

Research on Community Emergency Corridor Systems in Urban Fire Risk Governance: An Empirical Study of 77 Chinese Communities

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Article

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Posted Date: March 21st, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8982459/v1>

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Additional Declarations: No competing interests reported.

1 **Research on Community Emergency Corridor Systems in Urban Fire Risk**
2 **Governance: An Empirical Study of 77 Chinese Communities.**

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9 **Abstract**

10 Urban fires, characterized by high casualty rates and severe destructiveness, are capable of
11 inflicting enormous human and property losses. The obstruction of Community Emergency
12 Corridor System has become one of the critical factors contributing to fire-related casualties
13 among residents, posing a serious challenge to both individual life safety and the effectiveness of
14 public safety governance. Current Community Emergency Corridor System encounters significant
15 systemic bottlenecks in triadic space coordination, with information space lag emerging as a
16 critical constraint on emergency response. An integrated assessment framework is urgently
17 required to address this coordination dilemma. However, existing research predominantly focuses
18 on a single space and lacks a comprehensive evaluation framework for the coordinated
19 accessibility of physical, social, and information spaces. To fill this gap, this study adopts a triadic
20 space perspective by examining 77 typical Chinese communities as research subjects. It employs
21 the Entropy Weighted TOPSIS method to construct an evaluation index system for assessing the
22 accessibility of Community Emergency Corridor System, aiming to systematically measure their
23 levels of accessibility. The findings reveal the following: (1) Overall, the accessibility of
24 Community Emergency Corridor System across triadic space demonstrates uneven development,
25 highlighting systemic coordination bottlenecks within community emergency response networks.
26 There is an urgent need for structural optimization through the reorganization of spatial elements;
27 (2) Significant spatial disparities exist among triadic space, with social space accessibility
28 surpassing that of physical and information spaces; (3) Regionally, communities in Northeast
29 China exhibit significantly higher accessibility to emergency corridor compared to those in East,
30 Central, and West China. Given the disparities in development levels and community structures

across different regions, this study proposes strategies to overcome multi-agent coordination challenges, bridge digital platform gaps, address infrastructure bottlenecks, and enhance public emergency awareness, aiming to systematically respond to urban fire risks and improve the overall accessibility of the community emergency corridor system. The triadic space evaluation framework and methodological pathway developed herein provide a replicable analytical tool for emergency management in the context of urban fires, offering valuable insights for Chinese communities and other high-density regions seeking to strengthen fire resilience governance.

Keywords: Urban Fire; Community Emergency Corridor System; Triadic Space; Entropy Weighted TOPSIS; Chinese Communities; Emergency Management

1 Introduction

Global urban fires, in marked contrast to wildfires, are characterized by distinctive features such as high-rise building density and concentrated populations. Consequently, they exhibit significantly elevated casualty rates and pronounced structural destructiveness, leading to more substantial economic losses. As fundamental units of social governance, grassroots communities are pivotal in preventing and mitigating major safety risks. At the national level, systematic arrangements have been established to advance the modernization of the national security system and capabilities, which underscores the necessity to strengthen grassroots emergency resources and enhance disaster prevention, mitigation, and relief capacities. However, the blockage of emergency corridor in grassroots communities remains a persistent problem in reality. Numerous incidents demonstrate how such obstructions exacerbate disaster consequences—for example, fatalities caused by insufficient water pressure from fire hydrants during fires, or delayed ambulance responses due to private vehicles illegally occupying emergency lanes. These

blockages have significantly contributed to preventable casualties. According to a report by the National Fire Rescue Bureau, the China Fire and Rescue Team responded to 908,000 fire incidents in 2024, including 391,000 building fires (43.1% of total). Of these, residential fires accounted for 309,000 cases—79% of all building fires—and were characterized by high casualty rates and extensive damage [1]. The vast majority of these incidents occurred in communities where emergency corridor was partially or severely obstructed, indicating that blocked passageways are a critical factor in fire-related civilian casualties. Therefore, ensuring unimpeded access to Community Emergency Corridor System is an urgent imperative.

Current research on Community Emergency Corridor System, both domestically and internationally, primarily focuses on three dimensions. First, physical space accessibility: studies have developed assessment models such as the three-dimensional emergency rescue coordinate system, evaluations of community adaptive capacity, five core emergency capabilities, and evacuation planning models [2-4]. Scholars have proposed optimization strategies for infrastructure layout and resource allocation [5], while others have investigated spatial equity in emergency shelter distribution [6,7]. Second, social space accessibility: international research on community emergency response began earlier, with scholars analyzing how interpersonal networks [8], public participation [9], and social capital [10] influence the efficiency of community evacuations. Domestic studies have explored the role of communities within the broader social support system during safety emergencies [11] and the effectiveness of multi-stakeholder collaborative networks [12]. Third, information space accessibility: researchers have investigated the application of digital technologies in community-level governance [13], as well as innovative uses of artificial intelligence in grassroots emergency management [14]. A

growing consensus also supports transitioning toward a “platform-based governance structure” for digital emergency systems [15].

In summary, Community Emergency Corridor System is a crucial component of emergency response with significant practical relevance. While existing studies have accumulated substantial insights within the respective dimensions of the triadic space framework, they remain fragmented and isolated. Although some scholars have examined the interplay between physical emergency resources and social participation [16][17], few have attempted to integrate the physical, informational, and social dimensions into a cohesive analytical framework capable of revealing the intrinsic structure and operational mechanisms of community emergency passageways—complex systems that inherently couple human, material, and information flows. This gap limits comprehensive, multidimensional assessments of accessibility.

To address these limitations, this study develops an integrated analytical framework based on Triadic Space Theory. First proposed by French philosopher Henri Lefebvre [18] and later expanded by Academician Wu Zhiqiang in the context of urban development [19]. This theory posits that the world is composed of physical, social, and information space. An increasing number of scholars have introduced this framework into public administration, initiating explorations in areas such as digital space [20], territorial space [21], and national governance [22]. Although existing research has yielded substantial outcomes within this framework, significant gaps remain when focusing on the context of Community Emergency Corridor System: First, research perspectives remain fragmented. Much of the literature focuses exclusively on physical path planning and facility deployment [23], or isolates the impact of social capital on emergency preparedness [10], or unilaterally emphasizes the instrumental value of information technology

[13], lacking empirical examinations that integrate the three dimensions within a unified analytical framework to explore their coupled interactions. Second, measurement methods urgently require integration. Existing evaluation systems predominantly rely on subjective weighting or single-dimension indicators, making it difficult to objectively quantify the comprehensive contribution of triadic space to accessibility and its internal structural variations. Third, no optimization pathways have been proposed.

