Letter to the Editor

Distribution Characteristics of *Spermophilus dauricus* in Manchuria City in China in 2015 through '3S' Technology*

FAN Long Xing[1,^], WU En Qi[1,^], LIU Jun[3], QU Xiao Chen[1], LIU Chao[2], NING Bao An[2,#], and LIU Ying[1,#]

Plague is a virulent infectious disease in China. In this study, '3S' technology was used to perform spatial autocorrelation analysis and spatial interpolation analysis for *Spermophilus dauricus* (*S. Dauricus,* a species of ground squirrel) captured in Manchuria City in 2015. The results were visually inspected. During the two-month (May to July) plague surveillance in 2015, 198 *S. dauricus* individuals were captured in the study area in Manchuria City (48 monitoring areas) by using a day-by-day catching method. Spatial autocorrelation was conducted using the ArcGIS software, and the following significantly different results were obtained: Moran's I=0.228472, Z-score=2.889126, and P<0.05. Thus, a spatial aggregation was observed. In 2015, the distribution of *S. dauricus* diminished from west to east and from north to south of Manchuria. Geo Detector software was used to analyze the habitat factors affecting the spatial distribution of *S. dauricus*. This highly clustered species mainly exists in suburban communities, construction sites, and areas surrounding factories. In future studies, plague surveillances should be performed in areas around Manchuria and Zhalainuoer.

Plague is an infectious disease caused by *Yersinia pestis*. Historically, several human plague pandemics have affected various parts of the world[1]. For instance, a human plague pandemic occurred in Manchuria City twice before the Manchurian region was liberated; this pandemic posed a huge threat to the safety of local residents[2-3]. Manchuria is located in the western region of Hulun Buir City of Inner Mongolia Autonomous Region in China. Its western district is adjacent to Mongolia, and its northern borders are located near Russia. Because of the geographical position of Manchuria, this city is considered an important land port connecting China to Russia and other Eastern European countries.

Therefore, Manchuria City has been designated as a national level fixed monitoring point of the natural foci of *Marmota sibirica* plague. Since the liberation of Manchuria, antibodies against *Yersinia* have been detected in the serum of the primary host animals during rat plague monitoring[4], although the human plague pandemic has been eradicated. To develop new ideas and methods that can describe the characteristics and patterns of plague epidemics, we visually and intuitively presented our monitoring data analysis and developed early warning systems and specific prevention and control strategies. We also analyzed a part of the monitoring data from Manchuria in 2015 based on spatial epidemiology theory and spatial statistics. We further examined the obtained data by using a '3S' technology comprising global positioning system (GPS), geographic information system (GIS), and remote sensing (RS).

The rat plague monitoring data from a national level fixed monitoring point in Manchuria as reported by the Plague Monitoring Network Reporting System in mainland China (excluding Hong Kong, Macao, and Taiwan, China) from May to July 2015 were used in this study. According to the '*National Plague Surveillance Program*' (http://www.chinacdc.cn), each of the 48 monitoring areas was extracted within 25 hm^2, and the total research area measured was 1200 hm^2. *Spermophilus dauricus* (*S. Dauricus,* a species of ground squirrel) was captured via a day-by-day catching method. The selected monitoring data were filtered and modified to exclude the monitoring coordinates. A total of 198 *S. dauricus* individuals with clear geographic information were captured. The density of *S. dauricus* was calculated based on

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1. College of Public Health, Inner Mongolia Medical University, Hohhot 010110, Inner Mongolia, China; 2. Tianjin Key Laboratory of Risk Assessment and Control Technology for Environment and Food Safety, Tianjin Institute of Health and Environmental Medicine, Tianjin 300050, China; 3. Chinese PLA No.291 Hospital, Baotou 014040 Inner Mongolia, China

the sampling area in each monitoring region. The data for the remote sensing map were obtained from the Computer Network Information Center of the Chinese Academy of Sciences, Geo Spatial Data Cloud (http://www.gscloud.cn).

