International Journal of Disaster Risk Reduction 43 (2020) 101366

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: http://www.elsevier.com/locate/ijdrr

Evaluation of seismic evacuation behavior in complex urban environments based on GIS: A case study of Xi'an, China

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ARTICLE INFO

Keywords:
Evacuation behavior
Urban environment
Evacuation destination
Evacuation path
Seismic disaster
Xi'an

ABSTRACT

Building evacuation behavior research based on computer logical rule-based models and experimental studies has always taken the leading role in the field of evacuation behavior. However, there is still limited research on seismic evacuation behavior in complex urban environments. This paper empirically evaluates the seismic evacuation behavior in complex urban environments during a real-world earthquake in Xi'an, China. More specifically, safety and closeness of evacuation, as well as group differences are discussed. Questionnaires and behavior maps, as well as GIS methods, are used to provide some baseline analyses. Results indicate that even though most residents chose safe evacuation destinations, they were not the closest destinations to their homes. The evacuation paths are much longer than the distances from residents' homes to the nearest safe space. Sections of every evacuation path are at risk due to high-rise buildings by the street side. There are obvious group differences of evacuation behavior caused by differences in gender, age, education level, personal familiarity with living environment, and length of residency. Based on the evaluation results, this paper also attempts to provide some insights to urban seismic shelter planning, urban construction and planning to improve urban disaster prevention ability.

1. Introduction

Choosing an optimal evacuation path and a safe space under any natural or man-made disaster is a great challenge. Sometimes the real danger comes not from the actual disasters but from what is called "non-adaptive" behavior of people during disasters [1]. Both safety and efficiency issues are perpetual themes of evacuation behavior literature.

According to our knowledge, there is a rich body of literature capturing human behavior during emergencies through various computer evacuation models. However, predicting human behavior during emergencies is a highly complicated problem, since human behavior is unpredictable and complex. Therefore, human behavior is difficult to import into computer logical rule-based models as math equations. Additionally, human behavioral characteristics are mainly derived from observation data through experimental studies in laboratories under virtual environments or empirical surveys under certain hypothetical conditions. There are still limitations in getting complementary behavioral data under real emergency conditions. Furthermore, building evacuation behavior has always taken the leading role in prior studies. However, outdoor escape is also an important part of evacuation behavior, especially in non-destructive earthquake affected areas or during aftershocks following medium or strong earthquakes. Nevertheless, there has been little focus on seismic evacuation behavior in complex urban environments, which contain buildings, open space, street networks, potential safety hazards, and different land use patterns. Based on these shortcomings, this paper conducts empirical research on the seismic evacuation behavior of residents in complex urban environments by collecting data through questionnaires and behavior maps during a real-world earthquake.

At 21:00 Beijing Time, on August 8, 2017, a magnitude 7.0 earthquake occurred in Jiuzhaigou County, Sichuan Province. It was strongly felt over a wide area including Xi'an, China (Fig. 1). Many residents evacuated from their homes or residential districts that night. However, some of them could not find safe evacuation destinations or optimal (i.e. short and safe) evacuation paths due to panic, chaos, high crowd density, lack of evacuation knowledge, or other reasons. Under this background, this research is carried out. The paper is structured as follows: first, the literature in this field is reviewed and methodology is described. Secondly, this case study evaluates the seismic evacuation behavior. More specifically, safety of evacuation destinations and paths,

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https://doi.org/10.1016/j.ijdrr.2019.101366
Received 6 August 2019; Received in revised form 11 October 2019; Accepted 12 October 2019
Available online 17 October 2019
2212-4209/

as well as closeness of evacuation destinations are discussed using GIS (Geography Information System) methods, and group differences of evacuation behavior are compared in detail. Finally, some insights to policy recommendations are put forward.

The purpose of this paper is to show the characteristics of seismic evacuation behavior in complex urban environments during a real-world earthquake. In particular, this paper develops a detailed way about evaluation of safety and efficiency of evacuation destinations and paths. Additionally, this paper reports a concrete exploration process of safe space, which will be an expansion of existing emergency shelters planned by local government.

2. Literature review

Building evacuation behavior has always been the focus in human evacuation behavior research since the early 20th century and has become a hot issue after the 9/11 terrorists attack in the United States [2]. Various computational models that can simulate human evacuation behavior are now available. Agent-based model is one of the most extensively used computational methodologies [3]. It is very suitable for exploring the mechanisms and preconditions for panic and jamming [4], and can construct an artificial environment populated with autonomous agents, who are capable of interacting with each other and the environment around them [5]. In order to overcome the difficulty in predicting human behavior in complex and uncertain emergency situations, Joo et al. successfully integrated the agent-based simulation approach into the perception-based simulation model from an ecological concept of affordance theory [6]. Cellular automata technique is also widely accepted for its numerical efficiency and conceptual simplicity [7–10]. It is also combined with other techniques, such as agent-based simulation model [11], goal oriented intelligent agents [12], and neural network decision-making capabilities [13] to capture human evacuation behavior. Additionally, there are still numerous other computer and mathematical models simulating human evacuation behavior, such as social force model [14–16], object-oriented model [17], particle swarm optimization [18], game-theoretical model [19], cluster-specific multivariate ordered probit model [20], and so on. Lee and Son and Shendarkar et al. presented a BDI agent framework based on Bayesian Belief Network, Decision-Field-Theory, and Probabilistic Depth-First Search [21,22]. Musharraf et al. [23] described a virtual environment to measure behavioral indicators using Bayesian Network model. Haghani and Sarvi [24] used an econometric model to quantify the way passengers evaluate and prioritize various contributing factors, such as distance, crowding, impact of other passengers' decisions, and spatial distribution of exits.

Some scholars [25–28] showed concern for evacuation behavior of residents with disabilities, who are more likely to suffer from accidents and slow down the evacuation efficiency of other evacuees because of their larger space requirements and slower evacuation speeds. Christensen and Sasaki [29] explained the diversity of disabilities and their interaction with the built environment around them. Manley and Kim [30] discussed behavior of disabilities during disasters in terms of speed, ability to negotiate the environment, and normalcy bias associated with types of disability.

