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Research on Suitability Evaluation of Emergency Shelter based on RAGA-PP Model

--Taking Yangpu District, Shanghai as an Example

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Abstract

In order to quantitatively evaluate the disaster prevention suitability of urban emergency shelters, this paper construct an evaluation index system for evacuation site suitability from the three aspects of effectiveness, accessibility, and safety. Using real-coded accelerated genetic algorithm (RAGA) to optimize the projection pursuit (PP) model to analyze the suitability of emergency shelters in Yangpu District. The result shows: indicators such as effective evacuation area, distance from medical aid sites, and number of people that can be served have a greater impact on the disaster reduction capabilities of emergency evacuation sites. Among the existing emergency shelters in Yangpu District, the Public Green Space on Dalian Road is highly adaptable. the Fudan Science Park Primary School and Fifteenth Middle School are poorly adaptable, and urgently need to be optimized.

Keywords

Emergency Shelter; Public Safety; Suitability Evaluation; RAGA-PP Model.

1. Introduction

Various disasters occur frequently in cities today, not only natural disasters, but also many man-made disasters. With the continuous advancement of urbanization, the population within the city has become increasingly dense, and the scale of the city has also continued to expand. Once a sudden disaster breaks out, it will cause great damage to the emergency shelter. Scientific and reasonable planning, construction, and management of emergency shelters is an inherent requirement of public safety and a key guarantee for reducing residents' losses. Therefore, it is very necessary to conduct a comprehensive evaluation of the capacity of emergency shelters. In order to provide a quantitative basis for improving the level of emergency refuge and improving the ability of urban disaster reduction.

In terms of the evaluation indicators for the suitability evaluation of emergency shelters, scholars at home and abroad mainly conduct suitability analysis from the aspects of site effectiveness, safety, and accessibility. It mainly involves the internal service capability indicators of the premises, the environmental indicators of surrounding hazards, and the indicators associated with emergency support facilities [1-3], and there is a lack of a more systematic indicator evaluation system. In terms of suitability evaluation methods, it mainly focuses on the use of fuzzy set value [4], matter element extension model [5], analytic hierarchy process [6], grey relational analysis and ArcGIS spatial analysis [3] for static emergency shelters Overview. Less consideration is given to the impact of disaster intensity on the nonlinear attenuation of accessibility indicators with distance.

These methods all need to determine the evaluation index weight first, and the index weight does not change with the index data structure.

Therefore, on the basis of summarizing and analyzing the existing research results, this article constructs an evaluation index system for the suitability of emergency shelters from the perspective of comprehensive disaster prevention suitability. Besides,we consider the attenuation effect of accessibility index with distance under disasters and use RAGA-PP model to evaluate and analyze the suitability of urban emergency shelters.It could provide a scientific basis for the layout and transformation planning of emergency shelters.

2. Modeling

2.1 Selection and Quantification of Suitability Evaluation Index

There are many evaluation criteria for the emergency capacity of urban emergency shelters, and there are many qualitative factors contained therein. It is necessary to consider the planning and design of emergency shelters, internal hardware facilities, and external software environment [8]. The basic requirement of emergency shelters is to be able to provide safe shelters. The safety, accessibility and effectiveness of urban emergency shelters are an organic whole [9, 10]. Based on the inherent characteristics of their interrelationships, combined with the site selection and layout requirements of emergency shelters and the requirements and specifications of domestic and foreign shelters, this paper constructs an evaluation index system for the suitability of emergency shelters,see Table 1.

Table 1. Evaluation index system for suitability of emergency shelter

Target	Guidelines	Index	Indicator direction
Evaluation of the spatial suitability of emergency shelters	Effectiveness(A)	Serviceable population(A1)	Positive
		Effective evacuation area(A2)	Positive
		Openness of borders(A3)	Positive
	Accessibility(B)	Distance to medical aid(B1)	negative
		Accessibility of evacuation roads(B2)	Positive
		Psychological accessibility(B3)	Positive
	Safety(C)	Distance to hazard(C1)	Positive
		Distance to surrounding buildings(C2)	Positive
		Building safety(C3)	Positive

2.2 RAGA-PP Model

Projection Pursuit Model(PP) is driven by sample data, a method of processing high-dimensional data such as non-linearity and non-normality. It can project high-dimensional data into a low-dimensional subspace, and determine the best projection direction based on maximizing the projection objective function to obtain the structural characteristics of high-dimensional data [11]. This model is superior to the general traditional model in terms of robustness, anti-interference and accuracy. This paper introduce Real Coded Accelerating Genetic Algorithm(RAGA)on this method to find the best projection method, The specific modeling process is as follows [12]:

Step1 Standardized sample indicators.

