# A Spatial Point Pattern Analysis of the 2003 SARS Epidemic in Beijing

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## ABSTRACT

Beijing[1] was the most prevalent city of SARS in China in 2003. The study on the spatial distribution and clustering characteristics is helpful to deeply understand the epidemic of SARS in Beijing. In this paper, the home addresses of SARS patients accquired by investigation were considered as the spatial location, deriving 2321 cases of the spatial distribution and incidence rate of infected patients. Kernel estimation method is used to obtain the density distribution of SARS patients. The results indicate that the distribution density of infected people is gradually attenuated from the center of the city to the suburbs. Ripley'K function is also used to explore the spatial clustering characteristics of SARS infection. In addition, the influence of gender, contact history and SARS Beijing Xiaotangshan Hospital towards the spatial clustering of patients are analyzed and thus shows that the spatial clustering of patients is the strongest at 11km distance. Gender and history of exposure to SARS infection in the spatial clustering are of a small impact, while SARS Beijing Xiaotangshan Hospital on SARS infection in the spatial clustering are of a strong impact. The clustering characteristics are significantly weaker after the establishment of the hospital that shows the importance of the establishment of the hospital on prevent and control of SARS epidemic in Beijing.



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## CCS CONCEPTS

• **Information systems applications** → Spatial-temporal systems • **Artificial intelligence** → Knowledge representation and reasoning.

## KEYWORDS

SARS; Beijing, Point pattern analysis, Kernel estimation, Ripley'K function

## 1 INTRODUCTION

The understanding of epidemic law of infectious diseases is of great significance to scientific prevention and control. The cognition of the epidemic law of infectious diseases can be carried out from three aspects: temporal process, spatial process and spatio-temporal process. After the 2003 epidemic of Severe Acute Respiratory Syndrome (SARS), based on publicly released epidemiological data or epidemiological survey of infected information obtained, a large number of different backgrounds of the researchers carried out on the epidemic of SARS in-depth study. However, most of the research is based on the classical statistical analysis of the epidemiological survey and the mathematical modeling of the SARS sequence process [1-3]. There are very few studies on the spatio-temporal and spatial processes of SARS. The traditional statistical analysis method based on epidemiological survey and the mathematical modeling method based on the sequence process are difficult to reflect the spatial information (spatial pattern, hot spot area, clustering characteristics, etc.) of epidemic epidemics, and it is impossible to reveal the temporal and spatial laws of infectious diseases (spatio-temporal diffusion process, spatio-temporal hotspot region, space-time association, space-time clustering characteristics, etc.).

The epidemic process of SARS is a typical spatio-temporal diffusion process which is composed of the basic elements of time, space and attribute. It is helpful to fully optimize the spatial pattern and spatio-temporal laws of SARS epidemics to contribute to the optimization of limited resources (human, material and financial), configuration, prevention and control of the scientific development. Beijing is the most severe epidemic area of SARS in 2003, and it is of great significance to comprehensively understand the epidemic law of SARS in Beijing. Till now, there already have been a large number of studies on the prevalence of SARS in Beijing. However, most of the studies were based on classical epidemiologic surveys [4-6], or mathematical modeling analysis based on government published SARS epidemiological data [7-10], simulations [11-13], and some scholars have studied the risk factors affecting SARS epidemic [14, 15] and the impact of the SARS incident on China's economy [16,17]. In contrast, the research on the spatio-temporal and spatial laws of SARS epidemic in Beijing is relatively limited. Jinfeng Wang and his research team have actively carried out the research on the spatial characteristics of SARS in Beijing since the outbreak of SARS [18-21]. The results reveal the distribution characteristics, clustering characteristics and spatio-temporal variation of SARS close contacts in Beijing. Min Liu's comparative analysis of the characteristics of SARS epidemic in eight urban areas and surrounding suburbs in Beijing in 2003 [22], discussed the reasons for the differences between the two, in general, the spatial pattern o2f SARS epidemic in Beijing, but the spatio-temporal regular research remains to be further excavated. Depend on the spatio-temporal data of SARS-infected individuals in Beijing, this paper illustrates the spatial density and spatial clustering characteristics of SARS-infected people in Beijing by using point pattern analysis.

