

# Review of research on disaster mitigation emergency congregate shelter planning for vulnerable group

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**Abstract.** The elderly, including individuals with disabilities, women, and children, among other vulnerable evacuees, are the most fragile group during disasters. During major disasters, safely and rapidly transferring vulnerable evacuees to shelters that can meet their sheltering needs is crucial and challenging in emergency rescue work. This article systematically analyzes the sheltering behavior characteristics and sheltering needs of vulnerable evacuees based on relevant research at home and abroad. It also reviews the technical indicators and requirements for emergency shelter planning for vulnerable evacuees, and studies emergency shelter planning models from the perspective of vulnerable evacuees. Finally, it proposes prospects for emergency shelter planning indicators and models based on vulnerable evacuees, providing a reference and guidance for improving and enhancing emergency sheltering strategies for vulnerable evacuees.

**Keywords:** shelter, refuge vulnerable people, shelter needs, planning indicators, planning model.

## 1. Introduction

In recent years, China has frequently experienced major natural disasters such as earthquakes and floods, as well as accidents and catastrophes like harmful gas leaks and oil tank explosions. Major disasters or accidents can cause severe damage to buildings and infrastructure, leading to the loss of basic living conditions for many residents who need to be relocated to emergency shelters. According to statistics, in 2023 alone, various natural disasters affected 95.44 million people to varying degrees, resulting in 691 deaths and disappearances, and 3.344 million people were urgently relocated. The direct economic loss was 345.45 billion yuan [1]. Among the disaster evacuees, there is a particularly vulnerable group: the elderly, including disabled individuals and women and children. This group often struggles to access timely and effective information and take appropriate evacuation measures during disasters. Their ability to cope with, avoid, and prevent illness during disasters is even more fragile. Historical disaster statistics from both domestic and international sources show that vulnerable evacuees make up a significant portion of the total casualties. For instance, the 1995 Hanshin Earthquake resulted in 6,400 deaths and 40,092 injuries, with more than half being elderly; the 2011 Great East Japan Earthquake had a population mortality rate of 1.03 %, whereas the rate for disabled individuals was 2.06 %. Of the 9,362 deaths in Iwate, Miyagi, and Fukushima Prefectures, 5,132 were elderly over 65 years old, accounting for 54.8 % [2]. In the 2005 Hurricane Katrina disaster in the U.S., elderly individuals accounted for about 71 % of the casualties in Louisiana [3]. In 2008, the Wenchuan earthquake affected no less than 3.5 million people over the age of 65, no less than 1 million people in need of emergency resettlement, and about 30,000 orphaned elderly people lost their relatives [4]. With the increasing trend of population aging in China (as shown in Figure 1), the number of elderly evacuees is growing, presenting new challenges for disaster emergency rescue and management.

The study of emergency shelters in China started relatively late and has undergone a phase of preliminary exploration (2003-2007) and a rapid development phase (2008-2015) [5]. Existing research on emergency shelter planning primarily focuses on optimizing the layout of shelters [6]-[8], suitability assessments [9]-[11], site selection [12]-[16], and accessibility analysis

[17]-[18]. Most of this research is from the perspective of managers, establishing mathematical models based on conditions such as evacuation distance, evacuation time, and shelter capacity limitations, to provide a scientific basis for the planning and construction of emergency shelters. As research has progressed, more scholars have begun to pay attention to vulnerable evacuees [19]-[21], but the literature on this is limited, offering only general guiding principles [22]. Therefore, this paper summarizes and reviews relevant domestic and international literature, deeply explores the evacuation behavior characteristics and needs of vulnerable evacuees, and examines the standards and latest research on planning technical indicators for vulnerable evacuees in emergency shelters. It also analyzes existing planning models for emergency shelters to understand the dynamics of research development, providing references and insights for improving and enhancing the planning of emergency shelters for vulnerable populations.

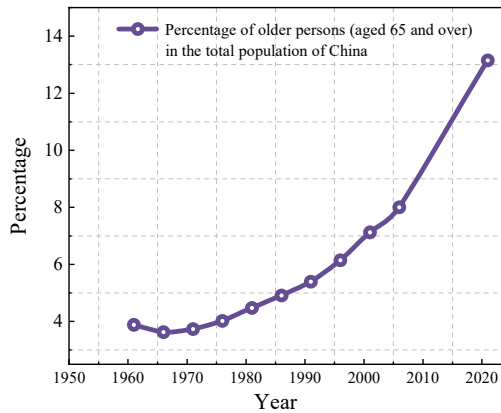


Fig. 1. Percentage of older persons (aged 65 and over) in the total population of China

## 2. Behavioral characteristics and refuge needs of vulnerable refugees

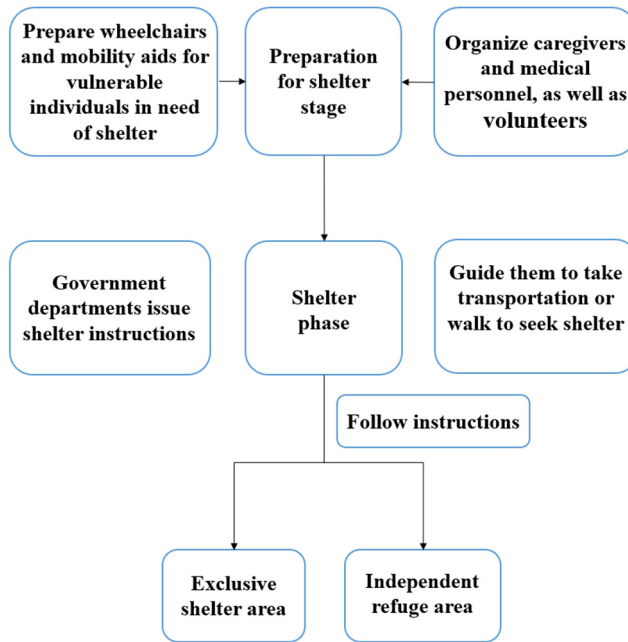
### 2.1. Definition and characteristics of vulnerable refugees

Generally speaking, vulnerable evacuees mainly refer to the “old, weak, sick, disabled, pregnant”, as well as foreign tourists with language barriers or intoxicated individuals. These individuals have weak abilities to access and relay disaster information and may have difficulties taking appropriate evacuation measures when their personal safety is threatened. They are a group of people who require special attention. Japan first proposed the concept of disaster vulnerability in 1987, categorizing vulnerable groups in the year following the Great Hanshin Earthquake, which included the elderly, physically disabled individuals, the injured and sick, infants and young children, pregnant women, those with difficulties returning home, and travelers. In August 2004, the U.S. FEMA introduced the term “Disaster for People with Disabilities and other Special Needs” in its preparedness plan. In March 2002, Premier Zhu Rongji used the term “vulnerable groups” in the Government Work Report during the 9th National People’s Congress session, popularizing the concept of vulnerable groups and drawing widespread attention domestically and internationally. This study compiles the characteristics of vulnerable evacuee groups based on Japanese and American literature, as shown in Table 1.

