Study of the exploration of fire occurrence spatial characteristics and impact factors – A Case Study of Tainan City

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1 ABSTRACT

In recent years, the urban fire prevention concept has gradually attracted more and more attention. However, in the relevant studies of disasters, issues seldom involve disaster prevention and reduction, but mostly focus on the demand of disaster rescue. As such, if one can gain a deeper understanding of urban fire occurrence spatial characteristics and impact factors, it can be used as a reference for the relevant planning of disaster prevention and disaster reduction.

This study used Tainan City, Taiwan as the study object. It adopted the information of 119 caller ID and dispatch information system and combined it with the geological information system to establish fire history case occurrence location information through the spatial coordinate transformation of Spatial Geo-coding Mapping Process spatial pattern analysis of fire occurrence locations through Point Pattern Analysis to understand the distribution condition, gathering level and its characteristics of the fire occurrence locations in Tainan City and to further explore the connections of fire disasters through using the Geographically Weighted Regression analysis method on different land use behaviors, real spatial structure and social economic statistic indicators. The study results, in addition to being able to analyze the spatial characteristics of urban disasters more clearly, can also be used as a reference for relevant urban disaster prevention strategy.

2 INTRODUCTION

Urban activities have become diverse from intensive development as a result of a booming economy and urbanization in Taiwan. This has caused increasingly higher disaster rates in cities each year, endangering lives and property. To this end, people have been paying greater attention to disaster prevention with regard to urban planning. However, most studies on disasters focus on relief, where only a few involve disaster prevention and reduction. To improve safety within the city, it is necessary to have a thorough understanding of factors that cause disasters and spatial characteristics as reference when planning disaster prevention (Wekerle, 1995). Locations of disasters may be connected to surroundings. Relevant analysis methods help understand spatial characteristics that affect disasters and draft plans for disaster prevention in cities.

This study examines locations of disasters from the Tainan 119 display system conducted in two parts: 1. spatial characteristics of disasters in quadrants to review the spatial gathering or dispersion of fire locations; 2. further generalization of man made environmental factors that affect the occurrence of disasters in combination with geographical weighting regression analysis to test coorelation between loss, the man made environment and the occurence of fires. The results better analyze spatial characteristics of disasters in cities and serve as reference for establishing policies of prevention or control of urban disasters.

3 STUDY OF BUILDING ENVIRONMENT AND FIRES

Earlier studies examine the occurrence of urban disasters with the surrounding environment. The man made or built environment refers to a number of dimensions such as type of land, buildings, facilities and even abstract feelings of landscape and flow of space. In a broad sense, the built environment includes models of land use, transportation systems and design characteristics offering living needs to residential areas. Models of land use refer to the space distribution of human activities; transportation systems are actual infrastructure and service for spatial connection; design characteristics refer to quality of beauty and actual function of the environment.

Covero and Kockelman (1997) discuss man made environment in three major aspects, density, diversity and design. Density is that of land use, such as population density and building density. Transportation systems refer to the density of the transportation network in an area. Higher density means greater transport availability and accessibility. Diversity refers to the mixture of land use. More types of land and a greater amount of land means higher diversity. Land use design is the actual environmental conditions of an area.

3.1 Land Use Density

Density is the total amount of activity of a unit area. The amount of activity can be defined as the population, number of employed people and land area. Coverage ratio and capacity rate are often the measurement indexes for density.

In light of loss degrees, Jennings (1999) claimed socioeconomic and environment factors outweighed fire rescue factors. Socioeconomic and environment factors include building stock, social or household systems, household demographics and household economics. Such factors can affect occurrence of fires directly or indirectly.

3.2 Diversity of Land Use

This refers to mixed use of lands in an area, including houses, stores, offices or other uses. It is believed the occurrence of disasters is related to different land use. Disasters are the result of external cost accumulation of incompatible land use activities. Land use is the outcome of interaction of people and land. This study of land use, seeks to understand mutual influence between people and the surrounding environment. Through overlapping spatial distribution maps of disasters in cities, potential factors affecting occurrence of disasters in the area become clear.

