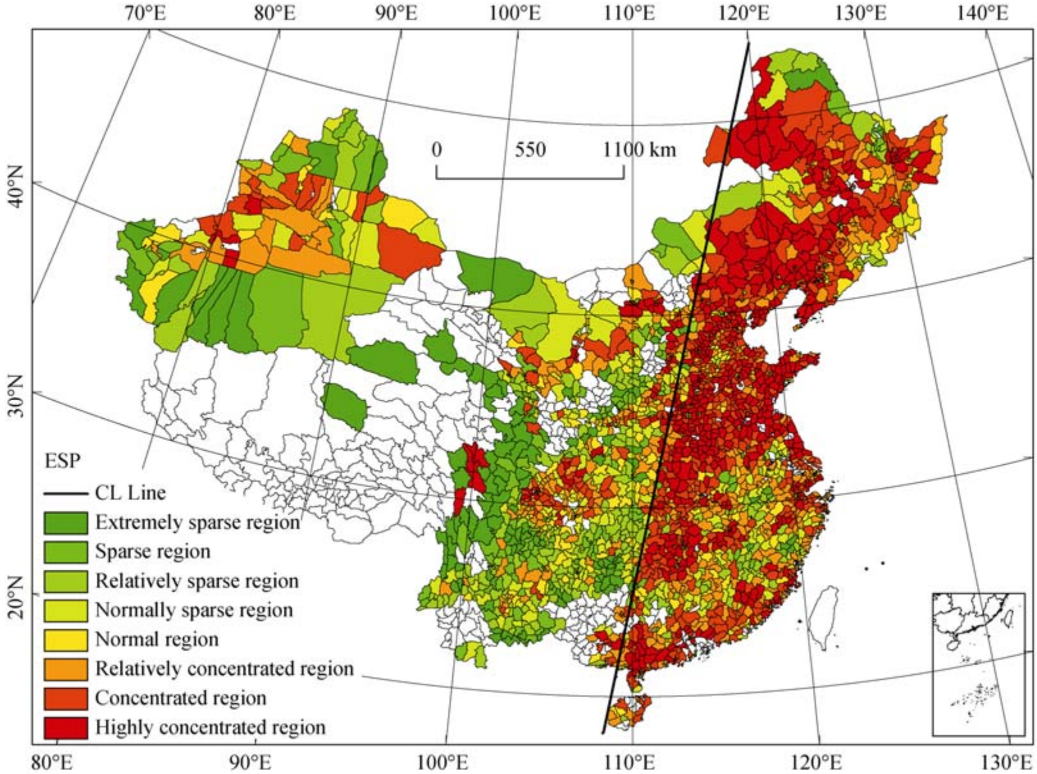

Figure 12 The adjusted classification map for ESP in 2007 at county level (8 types)

First, the extremely sparse region. In this type, there are 150 counties, corresponding to level 1 of TMS. In west side of CL line, there are 131 counties with 87% of all counties in this type, and these counties are mainly distributed in Sichuan and its surrounding regions, part of provincial boundary regions of Xinjiang. In east side of CL line, there are 29 counties with 13% of all counties in this type, and these counties are geographically dispersed.

Second, the sparse region. In this type, for ESP and PCLP, there are 151 counties, corresponding to level 2 of TMS. In west side of CL line, there are 105 counties with 70% of all 151 counties, and these counties are mainly distributed in Yunnan, Guizhou, central part of Shanxi, Shaanxi, Ningxia, and part of provincial boundary regions of Xinjiang. In east side of CL line, there are 46 counties with 30% of all 151 counties, and these counties are geographically dispersed.

By contrast, for PCP, there are 302 counties in this type, corresponding to levels 2 and 3 of TMS. In west side of CL line, there are 189 counties with 63% of all 302 counties, these counties are mainly distributed in Yunnan, Guizhou, Sichuan, Shaanxi, Chongqing, and provincial boundary regions of Xinjiang. In the east side of CL line, there are 113 counties with 37% of all 302 counties, these counties are mainly distributed in East China, and geographically dispersed in other regions.

