Suitability Assessment of Emergency Shelters Based on GIS: A Case Study in Urban Function Optimization Area of Shanghai

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Abstract. In recent years, major disasters have occurred frequently and they have various types, which has seriously affected the lives and property of urban residents. The planning and construction of emergency shelters has become an important factor affecting urban safety and livability, therefore, it is of great significance to study the location and spatial allocation of emergency shelters. This paper established a suitability assessment indicator system for urban emergency shelters, the assessment criteria of emergency shelters can be divided into three categories: applicability criterion, accessibility criterion and safety criterion. Each emergency shelter will get a score to quantify their suitability after assessment, the scores are classified as 5 levels: suitable, appropriate, generally appropriate, less suitable, and unsuitable. The map the suitability of emergency shelters on ArcGIS. A case study in 36 existing emergency shelters of Shanghai, China was conducted to demonstrate the feasibility of the proposed system.

1. Introduction

The development and construction of cities are always accompanied with cities’ resistance to various disasters. The concentration of population and wealth in cities makes the dangers of public security events magnified. China is a country with frequent natural disasters. In 2016, various disasters caused 137 million casualties in the country, among them, 1074 people died, 270 people were missing and 6.24 million people were resettled, more serious was that 400 thousand houses collapsed, 2.25 million houses were damaged in varying degrees, and the direct economic loss was 298.3 billion yuan [1]. Serious emergency events such as natural disasters and accident disasters have caused collapse or serious damage to houses, and infrastructure systems have been paralyzed, residents have lost their living environment and conditions, and a large number of people need to be transferred to emergency shelters [2].

China is one of the countries with the most serious natural disasters in the world. There are many types of disasters with wide geographical distribution, high frequency of occurrence and heavy losses. The ability to provide shelters in time for emergencies has become an important part of measuring government emergency management capabilities and disaster reduction capabilities [3]. Through the suitability evaluation for emergency shelters, emergency resources can be rationally allocated, evacuation and emergency rescue activities can be organized efficiently, government financial input can be saved, and the future planning of emergency shelters can be provided to government as a reference.

The studies on emergency shelters by scholars at home and abroad are divided into the following categories in terms of methodology:

(1) Analytic hierarchy process
(2) Network optimization model and weighted scoring method
(3) Weighted Voronoi diagram
(4) Gray correlation method
(5) Spatial/non-spatial (attribute) mixed stepwise regression model
(6) 2s FCA model method
(7) Other methods

On the basis of compliance with the design criterions of emergency shelters, this paper studies the suitability of the layout of emergency shelters in the downtown area of Shanghai. The author applies Grey Situation Decision, Entropy weight method and Grey Relational Analysis to the suitability assessment of urban shelters, selects 10 assessment indicators, mainly uses GIS network analysis method to evaluate and analyze suitability assessment indicators of emergency shelters. Thus, this paper serves as a useful reference for developing future catchment-based disaster-mitigation policies in the field of evacuation planning.

2. Establishment of Suitability Assessment Indicator System

This paper mainly studies the spatial layout and location suitability of the fixed and central emergency shelters. According to the planning and construction requirements of earthquake emergency shelter, considering the natural conditions of Shanghai, the assessment criterion of emergency shelters can be divided into three categories: applicability criterion, accessibility criterion and safety criterion [4].

2.1. Applicability criteria
Emergency shelters provide temporary shelters and disaster relief places for a large number of people when disasters occur. Therefore, the supply capacity of its location needs to be considered. The shelter should have enough open space to provide protection for the asylum-seekers. At the same time, we also need to consider the number of serviceable population in emergency shelters, and measure the effectiveness of the location of shelters, so as to identify emergency shelters with service efficiency.

2.2. Accessibility criteria
Accessibility criterions of emergency shelters is mainly to measure the relationship between shelter and other places of disaster prevention and disaster relief, emergency shelter planning should consider the disaster relief needs, allocation of emergency shelters should easily connect the other disaster relief units, so that can easily access to rescue resources, in order to give full play to the function of emergency shelters.

