Comprehensive Evaluation of Emergency Shelters in Wuhan City Based on GIS

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***Abstract*—Emergency shelters, which reflect the city's ability to respond to and deal with major public emergencies to a certain extent, are essential to a modern urban emergency management system. This paper is based on spatial analysis methods, using Analytic Hierarchy Process to analyze the suitability of the 28 emergency shelters in Wuhan City. The Technique for Order Preference by Similarity to an Ideal Solution is further used to evaluate the accommodation capacity of emergency shelters in central urban areas, which provides a reference for the optimization of existing shelters and the site selection of new shelters, and provides a basis for improving the service capacity of shelters. The results show that the overall situation of emergency shelters in Wuhan is good, with 96% of the places reaching the medium level or above, but the suitability level needs to be further improved, especially the effectiveness and accessibility. Among the seven central urban areas in Wuhan, Hongshan District has the strongest accommodation capacity while Jianghan District has the weakest, with noticeable differences.**

***Keywords*—Wuhan City; Emergency shelter; Spatial analysis; Analytic Hierarchy Process**

I. Introduction

With the rapid development of cities and the continuous improvement of city governance systems, urban emergency management has become the focus of work. Emergency shelter is significant as it is a major component of city emergency resources and the important guarantee of people's life safety. Nowadays, emergency shelters are required to be distributed evenly, safe and reliable, adaptive to local conditions, useful both in normal times and in an emergency as well as planned in the long term. However, at present, the construction of large emergency shelters has the problems of insufficient scale, uneven distribution, and incomplete functions.

Many current evaluations of emergency shelters focus on site selection and optimization, planning and design, spatial pattern, and serviceability. For instance, Japanese scholars Tetsuya and Kayoko [1] use Geographic Information Systems(GIS) and apply statistical methods and public open data related to population and emergency shelters. The present research aims to conduct a suitability analysis for the emergency shelter allocation quantitatively. Gu et al. [2] evaluated the rationality of the spatial layout of emergency shelters in the central urban area of Heyuan City from four aspects: accessibility, service area ratio, per capita accessible refuge area ratio, and population allocation gap, but did not combine the four aspects and conduct an overall evaluation. Xiong et al. [3] used AHP to evaluate the disaster reduction capability of the earthquake emergency shelters in Chaoyang District, Beijing, but did not evaluate the service capacity of the emergency places. Yin et al. [4] used AHP to evaluate the site selection of emergency shelters in Tianjin, combined with GIS spatial analysis methods to evaluate the satisfaction of 14 shelters in the central urban area. However, they did not establish a complete satisfaction evaluation system and did not compare and analyze the service capacity of the emergency shelters in each district.

Based on GIS spatial analysis methods, in this paper, we use AHP and Technique for Order Preference by Similarity to an Ideal Solution(TOPSIS) methods to evaluate the site selection and accommodation capacity of emergency shelters. The factors considered are relatively complete, and the analysis of population data is also combined. We clearly and intuitively demonstrated the current construction's shortcomings, thus facilitating future planning and layout of emergency shelters.

II. Study area and data sources

A. Overview of the study area

In this work, we study the emergency shelters in Wuhan City, Hubei Province, an important scientific and educational base, industrial base, and comprehensive transportation hub. It is located at the intersection of the golden waterway of the Yangtze River and the main artery of the Beijing-Guangzhou Railway and is known as the Nine Provinces Passage. Wuhan is also in an advantageous position in the economic geography circle of China and is the core city of the Yangtze River Economic Belt. Wuhan has a total area of 8,569 square kilometers, with a permanent population of about 11.45 million in 2021. Up to now, Wuhan has jurisdiction over 13 districts, including Jiang'an District, Jianghan District, Qiaokou District, Hanyang District, Wuchang District, Qingshan District, Hongshan District, Caidian District, Jiangxia District, Huangpi District, Xinzhou District, Dongxihu District, and Hannan District.

B. Data sources

The data of Wuhan's administrative divisions, traffic network, water system, etc., are from OpenStreetMap[1] and

[1]https://www.openhistoricalmap.org

were pretreated through ArcGIS software. The directory and relevant information of Wuhan emergency shelters, major hazard sources, hospitals, fire stations, and public security organs originate from Wuhan public data open platform[2]. The coordinates of these places are obtained through the Baidu map coordinate picking system and converted to the earth coordinates. The DEM data of Wuhan comes from geospatial data cloud[3]. The data on Wuhan City area, resident population, population density, and other data comes from the Wuhan City Statistical Yearbook (2021)[4].