Vulnerable evacuees exhibit information vulnerability, action vulnerability, and disaster adaptation vulnerability in disaster evacuation [23]. When receiving alerts of major natural disasters or when disasters have already occurred, vulnerable evacuees require assistance from government agencies and their caregivers to carry out evacuation actions (Fig. 2). Based on this, early scholars proposed the establishment of a database for vulnerable evacuees in advance, in order to provide assistance before disasters occur, effectively reducing the chances of vulnerable groups being affected by disasters when they strike [24]-[25].

**Table 1.** Vulnerable refugees and their main characteristics

Category		Key features
Elderly	Single	Can generally act independently, but may have delayed reactions in detecting disasters and taking shelter
	Bedridden person	Eating, excreting, dressing, and undressing all require assistance from others in daily activities
	Dementia	Has intellectual disabilities and finds it difficult to make judgments and act independently
Pregnant woman, postpartum woman		Can act independently, but finds it difficult to evacuate quickly
Infants and young children		Young age, requires supervision
Disabled people		Has visual, hearing, physical disabilities, making it difficult to evacuate independently
Severely ill patients		Lacks the ability to evacuate independently
Foreign tourists		Unable to receive disaster alerts in a timely manner due to the lack of a common language
Drunk person		Drinking excessively and unable to evacuate independently



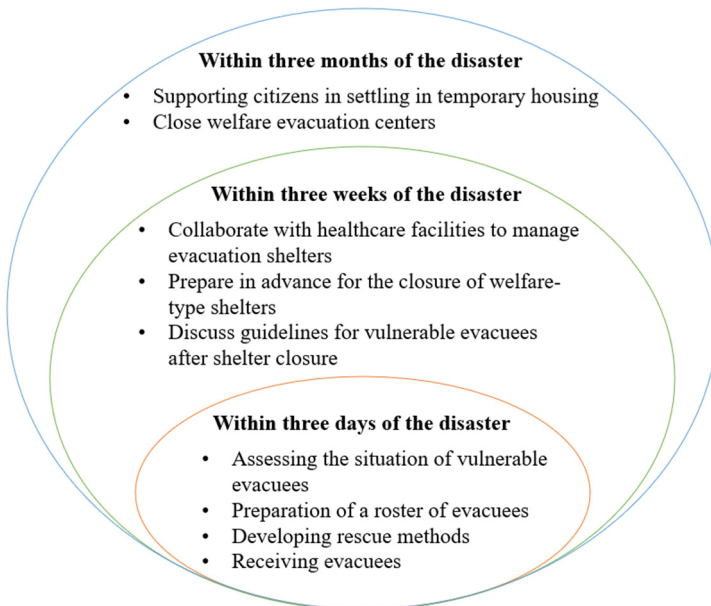
**Fig. 2.** Diagram illustrating the process of sheltering the vulnerable

## 2.2. Refuge needs of vulnerable refugees

Vulnerable evacuees have higher demands for the quality of life in shelters, safety facilities, and medical supplies, including shorter evacuation distances, a preference for indoor shelters, and larger shelter spaces [26]-[28]. Japan, as one of the first countries to focus on vulnerable groups, established “welfare-type shelters” in 2007, based on the “3-3-3” evacuation principle [29] (Fig. 3). These shelters are designed to provide more detailed evacuation services for vulnerable groups such as the elderly, weak, sick, disabled, and pregnant individuals. In the United States, special needs shelters have been established, which differ from welfare-type shelters by focusing on providing medical services, representing a further refinement of welfare-type shelters. Researchers in Japan and the U.S. continue to study the evacuation needs of vulnerable groups. Noguchi Sadahisa [30] pointed out that in Japan’s aging society, evacuation needs for the elderly and other vulnerable groups should be considered from multiple aspects including medical care, welfare, and housing. Tsujii Yasuo [31] analyzed the actual losses caused by aging populations in

the Hanshin Earthquake and the Great East Japan Earthquake, highlighting the importance of human resources in coordinating safe evacuation for the elderly and other vulnerable evacuees. Alisan et al. [32] considered the spatial distribution and special needs of the elderly, proposing strategies for converting functions between special needs shelters and regular shelters. Shinozaki Masami [33] analyzed the evacuation situations of vulnerable evacuees in different countries and suggested that accessible and safe evacuation facilities should be provided to meet their special evacuation needs.

At present, China has not established separate shelters specifically for special groups, and related research has also rarely considered the differences among shelter users. In recent years, some scholars have proposed strategies and planning research for vulnerable evacuees, such as the elderly. For example, Yang Xinjie [34] approaches the issue from the perspective of the elderly, advocating for horizontal evacuation and proposing improvement strategies based on planar types to address fire safety issues. Yu Shuijun [35], Xia Yang [36], and others have studied the safety evacuation issues of individuals with visual, auditory, and physical disabilities in the context of building fires, proposing corresponding evacuation plans to assist building fire protection designers. Some scholars, like Yang Guiying [37], have considered the vulnerabilities of evacuees such as the elderly, pregnant women, and children, suggesting that disaster victims in emergency shelters should be categorized and managed. Specific measures should be taken to ensure service and protection according to the vulnerabilities and needs of these special disaster victims. Li Wenjing [38], through research on the “6·17” earthquake in Changning, summarized the changing needs of vulnerable evacuees in the early, middle, and late stages after a disaster and proposed planning measures for shelters, including establishing a database for vulnerable evacuees, optimizing shelter site selection, and improving construction standards for shelters.



