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Geographic distribution of livestock products in China- an application of spatial autocorrelation analysis

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ABSTRACT

The rapid increase in the livestock industry in China in recent two decades has played an important role in the livelihoods of people and has become a very significant issue in terms of sustainable animal food supply chains. Knowledge gaps in the geographic distribution may hinder the sustainable development of livestock industry. This paper investigates the spatial distribution in the outputs of livestock products (meat, milk and egg, respectively) in China using exploratory spatial data analysis. This method is a set of GIS spatial statistical techniques that are useful in describing and visualizing the spatial distribution, detecting patterns of hot-spots, and suggesting spatial regimes. The global Moran's *I* statistics for the three products reveal strong positive and significant spatial autocorrelation. Furthermore, the Moran significance maps indicate four hot-spots (North-eastern cluster, Northern Coast cluster, Central Inland cluster and Southern cluster) and one cold-spot (Western cluster) in the meat product distribution, one large hot-spot (Northern cluster) and one large cold-spot (South-central cluster) for the milk product, four relatively small hot-spots (North-eastern cluster, Northern Coast cluster, Eastern Coast cluster and Central Inland cluster) and one large cold-spot (Western cluster) for the egg product. Based on the results, we show that livestock products are polarized into clusters and the outputs of the products tend to be reducing from east to west and from north to south China. Implications are drawn, such as priority of resource allocations for hot-spot area in terms of animal-source food security and the utilization of spillover effects from hot-spots.

Key words: Food security, Livestock products, Spatial autocorrelation, Spatial pattern.

INTRODUCTION

Livestock products are closely related to the livelihoods of almost a billion people (Cecchi *et al.*, 2010; Robinson *et al.*, 2014). In many developed countries, the outputs of livestock products account for more than 50% of the total agricultural products (Jefferson *et al.*, 2001). In developing countries (Cecchi *et al.*, 2010), livestock products are also considered a key asset, especially in the areas of crop failures, acting as a crucial food resource with ruminant-based products increasing the protein-rich food supply (Kabubo-Mariara, 2009) and improving the livelihoods of rural households (Robinson *et al.*, 2014), which may contribute to shrink the rural-urban disparity inside the region, and strengthen trade contacts with other regions through the networks of food supply in terms of livestock products. However, the livestock industry that increasingly competes for scarce resources (e.g., land, water, and energy) has a severe impact on air, water and soil quality because of its emissions (Fu *et al.*, 2012; Godber and Wall, 2014). Therefore, spatial distributions of livestock products will gain insights into pursuing sustainable food supply chains, poverty reduction and environmental protection as well for the region.

In China, the proportion of livestock output in agricultural products had increased from 18% in 1980 to 30% in 2010, and has increased more rapidly in recent years (Fu *et al.*, 2012). However, the growth of livestock products means increasing livestock breeding accordingly, which will lead to more serious environmental problems. It is claimed that livestock pollution has exceeded the industrial pollution and the regions with developed livestock industry are high-risk areas of surface water pollution (Fu *et al.*, 2012). In this context, reliable and accessible information on the spatial distribution of livestock products for China is needed. Such spatial distribution is also indispensable to the analyses of the social and economic aspects and the environmental impacts from livestock sector (Gao *et al.*, 2006; Robinson *et al.*, 2014).

A number of related studies have been done to understand the spatial pattern of livestock production systems in the world. Kruska *et al*. (2003) mapped livestock production systems using geospatial datasets on human population density, land cover, length of growing period, temperature and irrigation for the developing world, and identifying areas that are environmentally suitable for a given

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type of livestock products, while it did not specifically incorporate the distribution of livestock. The Gridded Livestock of the World database, produced in 2007, can be used for various decision-making activities but were based on poor quality livestock input data (Wint and Robinson, 2007; Bryssinckx *et al.*, 2012). Recently, Robinson *et al.* (2014) presented new global distribution maps at 1 km resolution for livestock products with more up-to date and detailed investigation. Other related researches on spatial distribution of livestock also have been carried out in Europe (Neumann *et al.*, 2009), South Africa (Hobololo, 2009) and Mongolia (Saizen *et al.*, 2010). However, there are limited literatures on the spatial distribution of livestock products, especially at the national level of China (Fu *et al.*, 2012). Verburg and Keulen (1999) explored the changes in the spatial distribution of livestock in China. More recently, Fu *et al.* (2012) used the total regional livestock population to examine the global and local clustering trends of livestock industry, which has great contribution to the agricultural non-point source pollution control and management in China. However, the quantity of livestock and poultry breeding could not be completely equal to the output. And from economic growth and development standpoint, the output of livestock products would be a better evaluation indicator of livestock industry. Furthermore, the study by Fu *et al.* (2012) tended to ignore the heterogeneity of resources and environmental dependencies of different kinds of livestock products by analyzing the livestock and poultry breeding as a whole. Therefore, more detailed information on the spatial distribution of livestock sector is needed by both initiatives for a range of policy and technical applications in livestock industry.

In general, the livestock production systems may be more similar in neighbouring locations than in locations further apart (Orhan *et al.*, 2009), which is referred to as spatial autocorrelation. Spatial autocorrelation is one of the conspicuous characteristic of non-independence of observations, which should be taken into account when carrying out statistical analysis (Anselin, 1995). Spatial autocorrelation of livestock products can describe spatial dependence and heterogeneity through the detection of clustering such as Moran's Index. Although spatial autocorrelation was defined decades ago, its application has been limited by spatial datasets availability and computation capacity (Saizen *et al.*, 2010; Zhang *et al.*, 2011). Current studies on spatial autocorrelation for spatial dependence and heterogeneity in either global or local scales have focused on spatial econometrics (Anselin and Rey 1997; Ping *et al.*, 2004; Cracolici *et al.*, 2009). As for all types of statistical analysis, the choice of a specific analytical technique must be based on a consideration of the characteristics of the data and on prior knowledge of the observations. Among them, the exploratory spatial data analysis (ESDA) based on Geographical Information Systems (GIS) techniques is often used as a basis of spatial analysis, and has been proved to be an effective method to measure both global and local spatial autocorrelation for observations (Anselin *et al.*, 2006).