Early studies investigated the human evacuation behavior only in the building with simple configurational space, usually one room or one

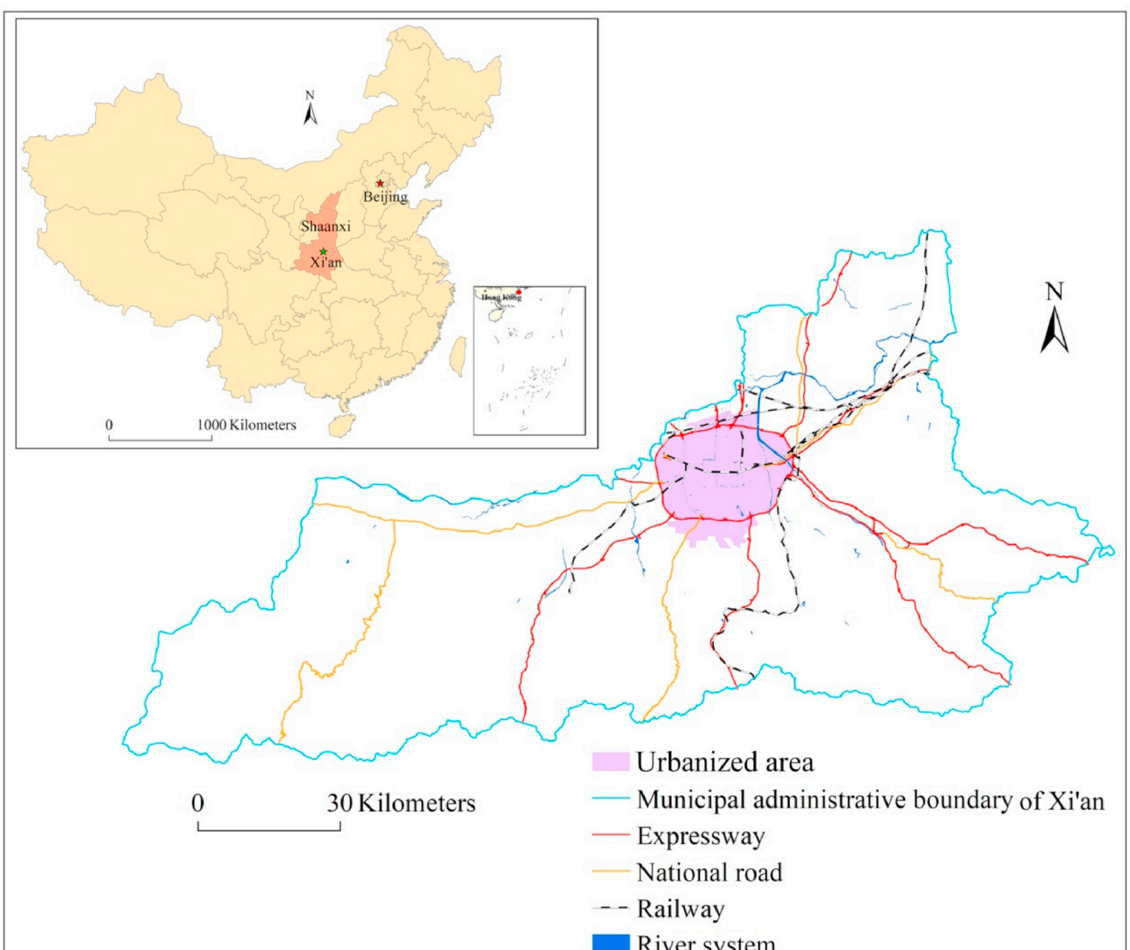

Fig. 1. Location of Xi'an.

floor. Accordingly, Ha and Lykotrafitis [31] tried to fully detail how complicated building architecture influences the evacuation behavior of individuals by using a social-force model, which was composed of employed motivational force, psychological repulsive tendency, compression, viscous damping/personal force, and sliding friction.

Varying from the above studies focused on building evacuation, some researchers were concerned about evacuation behavior outside of buildings. Cova and Johnson [32] presented a microscopic traffic simulation model to develop and test evacuation behavior in the urban-wild land interface. Georgiadou et al. [33] paid close attention to the area around hazardous facilities, and simulated the temporal and spatial distribution of the population under evacuation. Most recently, Dulebenets et al. discussed evacuation time periods from vulnerable population groups to emergency shelters through evacuation routes [34]. However, this study focused more on time expense, and neglected safety issues caused by complex urban environment.

Generally speaking, getting comprehensive human behavior features during evacuations is a great challenge. So far, most research collected data through observation experiments in laboratories under virtual environments, such as experiments on the dynamics of escape panic in mice [8], human-in-the-loop experiments in the virtual reality-based cave automatic virtual environment [21,22], spatial game experiments [35], comparison between two experimental groups (i.e., the social influence group and the control group in which participants were alone) in a 3D-multisensory cave automatic virtual environment laboratory [36], ambulatory virtual environment [37], and pedestrian flow simulation experiment in the waiting room of subway station [16]. Some others observe human escape behavior by conducting interviews and surveys with participants pre-selected on certain hypothetical conditions [23,24,38]. However, Gu et al. analyzed school students' emergency evacuation behavior in earthquakes based on data extracted from videos of real emergency evacuations [39]. Recently, some researchers provided detailed analysis of evacuation behavior after earthquakes based on mobile phone data. These studies have made significant contributions in providing insights of macroscopic, spatio-temporally precise, and often longitudinal analyses of evacuation behavior. However, these studies paid more attention to post-disaster mobility patterns [40], population flows and return rates [41], evacuation rates and evacuation distances [42], and did not analyze detailed evacuation behavior of individuals, especially the safety and efficiency of destinations and paths of individuals.

