Evacuation of vulnerable people during a Natech: a case study of a flood and factory explosion in Japan

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Abstract

Purpose – This study investigated pre-evacuation times and evacuation behaviors of vulnerable people during the 2018 flooding in Shimobara, Okayama, Japan, and the flood-triggered factory explosion, a natural hazard-triggered technological accident known as a natural-hazard-triggered technological accidents (Natech). This study examined factors that affected evacuation decisions and pre-evacuation time, estimated the evacuation time in case of no explosion and identified community disaster prevention organization response efforts for vulnerable people.

Design/methodology/approach – Interviews with all 18 vulnerable people who experienced the event were conducted. Multiple regression analysis was used to examine the effect of six factors on evacuation time and reasons for delayed evacuation.

Findings – Factors affecting evacuation decisions included the sound of the explosion, followed by recommendations from relatives and the community disaster prevention organization. Explosion-related injuries delayed early evacuation, but experience of previous disasters and damage had a

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positive effect on early evacuation. The explosion sound accelerated evacuation of non-injured people; however, explosion-related injuries significantly delayed evacuation of injured individuals. The Shimobara community disaster prevention organization's disaster response included a vulnerable people registry, visits to all local households and a multilayered approach that enabled monitoring of all households.

Originality/value – This is the first study to examine the evacuation behavior of vulnerable people and community responses during a Natech event.

Keywords Natech, Evacuation factors, Pre-evacuation time, Flooding, Vulnerable people, Community disaster prevention organization

Paper type Research paper

1. Introduction

1.1 Background

Floods are one of the most frequent disasters worldwide, affecting 86.7 million people annually (United Nations Office for Disaster Risk Reduction, 2019). Floods are also one of the most frequent natural disasters in Japan, and resulted in 285 deaths or missing persons in 2018 alone (Cabinet Office, Government of Japan, 2020). In recent years, floods in Japan have caused so-called natural hazard-triggered technological accidents (Natechs); Krausmann *et al.*, 2017). Examples include an aluminum factory explosion caused by flooding in Shimobara District, Okayama Prefecture, in 2018 (Araki *et al.*, 2021), a large flood-related oil spill at an ironworks factory in Omachi, Saga Prefecture, in 2019 (Misuri *et al.*, 2020) and a fire at a flooded carbon plant in Ashikita, Kumamoto Prefecture, in 2020 (Industrial Fire World [IFW] staff, 2020). These flood-related Natechs required evacuation of residents living near the factories. However, research on evacuation behavior, particularly of vulnerable people, during Natechs is scarce.

This study investigated the evacuation behavior of vulnerable people during a flood-triggered explosion at an aluminum factory in Shimobara District, Soja City, Okayama Prefecture, Japan, in 2018. All residents in the district were successfully evacuated under particularly difficult environmental conditions; therefore, we sought to clarify the factors that made this possible in this complex disaster. We used a survey of individual (flood and explosion) evacuation actions taken by the district's vulnerable people.

The study objectives were to clarify factors affecting evacuation decisions and pre-evacuation time, to determine the evacuation time if there had been no aluminum factory explosion and to identify response efforts by the community disaster prevention organization.

1.2 Definition of and problems concerning vulnerable people

Vulnerable people have been defined as people who need assistance

> [. . .] to take a series of actions, such as swiftly and precisely understanding necessary information and evacuating to a safe place in a disaster. This group generally includes the elderly, people with special needs, foreigners, infants and toddlers, and pregnant women (Committee on Evacuation Measures for People Requiring Assistance During Disaster, 2006, p. 2).

Vulnerabilities during disasters in Asia are often caused by poverty and associated difficulties (Rao and Maqbool, 2014), however, the vulnerabilities in this study were caused by physical special needs and older age, which make evacuation physically difficult. Based on the committee report, the Shimobara community disaster prevention organization has identified and registered vulnerable people in the community since 2012 to create a "vulnerable people list", which is revised annually. The organization identified 29 vulnerable people in the area, comprising older people, people with disabilities and people undergoing medical treatment. The number of vulnerable people in the district has decreased to 18 since the 2018 Japan floods owing to emigration or death unrelated to the disaster. These 18 people comprised the study participants.

The factors that accelerate or delay the evacuation of vulnerable people during Natechs remain to be clarified. Evacuation of vulnerable people is important because delay or hesitation to evacuate may endanger both them and the people who support them. For example, in the 2011 Great East Japan Earthquake and tsunami, 16.1% of deaths were vulnerable people and 18.9% were evacuation supporters (Isozaki, 2013). Appropriate evacuation behavior saves the lives of both vulnerable people and their supporters. Therefore, we examined factors affecting evacuation decisions and pre-evacuation time.

2. Literature review

Although there is work on various aspects of Natechs (European Communities, 2004), no studies have examined the responses of vulnerable people during Natechs. Therefore, we discuss here peripheral literature.