III. Suitability evaluation of emergency shelters

A. Evaluation system

Based on the functions and significance of emergency shelter, the suitability evaluation of emergency shelter is decomposed into target layer, criterion layer, and index layer by AHP. Combined with Construction Standard of Urban Community Emergency Shelters (JB 180-2017) and Wuhan Emergency Project Management Measures, the evaluation indexes are selected from the four dimensions of effectiveness, safety, reachability and supportability, and finally the analytic hierarchy process model for the suitability evaluation of emergency shelters in Wuhan is constructed (see Fig. 1).

B. Calculation of the model

In this study, following the working methods of Chu et al. [5], the relative importance of each element are obtained and then the judgment matrices of each criterion layer and index layer are constructed, and the weights are calculated after passing the consistency test (shown in Table 1).

TABLE I
Each evaluation index and its weight value

Index Layer	Weight(W)
Refuge area C_1	0.0930
Capacity C_2	0.0930
Functional facilities C_3	0.0465
Topography C_4	0.0841
Distance from major hazard installations C_5	0.1780
Avoid geological hazard-prone areas C_6	0.0519
Avoid hidden points of hydrology C_7	0.0519
Distance from nearest hospital C_8	0.0525
Distance from nearest fire station C_9	0.0597
Distance from nearest public security unit C_{10}	0.0294
Road accessibility C_{11}	0.1362
Daily management C_{12}	0.0928
Sustainable development C_{13}	0.0310

C. Calculation of the comprehensive index

Calculate the comprehensive indexes of emergency shelters in Wuhan, and get the results of suitability evaluation according to the comprehensive index. The calculation process mainly includes:

1) Establish a geographic information database of emergency shelters in Wuhan City using ArcGIS.
2) Give a score to each index. C_3, C_{11} and C_{13} were artificially graded according to the data of each site, and were given 2, 5 and 8 points respectively. Other indexes are divided into 10 levels by using natural breakpoint method in ArcMap, and 1-10 points are given according to the levels to minimize the influence of subjective factors.
3) Use the following formula to calculate the comprehensive index of each emergency shelter.
$$P = \sum_{i=1}^{13} W_i F_i, i = 1, 2, ..., 13$$
4) Conduct suitability evaluation. Divided the calculated comprehensive indexes into five grades (Table 2). The suitability evaluation results of emergency shelters in Wuhan are shown in Table 3 and Figure 2.

TABLE II
Classification of suitability grades

Composite Index(P)	Grade(G)	Grade Description
8.001-10.000	A	Better suitability, it is reasonable in terms of effectiveness, safety, reachability and supportability. It is a good emergency shelter and needs to be maintained and improved.
6.001-8.000	B	Good suitability, it needs to maintain good aspects, and make targeted improvements of deficiencies.
4.001-6.000	C	Medium suitability, it basically meets the functional requirements of emergency shelter and needs further improvement.
2.001-4.000	D	Poor suitability, it still has great room for improvement.
0.000-2.000	E	Poorer, it is not suitable to be used as an emergency shelter.

D. Results analysis

Overall, the emergency shelters in Wuhan are in good condition. Among the 28 selected emergency shelters, 14 are suitable, 13 are medium, and one is sub-standard. Qingshan Park, located in Qingshan District, has the highest suitability level, while the Zhuyehai Park in Qiaokou District is the lowest.

From the effectiveness perspective, more than 57 percent of emergency shelters scored less than 5 points, indicating that they have limited ability to provide help to surrounding citizens in response to emergencies, which is mainly limited by the number of people they can accommodate. Baibuting Garden, located in Jiang'an District, needs to be strengthened because of its small area, the small number of people, and low level of effectiveness.