As studies of evacuation behaviors developed, factors that affect people's evacuation decisions are also the emphases people focus on and research in. These researches tried to build multiple models to analyze factors influencing evacuation decision making, such as multiple regression and ethnographic decision model [43], highway-based evacuation model [44], mixed logit (also known as random-parameters logit) model [45]. Main factors summarized from these studies include risk perception affected by psychological, social, institutional and cultural processes [43], social network, distance to threat and capacity of street network [44], household's geographic location, source of evacuation notice and type of evacuation notice (mandatory or optional) received, house ownership status and previous hurricane experience [45].

3. Study area, methodology and data sources

3.1. Study area

The study area we have chosen is a typical area, which contains different kinds of residential districts in Xi'an, China (Fig. 2). Each of them is almost entirely inhabited by a single social group type. This is helpful in comparing the group differences of evacuation behavior. In this paper, four kinds of typical residential districts were selected, namely, Retired Military Cadre Sanatorium, Nanfangxingzuo residential district, Bali village, and Shaanxi Normal University dormitory district. These four residential districts represent major types of residential districts and social groups in Xi'an. Retired Military Cadre Sanatorium ran by Shaanxi provincial civil affairs department is inhabited by elderly that are retired military cadres. Nanfangxingzuo is a relatively high-grade commercial district inhabited by richer groups. Bali village is a "Village in City" (*Chengzhongcun* in Chinese), which is a village in suburbs gradually surrounded by urbanized area during the process of urbanization. There are a large number of low-income groups, especially migrant workers, living in Bali village. Shaanxi Normal University owned dormitory district is provided for their employees, who generally have higher education levels.

3.2. Methodology

3.2.1. Safety evaluation

By comparing the spatial differences between the evacuation destinations and the safe space we have assessed, the safety of the destinations can be evaluated. Only when the destination is located in a safe space, it will be considered as safe. The safety of the evacuation paths are decided by the spatial relationship between the evacuation path and the

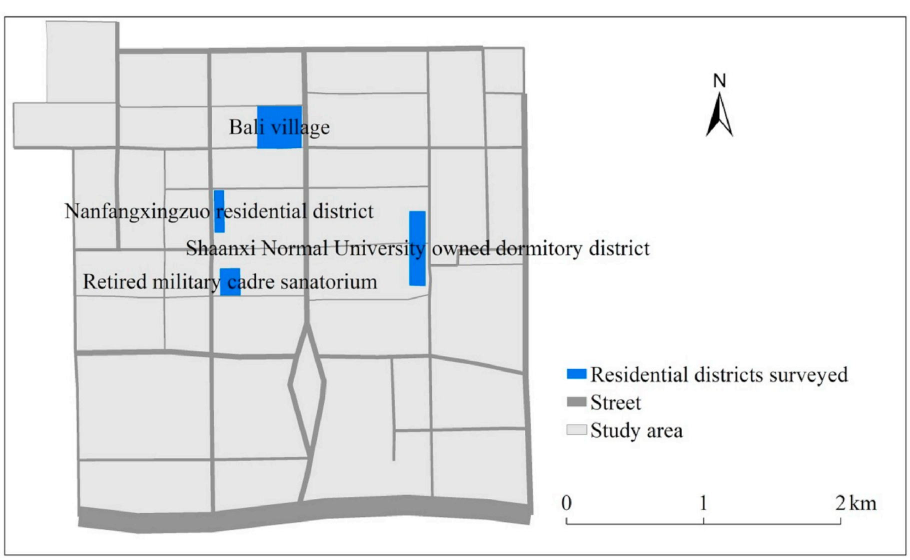

Fig. 2. Study area and residential districts surveyed.

possible sweep ranges of potential safety hazards. If the path wholly or even partially falls into the possible sweep ranges of potential safety hazards spatially, it will likely be at-risk.

To obtain safe spaces, it is necessary to take into account the impact of potential safety hazard sources, such as geologic faults, low-lying water-prone areas, high voltage lines, gas stations, high buildings, and so on. With regard to this study area, two kinds of urban environment elements need to be eliminated. The first is potential safety hazards and their possible sweep ranges. The second is places that cannot act as evacuation destinations. The former consists of 4550 buildings and their collapse ranges, 5 gas stations and 1 natural gas station and their explosion ranges, and areas at risk for geologic disasters. The latter includes 1 martyrs memorial park, 1 temple of heaven in the Tang Dynasty, lands under construction (these lands are all fenced to prohibit the entry of general public), and all streets (streets are essential evacuation passageways and cannot act as evacuation destinations) (Fig. 3). All the urban environment elements mentioned above are vectored in ArcGIS. The possible sweep ranges of all the potential safety hazards are as follows:

3.2.1.1. Collapse ranges of buildings. To determine the collapse ranges of buildings, we firstly use the floor numbers to calculate the heights. The height of each story is evaluated based on *Design code for residential buildings (GB 50096-2003)* published by Ministry of Housing and Urban-Rural Development of the People's Republic of China, which stipulates that the most suitable story height of residential buildings is 2.8 m. Since most of the constructive land of the study area is covered by residential and teaching buildings, the building height is equal to the floor numbers multiplied by 2.8 m.