An understanding of the spatial patterns of livestock products can help agricultural policy-makers and related governments to improve the layout of livestock industry in the country, promote the development of the local agricultural economy, provide better services and facilities to cater for the needs of food security and environment protection, and identify high-risk areas in terms of disease transmission. From regional planner's standpoint, it is also important to make appropriate spatial flow planning to determine the optimum locations of livestock industry. In this context, we use outputs of meat, milk and egg of 337 cities as indicators to describe and visualize spatial distributions of livestock sector in China with the help of ESDA technique. The aims are to examine whether regional disparity in livestock products exists among cities in China; to reveal the spatial patterns of livestock products at the national scale; and to locate the hot-spots and cold-spots in terms of livestock products at the city level.

MATERIALS AND METHODS

The data of outputs of meat (including pork, beef, mutton and poultry), milk (mainly including cow's milk and ewe's milk) and egg (mainly including chicken's egg, duck's egg, goose's egg and quail's egg) at the city level in 2011 were obtained from (China Statistical Yearbook For Regional Economy 2012), which were compiled by the Department of Comprehensive Statistics and Department of Rural Survey of National Bureau of Statistics (National Bureau of Statistics, 2012).

This study covers mainland China, with 337 cities as sample units of analysis. Cities in China are administrative and geographical entities that are smaller than province but larger than counties. Several issues about the sample cities should be highlighted. Firstly, the sample includes four province-level cities (municipalities directly under central government administration), such as Beijing, Tianjin, Shanghai and Chongqing, and many autonomous prefectures. They are generally considered as individual cities. Secondly, there are some special counties that have been administered directly by the province, such as Wujianqu, Tumushuke and Alear in Xinjiang, Jiyuan in Henan, Shennongjia in Hubei, Baiyin in Gansu and Bazhong in Sichuan, since the early twenty-first century. Data on some of these counties are unavailable or neglectable, so all these counties have been combined together to the cities they previously belonged to as well.

According to physical geography characteristics combining with economic conditions, China is usually divided geographically into seven zones (Cho *et al.*, 2010) (Figure 1): North (Beijing, Tianjing, Hebei, Shanxi and Inner Mongolia), East (Shanghai, Shandong, Jiangsu, Anhui,

Fig 1: Zoning of China

Jianxi, Zhejiang and Fujian), Central (Hubei, Hunan and Henan), South (Guangdong, Guangxi and Hainan), Northeast (Heilongjiang, Jilin, Liaoning), Southwest (Chongqing, Sichuan, Guizhong, Yunnan and Xizang) and Northwest (Shannxi, Gansu, Qinghai, Ningxia and Xinjiang).

In order to detect the existence of spatial dependence and heterogeneity in livestock products between cities in China, ESDA is employed in this study. ESDA is a set of techniques used to describe and visualize spatial distributions, to discover patterns of spatial associations, to identify hot-spots and cold-spots and to suggest spatial regimes (Anselin, 1999; Zhang *et al.*, 2011).

This study includes the followed steps: firstly, the spatial distribution of livestock products in the cities was mapped; secondly, the analysis focused on two aspects of spatial clustering, namely, the overall "global" spatial clustering and the "local" patterns of livestock products distribution.
The global measure of Moran's *I* is as follows:

$$I = \sum_i \sum_j w_{ij}(x_i - \mu)(x_j - \mu) / \sum_i (x_i - \mu)^2$$

where w_{ij} is the row-standardized contiguity matrix, x_i is the output of livestock products at city i, x_j is the output of livestock products at city j, and μ is the average output of livestock products in the nation.

The Moran's *I* statistic is used as a measure of the overall clustering and is assessed by testing a null hypothesis (i.e. the spatial pattern is random). If the spatial distribution of livestock products is completely random at the city level, then the absence of spatial autocorrelation is implied; on the other hand, if the null hypothesis is rejected, then a non-random spatial pattern is implied, which can be also termed spatial autocorrelation. The spatial autocorrelation measures the nature and strength of interdependence between cities in terms of livestock products. There is positive spatial autocorrelation when similar output of livestock products tends to occupy adjacent cities, whereas there is negative autocorrelation when high output tends to be located next to low output. Moran's *I* ranges approximately from +1 (for positive spatial autocorrelation) to "1 (negative autocorrelation) and its expected value in the absence of autocorrelation is approximately zero (Anselin, 1995).

The Moran's *I* statistic is a global statistic and cannot discover hot-spots/cold-spots between cities. Therefore, the Local Indicator of Spatial Association (LISA) is applied to measure local spatial association and to indicate the local spatial autocorrelation and the significance of hot-spots/cold-spots. Local Moran's *I* statistic is employed to show LISA in this research (Yang and Wong, 2013).
The local version of Moran's I statistic is as follows:

$$I = \frac{x_i - \mu}{\sum_i (x_i - \mu)^2} \sum_j w_{ij}(x_j - \mu)$$

Firstly, we incorporated the data of the outputs of livestock products for each city into a vector map of China with administrative boundary at the city level to create some new shape-files using ArcGIS. On the basis of the new shape-files, GeoDa software is then employed to conduct ESDA analysis in the present analysis. When running the program, neighbours are defined using the first order queen contiguity, which considers that all the cities with common borders are neighbours. To test for significance, a Monte Carlo permutation approach is used (Anselin, 2003). The significance of local Moran's *I* (LISA) is then determined by generating a reference distribution using 999 random permutations at 5% significance level. Finally, the LISA significance maps, incorporating information about the significance of the local spatial patterns, are created. In particular, the maps result in a spatial typology consisting of five categories of cities in terms of livestock products: (1) HH (hot-spots) indicates cities with high output of livestock products are adjacent to cities with high output (positive spatial autocorrelation); 2) LL (cold-spots) indicates cities with low output that are adjacent to cities with low output (positive spatial autocorrelation); (3) LH indicates cities with low output that are adjacent to cities with high output (negative spatial autocorrelation); (4) HL indicates cities with high output that are adjacent to cities with low output (negative spatial autocorrelation) and (5) "not significant" indicates cities with no spatial autocorrelation.