In terms of safety, the overall situation is quite good. The emergency evacuation places of Lianzheng Park, International Convention and Exhibition Center, Zhuyehai Park, and Wenti Square have potential safety hazards because they are close to

[2]https://data.wuhan.gov.cn
[3]https://www.gscloud.cn
[4]http://tjj.wuhan.gov.cn/tjfw/tjnj/

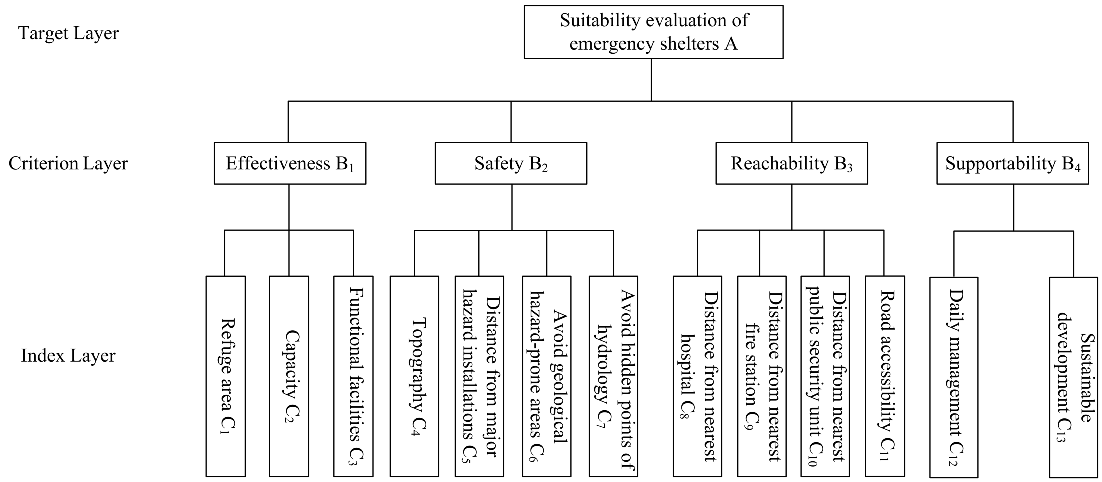

Fig. 1. The AHP model for the suitability evaluation of emergency shelters

TABLE III
SCORE OF EACH CRITERION LAYER AND COMPREHENSIVE INDEX

Administrative Division	Name	B_1	B_2	B_3	B_4	P
Jiang'an District	Baiduting Garden	1.800	8.088	7.161	5.000	5.986
JiangHan District	Zhongshan Park	4.800	4.459	8.305	8.000	6.045
	Changqing Park	6.000	6.345	6.753	8.000	6.583
	International Convention and Exhibition Center	2.600	3.858	9.811	8.000	5.732
Qiaokou District	Qiaokou Park	4.400	6.467	8.026	7.250	6.516
	Zhuyehai Park	4.800	3.345	4.667	2.750	3.977
	Hubei University of Plice	2.600	6.831	4.519	7.250	5.257
Hanyang District	Qintai Square	4.800	4.230	5.449	8.000	5.168
	Sports Training Base	4.200	6.440	7.148	5.750	6.030
Wuchang District	Shahu Park	5.800	5.716	4.459	8.000	5.669
	Integrity Park	4.600	3.973	6.141	8.000	5.220
	Wuhan Conservatory of Music	5.200	4.804	7.106	5.000	5.560
Qingshan District	Qingshan Park	8.600	7.433	5.189	8.000	7.151
	Heping Park	8.600	7.548	4.180	8.000	6.913
Hongshan District	Emergency shelter in Hongshan Square	5.600	5.115	5.426	5.750	5.393
Dongxihu District	Wuhan Dongxihu Vocational Technical School	3.600	7.601	3.478	5.000	5.204
	Wuhuan Square	4.600	6.433	4.010	8.000	5.528
Hannan District	Zhujiashan Park	4.600	6.061	2.060	8.000	4.850
	Shamo Riverbank Park	9.200	6.183	1.321	8.000	5.759
	Hubei Land Resources Vocational College	5.800	5.655	3.131	5.000	4.907
Caidian District	Emergency shelter in Wenti Square	4.400	5.222	3.449	8.000	4.883
	Emergency shelter in Riverbank Park	7.600	7.582	5.817	8.000	7.147
Jiangxia District	Civic Leisure Center	6.000	6.372	2.808	7.250	5.404
	Xiong Tingbi Park	7.800	7.885	2.298	8.000	6.327
	Century Square	5.800	7.088	3.635	8.000	5.942
Huangpi District	Erlongtan Park	3.000	7.946	3.032	5.750	5.159
	Huangpi Square	4.200	5.939	5.689	8.000	5.720
Xinzhou District	Human Defense Evacuation Base	4.000	9.345	4.807	7.250	6.582

major hazard sources such as hazardous chemical enterprises, which means it is necessary to make a response plan for major hazard sources. Human Defense Evacuation Base is located in a flat and high terrain, which effectively avoids geological and hydrological hidden danger points and has a high level of safety.