Based on the heights (h) of the buildings, the actual collapse ranges of buildings can be calculated as Fig. 4 (Ji et al., 2014). Here R represents the cumulative collapse range in all directions. θ is the angle between the collapsed and non-collapsed building. Supposing the equal probability for collapse in all directions, θ is taken from 0 to π. r is the average collapse range. Since the collapse ranges of buildings are determined by building structures and seismic-disaster magnitudes, it is necessary to provide two coefficients (a_i and b_i) to revise r. a_i represents the building damage ratio of seismic-disaster. Based on field survey, most of the buildings in our study area are steel reinforced concrete, and few are brick and concrete structure that are clustered in Bali village. Liu et al. has put forward a suitable building damage ratio standard of seismic-disaster in China [46]. According to this standard, the damage ratio of steel reinforced concrete building ranges from 60% to 100%, and brick

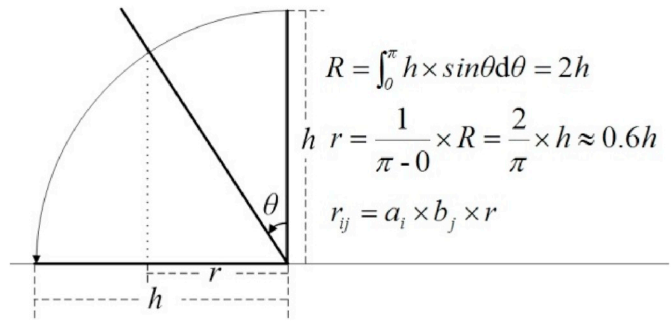

Fig. 4. Calculation of collapse range of buildings.

and concrete structure is between 83% and 100% during a serious seismic-disaster. Considering our goal to maximize the safety of the safe space that are completely unaffected by collapse ranges of buildings under any seismic magnitude, a_i is equal to 1. b_i is the seismic-disaster magnitude impact factor. It is normally equal to 1 [47]. r_{ij} represents the actual collapse range, and is 0.6 times the height of the building. The actual collapse range computing results are taken as buffer distance to spatially express possible sweep ranges of building collapse by *buffer tool* in ArcGIS (Fig. 5).

3.2.1.2. Explosion ranges of gas stations and natural gas stations. According to the *Code for design and construction of filling station (GB 50156-2012)* published by Ministry of Housing and Urban-Rural Development of the People's Republic of China, and General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, there are strict rules for the safety distance between gas stations (or natural gas stations) and civil buildings (including residential and public buildings). As shown by this standard specification, the minimum distance between the smallest gas station (or natural gas station) and the lowest protection level civil buildings ought to be 10 m. However, the distance between important public buildings and any grade gas station (or natural gas station) is at least 50 m. In order to maximize the safety of the safe space, we take the safety distance of 50 m as the standard to create *buffer* in ArcGIS to gauge the explosion range of gas stations (or natural gas stations) (Fig. 5).

3.2.1.3. Geologic disasters affected areas. He once provided a detailed seismic geologic disasters distribution map in Xi'an, China, mainly

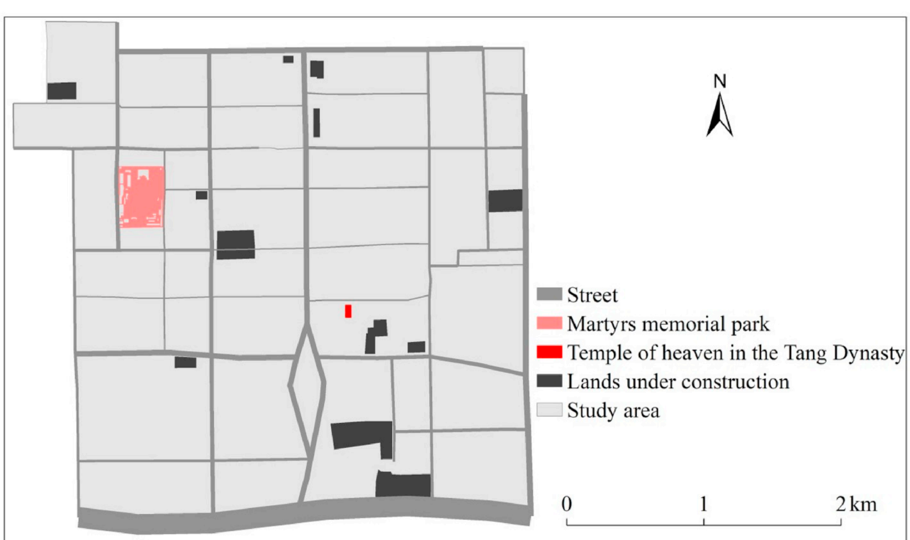

Fig. 3. Places that cannot act as evacuation destination.

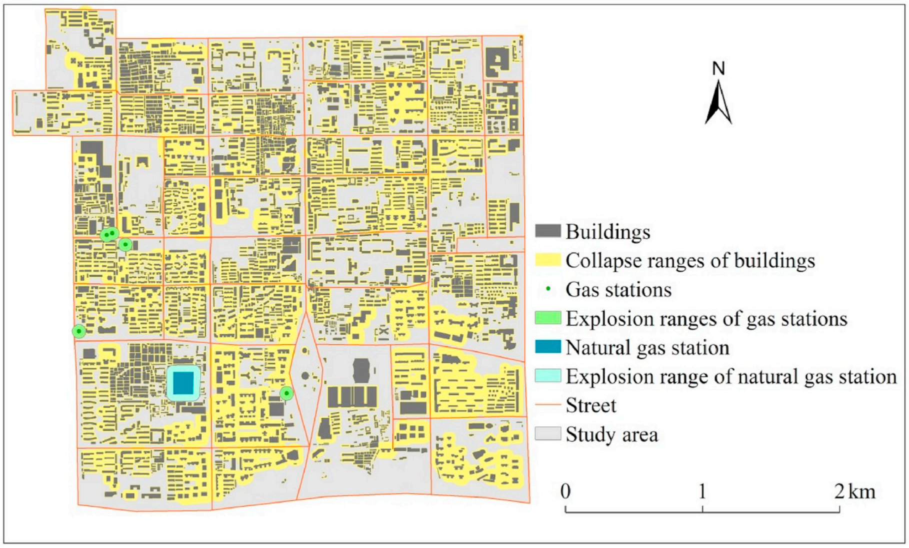

Fig. 5. Potential safety hazards and their possible sweep ranges.

including ground fissures, collapses, and landslides [48]. Gu believed that the possible affected range of geologic disasters is 50 m [49]. Based on vectoring He's map and the 50 m affected range by *buffer* tool in ArcGIS, we get the spatial distribution of geologic disaster sources and the affected area in Xi'an, China (Fig. 6).