**Fig. 3.** The “3·3·3” principle of welfare-based emergency shelters in Japan

### **3. Technical indicators and requirements for planning shelter for vulnerable refugees**

#### **3.1. Evacuation standards**

In terms of research on planning indicators for shelters, China has issued 41 emergency shelter-related standards, which mainly focus on site selection, planning, and design. These

standards cover various types of disasters including earthquakes, accidental disasters, and public emergencies. Although some standards have started to address the evacuation needs of vulnerable groups such as infants, the elderly, and individuals with disabilities, service standards specifically for groups with special needs, such as the elderly, the sick, the disabled, and pregnant women, are still lacking [39]-[40]. In contrast, the standards framework and content in regions and countries like Europe, the United States, and Japan are relatively comprehensive. These countries place high importance on the development of standards for shelters specifically for vulnerable evacuees. They have established standards dedicated to these groups and each standard takes into account the special evacuation needs of vulnerable evacuees, such as accommodation space and passageways. A summary of some related standards is shown in Table 2.

**Table 2.** Planning requirements for sheltering vulnerable populations in domestic and international standards

	Standard name	Related content
International organizations	Humanitarian Shelter and Settlements Guidelines [41]	The concept of putting people first was proposed, emphasizing that refuge and temporary shelter should be more humane
	Emergency Shelter Haiti, Field Notes [42]	It was suggested to upgrade shelters and provide assistance to vulnerable groups
United States	FEMA P-785: Shelter Field Guide [43]	Detailed planning indicators were outlined for the construction of indoor shelters, focusing on functional zoning for vulnerable evacuees, accessibility treatment, and facility optimization
	Sheltering Handbook [44]	
	Guidance on Planning for Integration of Functional Needs Support Services in General Population Shelters [45]	It is specified that disaster shelters must meet the needs of people with disabilities, and a set of accessible shelter design standards has been issued to help emergency management personnel and shelter planners provide more appropriate shelter spaces for children and adults with special needs
	ADA Checklist for Emergency Shelters [46]	
	Mega-shelter Planning Guide [47]	
Japan	Refuge Support Guidelines for Aid Providers during Disasters [48]	Provide definitions of those in need of assistance during disasters: specifically referring to elderly individuals, people with disabilities, foreigners, infants and young children, and pregnant women
	Refuge Action Support Strategy Guidelines for Supporters of Evacuation Actions [49]	The term “caregivers during disasters” replaces “those in need of assistance during disasters”
	Basic Act on Disaster Countermeasures (2013) [50]	Propose to establish a registry of support personnel for the elderly, people with disabilities, infants, and young children in need of assistance during evacuation actions
China	Earthquake Emergency Shelter Locations and Supporting Facilities [51]	Propose that all types of facilities should consider accessibility requirements and be set up in accordance with the provisions of JGJ50-2001 [52]
	Design Standards for Disaster Shelter Facilities [53]	It is proposed that specialized disaster shelters for vulnerable populations, specialized refuge areas, or specialized refuge units should meet accessibility design requirements and construction standards

### 3.2. Type of evacuation site

(1) Dedicated Shelters for Vulnerable Groups. Shelters that vulnerable groups can quickly reach and safely stay in must consider not only the scale and needs of these groups but also the primary types of disasters. In the case of disasters such as earthquakes, outdoor shelters like parks and squares should be prioritized. For disasters such as floods or hurricanes, indoor shelters should be emphasized; urban areas can set up shelters in places where the elderly typically gather, such as nursing homes, maternal and child hospitals, and senior activity centers. In rural towns, shelters can be established in familiar locations for vulnerable groups, such as village committees, nursing homes, and schools, to facilitate centralized management and special care during a disaster.

(2) Designated Areas for Vulnerable Groups within Fixed Shelters. The functional zoning within fixed shelters should be detailed and clear, creating relatively independent areas for vulnerable groups based on their numbers. Each shelter area should be equipped with guiding signs and layout maps to help vulnerable individuals conduct their shelter lives in an orderly manner. Within these areas, emergency medical facilities and other auxiliary services should be provided according to the needs of the vulnerable groups.

### 3.3. Plan technical specifications

(1) Evacuation Distance. According to the “Design Specifications for Disaster Shelters”, the evacuation distance indicators should comply with those shown in Table 3.

**Table 3.** Evacuation indicators

Venue category	Evacuation distance/km
Long-term fixed evacuation sites	≤ 2.5
Medium-term fixed evacuation sites	≤ 1.5
Short-term fixed evacuation sites	≤ 1.0
Emergency shelters	≤ 0.5

(2) Scale of the Shelter and Effective Evacuation Area per Person. According to the “Design Specifications for Disaster Shelters”, the effective evacuation area, short-term shelter capacity, and total population for emergency services in the shelter should comply with the indicators shown in Table 4. Depending on different shelter arrangements, the average net usable area per person (m<sup>2</sup>) is as shown in Table 5.

**Table 4.** Indicators of effective evacuation area, short-term evacuation capacity, and emergency service population

Venue category	Effective evacuation area / hm <sup>2</sup>	Short-term evacuation capacity (10,000 people)	The total population of emergency services in the area of responsibility (10,000 people)
Long-term fixed evacuation sites	≥ 5.0	≤ 9.0	≤ 20.0
Medium-term fixed evacuation sites	≥ 1.0	≤ 2.3	≤ 15.0
Short-term fixed evacuation sites	≥ 0.2	≤ 0.5	≤ 3.5
Emergency shelters	–	–	–

According to the standards for effective evacuation area per person in Japanese welfare-oriented disaster shelters, which require an area of 2 to 4 m<sup>2</sup>, the standards in China’s “Design Specifications for Disaster Shelters” are somewhat lacking. Taking long-term bedridden patients as an example, the footprint of a typical hospital bed is about 1.8 m<sup>2</sup>, with a spacing of approximately 0.8 m between adjacent beds and a 1 m wide aisle for wheelchair access. This results in an average usable area of about 4.25 m<sup>2</sup> per person. However, the Chinese standards

specify an average net usable area of only 4 m<sup>2</sup> for individuals who need to remain bedridden for extended periods. If additional barriers or enclosures are required in certain situations, the space needed will increase. Therefore, it is necessary to adjust the relevant control indicators for shelters at all levels to better meet the evacuation needs of vulnerable individuals.