Different studies of factors affecting fires are available. Karter et., al. (1978) combined urban socioeconomics and architecture management to generalize factors that are mostly related to fire occurrence rates from changes of intra-city fire occurrence. The results are used in residential areas in cities to evaluate fire danger levels in each area and estimate rates of occurrence. In other studies, basic data of fires in buildings is compared with the living environment to evaluate disaster occurrence rates. Correlation between land use and spatial structure is reviewed with fire characteristics. Simulation is made with fire cases to discuss how the environment affects disasters.

4 SPATIAL CHARACTERISTICS OF FIRES

From the Tainan 119 database with GIS for spatial conversion of house number plates, fires are coordinated with respect to distribution and frequency for ensuring spatial analysis.

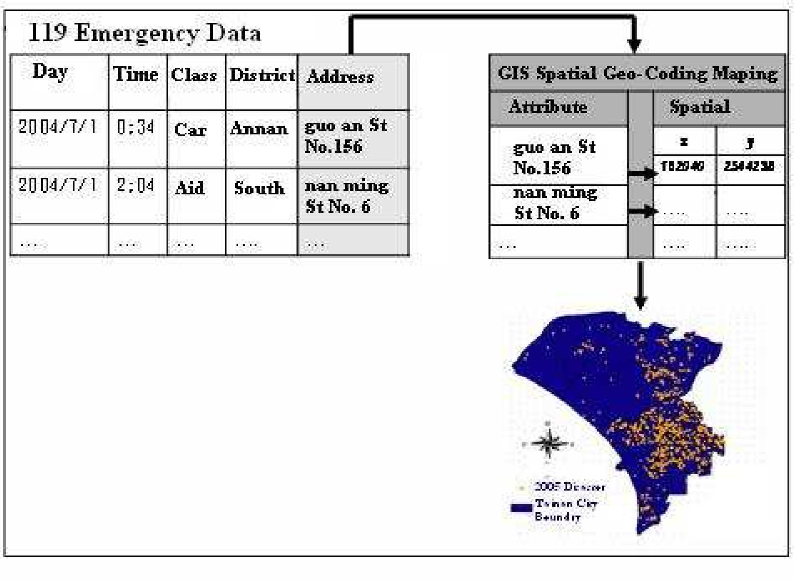

Fig 1 Illustration of coordinate conversion of disaster locations

From the spatial distribution and number of cases above, the South District has the greatest number of fires compared with the Anping District which has the fewest cases. From 2003 to 2005, fires in each district were more frequent (Table 1, Fig. 2).

year? · Ý	2003	2004	2005	Total
North district	49 (16.8%)	59 (16.4%)	123 (20.4%)	231
An-ping district	52 (17.9%)	44 (12.3%)	95 (15.8%)	191
Middle-west	33 (11.3%)	58 (16.2%)	112 (18.6%)	203
East district	60 (20.7%)	81 (22.6%)	121 (20.1%)	262
South district	97 (33.3%)	117 (32.5%)	152 (25.1%)	366
Total	291	359	603	1253