3.2.1.4. Safe space extraction. By applying *erase tool* in ArcGIS, areas with potential safety hazards and their possible sweep ranges and the places that cannot provide refuge service are excluded from the study area. This way, the remaining areas are the safe spaces we attempt to find; their total area is 2.34 km^2, accounting for 20.44% of the total study area. Besides three emergency shelters planned by the local government, the safe spaces also include open space among buildings, open space in campuses, parking lots around malls or supermarkets, and green areas (Fig. 7).

3.2.2. Closeness measurement

If the evacuation destinations are safe according to the safety evaluation results above, the closeness of these destinations will be further evaluated. Closeness can measure how close the evacuation destination the resident has chosen is to his/her housing (Fig. 8). It is also a kind of evacuation efficiency evaluation. For measuring the closeness of evacuation destinations, shapefile data base applied in ArcGIS needs to be prepared in advance. That being shapefiles of a) locations of evacuation destinations, b) places of residential districts surveyed, c) evacuation paths, and d) street networks.

Closeness of evacuation destination (C) represents the ratio of housing-closest safe space distance (D_c) to housing-evacuation destination distance (D_a). When searching for the closest safe space around housing and the housing-closest safe space street network distance (D_c), this study begins with *Closest Facility tool* in ArcGIS. D_a is the evacuation path, which is the street network distance connecting housing and evacuation destination. It can be calculated through *measure tool* in ArcGIS.

C is less than or equal to 1. When C equals to 1, the evacuation destination is the closest safe space, which means the shortest evacuation path. However, when C gets increasingly lower, the housing-evacuation destination distance (D_a) becomes bigger than housing-closest safe space distance (D_c). That is to say the evacuation destination is farther away from housing as well as the closest safe space.

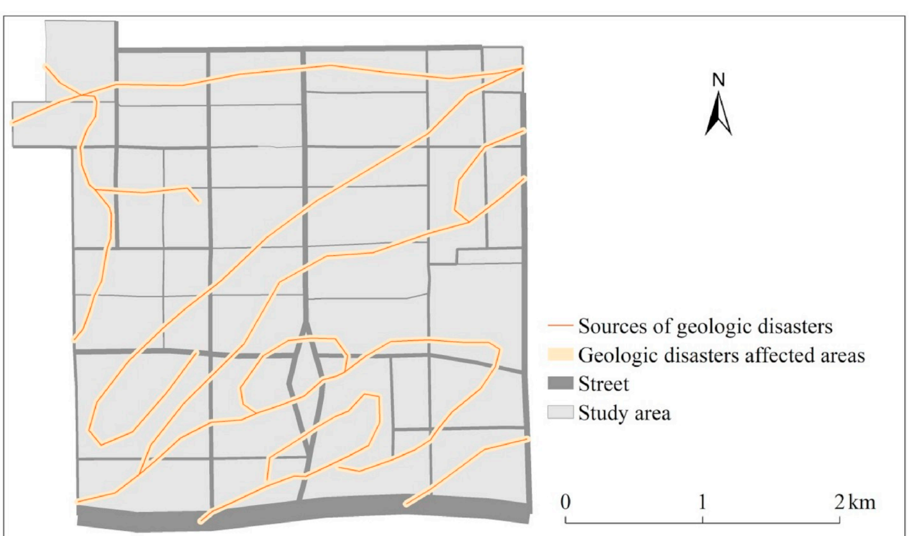

Fig. 6. Sources of geologic disasters and their affected areas.

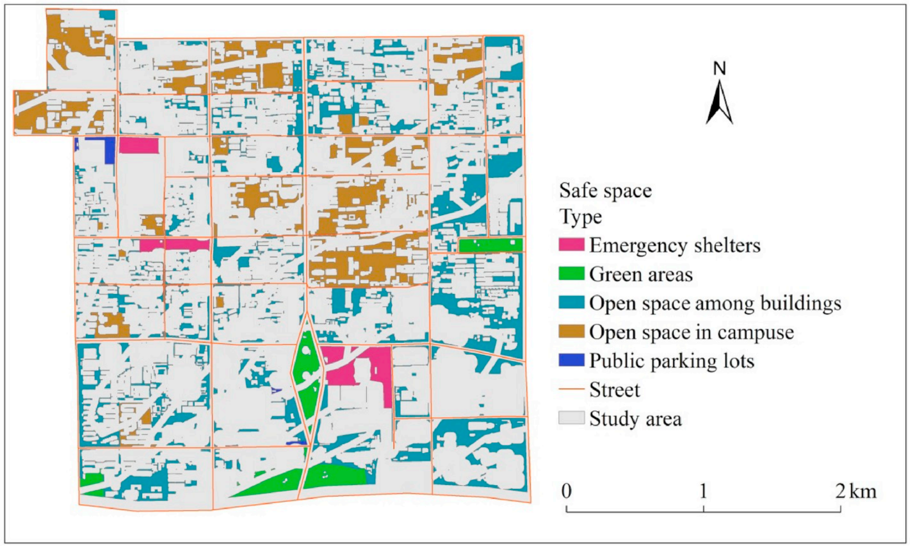

Fig. 7. The spatial distribution of safe space.

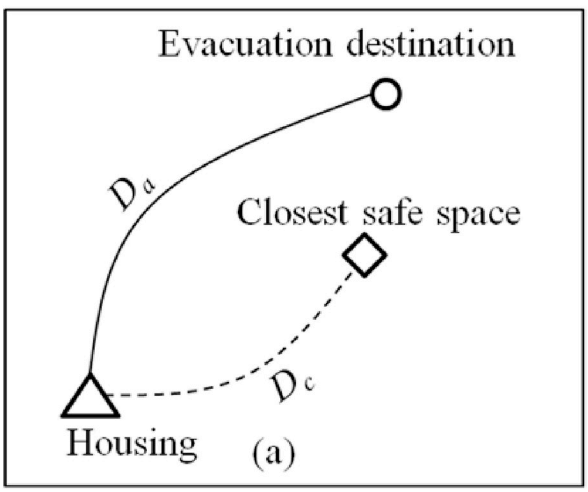

Fig. 8. Calculation principles of closeness.