**Table 5.** Indicators of effective evacuation area, short-term evacuation capacity, and emergency service population

Evacuation posture	Evacuation period				
	Urgent	temporary	short-term	medium-term	long-term
Stand or sit	0.50	0.70	–	–	– m <sup>2</sup>
Can be reclined and rested	0.70	1.08	1.08	1.50	2.00
Wheelchair users	1.00	2.00	2.00	3.00	3.00
Those who need to stay in bed for a long time	3.00	3.00	3.00	4.00	4.00

(3) Other Requirements. According to the “Practical Assessment Standards for Persons with Disabilities in China”, it is stipulated that medical personnel and caregivers should be assigned to individuals with severe or even moderate disabilities, with a caregiver-to-special-needs individual ratio of 1:1 for those with severe disabilities, pregnant women in labor, and elderly individuals over 70 years old. The “Design Specifications for Disaster Shelters” state that the effective evacuation area in the emergency medical health care zone of the shelter should be determined by the number of hospital beds, with the average effective evacuation area per bed not being lower than the values specified in Table 6. If there are critically ill patients requiring treatment, the area should not be less than 1.5 times the values specified in Table 6.

**Table 6.** The beds in the medical rescue area are all effective evacuation areas

Size (hospital bed)	Effective evacuation area (m <sup>2</sup> /bed)
30	40
60	30
100	20
200	15

In related research, scholars from Japan and the United States have achieved a series of results. Some researchers have focused on the operational issues of evacuation sites post-disaster, studying the evacuation management of elderly people after the Great East Japan Earthquake and tsunami, and have proposed effective internal medical and disaster relief recommendations [54]-[55]. Other scholars, such as Ishii et al. [56] and Kambara et al. [57], have studied evacuation assistance tools for vulnerable individuals, noting that about 60 % of elderly people in their later years find it difficult to evacuate to large-scale evacuation sites and need to consider the use of mobility aids like wheelchairs and stretchers with the support of caregivers.

Domestic scholars have focused on evacuation and sheltering issues. For example, Deng Zizheng [58] conducted field measurements to obtain data on the preparation time for fire safety for vulnerable evacuees, horizontal walking speed, vertical evacuation speed with backpacks, and vertical evacuation speed with stair-climbing devices. This data was organized into human factor data tables, providing a reference for improving the safety of vulnerable evacuees. Zhuang Ling et al. [59] analyzed safety evacuation issues in elderly care facilities, proposing evacuation width indicators based on the elderly’s physical ability or care level and providing specific calculation methods in combination with evacuation corridor widths. Cao Shasha [60] addressed evacuation issues in the old urban area of Qingdao, improving the age-friendly design of evacuation spaces from multiple dimensions, including shelters, evacuation routes, and auxiliary facilities, to enhance Qingdao's ability to respond to emergencies. Zhang Sen et al. [61] tested the walking speed of visually impaired individuals and, based on the results, redefined the service radius of shelters and planned a new blind pathway system, creating a multi-level evacuation system suitable for visually impaired people.

#### 4. Planning models and methods for sheltering vulnerable refugees

The rational planning and construction of emergency shelters play a crucial role in disaster warning responses, rescue operations, and transitional settlement processes. They are essential for relocating and protecting affected populations and maintaining social stability. In the planning and design of shelters, scholars often use objectives such as minimizing evacuation distance and time, with constraints including shelter capacity and service range. They construct mathematical models using various methods and design algorithms to verify the feasibility of these models. For layout optimization issues, methods such as social network models [6], GIS technology [7], and spatial syntax [8] are commonly used to evaluate and optimize the functional layout of shelters. In suitability assessment, methods like grey relational analysis [9], matter-element extension models [10], and entropy methods [11] are employed to assess the planning, design, rationality, and safety of shelters. Regarding site selection optimization, classic single-objective models such as the P-median model [62], P-center model [63], set covering model [64], and maximal coverage model [65], along with their improved versions [12]-[14], are widely applied by scholars both domestically and internationally. In recent years, researchers have begun to construct multi-objective, multi-constraint hierarchical models [15]-[16] that consider accessibility, equity, and public preference for shelter site selection. For accessibility analysis, methods like the Gaussian two-step moving search method [17] and statistical indicators [18] are used to provide references for adjusting and optimizing shelter layouts. It is evident that significant progress has been made in research related to emergency shelters in our country.

However, research specifically focused on planning models for vulnerable evacuees is scarce. Among the few international studies, Ozguven et al. [66] conducted a comprehensive assessment of the emergency evacuation needs of elderly people in Florida using metadata processing methods to promote the safe and accessible evacuation of seniors. However, their study did not address the evacuation issues of multiple types of vulnerable evacuees. Kocatepe et al. [67] focused on elderly individuals aged 85 and above with special needs in Southeast Florida. They used a GIS-based spatial capacity p-median optimization model to analyze case data and created various scenarios to simulate the evacuation of people aged 85 and over residing in evacuation zones. This provided dynamic congestion travel times to improve the accessibility of evacuation for this group. However, their study did not consider preparation and walking times before and during evacuation and also focused solely on the elderly as a vulnerable group. Horner Mark et al. [68] designed a GIS-based network optimization method for selecting special needs hurricane evacuation sites to maximize accessibility for vulnerable populations such as the elderly. They analyzed plans to increase special needs evacuation capacity considering potential uncertainties in transportation network availability. However, their focus was on macro-level control and did not adequately address the actual evacuation needs of vulnerable groups. Iwata Masashi et al. [69] used rank matrix methods to evaluate the fire evacuation safety of vulnerable evacuees such as people with disabilities, infants, young children, and the elderly, and selected building safety measures based on the evaluation results. However, their focus was on fire evacuation, and their methods may not be suitable for the needs of vulnerable evacuees under multi-hazard conditions such as earthquakes and floods. Fukamoto Ichiro [70] studied an evacuation route notification system friendly to vulnerable evacuees under major disasters, providing reference value for the traffic diversion of injured and ill individuals. However, their study did not consider the supply-demand matching issue between evacuation sites and the number of vulnerable evacuees.