Regarding reachability, emergency shelters located in the central urban area are generally better, mainly because of their strong road evacuation capacity, good road connectivity, and many surrounding hospitals, police stations, and fire stations. The emergency evacuation places of Hubei University of Plice, Zhujiashan Park, Shamao Riverbank Park and Wenti Square are relatively far away from the hospital, which is not conducive to rapid medical assistance; The stadium of the Hubei Land Resources Vocational College, Erlongtan Park, Huangpi square and Xinzhou District civil air defense evacuation base are far away from the fire station, which is not conducive to the development of rescue operations. For the above emergency shelters, small medical stations and firefighting strongholds can be added, with basic emergency rescue capacity.

From the perspective of supportability, the overall situation of emergency shelters in Wuhan is good, except for Zhuyehai

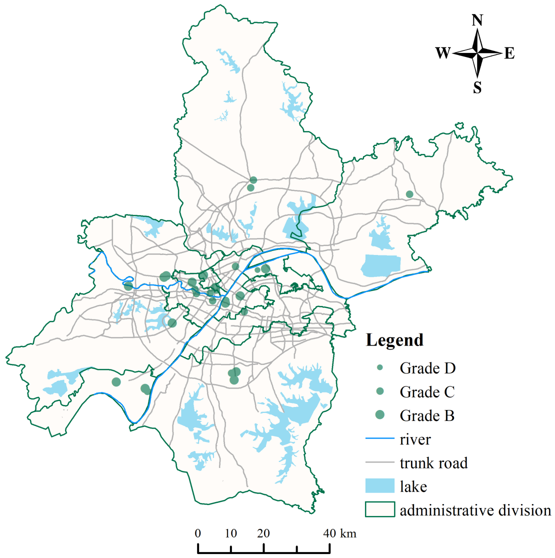

Fig. 2. The suitability evaluation results of emergency shelters

Park, reaching 5 points or more. For the above places, regular maintenance shall be carried out, daily management shall be strengthened, and a complete emergency plan shall be established to realize the sustainable utilization of materials and materials used in shelters.

IV. Capacity Evaluation of Emergency Shelters

A. Evaluation system

Based on the service capacity requirements of urban emergency shelters, this study evaluates the capacity of emergency shelters in Wuhan from three dimensions of satisfaction, effectiveness, and applicability by using TOPSIS according to the Overall Emergency Plan for Emergencies of Wuhan(see Table 4).

B. Build the model

Statistics on the basic situation of emergency shelters, and calculate the total refuge area, total refuge population, and average refuge area of a person, etc., of each administrative division (Table 5).

Determine effective service radius and generate the effective service range. Emergency shelters are places for emergency evacuation and refuge that can be reached within 5-10 minutes after the disaster, considering the collapse of buildings and road damage caused by disasters, the speed for people to move to emergency shelters is set at 4km/h. In this paper, 667m, a 10min walking distance, is taken as the service radius, and the buffers of emergency shelters are generated by using the analytical buffer tool of ArcGIS (Fig. 3).

Determine the coverage area of effective service. The buffer generated above is used to calculate the area of the effective refuge range, and the population density distribution is superimposed with the buffer for geographical statistical analysis so as to calculate the effective refuge population of each district

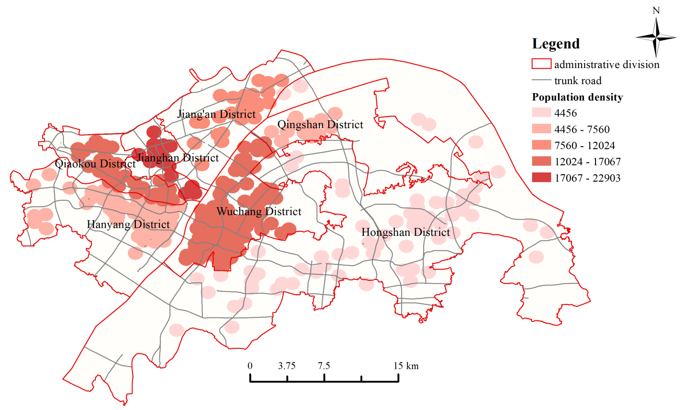

Fig. 3. The suitability evaluation results of the central urban areas

and further calculate the average effective refuge area of a person.