Accordingly, the evacuation path is longer and the evacuation efficiency becomes lower.

3.3. Data sources

The map of all buildings and the corresponding floor numbers are compiled by City Data Research Agency, which was establish by CAUP.NET and Metro Data Team. The streets, gas stations, and the natural gas station in the study area are vectored based on the Baidu Map (map.baidu.com), a popular search engine in China similar to Google Map. Alternatively, the land use pattern, including lands for green areas, residential areas, parking lots, emergency shelters planned by local government, cultural relics and historic sites, and lands under construction, is obtained through field surveys and Baidu Map.

To obtain residents' length of residency and familiarity with living environment, as well as other information about individual socio-economic background, 200 questionnaires were delivered randomly to residents living in the residential districts surveyed. Each questionnaire is equipped with a hand drawn behavior map of the study area, on which we ask the residents to draw their exact locations of evacuation destinations and evacuation paths. The questionnaires and behavior maps were conducted from April to July in 2018 and asked residents to look back upon their evacuation behavior during the earthquake which occurred on August 8, 2017. Ultimately, all the questionnaires were effective.

4. Results

4.1. Safety of evacuation destinations

From the locations of evacuation destinations overlaid on the safe space and the corresponding number of evacuees (Fig. 9), it can be seen that 61% of the residents arrived at the assessed safe spaces. As for the remaining 39%, 30.77% chose streets as their evacuation destinations, 26.92% remained at home, 10.25% preferred the exits of their residential districts; a total of 32.06% of the residents' evacuation destinations were located in the collapse ranges of buildings and geologic disaster affected areas. According to age and education level differences, the ratio of safe evacuation destinations to unsafe evacuation destinations increases with decreasing age and improving education level (Table 1). That is to say the number of residents who chose safe spaces reduces with increasing age, and higher education level meant a higher probability to choose a safe space.

4.2. Safety of evacuation paths

As we can see from the evacuation paths and number of evacuees (Fig. 10), streets near residential districts exits are the busiest (the red and orange sections) due to the limited number of exits. It is shown that every evacuation path is partially affected by safety hazards' possible sweep ranges. Fig. 11 indicates the sections of the evacuation paths at risk. They are mainly affected by two kinds of safety hazards, including collapse ranges of buildings and geologic disaster affected areas. The sum of all evacuation paths is a length of 118.52 km and the sections at risk are 47.88 km, meaning 40.40% of the evacuation paths may be affected by potential safety hazards. Sections of the evacuation paths possibly affected by collapse ranges of buildings make up a relatively significant share (36.33%) of the total length, and only 4.49% are affected by geologic disaster affected areas. Sections affected by both collapse ranges of buildings and geologic disaster affected areas only accounts for 1.45%. All in all, the safety of evacuation paths is seriously affected by the high-rise buildings by street sides.

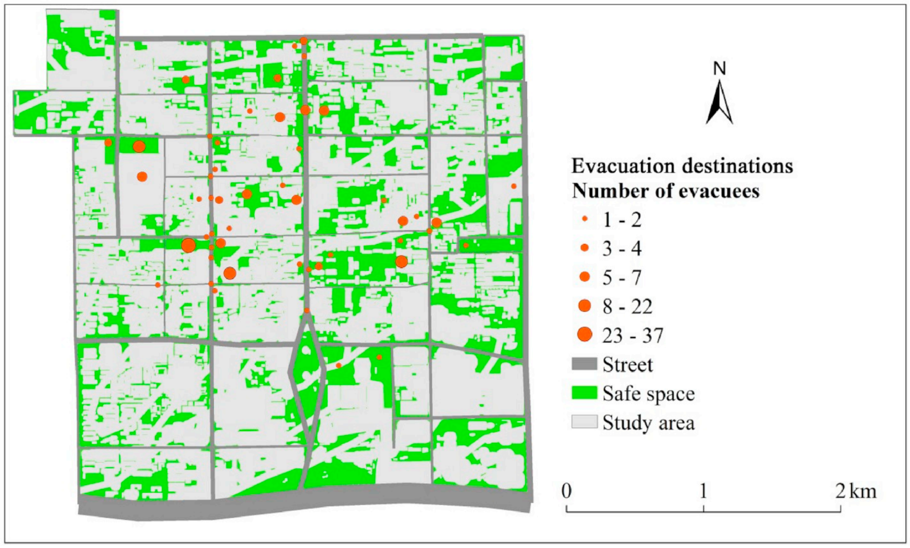

Fig. 9. Evacuation destinations and number of evacuees.

Table 1
Age and education level differences of the safety of evacuation destinations.

			Education level			
			Of or under junior high school	Senior or technical secondary school	Undergraduate or postgraduate	Total
			R	*R*	*R*	*R*
Age	under 30	*R*	1.80	1.83	6.50	3.07
	30–50	*R*	1.50	1.43	2.20	1.67
	50–70	*R*	1.00	1.29	4.00	1.61
	over 71	*R*	0.44	0.20	1.38	0.63
	Total	*R*	1.07	1.06	3.00	1.56

Notes: *R* represents the ratio of residents choosing safe evacuation destinations to residents choosing unsafe evacuation destinations.