In China, Bai Xuecen [71] developed a cellular automaton model for crowd evacuation that includes blind individuals based on cellular automaton theory. This model simulates the effects of various factors, such as crowd density, the proportion of blind individuals, and the probability of assistance from normal pedestrians, on the evacuation process in large halls. This provides theoretical guidance for evacuation strategies in places where blind individuals congregate, such as schools for the blind and communities for people with disabilities. However, it does not address the evacuation issues of other vulnerable groups. Wang Eryuan [72] constructed an evacuation



behavior model for the elderly based on five evacuation processes and used Pathfinder evacuation software to simulate the evacuation scenarios of different types of elderly individuals. This helped improve facility evacuation design and reduce evacuation time but did not consider the evacuation behavior of other vulnerable groups such as those who are weak, sick, disabled, or pregnant. Huang Jing et al. [73] used GIS to measure evacuation data for the elderly in the Sanxiaokou Street of Hefei City and utilized Pathfinder software for evacuation simulation. They determined the site selection for welfare-type evacuation sites and proposed strategies for age-friendly renovation but similarly did not consider the evacuation needs of other vulnerable groups. Wang Qiming [74] conducted a suitability evaluation of evacuation sites using four primary indicators: environmental safety, travel convenience, rescue assurance capacity, and service attractiveness, along with 15 secondary indicators. He optimized evacuation sites suitable for people with mobility impairments by constructing a crowd evacuation distribution optimization model with objectives such as minimizing evacuation distance and reducing congestion. He also proposed a new particle swarm optimization algorithm combining flow expansion and particle swarm algorithms, though the accuracy of case data measurement still needs improvement. Li Zeyong [75] analyzed rural community disaster prevention systems from macro, meso, and micro perspectives, constructing a hierarchical model of spatial impact factors for disaster prevention in aging rural communities. This model was used for design optimization in sample communities, but the general applicability of the cases used was limited and requires further optimization. Yang Zhu et al. [76] developed a multi-level structural model to create a comprehensive evaluation system based on the satisfaction of the needs of vulnerable evacuees. Using evacuation sites in Tongzhou Beiyuan Street as a case study, they evaluated the satisfaction of evacuation needs and proposed corresponding construction measures. However, their focus on needs evaluation makes it challenging to meet the demands for site planning and selection.

## **5. Conclusion and outlook**

### **5.1. Conclusions**

The planning of assistance for vulnerable evacuees is an important component of urban disaster prevention and mitigation work. Scientific and reasonable planning of evacuation sites can improve post-disaster rescue efficiency. In China, the planning and construction of evacuation sites have recently undergone new evaluations and reflections, shifting from initially focusing on single hazards like earthquakes to now developing comprehensive evacuation sites that address multiple types of disasters such as floods, windstorms, and fires [77]-[79]. Increasingly, scholars are also paying attention to vulnerable evacuee groups [20]-[22].

Firstly, research on the behavior characteristics and evacuation needs of vulnerable evacuees in China mainly comes from limited Japanese literature. Most of these studies are descriptive and suggestive, and they do not provide practical solutions to the evacuation actions and living issues faced by vulnerable evacuees during actual disasters.

Secondly, developed countries such as the United States and Japan began exploring emergency evacuation site planning earlier. Their standards for evacuation sites are comprehensive and highly operable. They place significant emphasis on the construction of evacuation sites for vulnerable populations, with specific standards addressing the needs of disabled individuals and gender minorities, and each standard considers the evacuation needs of such special groups. Although China has started to improve the planning and management of evacuation sites based on the characteristics of vulnerable evacuees, the consideration of these needs is still insufficient, and current planning standards need to be improved in terms of practical operability. Existing research has considered the impact of aging trends on evacuation site planning, but proposed strategies lack in-depth technical indicators.

Thirdly, in the area of evacuation site planning models, most existing research starts from the perspective of managers, establishing mathematical models based on factors such as evacuation

distance, evacuation time, and site capacity limitations, while neglecting the actual preferences and needs of vulnerable evacuees. The planning models for evacuation sites still require improvement and optimization.

## 5.2. Outlook

The expanding scale of vulnerable evacuees has introduced new requirements for the planning and construction of evacuation sites. To address the special needs of vulnerable evacuees at various stages of evacuation, it is advisable to draw on the experiences of countries such as Japan and the United States. This will help in formulating evacuation and rescue plans for vulnerable populations and provide scientific decision-making bases and practical guidance for disaster emergency rescue management in China.

Firstly, establish an information database for vulnerable evacuees, focusing on their living conditions at evacuation sites. This includes their evacuation times, living conditions and environment, medical treatment, and supply security, as well as understanding their behavioral characteristics and changes in evacuation needs during different disaster stages.

Secondly, to address the special needs of vulnerable evacuees, improve specific planning technical indicators related to site types, sizes, per capita effective evacuation area, responsibility zone scope, and emergency facility configurations. Additionally, drawing on the experiences of Japan and the United States, plan for dedicated fixed evacuation sites for vulnerable evacuees and establish separate evacuation areas for them within general evacuation sites. Enhance accessibility systems and building disaster resistance.

Thirdly, research evacuation site allocation models based on the needs of vulnerable evacuees. Combine decision-maker directives under major disasters with the self-selection preferences of vulnerable evacuees to optimize the planning and site selection of evacuation sites and the distribution of evacuees. This approach will improve the accuracy of evacuation site data from the perspective of vulnerable evacuees and provide decision-making support for disaster emergency rescue organizations.

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## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Author contributions

Lulu Sun: conceptualization, data curation, formal analysis, methodology, software, visualization, writing-original draft preparation. Jianyu Chu: investigation, project administration, resources, supervision, validation, writing-review and editing.

## Conflict of interest

The authors declare that they have no conflict of interest.

## References

- [1] W. X. Bai, "Everyone is involved in disaster prevention, mitigation and safety protection," (in Chinese), *Standard Living*, Vol. 4, No. 3, pp. 30–35, 2024.

