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.

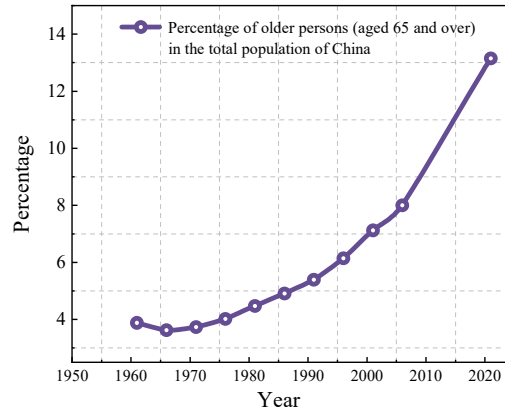

Fig. 1. Percentage of older persons (aged 65 and over) in the total population of China

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

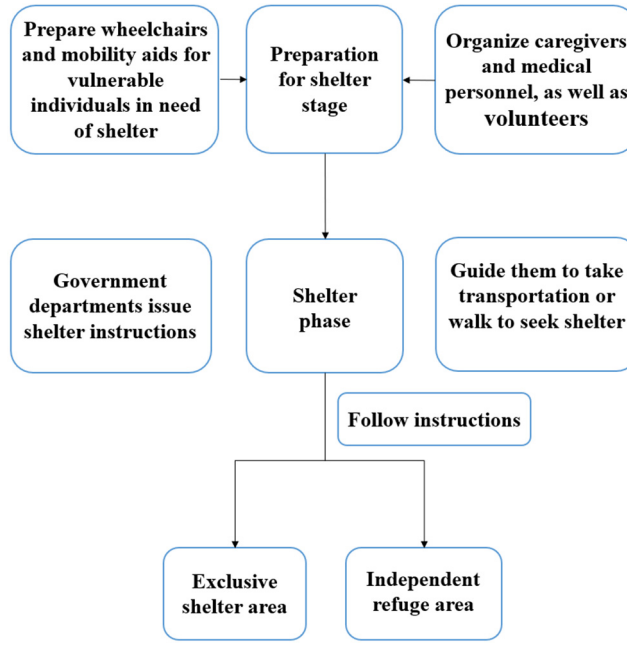

Fig. 2. Diagram illustrating the process of sheltering the vulnerable

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.

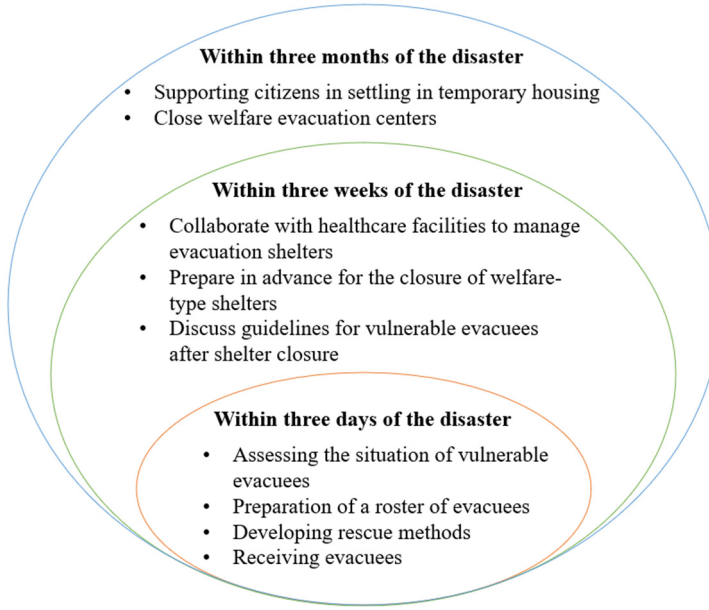

Fig. 3. The "3·3·3" principle of welfare-based emergency shelters in Japan

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]	Propose that shelter space planning should consider vulnerable groups, and provide guidelines for the location and planning standards of bathrooms, sinks, shower rooms, laundry areas, etc., for maintenance, medical services, and catering. This also includes planning guidelines related to temporary housing and child care information
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^2) 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^2	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^2, 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^2, 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^2 per person. However, the Chinese standards

specify an average net usable area of only 4 m^2 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^2
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^2/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.

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