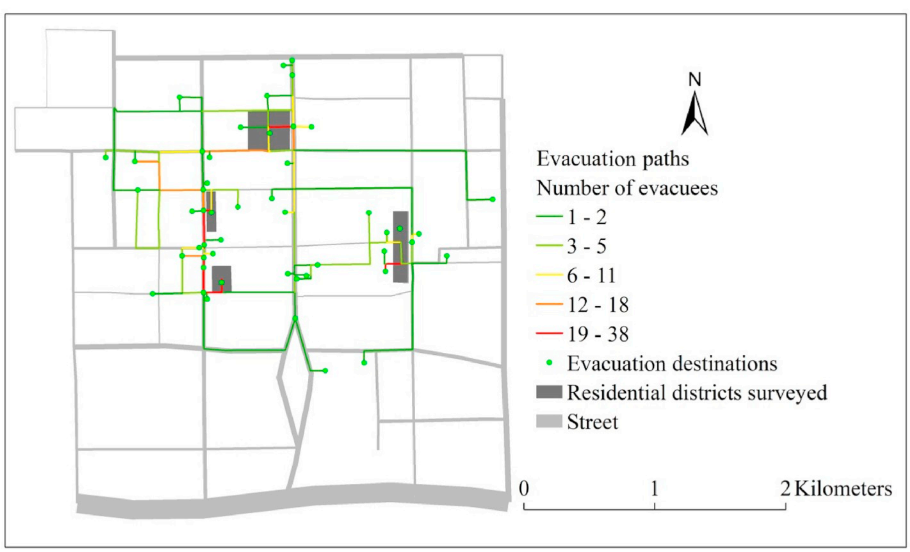

Fig. 10. Evacuation paths and number of evacuees.

4.3. Evacuation paths and closeness of evacuation destinations

Overall, the lengths of evacuation paths are relatively long. As calculated, 122 residents arrived at safe spaces, 82.79% of their destinations' closeness are less than 1. Only 17.21% equals to 1. This shows that the majority of the residents did not find the nearest safe space to their home, which means their evacuation path is much longer than the housing-closest safe space distance. According to the mean closeness, the evacuation path is 2.22 times as long as housing-closest safe space distance on average. As the closeness is not normal distribution, median (0.45) is used to express the mean closeness (Fig. 12).

There are obvious group differences of closeness of evacuation destinations (Table 2). The mean closeness of females is much higher than that of males, which means females tend to evacuate using shorter path

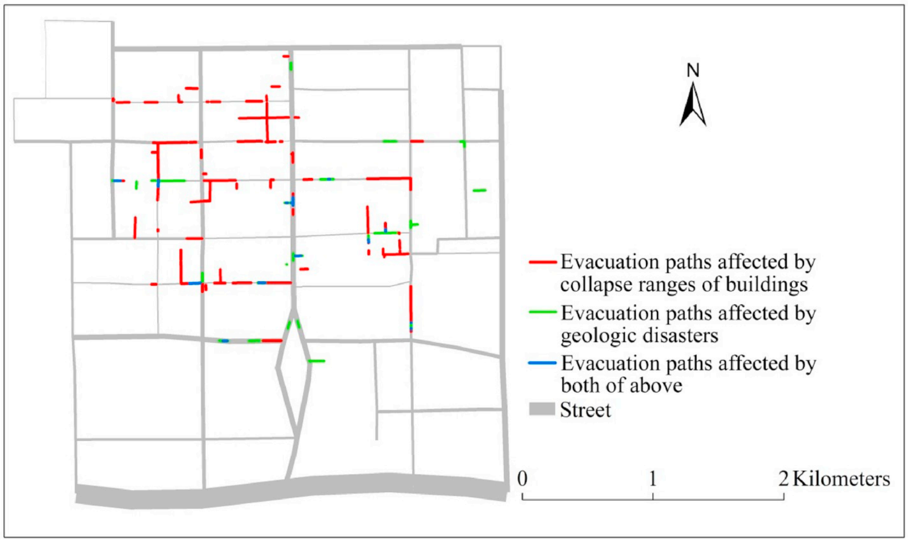

Fig. 11. Sections of evacuation paths at risk.

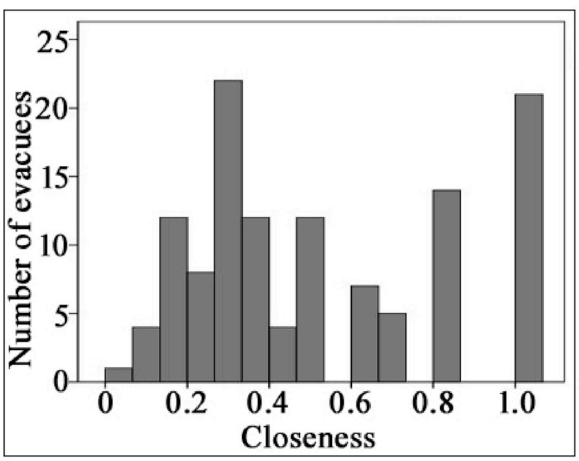

Fig. 12. Histogram of closeness.

Table 2
Group differences of closeness.

Group type	Attribute	Average closeness level
Gender	Male	0.30
	Female	0.52
Age	Under 30	0.49
	30–50	0.52
	50–70	0.65
Education level	Of or under junior high school	0.30
	Senior or technical secondary school	0.34
	Undergraduate or postgraduate	0.65
Length of residency	Less than 1 year	0.52
	1–4 years	0.45
	More than 4 years	0.39
Familiarity with living environment	Very familiar	0.39
	Familiar	0.44
	Slightly familiar	0.45
	Unfamiliar	0.78

than males. Also, the older the residents are, the nearer the safe spaces they prefer, thus they have higher closeness and shorter evacuation paths, and the higher the education level, the higher the closeness. In addition, with the increase of length of residency and familiarity with living environment, the mean closeness becomes lower. In other words, when residents live in their current housings for a shorter time and have less familiarity with their living environment, they are more likely to choose an evacuation destination closer to their housing, so their closeness of evacuation destinations are higher and the evacuation paths are shorter.