Suppose the evaluation index set $\{x^*(i,j)|i=1,2,\cdots,n\,;j=1,2,\cdots m\}$, $x^*(i,j)$ is the j index value of the i refuge place, and n and m are the number of refuge places to be evaluated and the number of evaluation indexes respectively. Since the dimensions of each index value are not uniform, the following methods should be used to standardize the data:

Positive indicators:

$$x(i,j)=\frac{x^*(i,j)-x_{min}(j)}{x_{max}(j)-x_{min}(j)} \tag{1}$$

Negative indicators:

$$x(i,j)=\frac{x_{max}(j)-x^*(i,j)}{x_{max}(j)-x_{min}(j)} \tag{2}$$

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$x_{max}\ (j)$, $x_{min}\ (j)$ are the maximum and minimum values of the j sample index value respectively. $x(i,j)$ is the normalized processing result of the sample index.

Step2 Construct the projection index function.

Project the index of the evacuation site into a one-dimensional space to obtain a projection value reflecting the suitability of the evacuation site, and the projection value can be considered as a quantitative value of its suitability. Let $a = \{a(1), a(2), \cdots a(m)\}$ be the projection direction vector, the one-dimensional projection value of sample i in this direction is:

$$z(i) = \sum_{j=1}^{m} a(j)\, x(i,j), i = 1,2, \cdots m \tag{3}$$

When optimizing the one-dimensional projection value, $z(i)$ is required to be scattered as much as possible in the overall distribution, and concentrated as much as possible locally, so the projection index function is constructed as:

$$T(a) = S_z D_z \tag{4}$$

S_z, D_z are the standard deviation and the intra-class density of $z(i)$:

$$S_z = \sqrt{\sum_{i=1}^{n} \frac{(z(i)-\bar{z})^2}{n-1}} \tag{5}$$

$$D_z = \sum_{i=1}^{n} \sum_{j=1}^{n} \left(R - r_{ij}\right) \cdot f\left(R - r_{ij}\right) \tag{6}$$

$\bar{z}$ is the average value of the projection value; R is the window radius of the local density; $f\left(R - r_{ij}\right)$ is a unit step function,when $R \geq r_{ij}$, the value is 1, otherwise it is 0.

Step3 Optimize the projection index function.

When the projection index function takes the maximum value, the corresponding vector reflects the best projection direction of the data, and searching for the best projection direction is transformed into a nonlinear optimal solution problem.

$$\begin{cases} max{:}\, T\,(a) = S_z D_z \\ s.t.{:} \sum_{j=1}^{m} a^2(j) = 1, a \in [0,1] \end{cases} \tag{7}$$

The traditional optimization method is not easy to solve the complex nonlinear optimization problem with the projection direction vector as the optimization variable, so this paper uses the RAGA based on real number coding to perform high-dimensional global optimization.

Step4: Rank the pros and cons

Incorporate equation (3) to calculate the projected characteristic value of the evacuation site to be evaluated without quantification processing. According to $z(i)$, the suitability of the shelter is ranked.

3. Empirical Research

3.1 Overview of the Study Area

According to "Shanghai Emergency Refuge Design Code", emergency shelters are divided into three levels: Class I, II, and III. Different levels of emergency shelters have different service radii and resource allocations. The higher the level, the greater the scope of impact and attractiveness of the emergency shelters on surrounding residents. Class I is a long-term fixed refuge in the national standard, with large scale, complete functions, and high safety factor. It is coordinated with the transitional Class II and Class III emergency refuges to provide service radiation to completely cover the research area.