RESULTS AND DISCUSSION

Spatial distribution of livestock products: Figures 2 through 4 are choropleth maps showing hierarchical structure of spatial distributions of livestock products (meat, milk and egg). Of these, areas have been shaded by different colors in according to the ratio of each city to the total outputs of the nation for the three products in 2011.

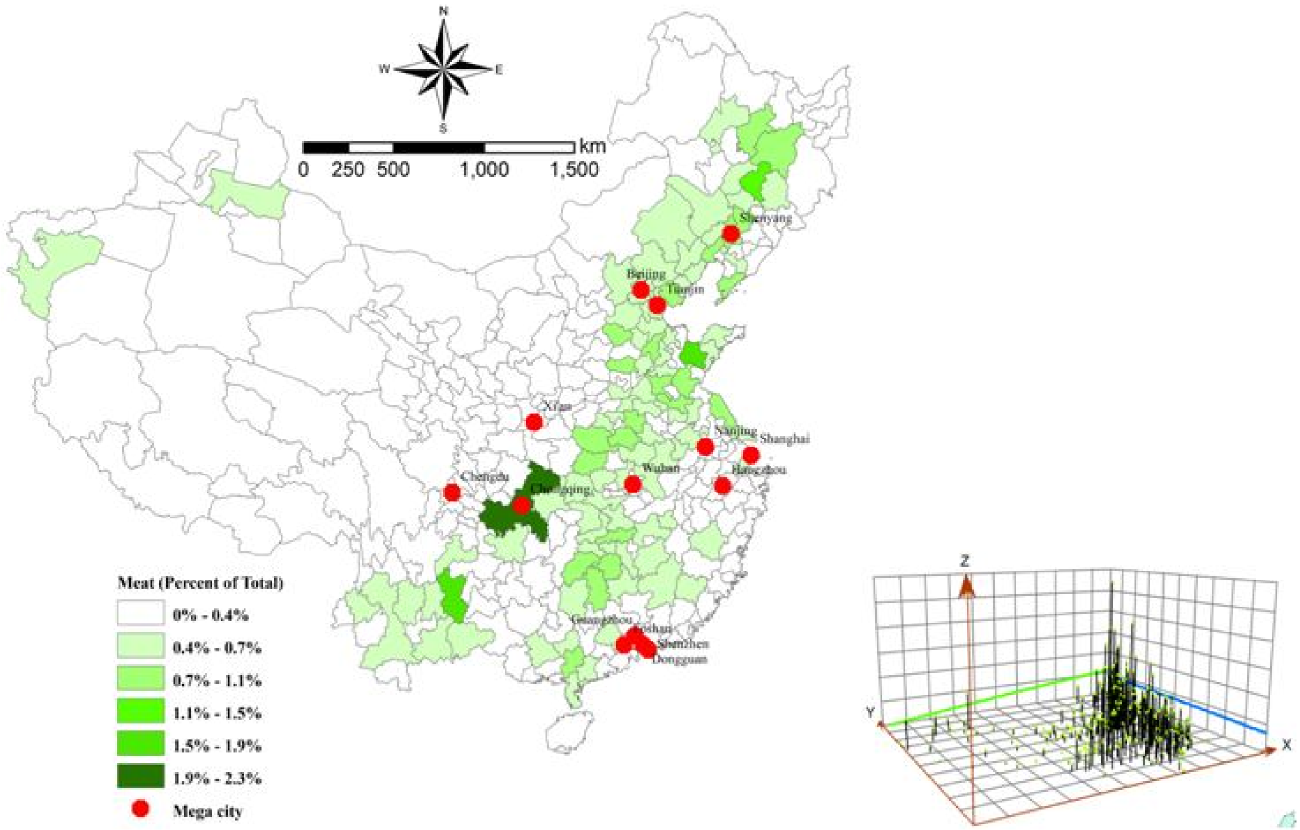

Fig 2: Spatial distribution of meat products (6 levels) and trend surface analysis. In trend surface analysis, *X* and *Y* are the geographic coordinate axes, *Z* is the response variable (production); the size of the pole is proportional to the value of production in each city. The blue curve indicates the variation tendency in the direction from north to south, while the green curve represents the tendency in the direction from west to east.

For the output of meat, the highest value regions are mainly distributed in eastern parts of Southwest and northern part of East China. The higher value regions are mainly distributed in western parts of Northeast China, northern parts of East, north and south poles of Central, and middle part of South China. It should be noted that, in these two categories of cities, only 9.8% of the number of cities shares 31.3% of the total amount of meat output in the nation. In addition, lower values are mainly distributed in the regions of Northwest, western parts of Southwest and southern parts of East China.

For the output of milk, the values of North and northern parts of Northeast China are much higher than the other parts of China, especially in regions of Inner Mongolia, Heilongjiang and Hebei. The output of milk in the three regions accounts for 50.0% of the total amount in the nation, with Inner Mongolia 21.5%, Heilongjiang 14.5% and Hebei 14.0%, respectively.

For the output of egg, higher value regions are distributed in northern parts of Northeast China, southeastern parts of North China, northern parts of East China, and eastern parts of Southwest China. While relatively low value regions mostly are distributed in Northwest China, South China and the other parts of North China, Southwest China and East China.

From the national perspective, there exist similar distribution characteristics of the outputs of meat, milk and egg in China, with the reducing trends from east to west and from north to south of China.

Global spatial autocorrelation of livestock products: Moran's *I* statistics are positive and significant (p-value <0.001) for all the three products. The Moran's *I* values of meat, milk and egg are 0.46, 0.50 and 0.56, respectively, indicating cities with high (low) output of livestock products have a propensity to be clustered close to other cities with high (low) livestock products in China. However, the Moran's *I* values show different intensities of spatial association in the distribution of the products. In this case, the intensity of spatial association of egg distribution is higher than that of milk and meat distributions.