2.1 Evacuation of vulnerable people

Evacuation of vulnerable people during disasters is crucial. Ohtsu *et al.* (2017) examined the evacuation behavior of vulnerable people requiring assistance during the 2011 Great East Japan Earthquake and tsunami. Ohtsu and Hokugo (2019) measured the speed with which residents evacuated vulnerable people (e.g. by wheelchairs, carts) in tsunami evacuation drills held by community disaster prevention organizations. However, these studies focused on the evacuation of people requiring assistance during non-Natech disasters.

2.2 Natechs

Natechs have received greater attention in recent years. Cruz and Suarez-Paba (2019) define Natechs as complex disasters and emphasize the importance of area-wide assessment of Natech risks at industrial facilities to determine the potential effect of natural hazards, such as heavy rain and floods, on exposed installations and their cascading effects on neighboring communities. Approximately 9.5% of all Natechs reported in 1990–2017 in the USA were flood-related, but most (>24%) were hurricane-triggered (Luo *et al.*, 2020). Hurricanes are accompanied by high winds, storm surges, heavy rain, flooding, lightning and tornadoes.

In the 1980s, research focused on earthquake-related Natechs but has now shifted to Natechs triggered by hydrometeorological hazards such as floods and lightning (Suarez-Paba *et al.*, 2019). Natech research has only recently focused on risk perception and risk communication, and there are few studies on Natech evacuation behavior. Yu *et al.* (2017) examined risk perception changes during evacuation from a Natech disaster during the 2011 Great East Japan Earthquake and tsunami. They found that people living closer to the Natech evacuated immediately, whereas those living further away remained at home. In a recent flood-triggered oil spill study, Misuri *et al.* (2020) found that residents living near the industrial plant attempted vertical evacuation and were thus trapped in their homes, surrounded by flood waters and strong oil vapors. However, none of these studies analyzed evacuation behaviors of vulnerable people. Despite research on flood-related Natechs, there seems little awareness and preparedness, particularly at the local community level (Yu and Cruz, 2016; Yu *et al.*, 2017). We argue here that Natech disaster preparedness and information for vulnerable people are needed.

2.3 Flood-related risks and evacuation decision factors

Previous studies have focused on the effect of factors such as the social tolerance of water levels, water utilization and flood risk on evacuation decisions; industrial disasters have been analyzed separately but not in the context of Natechs.

Baker (1991) observed that most residents who were made aware of two or more evacuation advisories or orders were efficiently evacuated during hurricane-related floods. In Mabi Town, Kurashiki City, Okayama Prefecture, which was damaged by heavy rains in 2018, the evacuation rate was higher among individuals who were aware of the evacuation advisory and order (Murakami and Honoki, 2019).

In a study of the 2010 heavy rains in Oyama Town, Shizuoka Prefecture, which did not involve a complex disaster, Ushiyama *et al.* (2012) found that environmental cues such as local rainfall and river levels were the most frequent reason for evacuation, followed by recommendations from neighbors and fire fighters. This study, however, did not focus on vulnerable people. A survey of the evacuation of vulnerable people during floods showed that encouraging people to evacuate together was key in persuading them to evacuate (Ohnishi *et al.*, 2006).

2.4 Community disaster prevention organizations

In Japan, community disaster prevention organizations are formed by volunteers to protect their area. They conduct activities to prevent and mitigate disaster-related damage. The Disaster Countermeasures Basic Act Government of Japan (1961) stipulates that municipalities must endeavor to enhance their activities based on the spirit of cooperation between neighbors. Community disaster prevention organizations are led by citizens and supported by municipal governments.

In Japan, community disaster prevention organizations are active during disaster events. A survey of the post-flood activities of community disaster prevention organizations following the 1993 Kagoshima Prefecture disaster, which was caused by heavy rainfall, identified the following factors as important in reviewing regional disaster prevention plans: an emergency information system involving TV and radio, installation of wireless systems and house-to-house receivers for disaster prevention radio broadcasts and evacuation measures for sick and older people (Takahashi *et al.*, 1996). Takahashi (1995) has summarized the development of and issues addressed by community disaster prevention organizations in Nagasaki Prefecture after the 1982 floods. During Typhoon Talas in 2011, the community disaster prevention organization of Funada District, Kiho Town, Mie Prefecture, appointed leaders to encourage voluntary disaster prevention measures (Okajima *et al.*, 2015).

So far, there is little to no research concerning evacuation behavior of vulnerable people during Natech. Therefore, we focused on the evacuation behavior of vulnerable people from a Natech caused by flooding in this study.