Yangpu District has built 1 emergency shelter for class I, 10 emergency shelters for class II, and 1 emergency shelter for class III. The relevant data comes from the Shanghai Civil Defense Network. Carry out the suitability assessment of the existing 12 emergency shelters to test the disaster prevention suitability status of the emergency shelters, and guide the optimization of the layout or transformation of the urban emergency shelters. According to the urban emergency shelter suitability evaluation index system and its quantitative method, the basic data of 12 emergency shelter suitability indexes are shown in Table 2.

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Table 2. Basic data of suitability index for emergency shelter

Name	Rank	Effectiveness (A)			Accessibility(B)			Safety(C)		
		A1	A2	A3	B1	B2	B3	C1	C2	C3
Zhongyuan Road Primary School	II	4000	0.79	3	0.743	6	0.105	0.606	0.567	2
Fudan Science Park Primary School	II	1900	0.38	1	0.908	5	0.024	0.631	0.712	1
Baotou Middle School	II	3200	0.64	2	0.242	7	0.068	1.201	1.034	2
Fudan Experimental Middle School	II	2500	0.56	3	0.998	8	0.047	0.675	0.856	2
Shaoyun Middle Schoo	II	5000	0.99	1	1.705	7	0.165	1.100	0.786	2
Junior High School Affiliated to USST	II	3000	1.18	2	0.296	6	0.118	1.625	2.345	2
Kongjiang Junior high school	II	2500	0.548	2	0.462	9	0.046	0.438	0.986	2
High School Affiliated to USST	II	2500	0.5	2	0.880	8	0.042	0.998	1.569	2
Tieling Middle School	II	2800	0.92	2	1.080	8	0.086	0.632	0.345	2
High School Attached to Education College	II	2000	0.485	1	0.971	6	0.032	0.487	0.483	2
Dalian Road Public Green Space	I	15000	2	5	0.374	12	1.000	0.794	1.987	3
Fifteenth Middle School	III	900	0.18	1	0.815	5	0.005	1.706	0.672	1

3.2 Suitability Analysis of Emergency Shelter in the Study Area

Substitute the data in Table 2 into the projection pursuit model, and use the RAGA-PP to solve the model [13, 14]. According to formula (1-7), MATLAB 2020 software is used to process the data. Setting $N = 400$, $P_c = 0.08$. The number of outstanding individuals is 20, and the number of accelerations is 7. Finally, we Get the best projection direction vector$a$ =(0.4531, 0.5098, 0.3244, 0.4929, 0.1392, 0.2295, 0.3094, 0.1218, 0.0916), the projection direction value of each evaluation index is shown in Figure 1. Putting into equation (3) to get the projection value of each emergency shelter, see Figure 2.

The best projection direction vector essentially reflects the degree of influence of each evaluation index on the suitability of emergency shelters. The larger the value, the greater the influence. It can be seen from Figure 1 that indicators A2 (effective evacuation area), B1 (distance from medical assistance sites), and A1 (serviceable population) have a greater impact on the suitability of evacuation sites. It can also be seen that the indicators C3 (building safety), C2 (distance to surrounding buildings), and B2 (accessibility of evacuation roads) have little impact on the suitability of evacuation sites.