Given this context, this study aims to systematically address the following core questions from a triadic space perspective: (1) How can a comprehensive evaluation framework be constructed to fully characterize the accessibility of physical, social, and information spaces? (2) What are the overall levels of emergency accessibility and the internal structural characteristics in typical Chinese communities, and does a significant spatial imbalance exist? (3) What systematic optimization strategies can address the identified structural deficiencies? To this end, this paper employs the Entropy Weighted TOPSIS model to conduct precise assessment and diagnostic analysis of the accessibility Community Emergency Corridor System in Chinese communities. This approach not only advances emergency management research from a “unidimensional static” paradigm to a “triadic dynamic” framework at the theoretical level but also provides actionable decision-making support for urban and community administrators.

2 Theoretical framework

With the advancement of digital technology and the transformation of social structures, the domain of human activities is shifting from traditional two-dimensional frameworks to a new three-dimensional paradigm [24]. The world has consequently evolved from a dual “physical-social” space into a tripartite “physical-social-information” space [25]. Within this

structure, the three dimensions are interdependent and interact dynamically to collectively constitute the human habitat [26]. Academic research on the triadic space model has expanded into diverse fields, such as public governance [20, 27], smart cities [28], information science [29], urban planning [30], and sociology [31]. Similarly, community emergency response encompasses governance paradigms with distinct spatial attributes, particularly in assessing emergency accessibility within specific grassroots community scenarios. “Physical space” refers to all objectively existing entities, forming the essential material foundation for human survival [32]. It supports residents' daily lives and emergency response through infrastructure such as public venues, emergency facilities, supplies, and shelters. “Social space” denotes the realm of social relations and networks where dynamic interactions occur. Originating in the family sphere and continuously evolving through social interaction [33], it serves as a core dimension of urban governance by strengthening public safety through community networks such as neighborhood mutual-aid groups, formal organizations, and residential security systems that enhance living environments and social cohesion. “Information space” emerges from the reciprocal interaction and digital mapping between physical and social spaces [34]. It is a product of the technology-driven digital transformation of human activity. Within the digital space, human society's living space is continually extended through digital platforms and information carriers [35]. This is evidenced by the efficiency of residents' access to critical information and the timeliness of digital information dissemination.

Based on Triadic Space Theory, this study develops an assessment model for the accessibility of Community Emergency Corridor System by integrating the dimensions of physical, social, and information spaces. The “Community Emergency Corridor System” is conceptualized as a

141 composite system—integrating physical, social, and informational elements—that facilitates the
142 safe, efficient movement of people, materials, information, and energy during emergency
143 preparedness and response phases. Going beyond the conventional understanding of “physical
144 roads,” it emerges as an organic whole formed by the mutual coupling and synergistic interaction
145 of physical space (tangible pathways like roads and facilities), social space (behavioral norms such
146 as resident awareness and organizational coordination), and information space (communication
147 networks for data transmission and warning dissemination). This integrated framework
148 demonstrates systemic integration, multidimensional functionality, and spatial embeddedness.
149 Consequently, the accessibility Community Emergency Corridor System reflects the system’s
150 overall capacity to withstand disruptions, sustain essential operations, and function reliably,
151 efficiently, and equitably under crisis conditions. It encompasses not only the removal of physical
152 barriers but also the effectiveness of social coordination mechanisms and the timeliness and
153 accuracy of information transmission.

154 Specifically, physical space accessibility in community emergency management centers on
155 the functionality of infrastructure. By upgrading physical emergency facilities, communities
156 enhance their resilience and capacity to withstand sudden incidents, thereby increasing residents’
157 speed and likelihood of safe evacuation. This dimension encompasses two key components:
158 community emergency evacuation and emergency resource support. Emergency evacuation
159 addresses issues such as community fire safety, emergency signs, and the unobstructed nature of
160 evacuation routes. Emergency resource support includes emergency supplies, emergency shelters,
161 and emergency response agencies. Information space accessibility focuses on the efficiency and
162 reliability of information flow, reflecting a community’s ability to maintain functional information

systems amid sudden and uncertain risks. It consists of two principal aspects: information release and acquisition. Information release should ensure timeliness, speed, openness, and transparency; information acquisition should guarantee diverse channels, ease of collection, and proactive sharing by the public. Driven by contemporary digital technology, individuals function as essential nodes within social information networks. The public's ability to accurately assess, rapidly disseminate, and effectively act upon emergency information constitutes a core mechanism for strengthening grassroots emergency management. Emergency accessibility in community social space emphasizes organizational connectivity. This dimension relies on the relational networks and social structures within grassroots communities to withstand public emergencies and enhance response capabilities. It includes three principal elements: neighborhood emergency mutual aid, community emergency preparedness, and community emergency education. Neighborhood emergency mutual aid relies on interpersonal relationships, where neighborly bonds are pivotal for seeking and offering assistance during a crisis. Community emergency preparedness involves the community's organizational management systems, mobilization mechanisms, and emergency drills. Community emergency education highlights the vital role of local initiatives in emergency awareness and education efforts.

The accessibility of Community Emergency Corridor System stems from the integrated functioning of triadic space: the physical space accessibility of community infrastructure, the social space accessibility of social networks, and the informational space accessibility of communication channels. Only through the coordinated development of these triadic space can the overall accessibility of Community Emergency Corridor System be ensured, thereby strengthening local emergency response capabilities. This integration enables timely interruption of the chain

that transforms minor fires into major disasters, ultimately achieving the goal of strengthening grassroots community emergency preparedness. Improving the accessibility of Community Emergency Corridor System requires synergistic support across the tripartite dimensions of physical, social, and informational spaces: physical infrastructure provides the material foundation, social organization and mobilization constitute the operational core, while informational data flow amplifies effectiveness. While each space maintains functional independence, they also demonstrate strong coupling effects. Blockages in any single dimension can disrupt the overall Community Emergency Corridor System. Conversely, optimizing a specific dimension can generate positive spillover effects through spatial coordination mechanisms, ultimately enhancing the overall effectiveness of the Community Emergency Corridor System.

This study adopts a structured research framework of “Indicator system construction—Data collection—Data evaluation—Result analysis—Improvement pathways,” with the technical route illustrated in Fig1. First, an evaluation indicator system for the accessibility of Community Emergency Corridor System was developed based on Triadic Space Theory. Data collection employed a combination of questionnaire surveys and semi-structured interviews. Subsequently, the Entropy Weighted TOPSIS method was applied for comprehensive data assessment. Evaluation results were analyzed by dimension and region, culminating in the proposal of specific optimization pathways to enhance the accessibility of Community Emergency Corridor System.