Global Moran's *I* was used to describe the overall spatial clustering of the residential community and observation points, to determine the correlation between neighboring residential communities and observation points, and to identify spatial clustering patterns and levels among the neighboring residential communities and observation points[5-6]. Moran's *I* was calculated using Equations (1) and (2):

$$I=\frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}(x_i-\bar{x})(x_j-\bar{x})}{(\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij})\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{1}$$

$$\bar{x}=\frac{1}{n}\sum_{i=1}^{n}x_i \tag{2}$$

Getis-Ord *Gi** (local Getis-Ord statistics) can be used as a model to describe the correlation and clustering of an individual residential community or observation points and neighboring residential communities or observation points, and to detect clustering hotspots. *Gi** can be calculated using Equations (3) and (4):

$$G_i^*=\frac{\sum_{j=1}^{n}W_{ij}(d)x_j-W_i^*\bar{x}}{S\sqrt{(nS_{1j}-W_i^{*2})/(n-1)}} \tag{3}$$

$$W_i^*=\sum_{j=1}^{n}W_{ij},\quad S=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2},\quad S_{1j}=\sum_{j=1}^{n}W_{ij}^2 \tag{4}$$

Most administrative divisions consider township and county as a unit in China; that is, the boundaries of administrative divisions for township and county are clear, but the boundaries for villages and residential communities are generally vague. Referring to *'The Brochure of Administrative Divisions of Township in P.R. China 2014,'* we used ArcGIS software to extract a map of Manchuria City from the township and county maps of China (Figure 1A). Using 'Create Thiessen Polygons' in 'Analysis Tools,' we created a boundary of simulated administrative divisions with the centroid coordinates of communities and observation points (48 monitoring areas; Figure 1B). Based on the coordinate positions, we incorporated the number of captured *S. dauricus* into the simulated administrative divisions (Figure 1C).

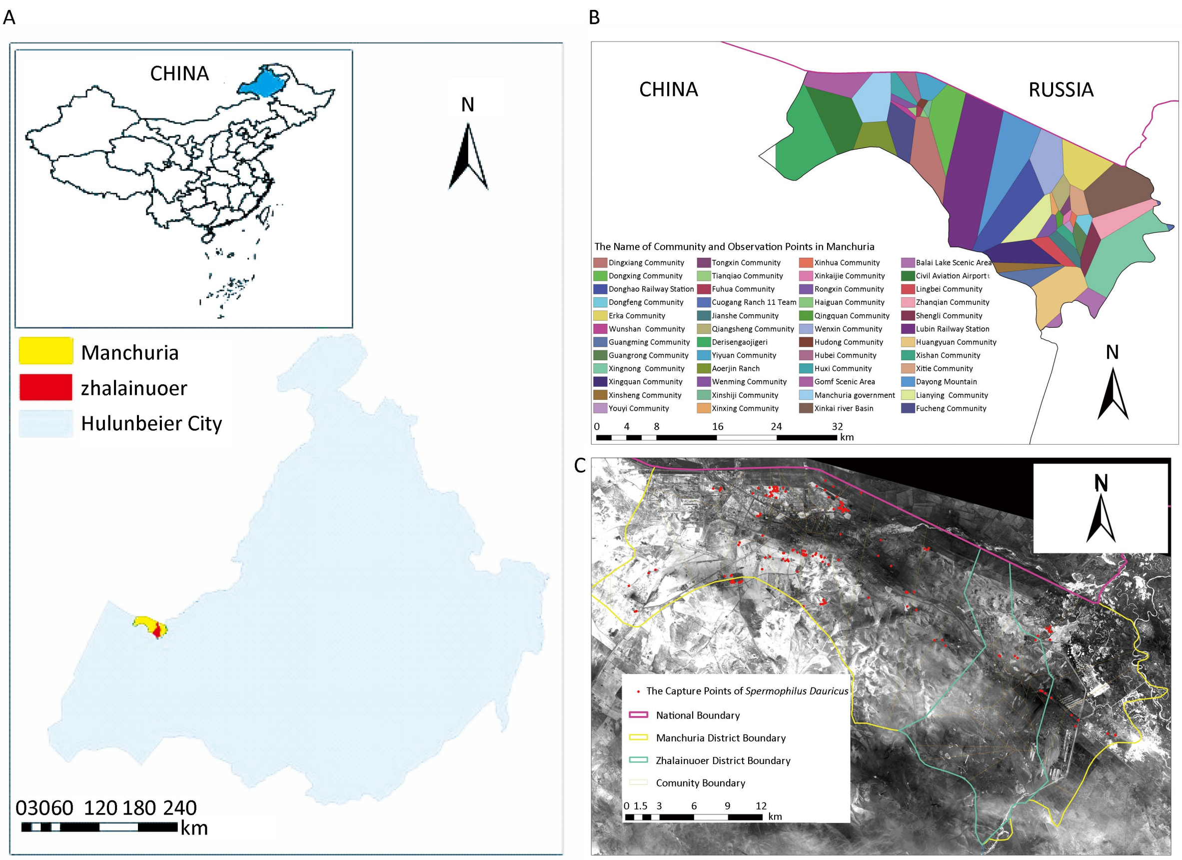

Figure 1. (A) Location of Manchuria City; (B) Simulated administrative divisions by community in Manchuria City. (C) Spatial distribution of *Spermophilus dauricus* in Manchuria City in 2015 based on a remote sensing map.

