Spatial Distribution Pattern Analysis of Unsafe Setting of Electric Wires in Urban Area Using K-function Methods: A Case Study of Guangming District

Cong Liao\textsuperscript{1,2}, Xiao Pang\textsuperscript{1,2}, Heng Cai\textsuperscript{1,2} and Yuan Tian\textsuperscript{1,2*}

\textsuperscript{1} Institute of Remote Sensing and Geographical Information Systems, Peking University, Beijing 100871, China
\textsuperscript{2} Beijing Key Laboratory of Spatial Information Integration & Its Applications, Beijing 100871, China
Email: tianyuanpku@pku.edu.cn

Abstract. Hidden fire risk are important disaster-inducing factors for potential fire accidents, which provides a breakthrough point for early intervention and prevention of potential fire accidents. Unsafe setting of electric wires is a very dangerous type of hidden fire risk that could cause fire accidents. It is of great significance to analyze the distribution pattern of hidden fire risk and related factors of this type of hidden fire hazard for early intervention. However, few researches have been done in the field of hidden fire risk. In this study, two network K-function methods, the univariate network K-function method and the bivariate network K-function method, were applied to analyze spatial patterns and its related factors of unsafe setting of electric wires as a hidden fire risk. The research data came from daily inspection in urban grid management of Guangming district, Shenzhen. The results indicated that the spatial distribution of unsafe setting of electric wires is highly related to the transportation network in the study area. The distribution pattern is influenced by the distribution of residential quarters and office buildings. The methods in this study can also be used to analyze other types of hidden fire hazards.

1. Introduction

In recent years, the frequent occurrence of disastrous fire accidents in cities has led to many casualties and severe property damage [1-2]. In order to reduce the risk of fire accidents occurrences, the idea of shifting focus from disaster rescue to disaster prevention is widely accepted. According to theories of accident causes, obvious but neglected disaster-inducing hidden fire risk leading to fire accident often exists before the occurrence of fire disasters, such as stacking flammables and wire aging. Revealing the distribution pattern of these hidden accident risk plays an important role in blocking the chain of potential fire accidents caused by hidden fire risk.

The occurrence of single fire accident could be random, and it could be difficult to get valuable information based on cause analysis of fire accidents in certain circumstances. When the sample becomes larger, the regularity of the occurrence of a certain type of fire accident would be obvious. Many studies have been carried out to analyze the regularity of fire accident distribution and its influencing factors [3-4]. The scenarios of fire accidents include forest fire, grassland fire, building fire, etc. The temporal and spatial characteristics of fire distribution in different scales were revealed. The influencing factors of fire accident are related to social and economic factors, education level, climate conditions and other indicators from a macro perspective [5]. In general, it is difficult for these studies...
to serve to the daily management and prevention of urban fires directly.

The mechanism of urban grid management provides opportunities for more refined urban fire accident prevention. In this management mode, the city is divided into several regular or irregular grids, each grid can include one or more communities, or can be composed of multiple grids into one community. The hidden fire risk of fire accidents in each grid shall be inspected and reported to the urban smart management system by the persons in charge of inspection of the grid. Urban grids provide a more refined research scale for analysis of distribution pattern of urban hidden fire hazards and provide a new chance to shift focus towards pre-warning in management of urban fire accidents. By mining the pattern of hidden fire hazards based on inspection data in urban grid management system, the regularity of potential fire accidents can be better revealed and could further conduct accurate early intervention for potential fire accidents.

Unsafe setting of electric wires is a disaster-inducing factor that could easily lead to potential fire accidents. The analysis of distribution pattern of this hidden fire risk serves as an important guide for future routine inspection. In this paper, Guangming District of Shenzhen was taken as research area and unsafe setting of electric wires is used as the research objective. The univariate network K-function method and the bivariate network K-function method were applied to analyze spatial patterns and its related factors of unsafe setting of electric wires. The research focuses on the analysis of whether unsafe setting of electric wires is affected by the distribution of residential quarters and office buildings. The study further analyzes the distribution of unsafe setting of electric wires in different scales, which hopes to provide a new perspective for analyzing urban fire accidents.