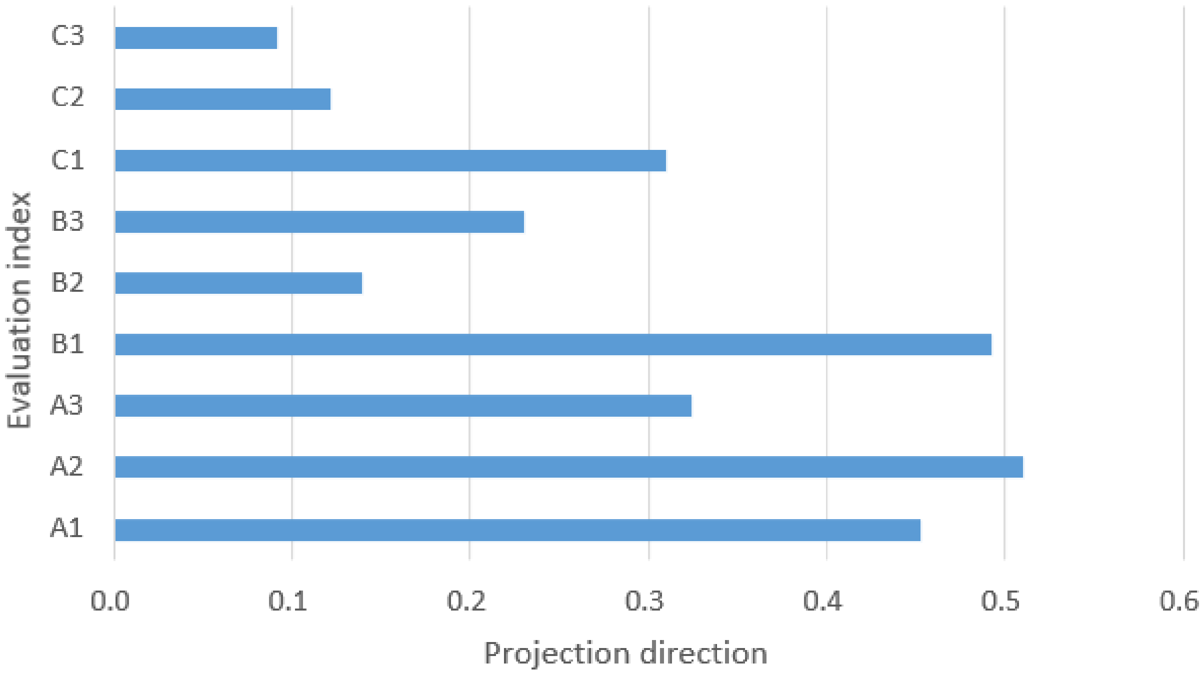

Fig. 1 Projection direction of each evaluation index

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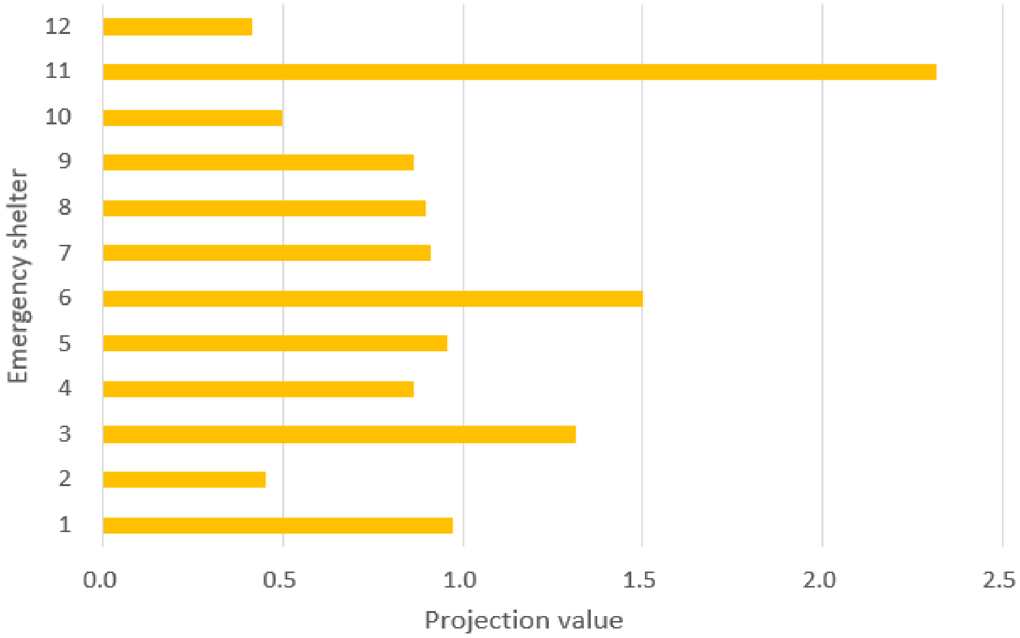

Fig. 2 Projection value of each emergency shelter

According to the sorting characteristics of the projected value of the shelter, the suitability of the shelter is divided into four levels: very suitable ($z(i) > 1.5$), suitable ($1.5 \geq z(i) > 1.0$), relatively suitable ($1.0 \geq z(i) > 0.5$) and inappropriate ($z(i) \leq 0.5$). It can be seen from Figure 2 that refuge area 11# is extremely suitable, refuge area 3 and 6 are suitable, refuge area 2, 12 is unsuitable, and other refuge areas are more suitable. In order to analyze the influencing factors of 2,12# unsuitable refuge places, a dimensionless radar chart of the suitability index of 2,12# refuge places was drawn, see Figure 3 and Figure 4.