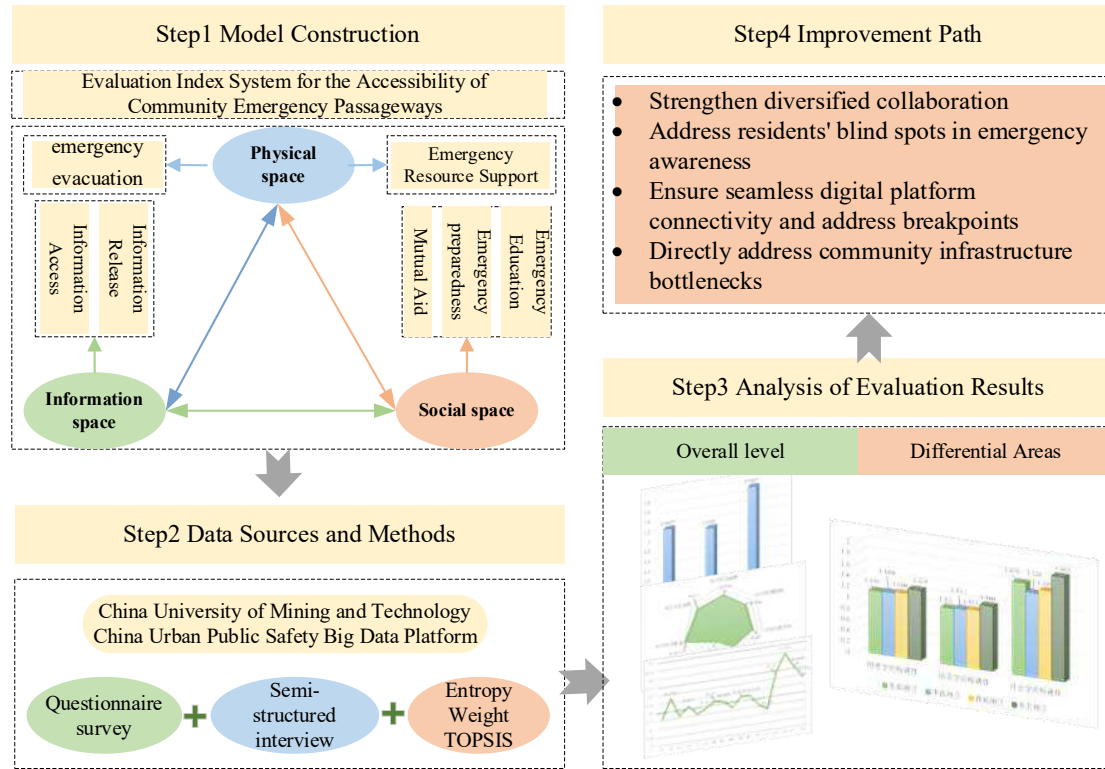


Fig 1: Technology roadmap

3 Materials and methods

3.1 Indicator system

This study systematically constructs an evaluation indicator system for the accessibility of Community Emergency Corridor System by integrating established frameworks, including the U.S. state government's Capability Assessment for Readiness (CAR) [36], the U.S. local government's Local Capability Assessment for Readiness (LCAR) [37], and systems developed by Henstra and Wang et al. [38][39], Guan, X. et al. [40], Lu Pingjun et al. [41], and Jie Liu et al. [42]. During the initial indicator selection phase, based on the Triadic Space Theory framework, existing evaluation elements underwent dimensional deconstruction and reorganization. This formed a set of secondary indicators covering three spatial dimensions: physical facilities, social organizations, and information exchange. These were further refined into 17 quantifiable tertiary indicators, ensuring that each component of the Community Emergency Corridor System assessment could

be measured through specific statistical indicators. To validate and refine the system, three rounds of expert consultation (n=7) were conducted using the Delphi method. The Analytic Hierarchy Process (AHP) was applied to assess indicator validity and assign weights. During the first round, experts were invited to contribute additional critical indicators via an open-ended question format and to assign preliminary weights. Resulting weight coefficients were analyzed, and indicators with values below 0.05 were excluded as insignificant. Combined with expert consensus (Kendall's $W=0.82$), the indicator system was targeted for optimization, ultimately forming a community emergency accessibility assessment framework comprising 3 dimensions, 7 elements, and 17 measures (Table 1).

Table 1: The evaluation index system for the accessibility of community emergency corridor system

Primary indicator	weight	Secondary indicator	Weight	Tertiary indicator	Specific questions
Physical sphere accessibility (A)	0.2857	Community evacuation	0.1452	Emergency signs A1	Community sets safety/emergency signs/indicators in conspicuous locations like shelters/key intersections, posts evacuation route maps.
					Community has signs for hazardous areas, fire lanes, etc.
				Fire safety A2	Community regularly inspects building elevators for safe operation.
					Community actively manages illegal parking of electric bicycles.
					Community electric bicycle parking areas meet fire safety conditions.
				Evacuation routes A3	No illegal structures between buildings occupying fire separation distances/fire truck operational areas.
					Community regularly inspects fire lanes, evacuation routes, exits to ensure they are clear.
		Emergency resource support	0.1406	Emergency supplies A4	Community is equipped with complete emergency facilities, such as fire extinguishers and AED defibrillators.
					Community has stocked sufficient emergency supplies.
				Emergency	Community fully utilizes parks, squares, green spaces

				shelters A5	paces, schools, stadiums, community service facilities to meet urgent evacuation/relocation needs.
					There are parks, stadiums, schools etc. near community usable as emergency shelters.
				Emergency agencies A6	Presence of community hospitals, Red Cross etc. capable of providing emergency medical care.
					Community is equipped with emergency supply storage points or mini fire stations.
Information sphere accessibility (B)	0.2697	Emergency info release	0.1532	Information resources B1	I often pay attention to emergency disaster info on community apps, government websites, community bulletin boards.
					I can promptly obtain early warning info (earth quakes, extreme weather) from phone/internet.
				Information symmetry B2	I understand policies/regulations released by govt/community for various emergencies.
					I have confidence in the government's or community's ability to respond to various accidents and disasters.
		Emergency info acquisition	0.1165	Information openness B3	I believe that the street and government should disclose relevant information about emergencies and disasters in a timely and complete manner.
					I believe the government is very transparent in disclosing emergency response information for sudden incidents.
				Information gathering B4	I learn about disaster info through private WeChat groups, friends/relatives.
					I learn about disaster info through community grid groups, community apps.
Social sphere accessibility (C)	0.4446	Neighborhood mutual aid	0.0704	Receiving help C1	I actively share learned disaster/response info via WeChat groups, personal accounts.
					I believe disaster information spreads quickly and truthfully within the community.
				Providing help C2	In emergencies, my neighbors/friends will proactively help.
					In emergencies, I can receive support/help from the govt/community.
		Community Emergency preparedness	0.2049	Emergency Foundation C3	In daily life, if others face emergencies, I proactively offer help.
					In emergencies, I am willing to offer whatever help I can to neighbors in need.
					Community fully implements grid-based management of disaster/accident risks/hazards.
					Community encourages/guides families to reserv

					e necessary emergency supplies, promotes family emergency kits.
					Community has volunteer teams participating in daily comprehensive disaster reduction work.
				Emergency drills C4	Community regularly conducts emergency drills for fires, floods, earthquakes, etc.
					I actively participate in community-organized emergency drills.
					Community emergency drills are very helpful in improving my ability to handle emergencies.
		Community emergency education	0.1693	Implementation status C5	Community organizes activities regularly in various forms for disaster prevention/reduction education.
					Community often uses loudspeakers, electronic screens to remind residents of safety hazards.
					Community regularly holds emergency safety training, distributes family emergency guidance manuals.
				Education effectiveness C6	I have participated in community-organized safety/emergency education activities.
					I find the safety/emergency education provided by the community very helpful.