2.3. Safety criteria
The safety indicators mainly aim at different disasters, comprehensively consider the construction indicators of emergency shelters, analyze the impact of potential disasters on emergency shelters, avoid the invalid of emergency shelters when disasters occur, or occur secondary disasters or other disasters to impair the effect of emergency shelters when the asylum-seekers take refuge. Due to the different impact of different disasters, secondary disasters may also be different (Table 1.).
Table 1. Emergency shelter’s suitability assessment indicator system

| Category | Indicators                                      | Explanation of indicators                                                                 |
|----------|------------------------------------------------|-------------------------------------------------------------------------------------------|
|          | The ratio of open space                        | The ratio of open space is the ratio of the effective evacuation area of emergency shelters to the area of emergency shelters. |
|          | The population number of available asylum-seekers | Divide the area of open space of emergency shelters by the minimum required evacuation area per person. |
|          | The minimum distance to the hospital           | Lakes, rivers and reservoirs                                                              |
|          | The minimum distance to the fire station       | Public Security Bureau, police station                                                    |
|          | The minimum distance to the safe water source  | Easy access to relief supplies                                                           |
| Accessibility | The minimum distance to the commanding evacuation unit | Type I-II shelters should be within walking distance of 45 minutes and 30 minutes in neighbouring communities respectively |
|          | The minimum distance to the commercial service area |                                                                                      |
|          | Walking accessibility                          |                                                                                          |
|          | The minimum distance to flammable and explosive warehouses | Gas station, warehouse                                                                 |
| Safety   | The slope of emergency shelters                | DEM                                                                                      |

3. Study Area
Shanghai is located in the middle of the north-south curved coastline of China. It is 120km long from north to south and 100km from east to west. There are 3 islands in the territory, they are Chongming, Changxing and Hengsha. Chongming Island is the third largest island in China [5]. Shanghai is China’s largest economic city and one of the 15 largest cities in the world. It is located along the coastline or in estuaries [6]. The resident population in Shanghai was 24.1527 million in the end of 2015.

According to the "Shanghai’s Main Function Zone Plan" formally issued by the municipal government on January 22, 2013, Shanghai's urban territory space is divided into four functional areas: 1) Urban function optimization area (downtown and Baoshan District, Minhang District); 2) New urban development area (Pudong New District); 3) New urbanization area (Jiading District, Jinshan District, Songjiang District, Qingpu District and Fengxian District); 4 ) Integrated ecological development area (ie Chongming Island); and restricted development areas and prohibited development areas. This paper selects Shanghai Urban Function Optimization Area as the study area, because the area accounts for 15% of the city's total area, and the population accounts for 47.5% of the city's population, which is nearly half of the city’s population, and the population density is far more than other areas. Once a disaster event occurs, traffic congestion and lack of emergency shelters are easily occur, and disaster losses are more serious. The study area is shown in Fig. 1.

4. Data
The data of the Shanghai emergency shelters used in this study comes from the "Shanghai Emergency Shelters Construction Plan" (2013-2020) (Description) [7] released by Shanghai Civil Defense Office in 2016; The information of the fire stations in the study area comes from the data released by the official website of the Shanghai Municipal Fire Bureau; The data of hospitals, rivers, lakes and reservoirs as well as the data of public security bureaus and police stations are obtained by the Baidu API developer platform; All residential community information (including residential community
names and total number of households) of this study was obtained from Anjuke website [8] through Python; DEM data and precipitation data are collected by our research group.

The emergency support performance requirements at the time of disaster occurrence are divided into three categories according to service time: emergency, fixed, and central. The division method is shown in Table 2.

![Figure 1. Study Area](image)

**Table 2. Classification of emergency shelters in Shanghai**

| Type     | Site area (m²) | Per capita shelter area (m²) | Refuge time (days)         | Service radius (m) |
|----------|----------------|------------------------------|----------------------------|--------------------|
| Type I   | >20000         | 3                            | Long term (over 30 days)   | 5000               |
| Type II  | >4000          | >2                           | Temporary (10~30)          | 1000               |
| Type III | >2000          | >1.5                         | Urgent(within 10)          | 500                |

According to survey statistics, as of the end of December 2015, there are 46 emergency shelters have been established in Shanghai. Among them, there are 3 Type I emergency shelters, 25 Type II site type emergency shelters, and 31 Type II location type emergency shelters. There are 36 emergency shelters in the study area, and the specific names and distributions are shown in Fig. 2.

5. Quantification of suitability assessment indicators for emergency shelters

5.1. Quantification methods for each indicator

The quantification methods for each indicator are shown in Table 3.
5.2. Applicability criteria
The population number of available asylum-seekers is calculated by dividing the open space of emergency shelters by the area of the minimum demand evacuation per person. According to the "Shanghai downtown area Emergency shelters Layout Plan" (2009) [9], the actual per capita real effective land area for planned emergency shelters in the downtown area is controlled to be 3.0 m$^2$ per person (not less than 2.5 m$^2$ per person within Puxi Inner Ring).

5.3. Accessibility criteria
The indicators of accessibility were calculated in the case of walking. The measured data show that the basic data of pedestrians in large cities in China differs slightly from the situation in foreign countries, but the distribution of pace and frequency is the same as Gauss distribution. The pace is 1.24 m/s and the average step frequency is 1.96 steps/s [10]. Set the speed of each road on the road network to be 1.24m/s. Then you can get the time required for each road to walk. Find these two items to facilitate the subsequent calculation of the minimum distance.