Local indicator of spatial association (LISA) of livestock products: The global spatial autocorrelation analysis (global Moran's *I*) above can detect whether there exist spatial clustered regions and spatial isolated regions, thereupon can detect the spatial clustering dynamics. While the local spatial

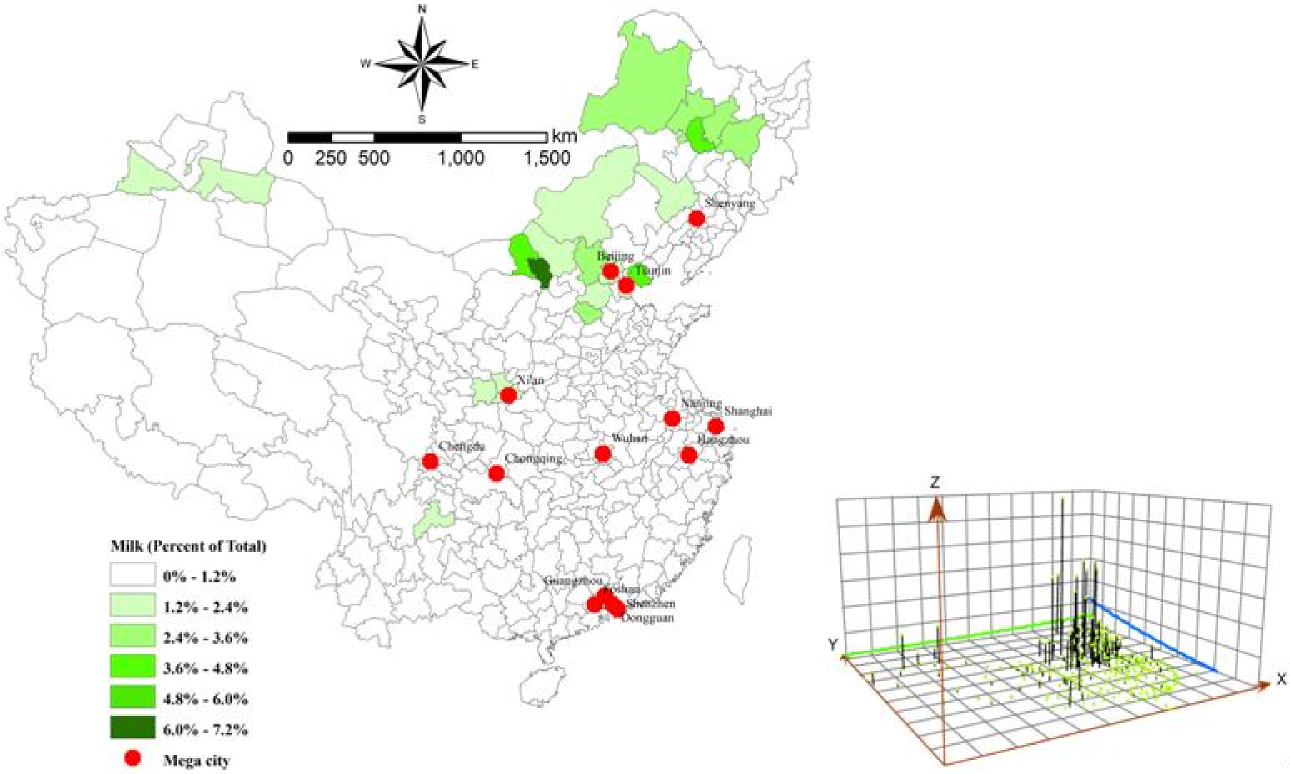

Fig 3: Spatial distribution of milk production (6 levels) and trend surface analysis