Third, the relatively sparse region. In this type, for ESP and PCLP, there are 302 counties, corresponding to levels 3 and 4 of TMS. In west side of CL line, there are 170 counties with 56% of all 302 counties, and these counties are mainly distributed in Yunnan, Guizhou, Shaanxi, Chongqing, parts of Sichuan and Xinjiang. In east side of CL line, there are 132

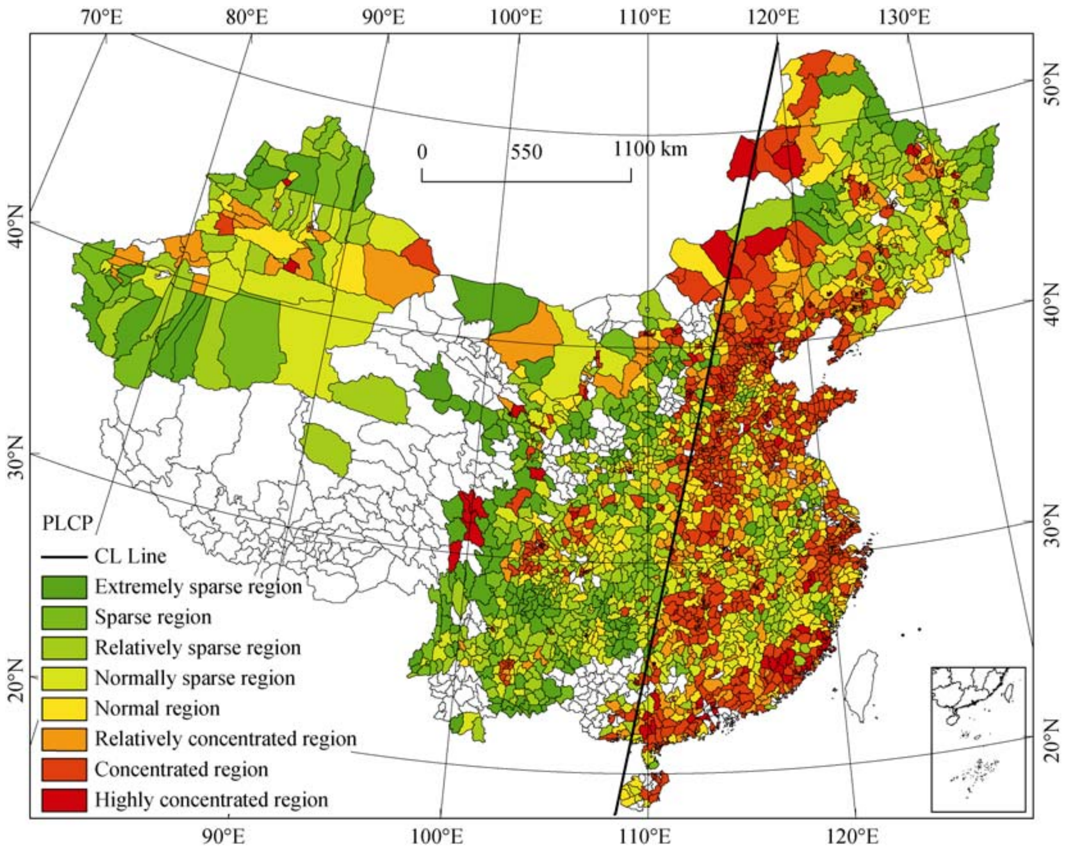

Figure 13 The adjusted classification map for PCLP in 2007 at county level (8 types)

counties with 44% of all 302 counties, and these counties are mainly distributed in Central China, South China and geographically dispersed in other regions.

By contrast, for PCP, there are 151 counties in this type, corresponding to level 4 of TMS. In west side of CL line, there are 86 counties with 57% of all 151 counties, these counties are mainly distributed in Yunnan, Guizhou, parts of Xinjiang, Shaanxi and Chongqing. In east side of CL line, there are 65 counties with 43% of all 151 counties, and these counties are mainly distributed in Southeast China.