Spatial autocorrelation (Moran's *I* and Getis-Ord *Gi**) was used with the spatial statistical tool module of ArcGIS, and we found that Moran's I=0.228472, Z-score=2.889126, and P=0.003863. The results significantly differed (P<0.05), and the aggregation level was low. Getis-Ord *Gi** Z-scores range from -2.79 to 3.67. The confidence intervals and other data are shown in Figure 2. Using the spatial module of Open Geoda, we conducted spatial autocorrelation (univariate local Moran's *I* and local *G* statistics). The spatial data weighting method of Open Geoda is different from that of ArcGIS. Using the former, we obtained Moran's I=0.259547, which implies the occurrence of aggregation (Figure 3). Interpolation analysis (empirical Bayesian kriging) was performed under the 'Geostatistical Analyst' module of ArcGIS. Based on the density of *S. dauricus*, we predicted the spatial distribution map of *S. dauricus* in Manchuria City in 2015 (Figure 4).

GeoDetector Software (http://www.geodetector.org) was used to analyze the habitat factors affecting the spatial distribution of *S. dauricus*[7]. It was divided into two levels: based on human activities, it was divided into natural environment, symbiotic environment, and human environment; and based on geography, it was divided into typical steppe,

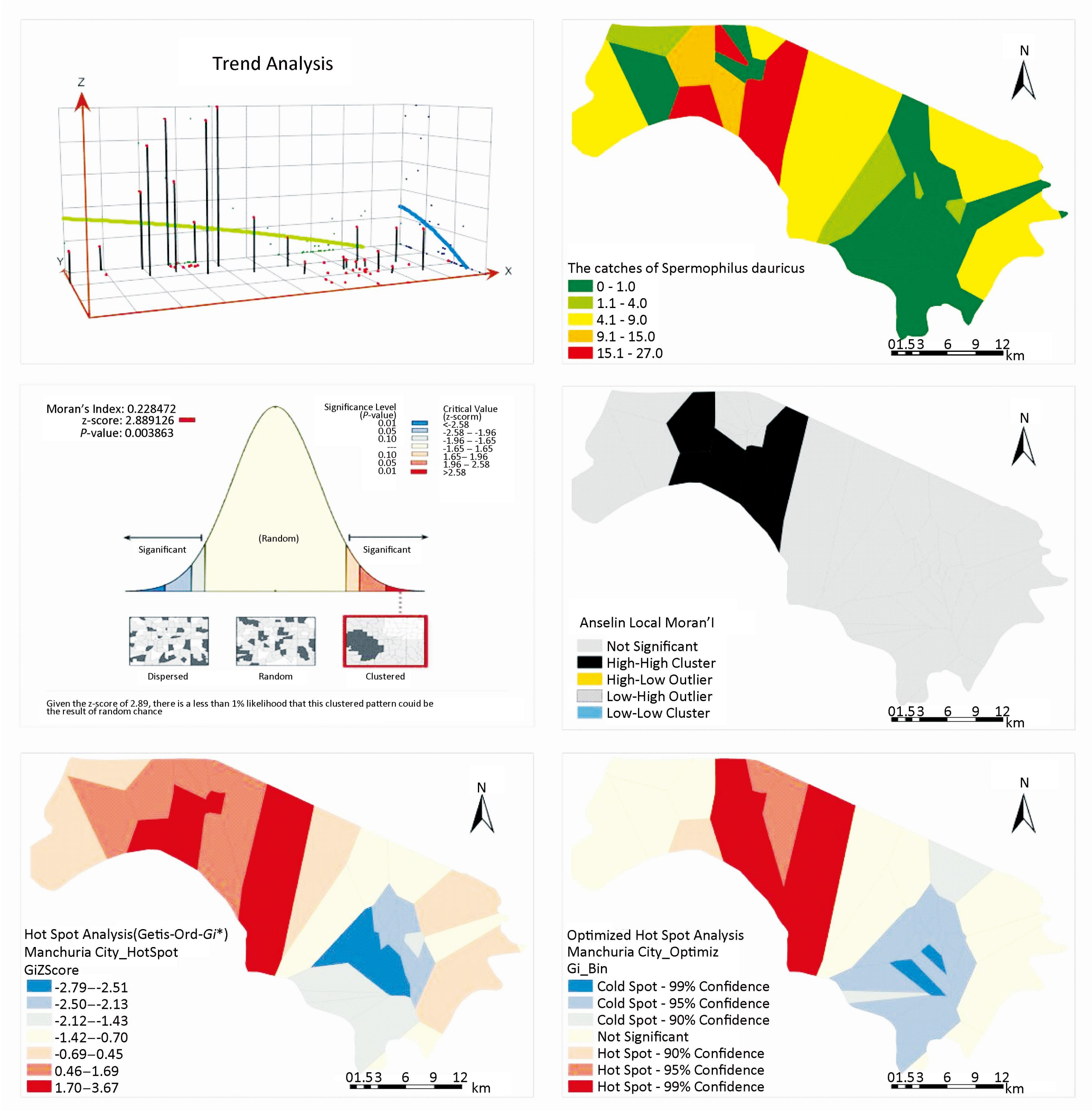

Figure 2. Spatial statistical results of the number of *Spermophilus dauricus* in Manchuria City in 2015 provided by ArcGIS (Moran's *I* and Getis-Ord *Gi**).

meadow steppe, desert steppe, hilly land with gentle slope, and factory ruins. The factor detector q-statistic of the two levels were 0.516 (P=0.000) and 0.304 (P=0.017), respectively. *S. dauricus* mainly existed in the natural environment and symbiotic environment, more commonly in the symbiotic environment, which may be related to the natural environment and to the possibility that they were migrating. They tended to exist in hilly land with a gentle slope, which is more conducive to obtaining

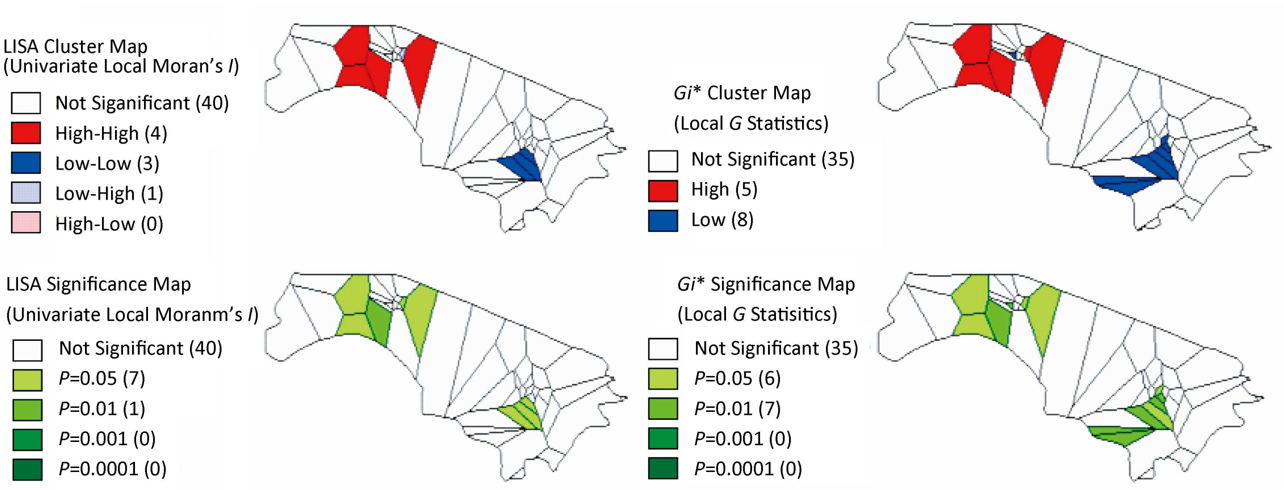

Figure 3. Spatial statistical results on the number of *Spermophilus dauricus* in Manchuria City in 2015 provided by Open Geoda (univariate local Moran's *I* and local G statistics).