- [2] J. Kuno and T. Tanno, "Investigate the causes of new falls among elderly people in areas affected by the Great East Japan Earthquake," (in Japanese), *Japan Journal of Public Health*, Vol. 68, No. 4, pp. 255–266, 2021.
- [3] F. H. Xu, "Elderly people in Hurricane Katrina Disaster," (in Chinese), *China Disaster Reduction*, Vol. 3, No. 4, pp. 52–55, 2015.
- [4] Y. P. Su, Y. H. Chen, and J. W. Chen, "Emergency rescue of elderly in major earthquake disasters in aging society," (in Chinese), *World Earthquake Engineering*, Vol. 31, No. 4, pp. 31–35, 2015.
- [5] B. Tang, F. P. Qiu, and J. Y. Huang, "Research progress on emergency shelters in China from the perspective of resilient cities," (in Chinese), *Modern Urban Research*, Vol. 14, No. 9, pp. 25–31, 2015.
- [6] M. J. Chen and F. Lv, "Optimization of layout of emergency shelters in Suzhou Ancient City based on social network analysis," (in Chinese), *Urban Development Research*, Vol. 29, No. 4, pp. 1–8, 2022.
- [7] Y. J. Shi, P. M. Wang, and R. Dao, "Optimization of layout of emergency shelters in mountainous small cities – a case study of Jianchuan, Yunnan," (in Chinese), *Modern Urban Research*, Vol. 16, No. 5, pp. 92–99, 2016, <https://doi.org/10.3969/j.issn.1009-6000.2016.05.016>
- [8] Z. T. Wang, J. F. Wu, and X. D. Guo, "Research on optimization methods for the functional layout of disaster prevention and evacuation sites," (in Chinese), *Journal of Disasters*, Vol. 38, No. 4, pp. 127–133, 2023.
- [9] Y. Q. Liu, Q. W. Hu, and G. Cheng, "Suitability evaluation of shelters based on gray relational analysis and entropy weighting," (in Chinese), *Journal of Wuhan University of Technology (Information and Management Engineering Edition)*, Vol. 39, No. 6, pp. 669–673, 2017, <https://doi.org/10.3963/j.issn.2095-3852.2017.06.005>
- [10] J. Jiang and D. P. Li, "Resilience perspective the campus emergency shelters suitability evaluation," (in Chinese), *Journal of Shanxi Building*, Vol. 49, No. 2, pp. 60–63, 2023, <https://doi.org/10.13719/j.cnki.1009-6825.2023.02.016>
- [11] J. X. Sun, C. X. Wang, and G. L. Yu, "Suitability evaluation of earthquake emergency shelters in Yinchuan City," (in Chinese), *Journal of Disaster Prevention and Mitigation*, Vol. 38, No. 3, pp. 63–70, 2022, <https://doi.org/10.13693/j.cnki.cn21-1573.2022.03.010>
- [12] D. X. Ma, Y. P. Su, and J. Y. Chu, "Site selection and responsibility zone division model of emergency shelters based on two-layer planning," (in Chinese), *World Earthquake Engineering*, Vol. 31, No. 4, pp. 139–145, 2015.
- [13] J. Y. Chu, J. W. Liang, and Y. P. Su, "Layout optimization and responsibility zoning method for disaster prevention and emergency shelters," (in Chinese), *World Earthquake Engineering*, Vol. 31, No. 1, pp. 89–96, 2015, <https://doi.org/10.19981/j.cn23-1581/g3.2023.16.026>
- [14] F. Z. Huo, J. J. Yu, and Y. P. Zeng, "Optimization of emergency shelter site selection based on service utility and redundant coverage," (in Chinese), *Journal of Safety and Environment*, Vol. 23, No. 5, pp. 1449–1456, 2023, <https://doi.org/10.13637/j.issn.1009-6094.2022.1654>
- [15] W. Xu et al., "A multi-objective optimization based method for evaluating earthquake shelter location-allocation," *Geomatics, Natural Hazards and Risk*, Vol. 9, No. 1, pp. 662–677, Jan. 2018, <https://doi.org/10.1080/19475705.2018.1470114>
- [16] Y. F. Han, W. Lv, and W. N. Zhou, "Two-stage model for emergency shelter site selection and allocation considering public preference," (in Chinese), *China Safety Science and Technology*, Vol. 19, No. 3, pp. 20–26, 2023.
- [17] X. Y. Li, L. Wang, and P. Du, "Research on spatial layout and accessibility of emergency shelters based on GIS," (in Chinese), *Science and Technology Innovation and Application*, Vol. 13, No. 16, pp. 110–112, 2023.
- [18] Y. L. Sun, J. R. Li, and X. K. Zhang, "Accessibility evaluation of emergency shelters based on day and night population changes – a case study of Xiqing District, Tianjin," (in Chinese), *Journal of Safety and Environment*, Vol. 22, No. 6, pp. 3342–3349, 2022, <https://doi.org/10.13637/j.issn.1009-6094.2021.1216>
- [19] B. Tang and J. N. Qiu, "Knowledge map and progress analysis of emergency shelters based on WoS and Citespace," (in Chinese), *World Geography Research*, Vol. 28, No. 4, pp. 85–95, 2019, <https://doi.org/10.3969/j.issn.1004-9479.2019.04.2018191>
- [20] J. W. Chen, W. G. Wang, and Y. P. Su, "Planning for rescue of vulnerable people in earthquake disasters," (in Chinese), *World Earthquake Engineering*, Vol. 29, No. 2, pp. 52–56, 2013.
- [21] W. G. Wang, "Research on resource allocation planning for urban earthquake emergency rescue," Tianjin University, 2017.