Fourth, the normally sparse region. In this type, there are 302 counties, corresponding to levels 5 and 6 of TMS. In west side of CL line, there are 142 counties with 47% of all 302 counties, and these counties are geographically dispersed in Yunnan, Guizhou, Sichuan, Shaanxi, Chongqing, Inner Mongolia and Xinjiang. In east side of CL line, there are 160 counties with 53% of all 302 counties, and these counties are mainly distributed in Southeast China, followed by North China and Northeast China.

Fifth, the normal region. In this type, for ESP, there are 151 counties, corresponding to level 7 of TMS. In west side of CL line, there are 76 counties with 50% of all 151counties, and these counties are mainly distributed in Shaanxi, Chongqing and their surrounding regions, and sporadically distributed in Ningxia and Xinjiang. In east side of CL line, there are 75 counties with 50% of all 151 counties, and these counties are mainly distributed in Southeast China, eastern border of Northeast China, and sporadically distributed in other regions.

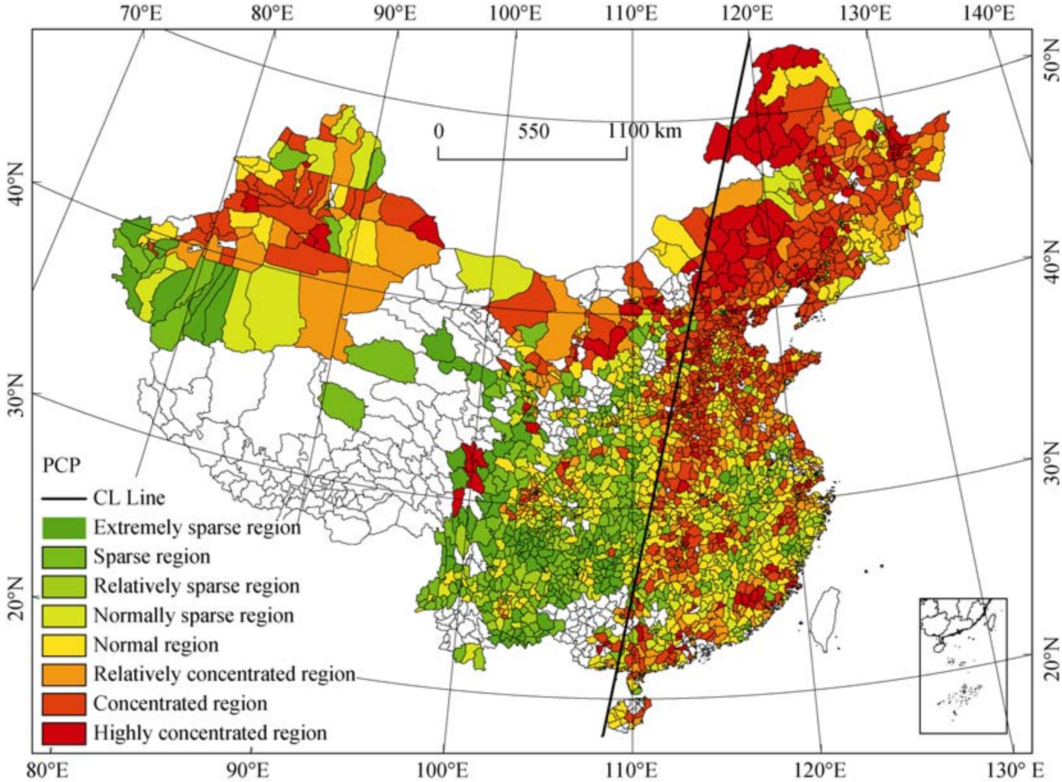

Figure 14 The adjusted classification map for PCP in 2007 at county level (8 types)

By contrast, for PCLP, there are 302 counties in this type, corresponding to levels 7 and 8 of TMS. In west side of CL line, there are 125 counties with 41% of all 302 counties, these counties are mainly distributed in surrounding regions of the junction of Sichuan, Shaanxi, Chongqing, and parts of Inner Mongolia and Xinjiang. In east side of CL line, there are 177 counties with 59% of all 302 counties, and these counties are mainly distributed in Southeast China such as Anhui, Zhejiang, Jiangxi, Fujian, and a few counties in North China and Northeast China.