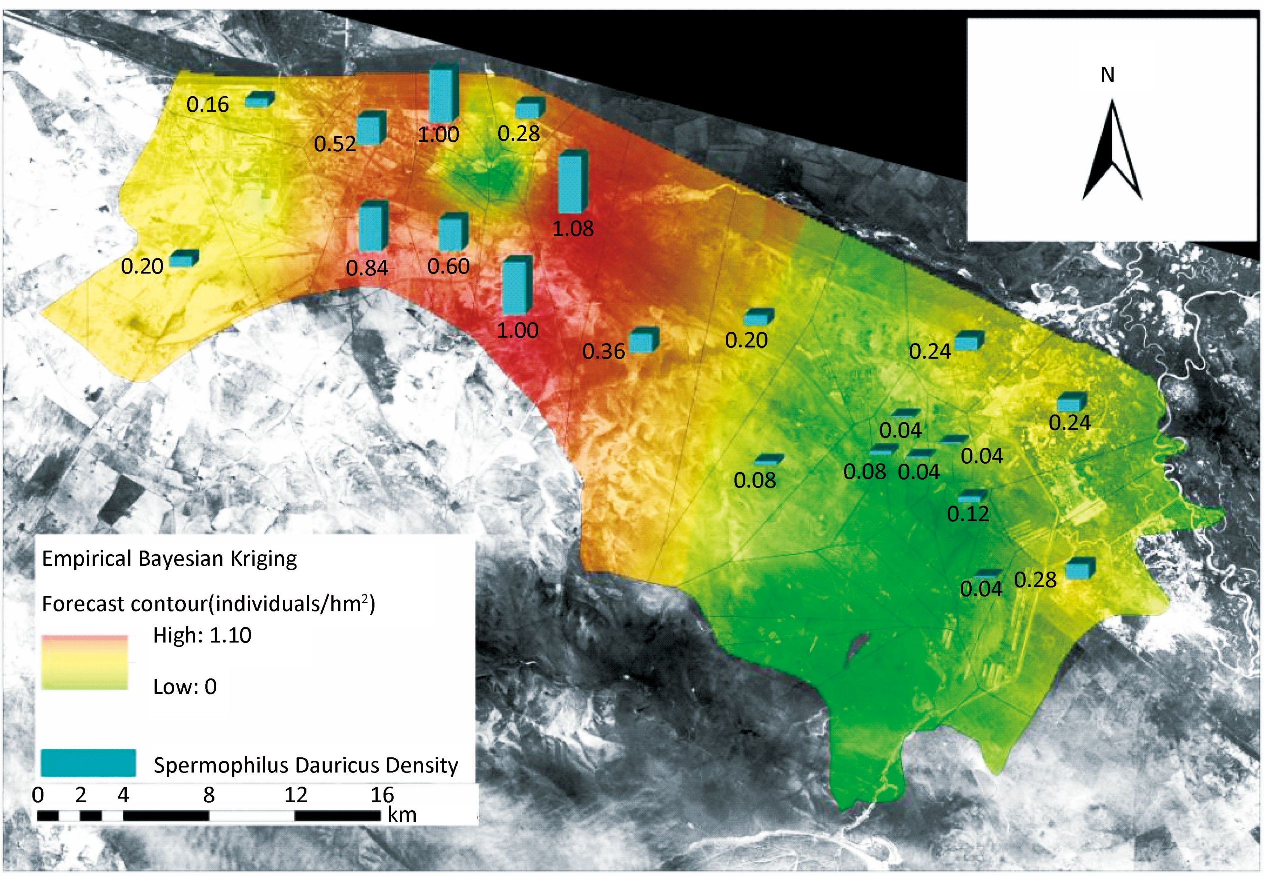

Figure 4. Predicted result of the spatial distribution of *Spermophilus dauricus* provided by ArcGIS (empirical Bayesian kriging).

a wide field of vision, finding food, and avoiding predators. The q-statistic was not significant among the other four landforms. We can also observe the above phenomenon in the remote sensing map.

Data analyses were conducted using different spatial statistical software. We found that the distribution of *S. dauricus* was spatially aggregated in Manchuria City in 2015. The overall distribution of *S. dauricus* diminished from the west to east and from the north to south. The density and aggregation of *S. dauricus* in Manchuria was relatively higher than in Zhalainuoer. *S. dauricus* was highly aggregated in the communities and streets surrounding Manchuria City but not in the communities and streets of the urban areas. *S. dauricus* was also relatively more common in areas surrounding factories, industrial parks, and new real estate construction sites than in other locations.