3.2 Data sources

This study utilizes the China University of Mining and Technology China Urban Public Safety Big Data Platform(<https://ccps.cumt.edu.cn/>), adopting a mixed-methods approach that integrates questionnaire surveys with semi-structured interviews. A data support system was established, prioritizing quantitative analysis as the core methodology. The questionnaire was designed based on the evaluation index system of Community Emergency Corridor System accessibility, and administered through targeted field surveys. Residents' perceptions of the accessibility Community Emergency Corridor System were measured using a five-point Likert scale. All procedures performed in studies involving human participants were in accordance with the 1964 Helsinki Declaration and its later amendments. The protocol was approved by the Institutional Review Board of the School of Public Policy and Management, China University of

Mining and Technology on June 20, 2024 (No. QN-2024-0019) . Data collection began after obtaining ethical permission. The recruitment period for this study began on 1/7/2024, and ended on 31/8/2024. Written informed consent was obtained from all participants.

A multistage sampling strategy was implemented, with cities serving as primary sampling units, followed by systematic selection of streets, communities, residential complexes, households, and individual respondents. This ultimately formed a sample network covering 77 communities across 36 cities in Eastern, Central, Western and Northeastern China. A total of 7,298 questionnaires were distributed, with 6,958 valid responses recovered after data cleaning, resulting in a valid response rate of 95.34% (Table 2). All those who recognized the value of this study and understood its purpose and objectives participated. The participants were all adults, and their participation was entirely voluntary after being assured of their anonymity and the academic use of the collected data. The participants have also consented to the submission of the article to the journal. Informed consent was obtained between July to August 2024. The collected data were analyzed using SPSS software for reliability and validity assessment. Cronbach's alpha coefficient was 0.964, and the KMO value reached 0.976, indicating high internal consistency and strong construct validity, thereby confirming the dataset's analytical robustness.

Because the accessibility levels of Community Emergency Corridor System in different regions are constrained by objective conditions such as local economic development, this study divides the country into four regions—Eastern, Central, Western, and Northeastern—based on the economic zone classification standards established by the National Bureau of Statistics [43]. Accessibility assessments are conducted separately for each region. The Eastern Region comprises 10 provinces and municipalities: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian,

Shandong, Guangdong, and Hainan. The Central region comprises six provinces: Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. The Western region encompasses twelve provinces, autonomous regions, and municipalities: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The Northeastern region consists of Liaoning, Jilin, and Heilongjiang. Survey results are presented in Table 2.

Table 2 Distribution of surveyed cities and valid sample size

Region	City	Number of questionnaires distributed	Number of valid questionnaires	Efficient	City	Number of questionnaires distributed	Number of valid questionnaires	Efficient
Eastern	Beijing	200	173	86.50%	Nanjing	190	166	87.37%
	Tianjin	200	189	94.50%	Hangzhou	208	206	99.04%
	Shijiazhuang	225	223	99.11%	Fuzhou	147	143	97.28%
	Shanghai	195	168	86.15%	Xiamen	288	281	97.57%
	Jinan	206	202	98.06%	Haikou	200	186	93.00%
	Qingdao	200	196	98.00%	Guangzhou	200	197	98.50%
	Ningbo	215	210	97.67%	Shenzhen	200	188	94.00%
Northeastern	Harbin	200	183	91.50%	Shenyang	208	191	91.83%
	Changchun	200	184	92.00%	Dalian	200	176	88.00%
Central	Taiyuan	216	208	96.30%	Hefei	198	187	94.44%
	Nanchang	200	191	95.50%	Zhengzhou	201	199	99.00%
	Wuhan	199	188	94.47%	Changsha	195	178	91.28%
Western	Kunming	220	209	95.00%	Lanzhou	196	193	98.47%
	Hohhot	200	194	97.00%	Nanning	200	198	99.00%
	Xining	200	192	96.00%	Guiyang	199	199	100.00%
	Yinchuan	200	199	99.50%	Xi'an	205	189	92.20%
	Lhasa	200	199	99.50%	Chengdu	201	194	96.52%
	Wulumuqi	186	180	96.77%	Chongqing	200	199	99.50%

3.3 Evaluation method

The study applies the Entropy Weighted TOPSIS method to conduct a comprehensive evaluation of triadic space accessibility for Community Emergency Corridor System. The TOPSIS

method comprehensively evaluates objects based on their distances from the ideal point. The entropy weight method employs information entropy from information theory to determine indicator weights, serving as an objective weighting approach [44]. By integrating the entropy weight method into TOPSIS, the combined approach establishes objective dimension weights, thereby reducing arbitrariness in the evaluation process [45-46]. The specific steps are as follows:

1. Construct the initial evaluation matrix. Assuming there are m survey questionnaires, each comprising n evaluation indicators, establish the community emergency access accessibility indicator matrix A by using equation (1) :

$$A=(a_{ij})_{m \times n} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix} \quad (1)$$

In equation (1) , a_{ij} denotes the value of the jth evaluation indicator from the ith survey questionnaire, where $i = 1, 2, \dots, m$; $j = 1, 2, \dots, n$.

2. Data Standardization. Within the evaluation indicator system, differences in the nature of various indicators result in varying units of measurement. To eliminate the influence of unit discrepancies, standardization of indicator values is necessary.

This study involves no negative indicators. For positive indicators, the standardization formula is applied:

$$a'_{ij} = \frac{a_{ij} - \min(a_{ij})}{\max(a_{ij}) - \min(a_{ij})} \quad (2)$$

In equation (2) , a'_{ij} denotes the normalized value of the jth evaluation indicator from the ith survey questionnaire. This process results in the standardized dimensionless matrix A' by using equation (3) .

$$A'=(a'_{ij})_{m \times n} = \begin{pmatrix} a'_{11} & a'_{12} & \cdots & a'_{1n} \\ a'_{21} & a'_{22} & \cdots & a'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a'_{m1} & a'_{m2} & \cdots & a'_{mn} \end{pmatrix} \quad (3)$$

3. Construct an information entropy model. The higher the information entropy value, the smaller the contribution of that factor to the accessibility of Community Emergency Corridor System.

$$e_j = - \frac{\sum_{i=1}^m p_{ij} \ln p_{ij}}{\ln m} \quad (4)$$

$$p_{ij} = \frac{a_{ij}}{\sum_{j=1}^m a_{ij}} \quad (5)$$

$$d_j = 1 - e_j \quad (6)$$

In equation (4) : e_j denotes the information entropy value of evaluation indicator j; In the equation (5) : p_{ij} denotes the proportion of questionnaire i relative to indicator j, where $0 \leq p_{ij} \leq 1$; In equation (6) : d_j denotes the redundancy of information entropy.