C. Calculation of the model

1) Use the following formula to standardize all secondary indexes and construct the standardization matrix of secondary indicators (Table 6).

$$z_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{7} x_{ij}^2}, j = 1, 2, ..., 6$$

2) $Z^+ = (0.6817, 0.6647, 0.5668, 0.7559, 0.5765, 0.6838)$ is the optimal solution, and $Z^- = (0.1457, 0.1481, 0.0794, 0.0737, 0.1491, 0.0653)$ is the worst according to the standardized matrix.
3) Use the following formulas to calculate the weighted distance between each evaluation object and the optimal solution and the worst.

$$D_i^+ = \sqrt{\sum_{j=1}^{6} w_j (Z_j^+ - z_{ij})^2}$$

$$D_i^- = \sqrt{\sum_{j=1}^{6} w_j (Z_j^- - z_{ij})^2}$$

4) Use the following formula to calculate the degree of closeness between the evaluation object and the optimal solution. The larger Si is, the higher the closeness degree is. The evaluation results are shown in Table 7 and Figure 4.

$$S_i = D_i^- / (D_i^+ + D_i^-)$$

D. Results analysis

Combined with Figure3 and Figure 4, it can be seen that the distribution of emergency places in the central urban area of Wuhan is uneven. From Figure 4, it can be seen that Hongshan District has the strongest capacity of emergency shelters in the central urban area of Wuhan, and Jianghan District has the worst, and there is a noticeable gap. Combined with Table 6 and Table 7, it can be found that Jianghan District has a pronounced disadvantage in terms of effective refuge area,

TABLE IV
THE EVALUATION INDEX OF CAPACITY OF EMERGENCY SHELTER

First index	First weight	Secondary index	The calculation method of secondary index	Secondary weight
Satisfiability	0.35	Total refuge area	The total area of the shelters	0.5
		Total refuge population	Total number of people accommodated in the shelters	0.5
Effectiveness	0.35	Effective range of refuge	The total area of effective service coverage of the shelters	0.5
		Effective range of refuge	The total area of effective service coverage of the shelters	0.5
Applicability	0.3	Average refuge area of a person	Ratio of total refuge area to permanent population	0.5
		Average effective refuge area of a person	Ratio of total refuge area to effective refuge population	0.5

TABLE V
STATISTICS OF EMERGENCY SHELTERS OF CENTRAL URBAN AREA

Administrative Division	Area of administrative division /km10^2	Permanent population /(10^4·cap)	Population density /(cap/ha)	Number of emergency shelters /pcs	Total refuge area /ha	Total refuge population /(10^4·cap)	Average refuge area of a person /m^2
Jiang'an District	80.28	96.53	120.24	60	59.61	28.545	0.6175
Jianghan District	28.29	64.79	229.03	14	55.4522	50.9871	0.8559
Qiaokou District	40.06	66.67	166.42	62	133.301	56.8943	1.9994
Hanyang District	111.54	83.73	75.06	76	173.2681	37.139	2.0694
Wuchang District	64.58	110.22	170.67	100	111.5981	89.9178	1.0125
Qingshan District	57.12	43.18	75.60	22	103.1	68.02	2.3877
Hongshan District	573.28	255.43	44.56	85	259.41	128.14	1.0156
Central urban area	955.15	720.55	75.44	419	895.7394	459.6432	1.2431