- [22] W. J. Li, G. F. Zhai, and F. M. Gu, "Revelation of welfare-oriented shelter construction in Japan for the shelter planning and construction in the aging background in China," (in Chinese), *International Urban Planning*, Vol. 34, No. 1, pp. 119–126, 2019.
- [23] X. K. Zhang, "Discussion on earthquake emergency evacuation issues for the elderly," (in Chinese), *Urban and Disaster Reduction*, Vol. 12, No. 2, pp. 23–24, 2014.
- [24] Y. S. Jiang, "Utilization of community networks in disaster support for vulnerable people," (in Japanese), *Journal of Local Government Crisis Management*, Vol. 13, No. 3, pp. 29–40, 2014.
- [25] J. K. Newport and G. G. P. Jawahar, "Community participation and public awareness in disaster mitigation," *Disaster Prevention and Management: An International Journal*, Vol. 12, No. 1, pp. 33–36, Mar. 2003, <https://doi.org/10.1108/09653560310463838>
- [26] H. Onishi, O. Yamamura, and T. Yamamoto, "Comparison of development of deep vein thrombosis detection rates between groups of people in the general shelters and welfare type shelters in the Kumamoto earthquake area," (in Japanese), *Journal of the National Institute of Public Health*, Vol. 66, No. 6, pp. 620–629, 2017.
- [27] X. Y. Zhang, "Research on system planning of urban three-dimensional shelter system," (in Chinese), *Urban Architecture*, Vol. 17, No. 5, pp. 21–24, 2020, <https://doi.org/10.19892/j.cnki.csjz.2020.05.004>
- [28] W. J. Li, "Analysis on emergency shelter planning and resilience enhancement under the aging context," (in Chinese), *Urban and Disaster Reduction*, Vol. 10, No. 5, pp. 44–48, 2022.
- [29] Fujiuchi, "Assistant of health countermeasures division, Oita prefecture welfare and health ministry," (in Japanese), *Monthly Journal of District Health Care*, Vol. 16, No. 37, pp. 1–5, 2006.
- [30] N. Sadayuki, "Suggestions for large earthquakes and social welfare policies," (in Japanese), *Social Work*, Vol. 11, No. 4, pp. 4–8, 2012.
- [31] T. Tsuji, "Social disasters of the super-aged and urban communities," (in Japanese), *Regional Development*, Vol. 32, No. 11, pp. 25–28, 2011.
- [32] O. Alisan, A. Kocatepe, and H. Tuydes-Yaman, "Benefits of managing the capacity of special needs shelters with cross-county collaboration: case study in Florida," *Transportation Research Record*, Vol. 2604, No. 1, pp. 131–143, 2017.
- [33] S. Masami, "A study on the legal regulations of evacuation safety for self-evacuees – international comparison," (in Japanese), *Bulletin of Japan Association for Fire Science and Engineering*, Vol. 66, No. 2, pp. 21–30, 2016.
- [34] X. J. Yang, "Discussion on fire safety of facilities for the elderly based on plan types," (in Chinese), *Architectural Journal*, Vol. 23, No. 91, pp. 167–177, 2020.
- [35] S. J. Yu, G. C. Xie, and R. K. Pan, "Study on safety evacuation of disabled people in building fires," (in Chinese), *Education and Teaching Forum*, Vol. 3, No. 4, pp. 141–143, 2020.
- [36] Y. Xia, "Analysis of fire evacuation of people with disabilities in high-rise building fires," (in Chinese), *Fire Technology and Product Information*, Vol. 6, No. 4, pp. 66–67, 2009, <https://doi.org/10.3969/j.issn.1002-784x.2009.04.021>
- [37] G. Y. Yang, "Management of shelter classification for vulnerable groups in urban emergency evacuation," (in Chinese), *Disaster Study*, Vol. 32, No. 3, pp. 176–182, 2017, <https://doi.org/10.3969/j.issn.1000-811x.2017.03.030>
- [38] W. J. Li, G. F. Zhai, and W. Chen, "Research on county-level refuge site planning from the perspective of the needs of the disadvantaged evacuees-A case study of the post-disaster investigation of the "6-17" earthquake in Changning," (in Chinese), *Disaster Defense Technology*, Vol. 17, No. 4, pp. 764–774, 2022.
- [39] Y. T. Xu, H. Chen, and W. Wang, "Research on foreign emergency shelter standards," (in Chinese), *Disaster Study*, Vol. 37, No. 2, pp. 145–149, 2022.
- [40] Q. Zhou, Y. Qu, and T. X. Qin, "Research on the construction of china's emergency shelter standard system," (in Chinese), *Standard Science*, Vol. 33, No. 11, pp. 11–14, 2023.
- [41] "Humanitarian shelter and settlements guidelines," European Commission (EU), 2017.
- [42] "Emergency shelter Haiti, field notes," Inter-Agency Standing Committee (IASC), International Federation of Red Cross and Red Crescent Societies (IFRC), 2014.
- [43] "FEMA P-785: shelter field guide," Federal Emergency Management Agency (FEMA), American Red Cross (ABC), 2015.
- [44] "Sheltering handbook," American Red Cross (ARC), 2012.
- [45] J. D. Aileen Xenakis, "Federal emergency management agency's guidance on planning for integration of functional needs support services in general population shelters: progress despite practical