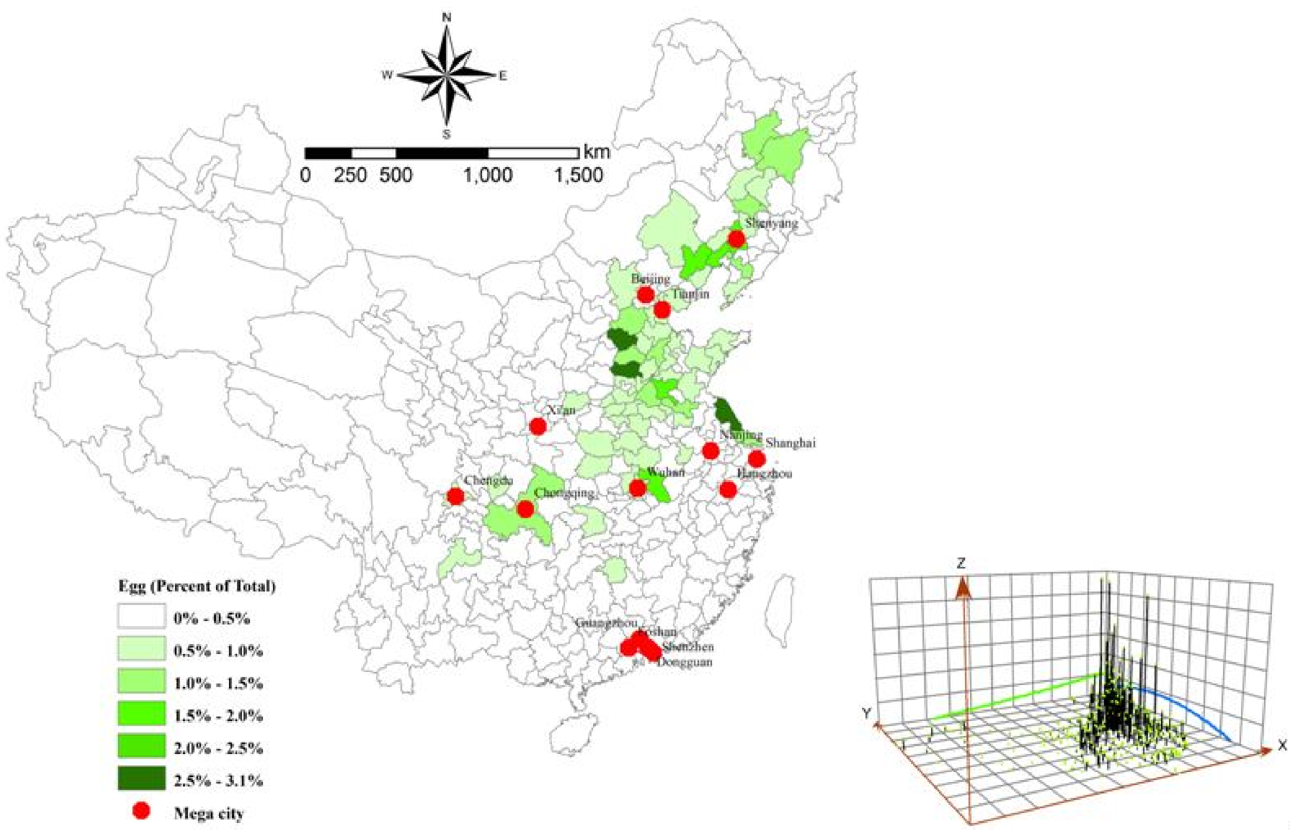

Fig 4: Spatial distribution of egg production (6 levels) and trend surface analysis

autocorrelation analysis can reveal the specific spatial patterns, and find the location of the spatial clustered and isolated regions, therefore, in our study, the local spatial autocorrelation analysis was done by using a common LISA tools in GeoDa program.

Table 1 shows the numbers of cities located in a particular Moran scatterplot quadrant. The associations in most of the cities are noted to be not significant. For meat, milk and egg products, only 36.8%, 29.1% and 36.8% respectively, are significant at 5% level, and a positive spatial association (including category HH and LL) characterizes approximately most of the significant cities. This outcome could be explained by the fact that regional inequities and uneven growth in livestock products prevailed in the country in the year of 2011.

Figures 5 through 7 show the LISA statistics of livestock products on the Moran significance maps at 5% level. The figures indicate that obviously spatial clustering

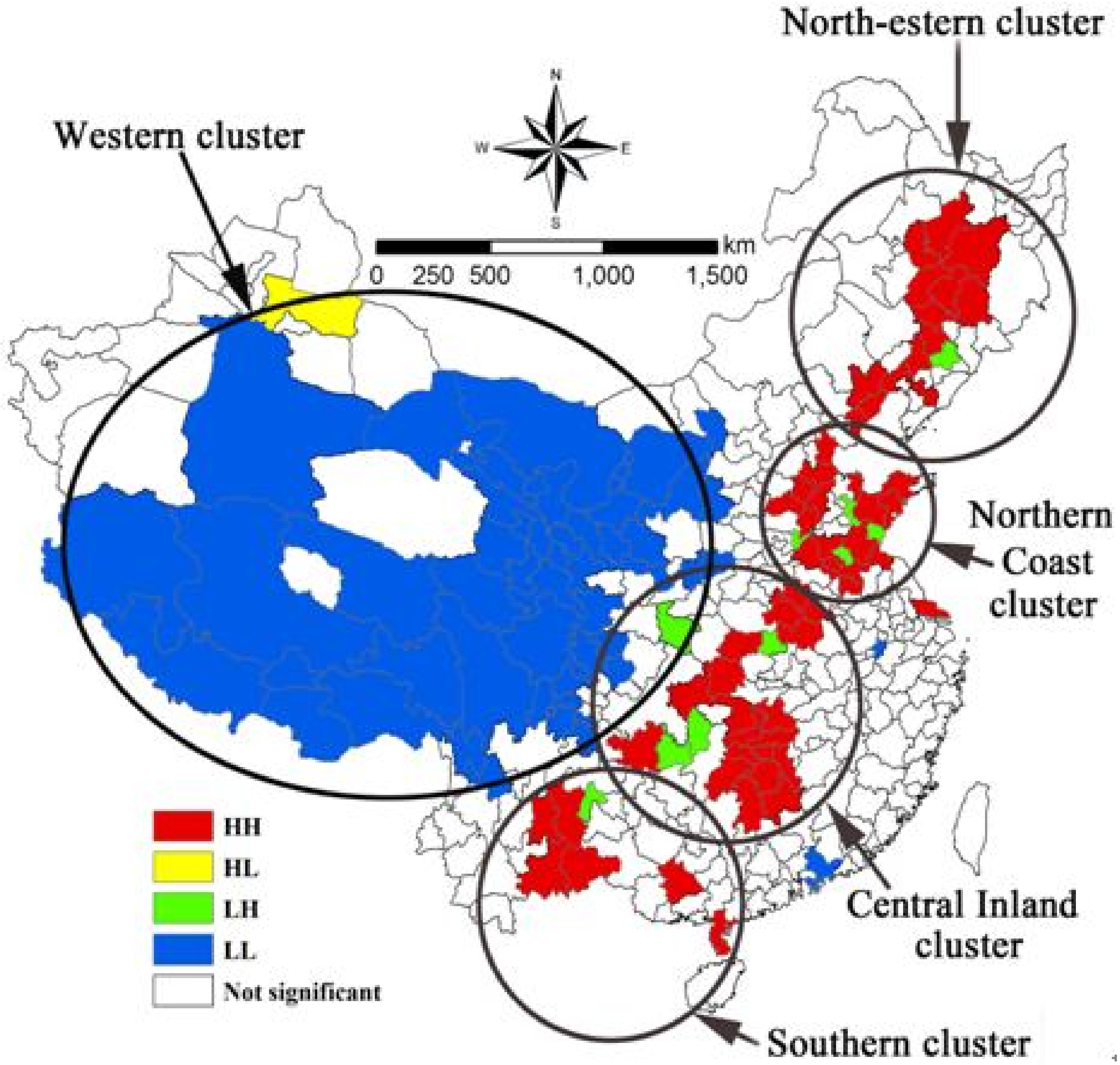

Fig 5: The LISA cluster map for meat in 2011

Table 1: Number of cities in various LISA clusters

Meat					Milk					Egg				
HH	LL	LH	HL	Not Sig.	HH	LL	LH	HL	Not Sig.	HH	LL	LH	HL	Not Sig.
57	56	10	1	213	23	71	4	0	239	46	75	3	0	213