5. Conclusions and discussion

5.1. Conclusions

This research, although exploratory in nature, is one of the few researches that look into the seismic evacuation behavior in complex urban environments. In order to get complementary behavioral data, both questionnaires and behavior maps were applied based on a real-world earthquake. Aiming to evaluate the seismic evacuation behavior and to fill the knowledge gap concerning the safety of evacuation destinations and paths, this paper firstly provides a concrete process of safe space exploration in complex urban environments. Then, measures the spatial relationship between evacuation destinations and safe space, as well as the spatial relationship between evacuation paths and potential safety hazard sweep ranges, based on GIS spatial overlay methods. The closeness of evacuation destinations are also calculated through network analysis and distance measure tool in GIS. At the same time, group differences of seismic evacuation behavior are described at length.

Results indicate that most of the residents' evacuation destinations are safe spaces. However, the amount of residents who chose safe spaces reduces with increasing age and declining education levels. Additionally, streets near residential district exits are the busiest and partial sections of every evacuation path are at risk, mainly because many streets are lined with high-rise buildings. As for the evacuation destinations that are safe as evaluated above, the closeness is low overall, meaning the evacuation paths are much longer than the distances from residents' housing to the nearest safe space. In other words, even though most of the residents chose safe evacuation destinations, they are not the closest to their homes. Meanwhile, females tend to evacuate using a shorter path than males; older residents prefer safe spaces near their homes, and the higher the education level, the higher the closeness. Also, when residents live in their current housing for a shorter time and have less familiarity with their living environment, their closeness of evacuation destinations are higher and evacuation paths are shorter.

5.2. Policy recommendations

Earthquakes test our urban construction and emergency shelter planning in extreme ways. With respect to policy implication, this study suggests that future emergency shelter planning in the future ought to take evacuation behavior into account. This is because evacuation behavior determines the necessity, supply-demand ratio, accessibility, and service areas of emergency shelters. Secondly, it is necessary to thoroughly reconcile safe spaces with existing emergency shelters to increase the capacity and supply elasticity of emergency shelters. Thirdly, in order to ensure the safety and efficiency of evacuation, coming urban construction needs to allow sufficient open space, which fulfills the requirements of safe space and is close to densely inhabited districts. At the same time, building height and density along streets need to be reasonably controlled by government to ensure evacuation safety, especially for streets that are key evacuation passageways. To achieve the same goal, the seismic design level for building structure should also be improved. All the recommendations above are instrumental in improving the urban disaster prevention ability. Lastly, it is essential for governments to strengthen publicity and education in various forms for better awareness of disaster prevention awareness, which can greatly increase the safety and efficiency of evacuation for urban residents.

5.3. Suggestions for future researches

The evacuation behavior in complex urban environments merits additional research. Although this research helps to better understand seismic evacuation behavior, many questions still need to be addressed. For example, researchers may conduct more in-depth studies that study the evacuation motivations of residents and the reasons for choosing their evacuation destinations and paths. Meanwhile, it is essential to further assess critical factors that influence residents' evacuation behavior, such as accessibility of street network, residents' conformity psychology, physical conditions of residents, and so on. It is also necessary to take into consideration the actual demand-supply of safe spaces (or evacuation destinations) and the second time evacuation. In other word, if the evacuation destination the resident wants to go is already fully occupied, where will be his/her next evacuation destination and path.

Funding

This work was supported by the National Natural Science Foundation of China [grant number 41601158].

Declaration of competing interest

None.

Acknowledgements

The authors wish to thank some of the undergraduate students (Yumeng Ning, Qingwen He, Ping Ni, Yanfang Kong, Yuyang Yao) from School of Geography and Tourism of Shaanxi Normal University who helped to draw behavior maps and conduct questionnaires.

Appendices.

Behavior map

Behavior map is an important method of this study. It exhibits evacuation behavior both spatially and visually. In order to make it easily identified by residents, landmarks, important business outlets and supermarkets, schools, parks and green areas, detailed street networks, as well as locations of the residential districts surveyed in the study area were hand drawn. For the sake of showing in detail the inner and surrounding layout of every residential district, such as residential buildings, street, exits, and so on, four behavior maps were drawn for the four residential districts surveyed. Based on the behavior map, the residents are required to draw the locations of their evacuation destinations and specific evacuation paths. Through this, the evacuation destinations and paths were extracted and vectored in ArcGIS.

Fig. 1 is one example of behavior map conducted in the Retired Military Cadre Sanatorium. As the residents surveyed are all Chinese, the written language on the original behavior maps is Chinese characters. The right side of the figure is the corresponding English translation for the inner residential buildings and exits, and the peripheral important landmarks and main roads. The red arrow, which was drawn by one of the residents, indicates her evacuation destination and path.

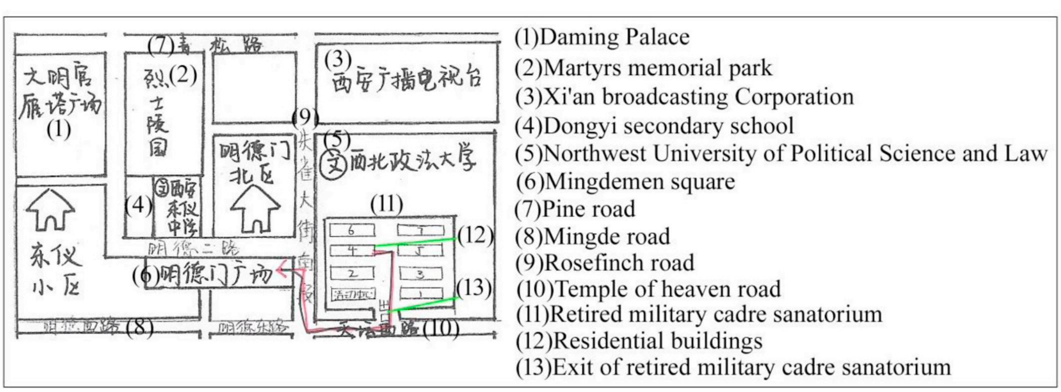

Fig. 1. One example of evacuation behavior based on behavior map.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2019.101366.

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