And for PCP, there are 453 counties in this type, corresponding to levels 7–9 of TMS. In west side of CL line, there are 173 counties with 38% of all 453 counties, these counties are mainly distributed in Guizhou, Sichuan, Shaanxi, Chongqing, Xinjiang, and parts of Yunnan, Ningxia and Inner Mongolia. In east side of CL line, there are 280 counties with 62% of all 453 counties, and these counties are mainly distributed in most parts of Southeast China, eastern part of Northeast China, central part of North China.

Sixth, the relatively concentrated region. In this type, for ESP, there are 453 counties, corresponding to levels 8–10 of TMS. In west side of CL line, there are 140 counties with 31% of all 453 counties, and these counties are mainly distributed in Sichuan, Chongqing, Shaanxi, Shanxi, central part of Ningxia and Xinjiang, and part regions of Yunnan, Guizhou and Guangxi. In east side of CL line, there are 313 counties with 69% of all 453 counties, and these counties are mainly distributed in most parts of Central China, East China, South China, and in North China and Northeast China.

By contrast, for PCLP, there are 302 counties in this type, corresponding to levels 9 and 10 of TMS. In west side of CL line, there are 91 counties with 30% of all 302 counties, these counties are mainly distributed in Sichuan, Shaanxi, Chongqing, central part of Xinjiang, and sporadically distributed in other regions. In east side of CL line, there are 211 counties with 70% of all 302 counties, and these counties are mainly distributed in Hebei, Anhui, Zhejiang, Jiangxi, Fujian, Guangdong, and partly in North China and Northeast China.

And for PCP, there are 302 counties in this type, corresponding to level 10 to 11 of TMS. In west side of CL line, there are 80 counties with 26% of all 302 counties, these counties are mainly distributed in Sichuan, Chongqing, central part of Xinjiang, central part of the junction regions of Yunnan and Guizhou, part of Ningxia and Shaanxi. In east side of CL line, there are 222 counties with 74% of all 302 counties, and these counties are evenly distributed in all regions east of CL line, and relatively concentrated in Southeast China, North China and Northeast China.

Seventh, the concentrated region. In this type, for ESP, there are 453 counties, corresponding to levels 11–13 of TMS. In west side of CL line, there are 88 counties with 19% of all 453 counties, and these counties are relatively concentrated in the junction regions of Sichuan and Chongqing, central and western part of Xinjiang, the junction regions of Shaanxi and Shanxi. In east side of CL line, there are 365 counties with 81% of all 453 counties, and these counties are concentrated in all east regions except Anhui, Jiangxi, Fujian, Inner Mongolia, and mostly concentrated in North China, Central China and South China.

By contrast, for PCLP, there are 755 counties in this type, corresponding to levels 11–15 of TMS. In west side of CL line, there are 122 counties with 16% of all 755 counties, and the distribution of these counties is consistent with that of ESP. In east side of CL line, there are 633 counties with 84% of all 755 counties, and these counties are concentrated in all east regions except Anhui, Jiangxi, Fujian, Inner Mongolia, and more concentrated in eastern Inner Mongolia, most parts of Northeast China, South China, and mostly concentrated in North China and Central China.

And for PCP, there are 604 counties in this type, corresponding to levels 12–15 of TMS. In west side of CL line, there are 85 counties with 14% of all 604 counties, these counties are relatively concentrated in eastern Sichuan, Shanxi, Shaanxi, central and western parts of Xinjiang. In east side of CL line, there are 519 counties with 86% of all 604 counties, and these counties are mainly concentrated in North China, Northeast China, Hubei, Hunan, Fujian and Guangdong.

Eighth, the highly concentrated region. In this type, for ESP, there are 454 counties, corresponding to level 14–16 of TMS. In west side of CL line, there are 44 counties with 14% of all 454 counties, and these counties are sporadically distributed in Sichuan, Shaanxi and Shanxi. In east side of CL line, there are 410 counties with 86% of all 454 counties, and these counties are mainly concentrated in North China, Inner Mongolia, Liaoning, Hunan and Hubei.