## 2 POINT PATTERN ANALYSIS

Point pattern analysis (PPA) is widely used in the geography since the late 1950s and early 1960s. And it is mainly used to excavate the spatial distribution characteristics and spatial patterns of point objects [23, 24], which are based on spatial data. At present, point pattern analysis has been widely used in forestry, geology, earthquakes, exploration, ecology, geography and other aspects [25-28], and point pattern analysis is also applied successfully in the epidemic, urban crime and other social sciences. [29, 30]. For a series of spatial points, the most relevant question collected is about spatial distribution, is the distribution of spatial points random? If it is not random, then how large is the degree of space gathering? How much space is the strongest in the distance? The first-order feature mainly describes the trend of the expected value (mean) of the point process with the spatial change, and the second-order feature mainly describes the association of the different regional spatial points (or self-similarity). The first-order characteristic of the point process and the mathematical description of the second-order feature are described as follows:

Assume that there is a set of spatial points called s1, s2...si.... The first-order feature of the point data can be quantitatively described by the intensity λ (s), which means the number of spatial points appear in the area when s is considered as the center of the unit, the mathematical expression of [31]:

$$\lambda(s) = \lim_{ds \to 0} \left\{ \frac{E(Y(ds))}{ds} \right\} \quad (1)$$

Where E () is the mathematical expectation, and Y (ds) represents the number of spatial points appearing within the ds area of s.

The second-order feature of the point data can be quantitatively described by the covariance of the two sub-regions centered on the center [29], whose mathematical expression is:

$$\gamma(s_i, s_j) = \lim_{ds_i, ds_j \to 0} \left\{ \frac{E(Y(ds_i)Y(ds_j))}{ds_i ds_j} \right\} \quad (2)$$

The following subsection describes the point process of the first and second order characteristics of the quantitative calculation method.

### 2.1 Kernel estimation

The easiest way of one-dimensional feature of spatial points of the quantitative calculation method is to use a mobile window to traverse the entire region. The calculated number of spatial points in each window is the density value of the central point of the window. This method is straightforward but the disadvantage is that the distribution of the spatial points in the window is not taken into account and the information is not fully expressed. The improvement is to use a certain method to weight the spatial points of different positions in the window so that the when the weight of the center point is higher, the density of the center point is equal to the weighted sum of all the spatial points in the window. This method is called Kernel estimation, which is currently the most widely used point mode analysis method.

The Kernel estimation is mainly to establish a three-dimensional density function in the window. The Z value of the density function corresponding to any point is the weight of the point. The weight value is mainly determined by the density function and the distance from the point to the center point of the window. The volume covered by the entire density function is 1, and the density of the s point is calculated using the Kernel density estimation method [29]:

$$\hat{\lambda}_\tau(s) = \sum_{i=1}^{n} \frac{1}{\tau^2} k\left(\frac{s - s_i}{\tau}\right) \quad (3)$$

Where k is the Kernel function, τ is the Kernel radius, s is the position of the point to be estimated, si is the position of the point within the circular range, where s is the center and τ is the radius.

### 2.2 Ripley'K function estimation

The second-order feature of the spatial point can be more understandable on the relationship between the spatial point processes. At present, the most commonly used method for quantitatively expressing the second order feature is the Ripley's K function, which is a quantitative expression of spatial points between non-random index [32, 33],

$$\lambda K(d) = E\ (\mathrm{N(d)}) \quad (4)$$

Where E is the expected value and K(d) is the Ripley'K function of the independent variable, where λ is the average density (the average number of spatial points in the unit area), N(d) is the number of spatial points within distance d.