The most likely explanations for the described phenomena are as follows: (1) *S. dauricus* distribution is related to their wild habits and other geographical factors. *S. dauricus* mainly inhabits steppe, hilly, and plain areas, where the landscape is open and the environment is relatively dry. This kind of terrain is commonly found in Manchuria City. (2) The distribution is also related to the migration of *S. dauricus* after its habitat is destroyed. This phenomenon can result in a high local density of *S. dauricus* even when its distribution is relatively uniform in other regions. (3) Species distribution is related to the route used in plague monitoring. The distribution of the monitoring points throughout Manchuria is uniform because of the limited manpower for the monitoring process. Therefore, uneven distribution may have caused a large difference in the number of captured individuals.

In future monitoring experiments, the areas surrounding Manchuria and Zhalainuoer should be considered, and the spatial distribution of monitoring points in Manchuria City should be properly planned to ensure the equal distribution of monitoring points without any repetition or omission. In combination with the monitored data accumulated throughout the years, spatial distribution maps can be drawn and used to observe the changes in trends and to adjust monitoring plans accordingly.

Further studies should be implemented by the Chinese government to collect and process large amounts of data. With advancements in theoretical knowledge and application software for spatial statistics in public health[8-9], spatial epidemiology has emerged as a new discipline. In China and other developing countries, provincial regions constitute the smallest unit of public health large data processing and analysis. However, provincial regions have rarely been explored, and rural communities have seldom been analyzed at a street level. For this reason, small area analysis has been developed by integrating large data processing into micro and small geographical data analysis. Compared with provincial or nationwide regions, the research area used in small area analysis is relatively small. Thus, the sensitivity and accuracy of data analysis can be greatly improved. Dynamic changes in diseases should be monitored, early warnings should be determined, and management of sudden public health incidents should be improved, especially in precision disease control. In public health in China, professionals have rarely engaged in space-time data analysis. Theories and software related to spatial epidemiology and spatial statistics should be employed in disease prevention and control because China is characterized by its vast area and administrative divisions. Such methods should also be promoted to develop medical and health services in China.

The proposed analysis method can be applied to perform plague surveillance. This method can also be employed to monitor and control diseases, especially infectious, endemic, and other diseases closely associated in terms of regions and environments. In particular, ArcGis and Geoda should be combined to analyze data. Compared with Geoda, ArcGis provides an efficient visual function; in contrast, the analysis function of Geoda is more accurate and reliable than that of ArcGis[10]. They can be used as a common analysis method because of their complementarity. GeoDetector Software tests the spatial stratified heterogeneity of the phenomenon or tests the association among multiple factors according to the consistency of their spatial distributions. The proposed method is simple and convenient. It can be easily learned and understood by public health workers. Basic space-time data analysis can also be carried out after healthcare workers undergo a short training period.

‘3S’ technology exhibits a strong visual function and thus, it can be used to display traditional statistical data on maps. As such, data analysis results are intuitive and easily understood. The proposed technology also allows the use of real-time data, which can be presented on the map at any time point. As the amount of data increases and data collection time becomes longer, disease prediction becomes stable. Therefore, the proposed technology can elicit effects similar to weather forecasts. Data collection, collation, and analysis in local units are essential for disease prevention and control in local health administrative departments. Practical, effective, economical, and specific prevention and control strategies against specific epidemic diseases and characteristics, intensity, and scope should be developed to shorten response time. Furthermore, normative data collection, collation, and time-space analysis are necessary to collect and share data among units of equal or different levels. Unified and standardized operation ensures accurate and reliable data collection and result analysis. With such methods, authentic data and results can be obtained, and digital information platforms in the public health field in China can be constructed and managed.

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^FAN Long Xing and WU En Qi contributed equally to the work.

#Correspondence should be addressed to LIU Ying, Tel: 86-13864784516, E-mail: yingruru@sina.com; NING Bao An, Tel: 86-13821767934, E-mail: 13821767934@139.com

Biographical notes of the first authors: FAN Long Xing, male, born in 1988, enrolled postgraduates, majoring in epidemiology and biostatistics; WU En Qi, female, born in 1991, enrolled postgraduates, majoring in epidemiology and biostatistics.

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