4. Calculate the weights of evaluation indicators by using equation (7) .

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j} \quad (7)$$

In equation (7) , w_j represents the weight of the evaluation indicator, and $0 \leq w_j \leq 1$.

5. Determine the optimal and suboptimal points. The optimal point is $r^+ = (r_1^+, r_2^+, \dots, r_n^+)$, where r_n^+ is the maximum value of the nth indicator. The suboptimal point is $r^- = (r_1^-, r_2^-, \dots, r_n^-)$, where r_n^- is the minimum value of the nth indicator.

6. Compute the distance from optimal and suboptimal points. The weighted Euclidean distances d_{ij}^+ , d_{ij}^- between the current point $(r_{ij1}, r_{ij2}, \dots, r_{ijn})$ and the optimal point r^+ , suboptimal point r^- are defined as:

$$d_{ij}^+ = \sqrt{\sum_{k=1}^n w_k (r_{ijk} - r_k^+)^2} \quad (8)$$

$$d_{ij}^- = \sqrt{\sum_{k=1}^n w_k (r_{ijk} - r_k^-)^2} \quad (9)$$

7. Calculate scores. The score s_{ij} for questionnaire i in indicator system j is defined as

$$s_{ij} = \frac{d_{ij}^-}{d_{ij}^+ + d_{ij}^-}.$$

8. After obtaining scores for each questionnaire across indicator systems, recalculate the comprehensive score using the TOPSIS method.

4 Results analysis

4.1 Overall analysis

Empirical results from the entropy-weighted TOPSIS model reveal significant structural imbalances in the accessibility of Community Emergency Corridor System across the triadic space, as illustrated in Fig.2. The overall score for emergency accessibility across these domains is 3.9715. Among the primary indicators, the accessibility of Community Emergency Corridor System in the social space scored highest at 1.7567, while that in the information space scored the lowest at 1.0531, resulting in a gap of 0.7036. Both the physical and information spaces exhibit relatively low accessibility levels, indicating considerable potential for improvement. At the secondary indicator level, community emergency preparedness attained the highest score of 0.7891, reflecting strong emergency awareness in most communities. In contrast, neighborhood emergency mutual aid scored the lowest at 0.2918, reflecting the indifference and social estrangement in contemporary neighborhood relations, as shown in Fig.3. This reveals that the uneven development of Emergency Corridor System across the triadic space exposes systemic coordination bottlenecks within community emergency response networks. Structural optimization through spatial element reorganization is urgently needed.

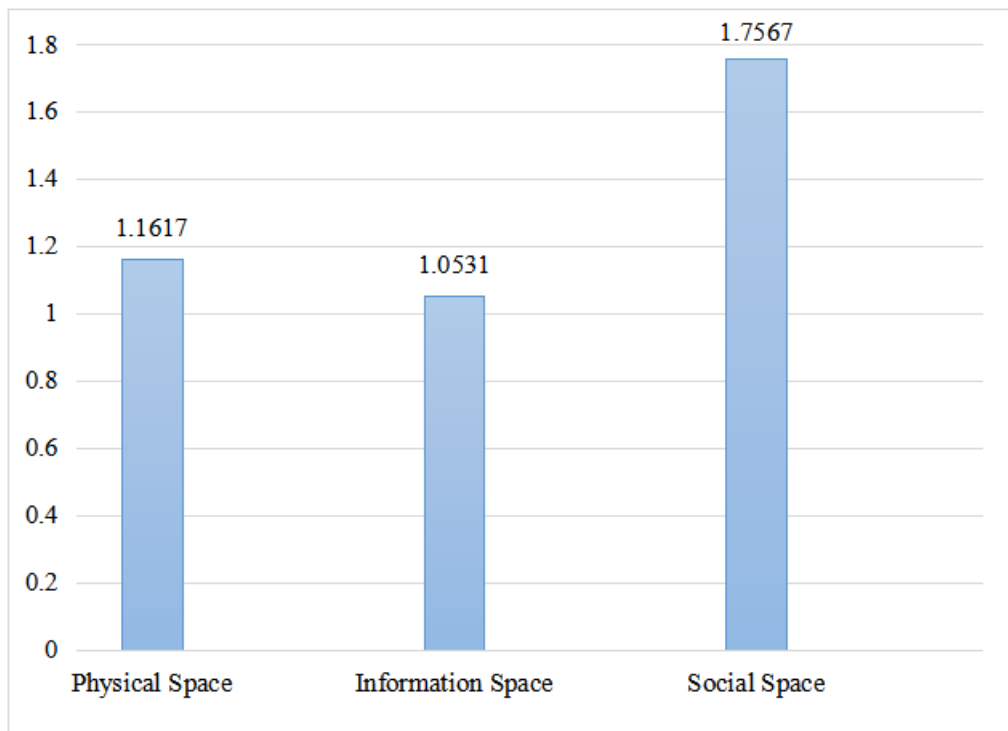


Fig 2: Scores for primary indicators of Emergency Corridor System accessibility in triadic

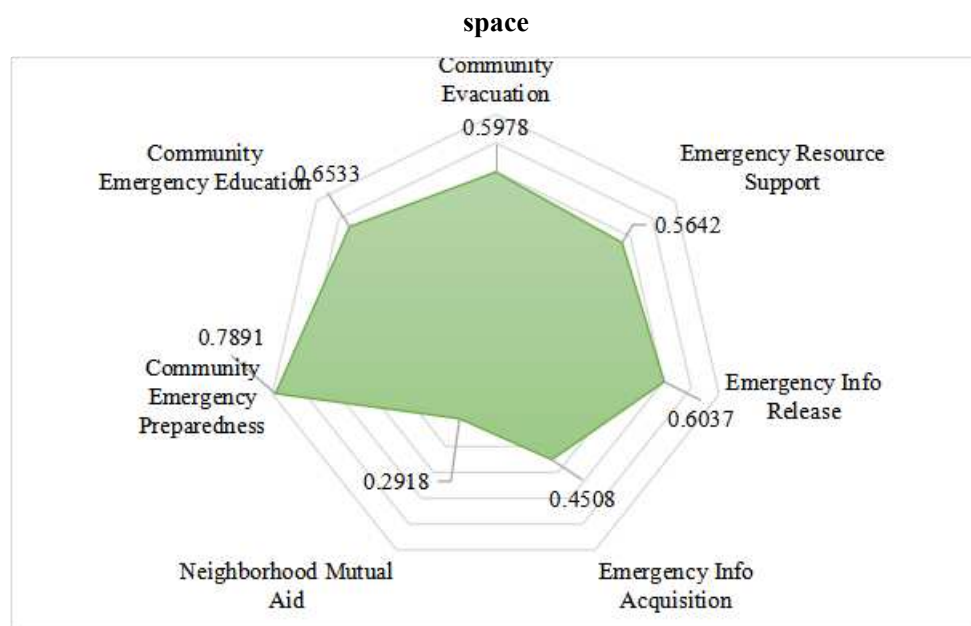


Fig 3: Scores for secondary indicators of Emergency Corridor System accessibility in triadic