The total area of the study is A, the total number of all spatial points in the study area is N, and the assumed point is Complete Spatial Randomness (CSR), then the expected value E (d) of the number of spatial points in the circular range of radius d should be equal to the total number of points N multiplied by the ratio of the circular area to the entire study area, ie. E (the number of spatial points in the range d) =N. π d2/A, and λ =N/A, put it into equation (4) has K(d)= π d2, which corresponds to the point in the space completely random distribution of the situation. If K (d) is equal to π d2, it can be judged that the points are completely randomly distributed in space, and if it is larger than π d2, it means that the points are spatially aggregated. If less than π d2, then the points are spatially more regular than the CSR. In the case of unconstrained, the spatial point Ripley'K function is estimated as [34].

$$\widehat{K}(d) = \frac{A}{N^2}\sum_{i=1}^{N}\sum_{j\neq i}^{N} I\left(d_{ij}\right) \quad (5)$$

Where I ($d_{ij}$) is the instruction function, if dij ≤ d, then I (dij) is equal to 1, otherwise 0. K value is an absolute quantity, the aggregated distribution cannot be determined only by the numerical size. Only with the CSR distribution under the value of π d2 in order to make effective judgments. Under normal circumstances, the general use of a new conversion variable L (d) is to indicate whether the spatial point is completely random or not,

$$L(d) = \sqrt{\frac{\widehat{K}(d)}{\pi}} - d = \sqrt{\frac{A\sum_{i=1}^{N}\sum_{j\neq i}^{N} I\left(d_{ij}\right)}{\pi N^2}} - d \quad (6)$$

Obviously, it is only necessary to determine whether L (d) is greater than zero or not. If it is greater than zero, then it tends to be aggregated. If it is less than zero, it tends to be ordered. If it is equal to zero, then it is completely random. Because of the existence of randomness, the set of points (CSR implementation) obtained by CSR distribution cannot accurately make L (d) equal to zero, but a value near zero. Therefore, in terms of probability statistics, whether it is random or not mainly depends on the degree of L(d) deviation from zero. When the deviation is large, small or zero indicating that is aggregated, ordered or completely random respectively. Practically, Monte Carlo is often applied repeatedly to achieve the aim.

# 3 CASE STUDY

## 3.1 Data and its spatial processing

The experimental data are derived from the CDC, which is based on a retrospective survey of SARS-infected people (or relatives), with a total of 2444 infectious subjects. The time of infection is from 8th March to 28th May. The daily changes in SARS infection are shown in Figure 1. The 2003 SARS epidemic in Beijing experienced a slow growth in the early period, a rapid increase in the middle period and an obvious decline in the late period before the complete disappearance of the timing process.

The original infected patient information is a text data expressed in tables. The point pattern analysis method needs to be spatially processed in advance, that is, the text data representing the infected person information is converted into spatial data having a specific spatial position. Spatial location information can be infected patients' home addresses or work units. The specific choice needs to be determined according to the actual situation and research purposes. The main spread of SARS is the close contact between each person and near-distance droplets spread. Hospital and family spread are currently known as the two main infection ways. In addition, given that the experimental data in the home address information is relatively complete, so the home address is chosen to be the spatial location of infected patients. When the home address information is not available (missing or wrong), then the work unit information can be applied. When neither are available, then abandoned both of them.

Spatial processing mainly matches home addresses of SARS infected people with Beijing electronic map data base. Figure 2 (a) is the spatial distribution of 2321 SARS cases in Beijing. The spatialization rate is about 2321/2444 = 95%. From Figure 2 (a), most of the SARS-infected people in Beijing are concentrated in high population density in the urban area, the number of infected people in the surrounding suburbs is relatively scarce. In order to eliminate the negative impact of the few people who were away from the SARS epidemic center, this paper selects the geometric center of the spatial distribution of SARS infection as the general center, twice the standard deviation of the radius of the epidemic area of the infected area as the object of study. As shown in Figure 2 (b), the number of infected patients is 2227 cases, accounting for about 91.12% of the total number of SARS patients in Beijing.

Morbidity refers to the frequency of occurrence of new cases in a given period. The formula is: morbidity = number of new cases / mean population during the observation period.