5.4. Safety Criteria
In accordance with the planning and construction guidelines for emergency shelters, the topographic relief in emergency shelters should not be too excessive, and the slope of the terrain after the project treatment should not exceed 7°.

![Figure 2. Illustration of the spatial distribution of emergency shelters in the study area](image-url)
Table 3. Quantification methods for each indicator

| Indicators                                      | Quantification method                                                                 |
|------------------------------------------------|----------------------------------------------------------------------------------------|
| the ratio of open space                        | The open space ratio is the ratio of the effective evacuation area of emergency shelters and the total area of emergency shelters. |
| the population number of available asylum-seekers | The population number of available asylum-seekers is calculated by dividing the open space of emergency shelters by the area of the minimum demand evacuation per person. |
| the minimum distance to the hospital           | ArcGIS10.3——Network Analyst——New Closest Facility                                      |
| the minimum distance to the fire station       | idem                                                                                   |
| the minimum distance to the safe water source  | idem                                                                                   |
| the minimum distance to the commanding evacuation unit | idem                                                                                   |
| the minimum distance to the commercial service area | idem                                                                                   |
| walking accessibility                          | ArcGIS10.3——Network Analyst——New Service Area                                         |
| the minimum distance to flammable and explosive warehouses | ArcGIS10.3——Network Analyst——New Closest Facility                                      |
| slope of emergency shelters                    | ArcGIS10.3——Spatial Analysis——Slope                                                   |

6. Results

In grey theory, gray generation is a regular method of counting numbers, and it can be used to find out the hidden laws and information in disorganized data [11]. Due to the difference in the units of the suitability indicators of the emergency shelters selected in this study, and the large difference in values. Therefore, we use the gray generation for the attributes of the emergency shelters.

After calculating the entropy weight values of each indicator, put the grey generation results of each indicator attribute of emergency shelters and the entropy weight of each suitability indicator together, and use the relational analysis calculation method to calculate the degree of correlation of emergency shelters.

In order to better represent the suitability of emergency shelters, according to the distribution of decision values in emergency shelters, the emergency shelters should be classified to 5 levels, they are suitable, appropriate, generally appropriate, less suitable, and unsuitable. Divided by 0.49, 0.41, 0.37, and 0.35 respectively, the decision values greater than 0.49 belong to suitable emergency shelters, the decision values greater than 0.41 belong to appropriate emergency shelters, and the decision values less than 0.37 are belong to less suitable emergency shelters. Those with decision values less than 0.35 are unsuitable shelters, and those with a decision value between 0.41 and 0.37 are generally appropriate emergency shelters. The assessment results are shown in Fig. 3.

7. Conclusion

According to the above methods, the analysis of the suitability assessment results of 36 emergency shelters in the study area (Fig. 3), the following conclusions can be drawn:
(1) In general, the suitability of 36 emergency shelters in downtown Shanghai is relatively good; According to the above three assessment methods, a comprehensive comparison is made and divided into 5 levels, they are suitable, appropriate, generally appropriate, less suitable, and unsuitable. There are 4 emergency shelters that are unsuitable, namely Zhabei No.8 Middle School, Baoshan Sports Center, Shanghai University Affiliated School and Shanghai Minhang Middle School (Location type). There are six shelters that belong to the suitable category, they are Square Park, Zhongshan Park, People's Park, Shanghai Stadium, Yanzhong Greenland Phase III Civil Defense Project and Luxun Park. There are five Shelters belong to the appropriate level, they are Kaiqiao Greenland, Putuo Sports Center, Hongkou Football Stadium, Luwan Stadium and Shanghai Kongjiang Junior High School; the others are generally appropriate and less suitable places.

(2) Of the most suitable emergency shelters evaluated, two Type1 emergency shelters in the study area are included, and they are also the two highest rated emergency shelter, which proved that the assessment results are real and reliable, with a certain reference value. Among the emergency shelters, the two lowest rated shelters are located in Baoshan District. Currently, there are only two emergency shelters in Baoshan District, and the service coverage of them is very small. It also reflects the inadequacies of the planning of emergency shelters in the suburbs of Shanghai.

(3) The construction of the emergency shelter’s evaluation system established in this paper is based on multi-category evaluation indicators, combined with a variety of analysis methods. Compared with the previous evaluation system, it can obtain a more scientific and comprehensive suitability analysis results of emergency shelters.

Figure 3. Emergency shelters’ suitability assessment results
8. Acknowledgments
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