4.2 Sub-Dimensional analysis

The accessibility score for physical Emergency Corridor System is 1.1617, indicating a relatively low level. Specifically, community emergency signage constitutes the most significant

barrier to the accessibility of physical emergency corridor System , achieving the lowest score of only 0.1572. Community emergency evacuation route diagrams play a crucial guiding role during fires or earthquakes, enabling residents to evacuate more swiftly and safely while reducing congestion incidents. Simultaneously, signage for hazardous zones and fire lanes subtly enhances residents' emergency preparedness awareness. In terms of physical Emergency Corridor System accessibility, this primarily encompasses community emergency evacuation and emergency resource support. The score for community emergency evacuation is 0.5978, while that for emergency resource support is 0.5642, showing a relatively small difference and indicating a balanced state. Among the tertiary indicators, Physical Emergency Corridor System accessibility varies significantly across communities, ranging from 0.1572 to 0.2768, with A1 scoring lowest, A5 second lowest, and A2 achieving the highest score. Community infrastructure and emergency resources serve as essential hardware support for responding to sudden public incidents, facilitating emergency rescue operations and effectively preventing escalation, thereby safeguarding residents' lives and property. They represent fundamental pathways for improving the accessibility of Community Emergency Corridor System .

As an extension of the dual-space concept, the information space serves as a vital engine for enhancing community emergency corridor. However, overall, the community information space scored the lowest at only 1.0531, indicating persistent gaps in emergency information release and acquisition within communities. As shown in Table 5, the secondary indicator for emergency information release scored relatively high, reflecting increased emphasis on transparency in emergency communication in recent years, which is also closely linked to improvements in community informatization levels. The low score for residents' emergency information acquisition

reflects how technological advancements have transformed information dissemination channels, methods, and formats. The complex of safety-related information poses significant challenges to residents' abilities to collect, discern, and access information—particularly among elderly populations, who predominantly rely on neighborhood networks and lack independent information-seeking capabilities. Therefore, communities should establish effective emergency information release mechanisms to improve both the efficiency and effectiveness of information delivery, thereby strengthening residents' capacity to obtain critical emergency information.

As a key factor influencing the accessibility of Community Emergency Corridor System , the social space is closely linked to residents' daily lives. A safe and stable social space can effectively enhance community emergency response capabilities and individual preparedness, thus promoting the accessibility of Community Emergency Corridor System . Currently, the social space score of Community Emergency Corridor System accessibility is the highest among three spaces, at 1.7567. Nevertheless, internal weaknesses persist in the social space of emergency corridor accessibility. Secondary indicator scores range from 0.2918 to 0.7891, revealing significant variation. The lowest score is for neighborhood emergency mutual aid (0.2918), indicating weak community neighborly ties and limited interpersonal interaction. The highest score is for community emergency preparedness (0.7891). Among tertiary indicators, the social space score of emergency corridor accessibility ranged from 0.1293 to 0.4453. Indicators C1 and C2, representing the neighborhood emergency mutual aid sub-dimension, scored notably lower than other indicators. Therefore, fostering harmonious and supportive neighborhood relationships and community environments is crucial.

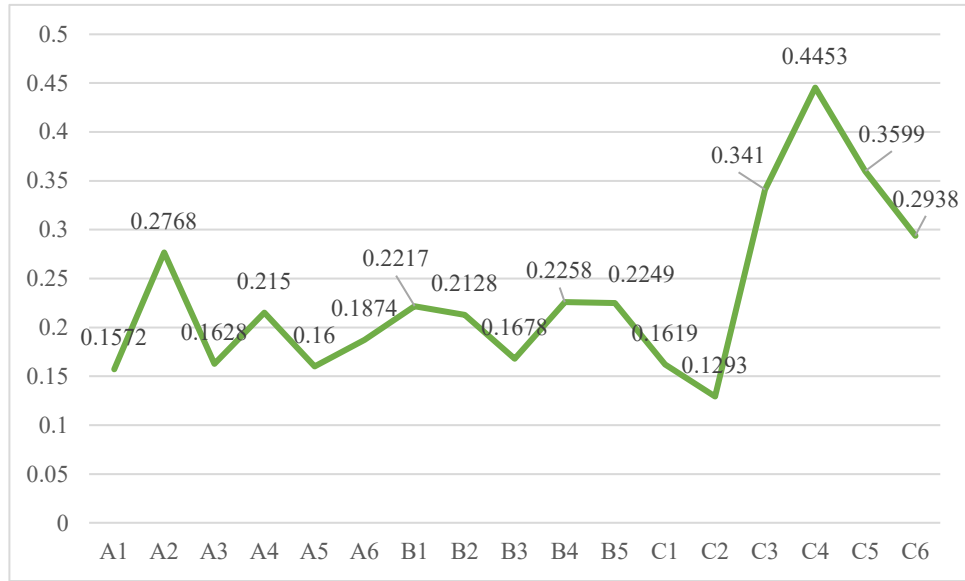


Fig 4: Scores of tertiary indicator for Emergency Corridor System accessibility in triadic space

4.3 Regional analysis

Analysis of accessibility across the four regions reveals that in the triadic space, all regions exhibit a consistent trend: social space accessibility ranks highest, physical space accessibility follows, while information space accessibility remains the lowest.

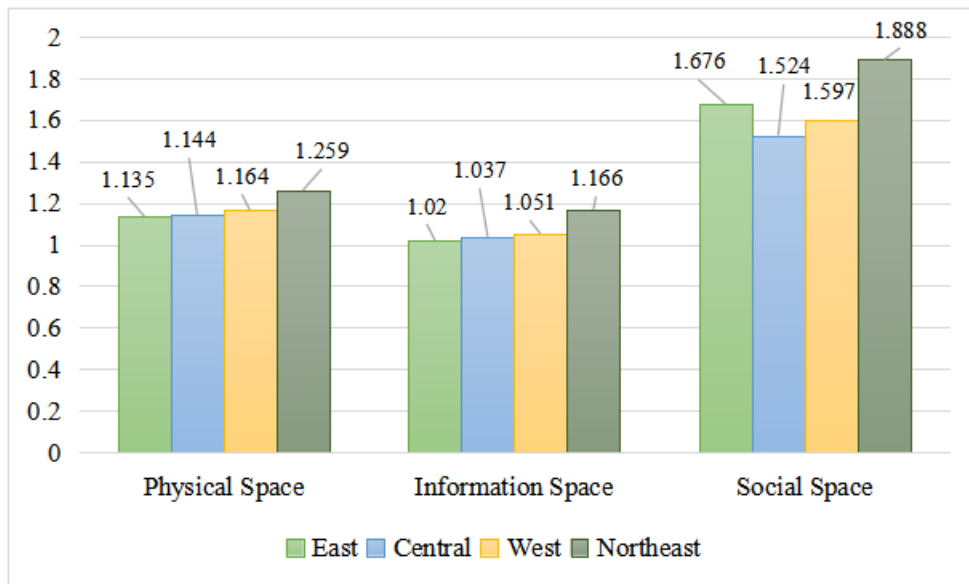


Fig 5: The regional scores of community Emergency Corridor System accessibility in triadic space