Table 1 Number of Man Made Disasters in Administrative Areas in Tainan

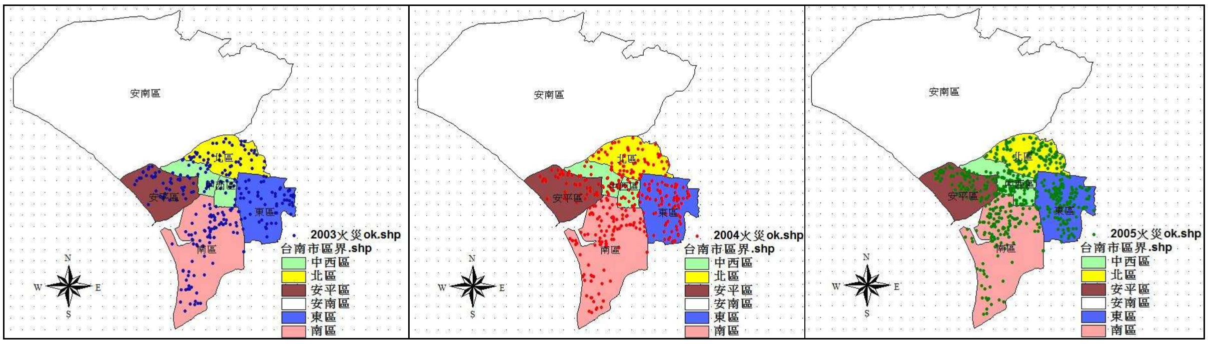

Fig 2 Distribution of Fires in Administrative Areas in Tainan from 2003 to 2005

Characteristics and changes of spatial gathering or dispersion are reviewed in quadrant analysis. The basic idea of quadrant analysis is to examine a number of points in a quadrant, or distribution density of points. Comparing the density of point distribution in space using a model of point distribution, it is possible to judge characteristics of spatial gathering of elements. A square is most often utilized to calculate the number of points in each quadrant in order to establish point layout distribution mode that has been actually observed. To calculate K-S test actual accumulation distribution and theoretic distribution difference, the formula is:

$$D = Max\left|O_i - E_i\right|$$

O_i is the accumulation distribution ratio of i points; E_i is accumulation distribution ratio of I in theory. D'($\alpha = 0.05$) is a reliable K-S theory value to explain whether there is a distinctive difference between actual observation and the theory to analyze spatial characteristics.

Based on five districts in Tainan, the research analyzes in 15 17 grids to calculate spatial distribution characteristics of fires in the city.

The sample size of fires from 2003 is 291; average number in each grid is 1.14118. K-S test actual D is 0.335559. The sample size of fires from 2004 is 359; average number in each grid is 1.40784; K-S test actual D is 0.402388. The sample size from 2005 is 603; average number in each grid is 2.3647; K-S test actual D is 0.541317. With a reliability of 95%, K-S theory D' is 0.0851665. Actual D value in each year outweighs that of theory of random distribution. This shows cluster characteristics of fires from 2003 to 2005 in Tainan are very distinctive.

year	Sample size	Average number in each grid	K-S test actual D	K-S test theory D'	Result
2003	291	1.14118	0.335559	0.0851665	distinctive
2004	359	1.40784	0.402388	0.0851665	distinctive
2005	603	2.36470	0.541317	0.0851665	distinctive

Table 2 Quadrant Analysis of Fires from 2003 to 2005

5 ANALYSIS OF SPATIAL CORRELATION BETWEEN MAN MADE ENVIRONMENT AND FIRES

Fires have spatial distribution characteristics. With geographical weighing regression analysis, analysis of spatial correlation between man made environment and fires was conducted.

5.1 Selection of study variables

From the three dimensions of main building body, use of buildings and surrounding environment, seven analysis variables were selected: types of buildings, structure of buildings, age of houses, floors of buildings, types of use, population density and adjacent road width.

Types		Indexes	Expected symbols
Main building body	Types of buildings	1 1r row houses2 2a apartments 3 3b buildings	+
	Structure of buildings	1 1r reinforced 2 2s steel bar, steel3 3b bricks 4 4w wooden, bamboo, others	+
	Age of houses	Actual age of houses	+
	Floors of buildings	1 11 1-5 floors 2 26 6-10 floors 3 31 11-15 floors 4 41 16-20 floors5 50 over 21 floors	+
Use of buildings	Types of use	1 10 others2 2s schools3 3 entertainment 4 4 houses5 5h hotels 6 6s stores7 70 offices 8 8f factories	..
Surrounding environment	Population density	Number of people in a square meter (number of people/square meter)	+
	Adjacent road width	1 1? 5 25m2 2? 8 18m~ ? 25m 3 3? m 8m~ ? 17m 4 4? ? 8m	+

Table 3 Factors of Variables. Remark: expected symbol +: the higher the index value is, the greater the impact on fire loss.

5.2 Analysis Mode Design

This study adopts the Spatial Lag Model, LAG and Spatial Error Model, ERROR for analysis of disasters to obtain the optimal regression model. Explanations of deviation of the two models:

5.2.1 LAG

$$In\ P_i = \alpha_0 + \rho \times W_{ij} \times P_j + \beta_1 DENSITY_i + \beta_2 ROAD_i + \beta_3 FORMS_i + \beta_4 STRUCTURE_i$$
$$+ \beta_5 AGE_i + \beta_6 FLOOR_i + \beta_7 USE_i$$

Spatial lag is the distributed lag between fire points, excluding fire loss in parcel i. It is, instead, averaged with regard to fire loss of nearby fire points. The most significant characteristic of spatial lag is to deem nearby fire points as variable within reason. It is an extension of the spatial autoregressive model. From which, p is fire loss vector; ρ is spatial lag coefficient; W is spatial weight matrix of $n \times n$; ε is i.i.d of independent and equal distribution. The spatial weight matrix is the interaction relation of nearby space. It is positive and non-zero. The diagonal line is zero and other line elements are zero or one.