2. Research Method

In this study, we use Ripley’s K-function method, which is a common method to analyze spatial point patterns, first proposed by Ripley [6]. The early K-function was based on Euclidean distance in continuous plane. The network K-function was developed by Okabe and Yamada to analyze point pattern with network structure in space [7]. That is, the shortest path of network is used to replace Euclidean distance, which has a better adaptability to point pattern in network space. Based on network K function, the point patterns of different types of geographical features were revealed, such as restaurants, ATM outlets, criminal events [8-10]. In this study, the univariate network K-function method and the bivariate network K-function method, were applied to analyze spatial point patterns and its related factors of unsafe setting of electric wires as a hidden fire risk.

2.1. The Univariate Network K-function Method

The univariate network K-function method is often used to reveal whether one type of geographical feature is aggregated in space. In the network data set $L_T$, the total length of the network is expressed as $|L_T|$. $P = \{p_1, p_2, \ldots, p_n\}$, which represent the set of event points in network. The network K function at $p_t$ is defined as:

$$K(t) = \frac{1}{\rho} * E \left( \frac{the\ number\ of\ points\ P}{within\ network\ distance\ t\ to\ point\ p_t\ of\ P} \right)$$

(1)

where $E()$ is the expected value with respect to $p_t$, $\rho$ is the density of points P, such that $\rho = \frac{n}{|L_T|}$, $n$ represents the number of event points other than $p_t$.

For the K-function value of event points in the whole network, it can be defined by the average value of each $p_t$, which is expressed as the following formula:

$$\tilde{R}(t) = \frac{|L_T|}{n(n-1)} \sum_{t=1}^{n} \left( the\ number\ of\ points\ of\ P\ on\ L_\rho(t) \right)$$

(2)

The statistical test of event point density can be realized by comparing the difference between the observed results and the completely random results. If the observation value is larger than the expected value, it is considered that aggregation exist. If the observation value is smaller than the expected value,
the distribution pattern is considered to be discrete. Different confidence levels can be set to interpret the zero hypothesis. The significance level of different confidence corresponds to different times of random simulation test. For example, the significance level of 0.01 corresponds to 99 times random simulation tests, and the significance level of 0.05 corresponds to 19 times.

2.2. The Bivariate Network K-function Method

The bivariate network K-function is mainly used to analyze whether the distribution pattern of a geographical feature is affected by the spatial distribution of another geographical feature, such as the relationship between commercial outlets and subway stations. The calculation process of bivariate network K-function is similar to that of univariate network K-function. When calculating the theoretical expected value of \( p_i \), the number of event \( p_i \) falling in the circle with another object \( q_i \) with radius \( t \) is counted. The K-function can be expressed as:

\[
R_B^b(t) = \frac{|E|}{\sum_{i=1}^{n_B}} \left( \frac{\text{the number of points } A \text{ within network distance } t \text{ to point } b_i \text{ in } B}{\text{the number of points } B \text{ within network distance } t \text{ to point } a_i \text{ in } A} \right)
\]  

(3)

The parameter and statistical significance test are same with the univariate network K function method.

Univariate network K-function method and bivariate network K-function method can be analyzed at different scales. By comparing the upper and lower bounds of the observed K-function values with those of the random simulation by Monte Carlo method, the point pattern was analyzed. If the K-function value of the observation value is between the upper and lower bounds of the simulation value, the distribution pattern of unsafe setting of electric wires is random. If the K-function value of the observation value is greater than the upper bound of the simulation value, the pattern is aggregated.