Comparing accessibility levels across regions, the eastern region scored the lowest in both physical and information space accessibility. With higher urbanization rates, densely packed urban structures, and limited land resources, emergency routes in eastern cities may be squeezed by commercial facilities or residential areas, resulting in insufficient width or lack of alternative paths. In contrast, the central and western regions benefit from abundant land resources, enabling community planning to better incorporate emergency evacuation requirements. Regarding information space accessibility, the eastern region's high internet penetration rate means residents are more familiar with and reliant on digital communication. This familiarity may lead to lower trust in official warning channels or increased susceptibility to rumors, thereby weakening the effectiveness of information dissemination.

The central region's physical and information space accessibility levels are broadly comparable to those of the eastern region. However, it scored the lowest among the four regions in social space accessibility. Social space primarily emphasizes organizational connectivity, encompassing both grassroots communities' emergency response and coordination capabilities during incidents, and the closeness of neighborly relationships and community cohesion among residents. The development model in central regions relies heavily on government policies and resource allocation, with residents and grassroots organizations accustomed to passively awaiting and executing directives, resulting in lower social connectivity.

The western region generally exhibits moderate connectivity across the triadic space, characterized by relatively fragmented development that necessitates sustained efforts to improve spatial coordination. Modern metropolises like Chengdu and Xi'an in the west demonstrate connectivity characteristics closer to the eastern region, while the vast rural areas and traditional

communities align more with the central region's patterns. The aggregation of subregional scores yields an overall stable trend. Consequently, strengthening grassroots emergency response capabilities in the West cannot rely on direct replication of models from other regions; instead, it demands more resilient and adaptive strategies that account for its internal heterogeneity.

The Northeast region achieved the highest score in triadic space accessibility, reflecting distinct emergency response potential and developmental advantages. As China's earliest industrialized region, Northeast China initiated urban and community planning began early, characterized by wide, straight roads, orderly blocks, and ample public space. This reduces obstacles for rescue vehicle access and personnel evacuation. In terms of information space accessibility, grassroots communities in the Northeast predominantly rely on traditional information dissemination methods, such as community announcements and unit leader notifications. Information can reach residents quickly, avoiding social panic and disorderly actions caused by information chaos. Regarding social space accessibility, the “unit-based” community structure established during the planned economy era has cultivated a strong sense of collective identity and a tradition of mutual neighborhood support. This has created a relatively stable “familiar society” where high levels of resident cooperation contribute to reduced communication costs.

5 Discussion

5.1 Theoretical contributions

This study adopts a triadic space perspective and employs the Entropy Weighted TOPSIS method to evaluate the accessibility of Community Emergency Corridor System across multiple representative Chinese communities. The findings reveal that overall, the accessibility of

Community Emergency Corridor System across the triadic space exhibits uneven development; social space outperform physical and information space; regionally, development follows the pattern Northeast > West > Central > East. This study creatively applies Triadic Space Theory to the specific context of grassroots emergency management, theoretically testing and enriching the explanatory power and applicability boundaries of this framework. It also addresses the limitations of previous research that isolated discussions of a single space in grassroots emergency scenarios [47][48][49]. By conceptualizing physical, information, and social spaces as an inseparable organic whole, the study elucidates their interactive relationships and coupling mechanisms, achieving cross-spatial integration. This enhances theoretical understanding of the complexity inherent in grassroots emergency management and advances a paradigm shift in the field—from “unidimensional static” to “triadic dynamic” frameworks. Furthermore, this study innovatively constructs an evaluation index system for assessing the accessibility of Community Emergency Corridor System, operationalizing the core concept of triadic space into a set of measurable and evaluable standards. This lays a foundation for subsequent empirical research in grassroots emergency management.

5.2 Cause analysis

The primary impediment to developing triadic space accessibility in community emergency pathways lies in fragmented spatial integration. Firstly, community physical space planning fails to adequately accommodate residents' social spatial needs, most evident in the chronic shortage of electric vehicle charging stations. The lack of charging infrastructure within residential compounds readily leads to unsafe practices like bringing electric vehicles indoors or using extension cords for charging, which in turn obstructs emergency corridor routes. This reflects a

disconnect between physical infrastructure planning and the mobility behaviors and safety requirements embedded in social space. Secondly, the digital transformation of physical space through the information space remains underdeveloped. The inability to connect the physical and social spaces through information technology limits the effectiveness of coordinated development across the triadic space. With regard to physical emergency accessibility, factors such as regional economic disparities, uneven resource distribution within areas, and varying levels of community development may prevent communities from regularly updating emergency infrastructure or allocating sufficient funds for maintenance. This results in suboptimal physical accessibility.

Compared to the traditional industrial era, information has become a central rather than secondary factor in the risk society of the digital age [35]. The quality of information transmission channels and communication within the information space significantly impacts the overall the accessibility of Community Emergency Corridor System. Key barriers in the information space include limited emergency information dissemination channels, the absence of community-wide emergency information sharing platforms, and residents' low sensitivity to emergency alerts coupled with inadequate preparedness. Currently, most communities rely on resident group notifications and bulletin board postings for emergency alerts. Although a small number of technologically advanced communities have established integrated emergency information platforms, such cases remain rare nationwide. In terms of emergency information access, most residents demonstrate insufficient awareness of emergency risks and weak preparedness, with the elderly group being particularly affected.

Within the Chinese cultural context, neighborhood mutual aid functions as an informal system in grassroots emergency scenarios. Researchers have identified that community-based

mutual assistance represents a “highlight” in urban resilience governance, particularly during events such as urban flooding [36]. However, regarding social space accessibility for Emergency Corridor System, the tension between traditional values and modern governance paradigms has subtly reshaped neighborhood relationships and spatial behaviors, emerging as a key obstacle to Emergency Corridor System efficiency. First, regarding neighborly relations, unlike the traditional adage “a good neighbor is better than a distant relative,” modern neighborly interactions increasingly lean toward estrangement, characterized by a “every man for himself” mentality that hinders mutual aid during emergencies. Second, spatial behaviors present challenges. Limited living space combined with traditional notions of resource efficiency leads many elderly residents to store belongings—including recyclables—in stairwells. This practice severely obstructs fire lanes and creates significant safety hazards.