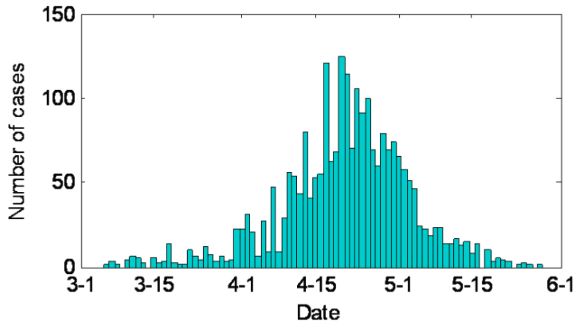
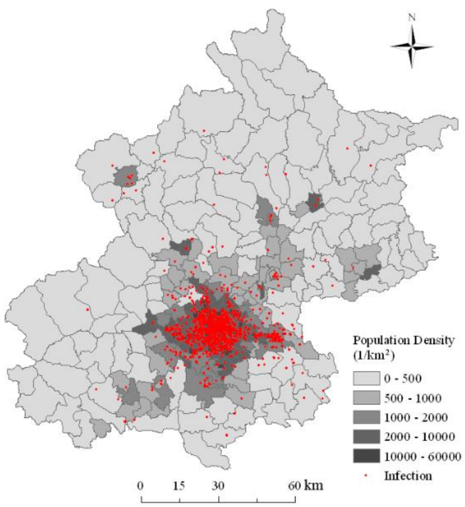
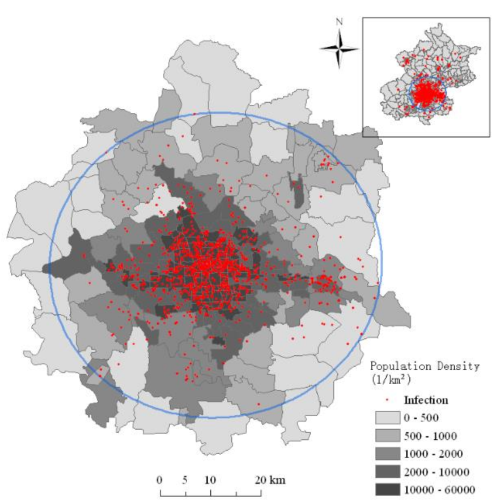



**Figure 1: The daily changes in SARS infection of Beijing in 2003.**




**(a)The spatial distribution of 2321 SARS cases in Beijing.**

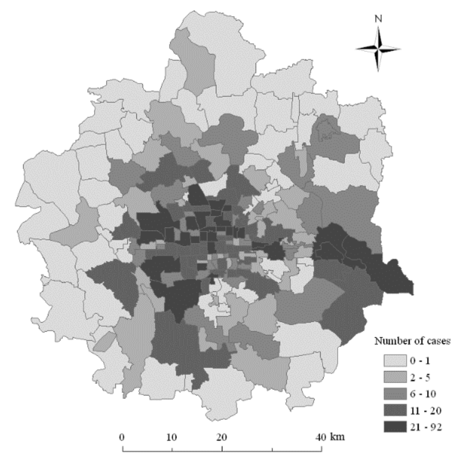



**(b) The spatial distribution of SARS cases in research area.**

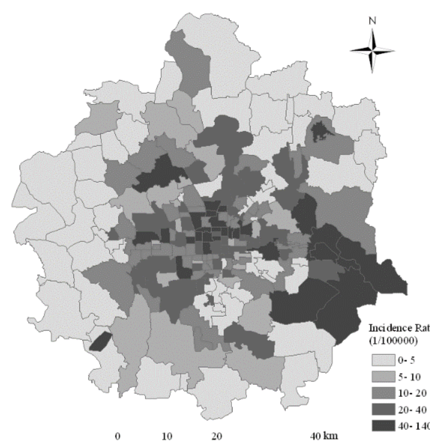
**Figure 2: The spatial distribution of the confirmed SARS cases in Beijing.**

## 3.2 The morbidity graph of SARS in Beijing

Based on the spatio-temporal data of SARS-infected people in Beijing, a spatial overlay analysis of the spatial points representing the infected people and the polygon representing the administrative partition can result in the total number of patients on the administrative division. The number of cases divided by the resident population in the administrative division can determine the morbidity graph of SARS in Beijing. The spatial distribution of the total number of infections during the 2003 SARS epidemic in Beijing in 2003 is shown in Figure 3 (a). The morbidity of SARS in Beijing is shown in Figure 3 (b).