- impediments,” *Journal of Emergency Management*, Vol. 9, No. 1, pp. 9–13, Jan. 2011, <https://doi.org/10.5055/jem.2011.0042>
- [46] “ADA checklist for emergency shelters,” U.S. Department of Justice, 2007.
- [47] “Mega-shelter planning guide,” International Association of Venue Managers (IAVM), American Red Cross (ARC), 2010.
- [48] “Guidelines for the evacuation support of people requiring assistance in disasters,” (in Japanese), 2006.
- [49] “Efforts to support the evacuation of people requiring assistance,” (in Japanese), Cabinet Office, 2013.
- [50] “Comparison of provisional articles of the disaster countermeasures basic law before and after amendment,” (in Japanese), Cabinet Office, 2013.
- [51] “Earthquake emergency shelter site and supporting facilities,” (in Chinese), National Technical Committee for Seismic Standardization, 2008.
- [52] “Chinese industry standard: urban road and building accessibility design code JGJ 50-2001,” (in Chinese), China Architecture and Building Press, 2001.
- [53] “Announcement of the ministry of housing and urban-rural development on the partial revision of the national standard. Code for the design of disaster prevention and shelters,” (in Chinese), *Standardization of Engineering Construction*, Vol. 3, No. 6, pp. 35–38, 2022.
- [54] H. Arai, “The 41st Scientific Meeting: perspectives of internal medicine; lessons from the disaster of the Great East Japan earthquake: 4. Proposal of an effective internal medical care against disaster; 3) An appropriate management of geriatric disorders following Japan catastrophic disaster and tsunami 2011,” (in Japanese), *Nihon Naika Gakkai Zasshi*, Vol. 103, No. 3, pp. 598–604, 2014.
- [55] H. Kikuchi, “Impact on healthcare and welfare functions and changes in residents’ lives caused by the Great East Japan earthquake,” (in Japanese), *Abstracts of the Japan Geographical Society*, Vol. 622, No. 3, pp. 132–136, 2013.
- [56] R. Ishii and N. Hitoshi, “Evacuation behaviors of elderly people and assisting behaviors of care managers in the event of an earthquake-induced fire or large-scale flood,” (in Japanese), *Journal of the City Planning Institute of Japan*, Vol. 53, No. 3, pp. 875–880, Oct. 2018, <https://doi.org/10.11361/journalcpj.53.875>
- [57] K. Kambara, A. Kubota, T. Kurose, T. Hagiwara, K. Fukushi, and A. Tanaka, “Study on the evacuation behaviors of elderly residents in rural communities during the great east Japan earthquake in relation to the built environment,” (in Japanese), *Journal of Architecture and Planning (Transactions of AIJ)*, Vol. 79, No. 701, pp. 1593–1602, Jan. 2014, <https://doi.org/10.3130/aija.79.1593>
- [58] Z. Z. Deng, W. W. Zeng, and Z. S. Shen, “Study on impact factors and survey of human factors data on evacuation of vulnerable people in building fires,” (in Chinese), *Journal of Architecture*, Vol. 19, No. 79, pp. 131–145, 2012.
- [59] L. Zhuang, E. T. Qi, and J. Li, “Safety evacuation and shelter space design for the elderly under new regulations,” (in Chinese), *Fire Science and Technology*, Vol. 36, No. 11, pp. 1512–1514, 2017.
- [60] S. S. Cao, Y. G. Liu, and Q. L. Wang, “Research on urban shelter space issues based on the behavioral characteristics of the elderly – a case study of Nan District, Qingdao,” (in Chinese), *Architecture and Culture*, Vol. 17, No. 8, pp. 116–117, 2022, <https://doi.org/10.19875/j.cnki.jzywh.2022.08.039>
- [61] S. Zhang, X. Y. Liu, and J. Zeng, “Urban safety evacuation strategy for visually impaired people,” (in Chinese), *Planner*, Vol. 34, No. 3, pp. 103–107, 2018, <https://doi.org/10.3969/j.issn.1006-0022.2018.03.017>
- [62] S. Kongsomsaksakul, C. Yang, and A. Chen, “Shelter location-allocation model for flood evacuation planning,” *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 5, No. 6, pp. 4237–4252, 2005.
- [63] F. Kılçı, B. Y. Kara, and B. Bozkaya, “Locating temporary shelter areas after an earthquake: A case for Turkey,” *European Journal of Operational Research*, Vol. 243, No. 1, pp. 323–332, May 2015, <https://doi.org/10.1016/j.ejor.2014.11.035>
- [64] F. Hu, W. Xu, and X. Li, “A modified particle swarm optimization algorithm for optimal allocation of earthquake emergency shelters,” *International Journal of Geographical Information Science*, Vol. 26, No. 9, pp. 1643–1666, Sep. 2012, <https://doi.org/10.1080/13658816.2011.643802>
- [65] T. Y. Zhou and F. R. Jian, “A study on the establishment of a decision support system for the location of emergency shelters,” (in Chinese), *Journal of Soil and Water Conservation*, Vol. 7, No. 1, pp. 17–24, 2001, <https://doi.org/10.3969/j.issn.1005-3409.2001.01.005>
- [66] E. E. Ozguven et al., “Metadata-based needs assessment for emergency transportation operations with a focus on an aging population: a case study in Florida,” *Transport Reviews*, Vol. 36, No. 3, pp. 383–412, May 2016, <https://doi.org/10.1080/01441647.2015.1082516>

- [67] A. Kocatepe, E. E. Ozguven, M. Horner, and H. Ozel, "Pet – and special needs-friendly shelter planning in south florida: A spatial capacitated p-median-based approach," *International Journal of Disaster Risk Reduction*, Vol. 31, No. 31, pp. 1207–1222, Oct. 2018, <https://doi.org/10.1016/j.ijdr.2017.12.006>
- [68] M. W. Horner, E. E. Ozguven, J. M. Marcelin, and A. Kocatepe, "Special needs hurricane shelters and the ageing population: development of a methodology and a case study application," *Disasters*, Vol. 42, No. 1, pp. 169–186, Apr. 2017, <https://doi.org/10.1111/disa.12233>
- [69] I. Masashi, K. Seiji, and K. Masahiko, "Fire evacuation method using elevators in high-rise residential buildings – recent technological progress and advances in elevators and amusement facilities," (in Japanese), in *Proceedings of the Conference on Technology and Technological Advances*, Vol. 2008, No. 110, pp. 55–59, 2009.
- [70] I. Fukumoto, "Attempt to study evacuation route notification systems for vulnerable people in major disasters," (in Japanese), *Japanese Journal of Disaster Medicine*, Vol. 19, No. 1, pp. 60–67, 2014.
- [71] X. C. Bai, Z. F. Geng, and X. L. Li, "Study on evacuation of special population with cellular automata," (in Chinese), in *Proceedings of the 17th Annual Conference of the Northern Seven Provinces and Cities Mechanics Association*, Vol. 6, No. 8, pp. 88–97, 2018.
- [72] E. Y. Wang, "Evacuation study of elderly facilities based on behavioral characteristics," Shenyang Aerospace University, 2017.
- [73] J. Huang, Q. Q. Yu, and H. Y. Yang, "Study on age-friendly shelters based on pathfinder evacuation simulation and GIS analysis," (in Chinese), *Smart Cities*, Vol. 9, No. 1, pp. 53–56, 2023, <https://doi.org/10.19301/j.cnki.zncs.2023.01.016>
- [74] Q. M. Wang, "Evaluation and optimization research on the suitability of emergency shelters for mobility-impaired population," Wuhan University of Technology, 2023.
- [75] Z. R. Li, "Optimization research on disaster prevention space design for rural communities in sichuan province under aging background," Southwest University of Science and Technology, 2020.
- [76] Z. Yang, G. Liu, and D. H. Ma, "Evaluation and analysis of urban shelter satisfaction based on vulnerable group needs," (in Chinese), in *Proceedings of the 2021 Chinese Urban Planning Conference on Spatial Governance for High-Quality Development (Session 01: Urban Safety and Disaster Planning)*, Vol. 10, No. 4, pp. 334–343, 2021.
- [77] L. Ding, G. F. Zhai, and S. S. Li, "Comprehensive emergency shelter planning for multi-disaster response in cities," (in Chinese), *Urban Planning*, Vol. 39, No. 9, pp. 107–112, 2015, <https://doi.org/10.11819/cpr20150918a>
- [78] C. J. Fan, "Optimization study on site selection of comprehensive emergency shelters for multi-disaster response," Nanjing University, 2016.
- [79] Y. H. Niu, S. Jiao, and T. T. Cao, "Risk assessment and planning response for urban multi-disaster with PSR model," (in Chinese), *Urban Development Research*, Vol. 29, No. 4, pp. 39–48, 2022, <https://doi.org/10.3969/j.issn.1006-3862.2022.04.006>



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