By contrast, for PCLP and PCP, there are 152 counties in this type, corresponding to level 16 of TMS. In west side of CL line, there are only 10 counties with 6% of all 152 counties, these counties are sporadically distributed in Sichuan, Inner Mongolia and Shanxi. In east side of CL line, there are 142 counties with 94% of all 152 counties, and these counties are mainly concentrated in North China, the junction regions of Northeast China and Inner Mongolia, and more concentrated in Hunan, Fujian, Guangdong and Guangxi.

4 Conclusions and discussion

The main conclusions are drawn in three perspectives, that is, spatial clustering analysis by globally and locally spatial autocorrelation analysis, spatial analysis methods and result, and the demarcation of Chinese livestock and poultry.

First, perspective of spatial clustering analysis. On one hand, the globally spatial autocorrelation analysis result shows both ESP and PCP have positive spatial autocorrelation characteristics, and are spatially clustered nationwide. However, PCLP is not significantly clustered in nationwide and has larger randomness. On the other hand, the locally spatial autocorrelation analysis shows ESP has an obvious trend of spatial clustering, and has more concentrated regions. But PCLP only has spatial clustered trend in some regions. And for PCP, it has more concentrated regions, and these regions are consistent with those of ESP.

There may be three reasons for these spatial patterns. Reason one, most of the concentrated regions are traditional agricultural areas, such as Northeast China, North China, East China, South China. The spatial patterns are influenced by each region's agricultural scale and level. Reason two, in northwest side of Hu Huanyong line, there is 12% of total cultivated land distributed in 60% of the country's land area. In southeast of Hu Huanyong line, there is 88% of total cultivated land distributed in 40% of the country's land area (Guan *et al*., 2010). PCLP is significantly influenced by the uneven distribution of cultivated land area. Reason three, more than 75% of Chinese total population is distributed in less than 25% of the country's land, and less than 2% of total population is living on more than half of the country's land (Ge *et al*., 2009). The very uneven distribution of Chinese population is also significantly influenced by the PCP spatial patterns.

Second, the perspective of spatial analysis methods and result. For TMS, GCC and classification maps of ESP, PCLP and PCP, there are more differences in TMS and GCC, meanwhile there are more similarities in classification maps. Such as type I and type IV are exactly the same, and level 2 in type II, level 4 in type III, level 7 in type V, level 10 in type VI, levels 12 and 13 in type VII and level 16 in type VIII are all similar in the specific types. Based on these analyses, different expressions (such as total quantity, per cultivated land quantity, per capita quantity) of the same feature will lead to different TMS, GCC and districting scheme. However, there exists a potential uniform districting scheme, and just needs to adjust the attribution of each level's gravity center. Therefore, it can be considered that every districting type of PCLP and PCP is adjusted according to the allocation influence of cultivated land area and population, and is also based on ESP.

The method of combining TMS, GCC and classification maps can not only be used to optimize the density classification result (Ge *et al*., 2009), but also applied to spatial patterns and differentiation analysis for administrative data. It should be noted that the administrative data should have spatial clustering trend characteristics. That is, it should show significantly spatial clustered both in globally and locally spatial autocorrelation analysis. Thus, the results of classification by TMS and GCC method could more appropriately reflect the real spatial patterns and differentiation characteristics. Therefore, it is recommended that relevant researches should better add spatial autocorrelation analysis, and use the result as reference in preliminary analysis and classification examination.

Third, the perspective of the demarcation of Chinese livestock and poultry (CL line). Based on the analysis result of CMC, spatial clustering trend analysis, TMS, GCC, classification maps, it is found that there exists a clear demarcation line between the concentrated and the sparse regions of livestock and poultry breeding in China. It starts from the county boundary between Xin Barag Left Banner and Xin Barag Right Banner, Inner Mongolia Autonomous Region to the west coast of Dongfang County, Hainan Province.

The discovering of CL line has greater practical significance, it can be an important reference for policy making in livestock industry management. However, time cross-section research could not replace the time series analysis. Therefore, it needs more time series and other in-depth research.

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