(a) **The spatial distribution of the total number of infections during the 2003 SARS epidemic in Beijing**




**(b) The morbidity of SARS in Beijing**

**Figure 3: The count number and morbidity of the 2003 SARS epidemic in district of the Beijing.**

## 3.3 Kernel estimation

Kernel estimation results are affected by many factors, for instance, the grid cell size, density function and the choice of radius are always determined as basic indexes.

In the analysis of geospatial objects, Modifiable Area Unit Problem (MAUP) often exists. There are some differences in the analysis results obtained under different scale conditions, and the analysis scale has a great influence on the analysis results. High-resolution grid unit is able to show more details, but the uncertainty would increase. Low-resolution grid unit would miss some of the details of the information, but the information reflected is more credible and could better reflect the general trend. In the estimation of the density of infected people, there are some errors in the spatial information obtained from the survey and the information of the underlying database space. In addition, there are errors in the matching process. Therefore, it is difficult to obtain accurate spatial location of the infected person. There will be some degrees of uncertainty in the spatial data obtained after the treatment, so the Kernel density estimation should not use grid units which are too small. If the grid is too big, some details would be missing. Thus 1km is an ideal grid unit size after consideration and comparation.

There are many Kernel density functions, the most commonly used is the normal Gaussian curve function (Bivariate normal) and the quadratic function (Quartic). Gaussian curve can make the distance with the weight value more smooth, so this article selects the normal Gaussian curve function to In order to estimate the function of the Kernel density of SARS patients in Beijing, the formula is expressed as follow [34]:

$$k(u) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}u^2\right) \tag{7}$$

The radius of the Kernel radius has a great impact on the Kernel density estimation results. The smaller the radius, the more details are reflected, but the trend is not general. The greater the radius, the less the details, but the overall trend is more general. The final choice of Kernel radius needs to be determined according to actual demand. In this study, the size of the grid unit is 1km, the diameter of the whole study area is only approximately 70km. 2.5km is eventually chosen as the Kernel radius after considerations and experiments. Thus enough detail information and overall trend of spatial distribution can both be retained.

Figure 4 is generated by ArcGIS9.2 to obtain the SARS epidemic spatial distribution Kernel density in Beijing. It can be seen that there is a significant clustering characteristic of the spatial density of SARS-infected people in Beijing. The density of urban centers in Dongcheng District, Xicheng District, Chongwen District and Xuanwu District is the highest. And the density gradually attenuates from urban center to sur-urban areas, which has a perfect match with the Beijing traffic ring (two rings, three rings, four rings, five rings).

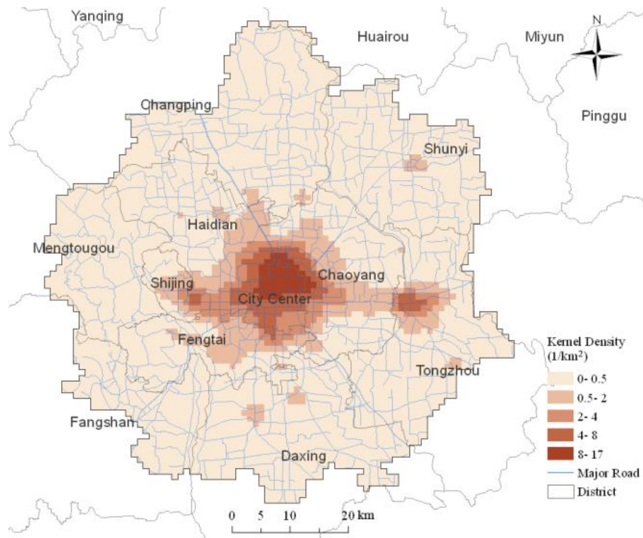



**Figure 4: Kernel density estimation of the 2003 SARS epidemic in Beijing.**

## 3.4 Ripley'K function estimation

The Ripley's K function diagram of the spatial distribution of SARS-infected people in Beijing is calculated using CrimeStat3.0 software. It can be seen from Fig. 5 (a) that the spatial distribution of SARS-infected people in Beijing is significantly clustered. With the increase of distance, the spatial clustering has experienced a weak and strong inverted U-shaped process. When the radius is 11km, the aggregation is the strongest. This distance reflects the Beijing residents of the most active range of activities radius.