There will be a nonlinear relation between model variables. In general, Maximum Likelihood is used to test whether the spatial lag coefficient is distinctive. If the coefficient is not zero, the spatial lag model has an interactive relationship with nearby areas.

5.2.2 Spatial Error Model

$$In\ P_i = \alpha_0 + +\beta_1 DENSITY_i + \beta_2 ROAD_i + \beta_3 FORMS_i + \beta_4 STRUCTURE_i$$
$$+\beta_5 AGE_i + \beta_6 FLOOR_i + \beta_7 USE_i + \varepsilon_i^{'}$$
$$\varepsilon_i^{'} = \lambda_i \times W_{ij} \times \varepsilon_i + \mu_i$$
$$i = 1.......,n$$

This model examines whether the spatial autoregressive model is in error. A regression model error, adds one more error in the multiplication of itself and the spatial weight matrix. λ is the spatial error coefficient; W is the spatial weight matrix; u is the error vector. The most significant spatial error model consideration is the interference factor. In spatial autoregressive errors, ε is non-spherical distribution. The variance -covariance matrix is a non-zero matrix (Anselin, 1999). U is typically independent and equal distributed (i.i.d); the variance-covariance matrix is zero; u is the (white noise) influence.

In general, Maximum Likelihood is used to test whether the spatial error coefficient is distinctively not zero. If yes, the spatial error model does have an interference factor causing a spatial auto relationship. The distance relationship between two fire points are very sensitive in the spatial lag model and spatial error model. A short distance between the two will lead to high spatial dependence.

5.3 Analysis Results

Data for man made environment of fires are from the Taiwan Real Estate Database. The analysis model is made in comparison with loss from fires. After deduction of incomplete data and fires on wastelands, there are a total of 153 pieces of data for analysis. It was found the difference of overall regression adaptability of two models is not great. The seven variables are distinctive in 99% reliability. Conditions of the built environment do affect fire occurrence. Results are in Tables 5 and 6.

Table 4 Test Items of Regression Model and Analysis Results

Regression	Test item	**LAG**	**ERROR**
overall regression adaptability	R-squared	0.0814	0.0815
	Log likelihood	-2393.62	-2393.61
	Akaike Info Criterion	4805.23	4803.22
	Scharz Criterion	4832.51	4827.46

Table 5 Estimation of Models. Note: ***p< 0.01

Variable	Spatial Lag Model	Spatial Error Model
Constant	8.2079 (2.3758)***	1.01612(1.0828)***
Types of buildings	3.9166 (5.2448)***	1.2268(2.6994)***
Floors of buildings	1.0565 (-3.0161)***	3.0514(-1.0853)***
Adjacent road width	4.6236 (-2.4839)***	3.2057(-3.6736)***
Structure of buildings	6.4013(-2.0958)***	2.7423(-4.8437)***
Age of houses	9.9613(-4.0674)***	0.0001(-2.3711)***
Types of use	1.3513(1.6361)***	5.2837(4.2035)***
Population density	0.0663(17.4427)***	0.1292(3.6345)***

6 DISCUSSIONS AND ANALYSIS

From the results, Tainan has seen more severe and increasingly frequent fires in recent years. Fires in Tainan can be isolated in clusters of certain areas such as East and South Districts.

From the geographical weight regression model, levels of loss from fires are related to seven factors—population density, adjacent road of buildings, types of buildings, structure of buildings, age of houses, floors of buildings and types of use. This means conditions of main building body, types of use of buildings and surrounding environment directly affect levels of loss from fires. In future urban planning for disaster prevention, it will be necessary to understand district characteristics and allocation of rescue as vital factors to consider.

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