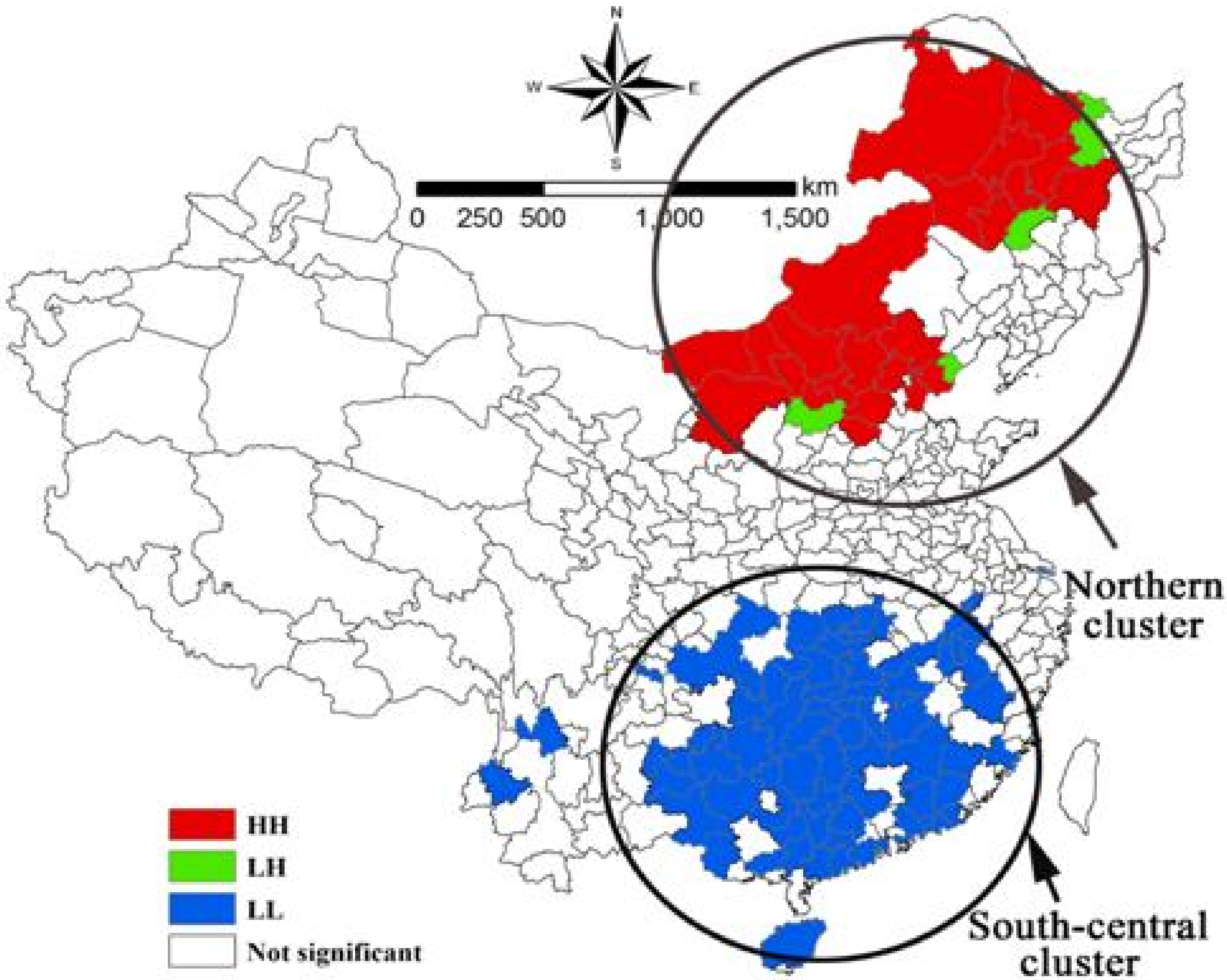

Fig 6: The LISA cluster map for milk in 2011

characteristics exist in the products. There are more clustered regions (HH and LL) relative to isolated regions (HL and LH). In the maps, the partition and definition of clusters is based on the zoning and the characteristics of each cluster itself.

Figure 5 shows that there are four significant hot-spots (HH clusters) in the distribution of meat products in 2011. These areas are the North-eastern cluster, including large areas of neighboring cities in Liaoning, Jilin and Heilongjiang; Northern coast cluster, including Tianjin and their neighbor cities in Hebe and Shandong; Central cluster, covering many cities in Hunan and some cities in Henan and Hubei; Southern cluster, composed of several interlaced regions in Yunnan and Guizhou, and some fragmentary cities in Guangxi and Guangdong. There is also a significant cold-spot (LL cluster), named Western cluster, including many cities in West China, such as Gansu, Ningxia and Qinghai.

Figure 6 shows an obviously spatial clustering characteristic in the distribution of milk products, composing of one large hot-spot area and one large cold-spot area. The hot-spot is Northern cluster, including Beijing, Tianjin, and many cities in Hebei, Inner Mongolia and Heilongjiang and some cities in Jilin and Shanxi. The cold-spot is South-central cluster, covering mainly contiguous cities in Guangdong, Guangxi, Hunan, Hubei and Chongqing.

Figure 7 shows that there are four significant hot-spots in China. These areas are North-eastern cluster, including many cities in Liaoning and some cities in Jilin; Northern coast cluster: covering many cities in Shandong and Hebei; Eastern coast cluster: including several cities in Jiangsu; Central inland cluster: including many cities in Henan and some cities in Anhui. Simultaneously, many northwestern and southwestern cities form a large cold-spot in the western part of China, and many southern cities form a cold-spot as well in the South China.