5.3 Path exploration

The accessibility of Community Emergency Corridor System encompasses three dimensions: physical space, information space, and social space. To resolve bottlenecks in accessibility and strengthen grassroots safety defenses, it is imperative to establish an “unobstructed community emergency access space.” This involves identifying convergence points among physical, social and information accessibility at the grassroots community level, thereby creating a triadic barrier-free environment that spans the individuals, communities, and society. The future development of this “barrier-free space for community emergency access” must adhere to the value principle of prioritizing people and lives. It should deliver actionable strategies to enhance accessibility through four dimensions: multi-stakeholder collaboration, awareness enhancement, digital empowerment, and spatial optimization.

Community emergency response systems cannot be built by a single entity operating in isolation. They must rely on the collaboration of multiple stakeholders to establish cooperative mechanisms linking communities, professional teams, and volunteer organizations [41]. Organizational coordination must overcome challenges in emergency response organization. This includes establishing community emergency command teams to centrally coordinate local resources; appointing dedicated emergency grid officers whose roles extend beyond routine oversight to include information dissemination, supply distribution and resident reassurance during emergencies. This ensures rapid response and timely coordination of resources and information within the 15-minute emergency response zone. Each residential building should designate a “building manager” to ensure unobstructed community emergency access. The effectiveness of community emergency response is also closely tied to the professional competence of grassroots rescue teams. Volunteer selection and training must follow standardized protocols. In addition to technical skills, volunteers should receive psychological resilience training to remain calm under pressure and effectively guide residents in evacuation or self-rescue. In daily life, organizing neighborhood mutual aid groups can enhance interaction and cooperation. These groups provide everyday support—such as grocery assistance for the elderly or childcare—fostering trust and responsibility among residents, thereby improving social space accessibility within emergency pathways.

Weak emergency awareness among residents is a key factor contributing to the lack of effective self-rescue or mutual aid actions during emergencies. Therefore, enhancing residents' emergency awareness and self-rescue capabilities—particularly through systematic community safety education—is essential for strengthening community resilience and protecting residents'

lives. To ensure comprehensive emergency education for all residents, communities should establish a safety education system covering all residents by integrating diverse resources based on local realities. Developing a holistic safety education framework, promoting active participation in skills training, and leveraging information technology can effectively enhance residents' emergency response capacities. Communities can also utilize observances such as International Day for Disaster Reduction and National Disaster Prevention and Mitigation Day to increase engagement. Initiatives may include targeted outreach for older adults, on-site emergency training led by firefighters and first responders, and simulation drills to build practical preparedness. Such measures effectively bridge gaps in emergency readiness.

Smart communities represent an emerging model of urban development that integrates resources and enhances management and service functions through digital tools[52]. Building smart community management platforms can break down information barriers and improve the efficiency of information sharing. By leveraging IoT and cloud computing, communities can develop integrated emergency management platforms that support monitoring, early warning, and real-time information exchange. Connecting these platforms with critical emergency infrastructure—such as evacuation routes, supply reserves, and shelters—enables sensors, IoT devices, and intelligent monitoring systems to provide continuous updates on facility status and availability. For example, infrared sensors and video surveillance can monitor evacuation route accessibility in real time, detect obstructions promptly, and automatically alert responsible personnel. Inspired by Singapore's satellite town model, Hangzhou Xiaoshan's Guali Rainbow Community has developed a "people-centered" digital safety ecosystem. It features a comprehensive, multi-layered security network with no blind spots, including AI-powered

one-click emergency alerts for blocked escape routes, substantially reducing labor demands.

As the lifeline of any community, physical space directly impacts emergency response efficiency. Ensuring unobstructed physical pathways requires two core strategies: first, optimizing spatial planning to enable rational allocation of emergency facilities, ensuring swift resident access to shelters and timely assistance during emergencies; second, conducting regular clearance of stairwells and fire lanes to maintain passageway accessibility. In this era of deep integration across three dimensions, overcoming barriers in the accessibility of Community Emergency Corridor System requires balanced and coordinated development across physical, information, and social spaces. Accelerate the renewal of aging communities, further upgrade emergency infrastructure, and improve the accessibility of physical emergency pathways. Promote diversified emergency information channels, expedite the construction of emergency information sharing platforms, and strengthen data protection to enhance information space accessibility. Encourage residents to actively participate in emergency governance, raise public safety awareness through sustained educational campaigns and community initiatives, and cultivate a supportive cultural environment to strengthen social space accessibility.

6 Conclusions and outlook

6.1 Conclusions

The study adopts a triadic space perspective to construct an evaluation framework for assessing the accessibility of Community Emergency Corridor System. By comprehensively evaluating accessibility levels across each spatial dimension, the following key conclusions are drawn:

(1) Regarding the overall accessibility of Community Emergency Corridor System, the

aggregate score was 3.9715. Among the three spatial dimensions, social space accessibility ranked highest, followed by the physical space, while information space exhibited the lowest level. The notably low performance in the information space indicates significant room for improvement and reveals spatial imbalances that impede the formation of an integrated community emergency response mechanism.

(2) Regional comparisons reveal that the eastern region scored lowest in both physical and information space accessibility, whereas the central region recorded the lowest score in social space accessibility compared to the other three regions. The western region demonstrated relatively stable accessibility across triadic space, while the northeastern region achieved the highest overall accessibility across three dimensions.

(3) Enhancing community emergency pathway accessibility requires balanced and coordinated development across all three spatial dimensions. While achieving maximum accessibility and balanced three-dimensional connectivity represents an ideal state, resource efficiency demands that communities scientifically allocate resources based on local economic conditions and comprehensive capabilities. Feasible plans for enhancing community emergency capacity must be rationally formulated accordingly.

6.2 Limitations and outlook

It should be acknowledged that this study has certain limitations. First, the breadth and depth of the sample are insufficient. Although the study covers multiple cities across different regions nationwide, constrained by research resources, the number of sampled communities within each city remains limited, thereby precluding a comprehensive assessment of Emergency Corridor System accessibility levels in those areas. Second, the refinement of sample classification is

inadequate. In selecting communities, this study did not systematically classify or compare them according to key characteristics such as built environment, social composition, and management models. This limitation may reduce the precision of the resulting policy recommendations.

Given these limitations, future research will focus on advancing and deepening these two aspects. With regard to sampling strategy, the scale of community sampling within each city will be expanded, and more rigorous stratified sampling methods will be employed to ensure that the sample more accurately represents the diversity of urban communities. Regarding classification research, a systematic community classification framework will be developed to deeply explore the coupling mechanisms and barriers influencing the accessibility of triadic space in different community types. This aims to formulate more targeted policies and interventions to enhance the accessibility of Community Emergency Corridor System.

Data Availability

The datasets analysed during the current study are not publicly available due to [The limitations of the Emergency Management Big Data Platform of China University of Mining and Technology] but are available from the corresponding author on reasonable request.

funding declaration

not applicable.

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774 **Competing interests:**

775 The authors declare no competing interests.