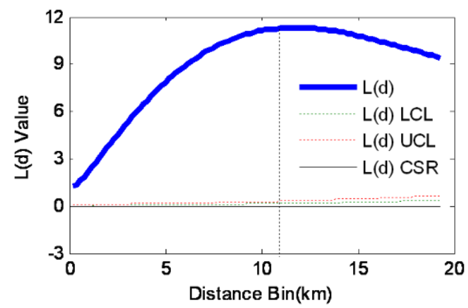
As a result of sex, age, occupation, living environment and other factors, SARS infectious diseases in different types of people in the dissemination of risk and spatial distribution characteristics would various. By comparing analysis of different people of spatial distribution of Ripley'K function diagram, different heterogeneity of SARS can be evaluated.

Gender has an essential impact on the immune capacity. Among the 2444 cases obtained of SARS in Beijing, 1229 cases of men are about 50.28% of the total number. The proportion of male and female population in Beijing is around 104: 100. Excluding the factor that men are more than women in the floating population, the resident population in Beijing for men and women are basically balanced. Therefore, from the quantitative point of view, gender impact on the risk of SARS infection is limited. Figure 5 (b) is the Ripley'K function diagram of the male and female infected people in the SARS infection in Beijing. It can be seen from the figure that the L (d) curve of the two variations is very close, and the self-correlation of the female infected is higher than men. Overall, gender has a little effect on the spatial distribution of SARS infection.

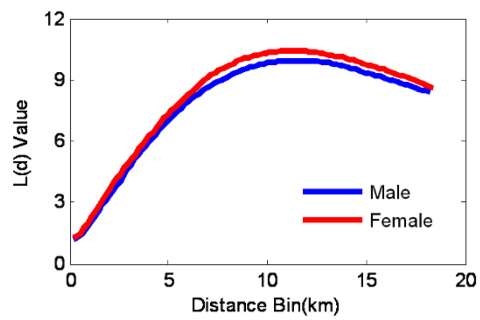
Whether there is a history of exposure or not is a critical part of the epidemiological retrospective survey. It has an important role in effectively tracking the source of infection and cut off the spread. Most people who have had contact history have been exposed to specific infected people or high-risk environment. And it is relatively straightforward to analyze the situation of this kind of people. Most of the infected patients who have not had contact history are unaware of an unknown source of infection that has been exposed. The source of infection is unknown, and thus researchers cannot effectively track and control the source of infection. The more the infected people who have the non-contact history, the more difficult prevention and control is. Decision-making departments need to take more stringent emergency prevention and control measures to achieve effective control. There were 1032 cases of non-contact history infected patients in Beijing, accounting for 42.22% of the total, which is high. If there were no government measures to restrict the activities of the crowd, it would be a catastrophe. Figure 5 (c) is the number of people with SARS in Beijing who have had contact history and no exposure history of the population of Ripley'K function diagram. It can be seen from the figure that the L (d) values of the two peaks are almost equal, indicating that the maximum degree of aggregation is close to each other. However, there is a significant difference in the distance to arrive at the peak. The most active activity radius of the infected person is about 4 km smaller than that of the non-contact person, which can be explained by the fact that most of the infected people who have had contact history are medical staff or have a certain relationship with the hospital (receive the treatment in the hospital or accompanied by family members). Their range of activities are affected by the hospital. Mostly patients live nearby the hospital (most of the medical staff live close to hospitals, normal patients are also used to the nearest treatment). Relatively speaking, infected people who do not have obvious contact history are less affected by the hospital. They live more dispersed and have a wider range of activities. So the people with a significant exposure history have a greater L (d) value than the non-contact history group of people.