TABLE VI
STANDARDIZED RESULTS OF EVALUATION INDEXES

Administrative Division	Total refuge area	Total refuge population	Effective range of refuge	Effective refuge population	Average refuge area of a person	Average effective refuge area of a person
Jiang'an District	0.1567	0.1481	0.3401	0.3195	0.1491	0.0825
Jianghan District	0.1457	0.2645	0.0794	0.1420	0.2067	0.1727
Qiaokou District	0.3503	0.2951	0.3514	0.4570	0.4828	0.1290
Hanyang District	0.4553	0.1927	0.4308	0.2527	0.4997	0.3032
Wuchang District	0.2933	0.4664	0.5668	0.7559	0.2445	0.0653
Qingshan District	0.2709	0.3528	0.1247	0.0737	0.5765	0.6189
Hongshan District	0.6817	0.6647	0.4818	0.1678	0.2452	0.6838

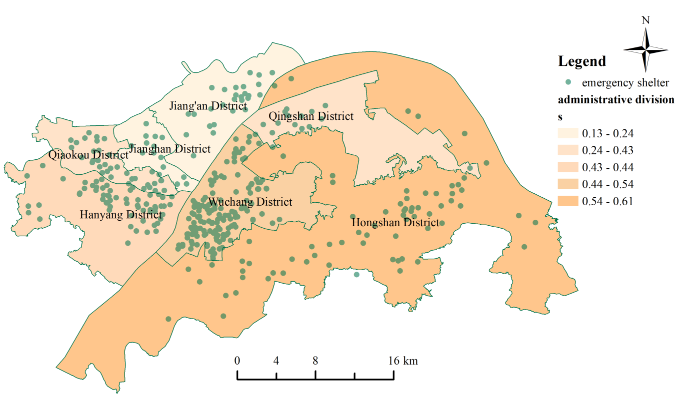

Fig. 4. The results map of evaluation

TABLE VII
THE EVALUATION RESULTS OF THE CAPACITY

Administrative Division	D^+	D^-	S	Ranking
Hongshan District	0.2797	0.4309	0.6063	1
Wuchang District	0.3274	0.3820	0.5385	2
Hanyang District	0.3437	0.2670	0.4372	3
Qiaokou District	0.3382	0.2590	0.4337	4
Qingshan District	0.4035	0.2895	0.4177	5
Jiang'an District	0.4679	0.1501	0.2429	6
Jianghan District	0.4955	0.0736	0.1293	7

and Hongshan District has a significant advantage in three indicators: total refuge area, total refuge population, and average refuge area of a person, which can meet the basic needs of emergency evacuation. In addition, further calculations found that Qiaokou District and Wuchang District have a high proportion of effective service areas. In contrast, Hongshan district and Qingshan District have a high proportion of blind service areas, which need to strengthen the construction of emergency shelters. Hanyang District and Jiangan District have many emergency shelters. However, the proportion of effective service areas still has room for improvement, indicating that the spatial distribution of emergency shelters is not reasonable and needs to be optimized for site selection.

V. Conlusion

In this paper, we mainly discuss the construction of emergency shelters in Wuhan City. Based on principles and methods of spatial analysis of GIS, AHP and TOPSIS were used to conduct a separate and comprehensive evaluation of the suitability and capacity of the shelters to offer a reference to evaluating emergency shelters in other modern medium or large size cities. The refinement of the emergency management governance system and the modernization of governance capabilities are essential links in today's urban governance. The comprehensive capacity of emergency shelters reflects the emergency response capabilities of cities to a certain extent. Each city should scientifically organize, rationally distribute and establish multiple emergency shelters of different types and levels that are appropriate and safe according to its unique circumstances and possible disasters to satisfy its actual needs.

Results show that the emergency shelters in Wuhan need to be improved in the following three aspects. Firstly, it is necessary to improve the status of uneven distribution and an insufficient number of emergency shelters in non-central urban areas, make full use of urban land and space and balance the layout. Secondly, the governance and maintenance of the emergency shelters need to be improved. Parks, squares, stadiums, schools, and other public service facilities should be utilized according to local conditions. Those public infrastructures should be transformed or upgraded into emergency shelters in accordance with the requirements of upgrading by different levels and improving functions. Materials should be reserved for possible disasters, emergency escape instruction signs and emergency broadcasting facilities should be set up, and emergency plan management and emergency drill evaluation should be strengthened. Thirdly, micro-fire stations, medical stations, and emergency rescue teams should be set up in some emergency shelters, medical, fire-fighting and other resources should be rationally integrated and allocated. Unified management and deployment should be conducted as well.

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