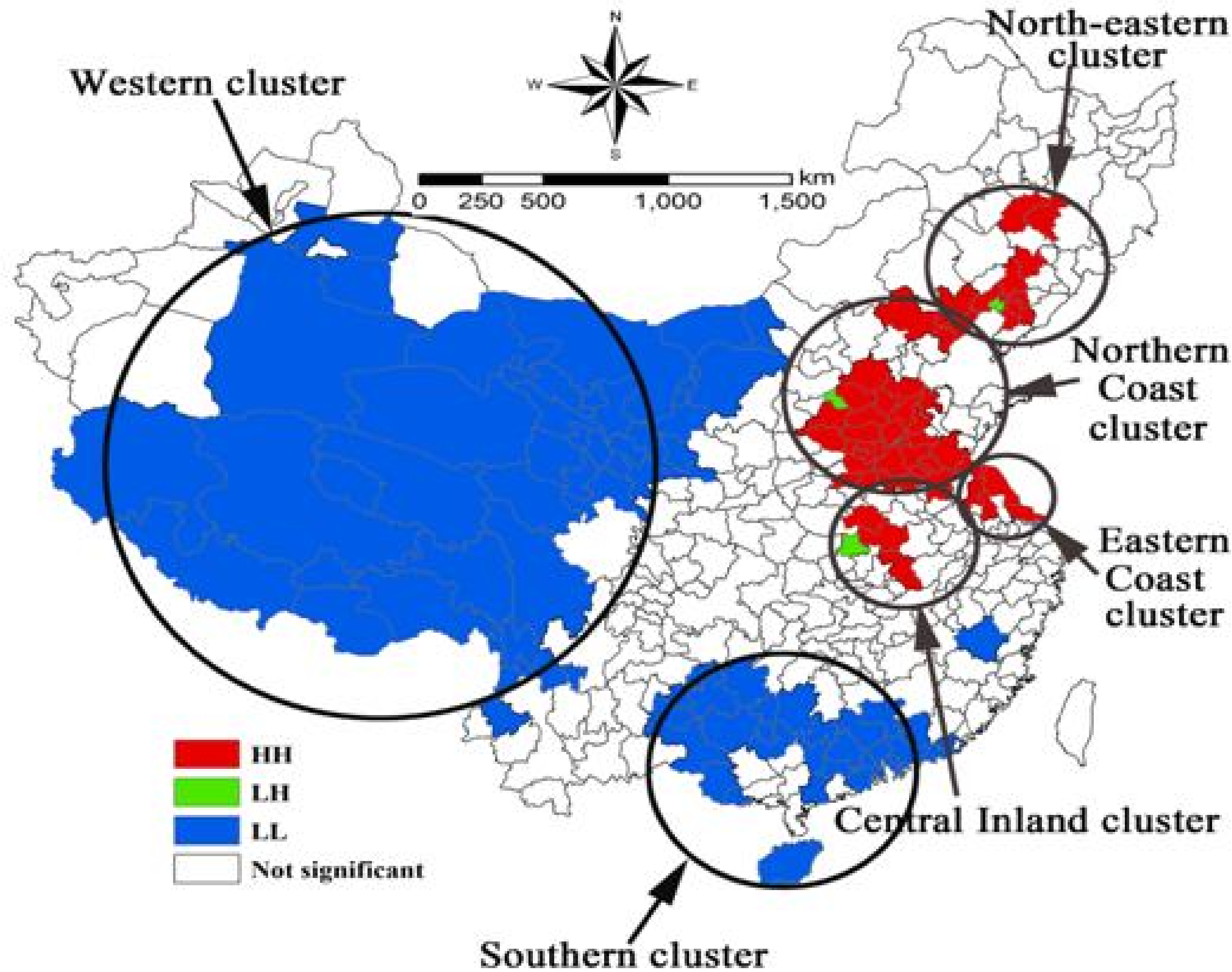

Fig 7: The LISA cluster map for egg in 2011

Improvements: In present study, ESDA technique is used to lay out spatial distribution characteristics of livestock products. Some improvements are highlighted in our study. The first and most important improvement is that we provide more contemporary data to analyze the distribution of livestock products in China. To our knowledge, the most recently map was published in 2012, but the reported statistics on which the distributions were based dated back to 2007 (Fu *et al.*, 2012).

The second important improvement is concerning the spatial scale of research area. Although some studies examined the global distribution maps for livestock production systems (Wint and Robinson, 2007; Bryssinckx *et al.*, 2012; Robinson *et al.*, 2014), their results were less accurate than national-level research because of ignoring the fact that even small administrative units are rarely homogeneous in terms of land use and farming so on. By using city-level data, we can draw more informative and reliable results with more detailed information on livestock products from the national scale rather than the globe scale. A third important improvement in our study is the breakdown of livestock production system, e.g., the previous estimates of livestock and poultry as a whole for China (Fu *et al.*, 2012), have been replaced by separate estimates of livestock production systems, such as meat, milk and egg. The goodness of this sorting treatment in our study is obvious. This level of categories detail is essential for some epidemiological investigations, such as in understanding the geographical distribution of the recently emerged H7N9 virus in China (Butler, 2013), where the sorting treatment of mixed-farming systems has greatly enhanced our ability to predict risk (Muzaffar *et al.*, 2010). In addition, from economic growth and development standpoint, these new outcome maps of our study may provide more important inputs for further efforts to map the demand and supply of animal-source foods (Robinson and Pozzi, 2011).

Finally, although some studies have examined spatial distribution of livestock production systems (Verburg and Keulen, 1999; Neumann *et al.*, 2009), they seldom utilized spatial statistical tools to make statistical inference. Saizen *et al.* (2010) pointed out that the distribution of livestock products do not necessarily correspond with the LISA statistics. ESDA can not only describe spatial distributions, also discover patterns of spatial association (spatial clustering) (Anselin *et al.*, 2006). Therefore, to overcome the weakness of some previous studies (Verburg and Keulen, 1999; Neumann *et al.*, 2009), we use this technique to obtain more information from a spatial perspective, to reveal local pockets of non-stationarity or hot-spots and cold-spots as well that cannot be found on the choropleth maps (Robinson *et al.*, 2014).