Compared with Guangzhou, Shanxi, Inner Mongolia and other epidemic prevention and control areas. A distinct feature of SARS prevention and control in Beijing is the establishment of a special treatment of SARS infection in the Xiaotangshan hospital which began to treat the first batch of SARS infection since 1st May, followed by other hospitals in Beijing and the new SARS infection were transferred to Xiaotangshan Hospital.

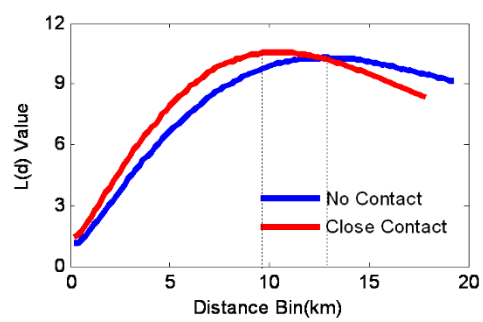
From the time domain, after 1st May, the number of new SARS infection every day rapidly declined. SARS epidemic has been effectively controlled followed by the upcoming a month of the victory over SARS epidemic. In order to examine the role of Xiaotangshan Hospital in SARS epidemic, the spatial distribution of SARS infection before and after May 1 was determined by the Ripley’K function. The results are shown in Fig. 4 (d). The number of infected person before and after May 1 was 1812 and 415 respectively. Because the sample size for Ripley’K function calculation was very different, to eliminate the effect of sample size difference on Ripley’K function calculation results, from 1812 cases of infection before 1st May data were randomly selected 415 cases of infected data, the simulation calculated Ripley’K function as shown in Figure 4 (d) in the red line. From Fig. 5 (d), it can be known that the L (d) value after the same distance on May 1 is significantly smaller than the simulated value after the difference before May 1. And the aggregation of the infected person decreases strongly after May 1, indicating that Xiaotangshan Hospital has a crucial role in the prevention and control of SARS.



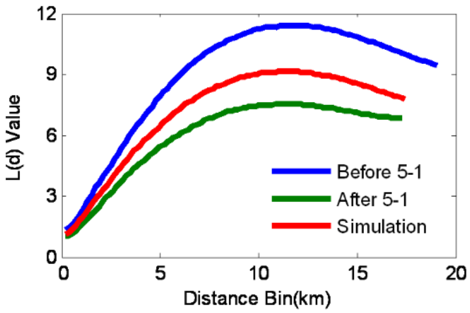

**(a)All the infected patients**




**(b) Male and female infected patients**




**(c) patients with and without contact history**




**(d) Infected patients around 1st May**

**Figure 5: Ripley' K estimation of the 2003 SARS epidemic Beijing.**

## 4 CONCLUSIONS

Beijing was the most seriously stricken area of SARS when the virus swept the entire world in 2003. For more scientific prevention and control of its possible re-occurrence and other acute infectious diseases, which might spread across the modern cities, having a full and deep understanding of SARS epidemic pattern in Beijing is of great significance. The traditional mathematical modeling analysis, aiming at the sequential process of infectious diseases, and the epidemiology investigation, which is based on classical statistical analysis, however, are insufficient to reflect the space information of SARS epidemic. This paper, using the spatialtemporal data of spatialized information of SARS infected people in Beijing, makes a quantitative analysis of the first-order and second-order characteristic of SARS victims in Beijing, by adopting the spatial point pattern analysis method. It reveals the spatial distribution density and the characteristics of aggregation of the SARS infected patients, and analyses how the gender and the history of contact respectively influence the spatial autocorrelation of the SARS infected people. By comparing the SARS infected people' s Ripley' K function curve before and after the foundation of Xiaotangshan Hospital, the paper proves that Xiaotangshan Hospital exerts a positive effect on the prevention and control of SARS in Beijing.

This study makes a quantitative analysis of SARS infected people' s spatial point pattern. It will further explore the temporal and spatial patterns of SARS in Beijing, from the perspectives of spatial patterns, high prevalence districts, clustering characteristics, temporal and spatial spreading, the Spatio-temporal hot spots, the Spatio-temporal correlation, the Spatio-temporal clustering characteristics and other aspects.

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