3. Case Study

3.1. Case Study Area and Data Description

This study selected Guangming District of Shenzhen as the case study area. Guangming district has 6 subdistricts and 31 communities, covering a total area of 156 square kilometers. There are 560,800 permanent residents in the District, including 67,900 registered population as of 2018. A large number of industrial enterprises with many employees is in the study area, which promotes the demand for electric vehicles and other electric products. The data came from the daily inspection of hidden hazards in April 2019 in the urban grid management system of Guangming district. The research was based on road network, and the related factors discovered were residential quarters and office buildings respectively. There were 879 incident locations of unsafe setting of electric wires, 229 office buildings and 474 residential quarters. The data of related factors were adapted from Baidu interest points and OpenStreetMap respectively. Figure 1 shows the overview of research area and data.

3.2. Result

The univariate and bivariate function methods were implemented by ESRI ArcMap and SANET plug-in tools, and model results were mapped by R software. Based on road network, this paper first used univariate network K-function to analyze the point pattern of unsafe setting of electric wires, and then used the bivariate network K-function to analyze the cross relationship between the distribution of unsafe setting of electric wires and the spatial distribution of residential quarters and office buildings. The analysis results were shown by K-function and cross K-function curves.

Figure 2 shows the analysis results of univariate variable network K-function method. In the figure, the horizontal axis represents the distance in meters; the vertical axis represents the value of K value. The significance level was set to 0.05. It can be seen from the figure that the K-function value of the observed value of unsafe setting of electric wires is above the upper bound of the simulated value between the range of 0-11 km, indicating that there is a significant difference between the observed value and simulation value. The results indicate obvious aggregation of unsafe setting of electric wires.
exist.

Figure 1. The overview of research area.

Figure 2. The analysis result of univariate network K-function method.

Figure 3 shows the analysis results of bivariate K-function method. The significance level was set at 0.05. The upper and lower bound curves were obtained by Monte Carlo complete random simulation model, and the significance level is 0.05. Figures 3a and 3b respectively shows the spatial interaction and correlation between unsafe setting of electric wires with the number of residential quarters and office buildings. The unsafe setting of electric wires was influenced by residential quarters and office buildings.

Figure 3a displays the two features affected by unsafe setting of electric wires at different scales based on road network. Within 0-12.5 km, significant interaction between the unsafe setting of electric
wires and the residential quarters exists. Within 0-13 km, significant interaction between the unsafe setting of electric and the office buildings also exists. Some observed value in the cross distribution between unsafe setting of electric and residential quarters is close to the maximum upper boundary of confidence interval. From the disparity between observed value and expected value in cross distribution pattern, office buildings have a more significant problem of unsafe setting of electric wires comparing to residential quarters.

From the results of univariate network K function methods, the unsafe setting of electric wires tended to aggregate under all levels of scales in the case area. The event points aggregated densely around the road network. From the results of bivariate network K function methods, the problem of unsafe setting of electric wires was demonstrated in residential quarters and office buildings at different scales. The results indicated that the possibility of occurrence of unsafe setting of electric wires near residential quarters is higher. One important purpose of unsafe setting of electric wires in reality was to charge electric vehicles near residential areas, which reminds us to pay more attention to the inspection of whether unsafe setting of electric wires is associated with the use of electric vehicles. The results of cross distribution between unsafe setting of electric wires and office buildings indicated that the unsafe setting of electric wires in public office buildings may cause potential fire accidents. In daily inspection, the grid managers will need to inspect in these places more carefully.

4. Conclusions
This study used the univariate network K-function method and the bivariate network K-function method to analyze the spatial point patterns and its related factors of hidden danger of unsafe setting of electric wires. The results of univariate network K-function method indicated that the unsafe setting of electric wires tended to aggregate under all levels of scales based on road network in the case study area. The results of bivariate network K-function method indicated that the dangers of unsafe setting of electric wires were demonstrated at residential quarters and office buildings at different scales, and the office buildings have a more serious dangers of unsafe setting of electric wires comparing to residential quarters.

By identifying the distribution pattern of hidden fire hazard of unsafe setting of electric wires, the fire accident management can be guided better, so that prevention measures can be done in advance. With analysis of more related factors, the distribution pattern of hidden fire hazard and the relationship with other related geographical features can be better described. The network K-function method used in this study can also be used for other geographical features.

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