Implications and extensions: The development and growing income of Asian nations might be expected to drive an increase in their demand for livestock products in the future (Thornton and Gerber, 2010). Therefore, we must pursue sustainable intensification and figure out how to keep livestock industry in ways that work best for individuals, communities and the planet. Or else, ill-advised schemes may be formulated, which will result in wrong operation, such as importing livestock to places where they are genetically unsuited, since maximizing yields of meat, egg and milk in the same area can disrupt finely balanced systems (Janzen, 2011; Eisler *et al.*, 2014). Following this logic, it is necessary to establish growth poles (HH clusters) in the regions to pursue sustainable food supply chains in China, and then the utilization of spillover effects from these hot-spots will lead eventually to the development of the surrounding area with similar resources and environment to raise regionally appropriate animals. All this information provides a good reason for us to employ LISA cluster maps to discover hot-spots of livestock products at the city level, especially with cluster maps constructed for meat, egg and milk, respectively.

To some extent, our research corroborates previous work that demonstrated that there exist spatial dissimilarities in livestock sector (Fu *et al.*, 2012). However, we detected distinct clusters (HH and LL) from the previous, e.g., Southern cluster has been identified in the distribution of meat production in our research, while not in previous study. The results fully embody the advantage of employing output of livestock products as statistics indicator to discover hot-spots at the city level. We also found that different category of livestock products has different spatial agglomeration regimes and different clusters (HH and LL), which may imply that most livestock products are ‘delivered’ from provisioning to benefiting areas through anthropogenic processes. So these new cluster maps of our study are proving important implications for further efforts to map the demand and supply of livestock-source foods, to plan to link these hot-spot cities (cores) to their peripheral cities by road networks and regional cooperations, thus more larger hot-spot areas can be constructed to raise outputs of livestock products, and to lessen the unequal intra-region distribution. The advantage of aggregating livestock products to a larger region has been already well known and often applied (Wint and Robinson, 2007). E.g., such extensive area will contribute to the livelihoods and the welfare of poor farmers in the future (Schmidhuber and Tubiello, 2007). Nevertheless, the extension of production systems to meet product demand will also give rise to disease risks and environment problems (Randolph, 2008). Therefore, our maps suggest that attentions should be focused on the hot-spot areas where are the most vulnerable in terms of animal-source food security.

Outlooks: The livestock products have an obvious spatial clustering trend and the clustered regions are also concentrated. There are some similarities in the spatial distributions between meat and egg production, with most of the HH clustered regions in Northeast China, Northern Coast and Central Inland and LL clustered regions in West China. Meanwhile, the difference between them is also obvious, such as meat production has HH clustered regions in South China, while where is LL cluster for egg production. For all the livestock products, LL clustered regions are mainly distributed in West and South China. In addition, there are relatively few isolated regions (LH and HL) sporadically distributed throughout the country. Such a spatial heterogeneity in the distribution of livestock products may occur on different scales (at the level of cities, provinces or regions) and different time-periods as well (Robinson and Pozzi, 2011). Therefore, it needs more researches on spatio-temporal pattern of livestock sector. Moreover, livestock production systems can be classified into more specific categories, e.g., meat including pork, beef, mutton and poultry, but due to the unavailability of the data on such finer level for every city in China, our study failed to get some more detailed results.

Livestock products distributions are changeable depending on natural conditions including land cover, precipitation, vegetation, temperature, altitude, and water availability so on (Thornton and Gerber, 2010; Fu *et al.*, 2012), and human factors such as population density and the demand for the products (Saizen *et al.*, 2010). In our study, LL clusters can be observed in the west of Mongolia (Figures 4 and 6). The reasons of taking on the distribution are that the region is arid area where annual precipitation is limited, making it an unsuitable habitat for the domestic animals. This limitation could be reduced by investments in transportation, communication and irrigation infrastructures (Schmidhuber and Tubiello, 2007). It is also worth to mention that global change will affect many of the environmental factors underpinning livestock industry in the future (Wall and Ellse, 2011). Thus, we are aware of the complex interactions among the underlying factors of livestock products distribution, which can not always be represented by a single model (Nahuelhual *et al.*, 2012), such as logistic regression model (Wint *et al.*, 2002; Gilbert *et al.*, 2005). In such a case, using geographic information techniques that combining spatial non-stationarity variables with environmental and socio-economic data will help improve future versions of the model (Poudyal *et al.*, 2012), such as geographically weighted regression (GWR) (Fotheringham *et al.*, 2003). Therefore, a better understanding of these relationships between spatial distributions of livestock products and environmental and anthropogenic processes will in turn help predict the evolution progress of spatial patterns in space and time.

CONCLUSIONS

This paper, for the first time, considers investigation of spatial associations of the three main kinds of livestock products (meat, milk and egg) at the city level in China, respectively. It highlights the importance of spatial distributions in livestock sector studies. In the present study, the spatial associations of meat, milk and egg products have been investigated respectively using the indicator – outputs of the products in 337 cities in the mainland China. Our analysis indicates a significant positive global spatial autocorrelation, which is dominated by HH clusters and LL clusters as well, suggesting that the city with a large (or small) outputs of livestock products has a propensity to be clustered close to other cities with large (or small) outputs of livestock products. Furthermore, as presented in the LISA cluster maps, hot-spots and cold-spots of the three livestock products are identified in 2011. Though, these outcomes highlight the different spatial patterns of meat, milk and egg production, implying that their determinants tend to be different, the spatial distributions for the outputs of all the three products reflect a reducing tendency from east to west and from north to south China, which may not only provide an important reference for policy making in livestock industry management, but also display the effectiveness of the LISA statistics technique.

In the end, we suggest that an effective link (e.g. transportation networks) between the core and its periphery cities should be formatted, which will further enhance regional competitiveness, facilitate the better use of existing resources and meet the increasing demand for livestock products.

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