Figures 3 and 4 show that the C3 (building safety) and B2 (accessibility of evacuation roads) indicators of 2, 12# emergency shelters are relatively good for disaster prevention, and the indicators B3 (psychological accessibility) and A1 (serviceable population) is very poor. These two emergency shelters and the surrounding environment, facility layout, etc. should be comprehensively transformed to enhance the comprehensive suitability of the shelter. Alternatively, a place with better surrounding conditions should be selected as a fixed emergency shelter.

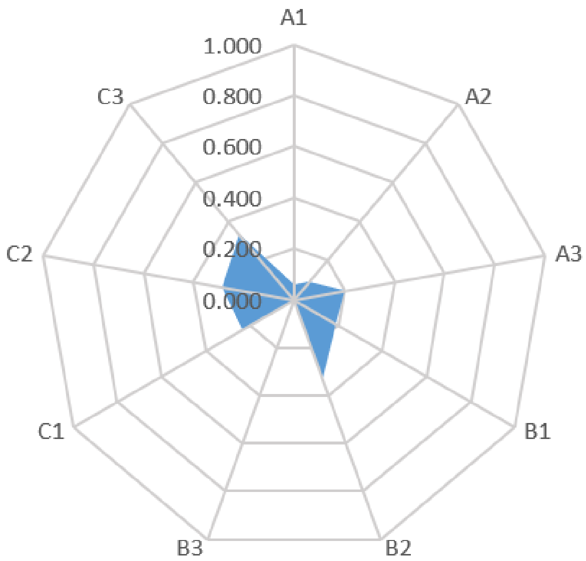

Fig. 3 2# Radar chart of evacuation site suitability factor

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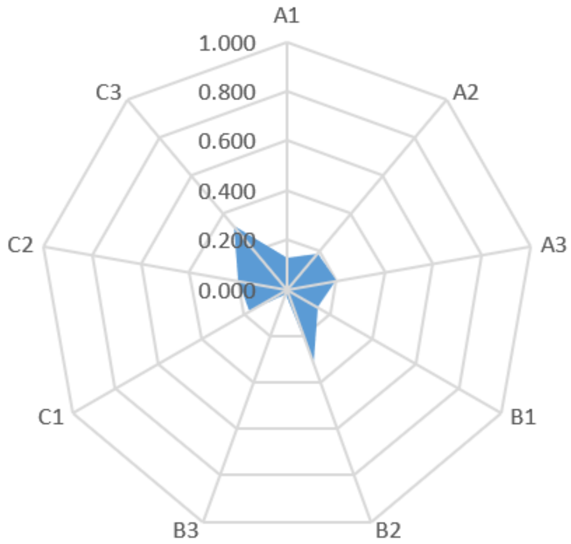

Fig. 4 4# Radar chart of evacuation site suitability factor

4. Conclusion

Based on the three first-level indicators of efficiency, accessibility and safety of emergency shelters, this paper constructed an evaluation index system for emergency shelters, and used the RAGA-PP model for empirical analysis to evaluate the disaster mitigation capabilities of emergency shelters Suitability evaluation in Yangpu District. This method overcomes the problems that traditional evaluation methods cannot satisfy the analysis of high-dimensional non-normally distributed data, and at the same time solves the problems that the evaluation deviates from the objective and cannot find the internal laws and characteristics of the data.

From the evaluation results, indicators such as the effective evacuation area, the distance from the medical aid site, and the number of serviceable population have a greater impact on the disaster reduction capacity of emergency evacuation sites. Among the existing emergency shelters in Yangpu District, the Public Green Space on Dalian Road is highly adaptable. the Fudan Science Park Primary School and Fifteenth Middle School are poorly adaptable, and urgently need to be optimized.

In the future, the index system will be refined, and residents' selection and evacuation behavior factors will be included in the index system, and the influence laws of evacuation demand and walking accessibility under the influence of different earthquakes will be quantified, and the disaster prevention suitability of refuge sites will be analyzed in a refined manner.

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