3. Description of the disaster

3.1 Disaster context

The 2018 Japan floods resulted in 237 fatalities and eight missing persons. Okayama Prefecture experienced considerable damage, including 66 fatalities and three missing persons. Of the 6,747 homes destroyed, 4,828 (71.3%) were in Okayama Prefecture (Emergency Response Office, Fire and Disaster Management Agency, Government of Japan, 2019). Flooding of the area in July 2018 caused an explosion at a local aluminum factory. However, there were no casualties among the Shimobara District residents, which included

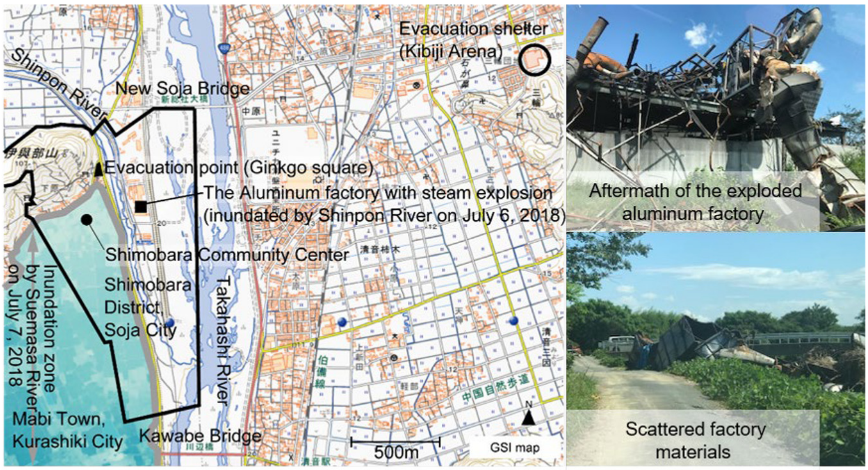
29 vulnerable people. To determine why, we explored evacuation behaviors and factors affecting pre-evacuation time.

We defined pre-evacuation time as the duration (in minutes) from the time the evacuation advisory was issued (in this case, 9:30 p.m. on July 6, 2018) to the horizontal evacuation start time. This is the time at which residents cross the property line just outside their houses. Initial evacuation does not include people who return to their homes (e.g. to collect necessary/personal items). Residents in their homes began their initial evacuation from Shimobara District after the evacuation start time. Here, "evacuation" refers to horizontal evacuation.

Some previous research contextualizes the 2018 western Japan heavy rains. Alexander *et al.* (2019) conducted an in-depth analysis of flood disasters and restoration activities. Bandaru *et al.* (2020) compared pre-disaster (2017) and post-disaster (2018) clinical data for health problems of residents of Inoshima Island, Hiroshima Prefecture. They found a substantial increase in urinary protein concentration among disaster survivors. Idehara *et al.* (2020) investigated the organizational structure and initial responses of fire-fighting teams to inundation in Mabi Town, Kurashiki City, Okayama Prefecture, which is adjacent to Shimobara District. Murakami and Honoki (2019) found that people in Arii District, Mabi Town, were triggered to evacuate by (in order) water level rise, the sound of the factory explosion and recommendations from neighbors.

3.2 Study location

The study focus was Shimobara District, in western Soja City, Okayama Prefecture. The district is bordered to the north by Mt. Iyobe and to the east by the Takahashi and Shinpon rivers. The western border is shared with Mabi Town, Kurashiki City (Figure 1). Owing to the mountainous border and the Takahashi River, which is 500 m wide, Mabi Town is the only district with residential areas next to Shimobara District. The Shimobara Community Center is surrounded by residential districts, many of which were in the inundation area. The aluminum factory where the explosion occurred is approximately 300 m east of Shimobara Community Center.



Source: Drawn by authors based on GSI map

Figure 1. Inundation zone and the exploded aluminum factory in Shimobara District

Shimobara District had two inundations. The Shinpon River inundation caused a steam explosion at the aluminum factory at 11:35 p.m. on July 6. The flooding did not affect the residential area, but the resulting explosion triggered fires at four locations and injured residents. Subsequently, there was a 3 m high inundation Geospatial Information Authority of Japan (2018) when the left bank of the Suemasa River burst Nihei (2019) in neighboring Kurashiki City, 2 km west of the district, at approximately 7:00 a.m. on July 7, 2018. There were 55 fatalities in Kurashiki City, but none in Shimobara District, because all 357 residents, including vulnerable people, evacuated horizontally.

Natechs are more difficult to respond to than single natural disasters because of the combination of fires, explosions, oil spills and other incidents. Shimobara District experienced floods, the explosion and fires during the 2018 heavy rains. To generate insights into best practices for evacuating vulnerable people during floods, we examined how residents survived the events and the response of the community disaster prevention organization in Shimobara District.

4. Methodology

We conducted on-site investigations from July 23, 2018, immediately after the heavy rains. Interviews were conducted in 2019 and 2020. As the investigation was requested by the community disaster prevention organization, the study location was within its jurisdiction. The research methodology is shown in Figure 2.

4.1 Interviews with vulnerable people

On May 31, June 1 and June 25, 2019, we carried out structured interviews at the Shimobara Community Center with vulnerable people and their families about their evacuation behavior on July 6 and 7, 2018. We identified the population using the Shimobara community disaster prevention organization household and vulnerable people registry. In 2018, the area contained 29 vulnerable people (25 households). However, three people had died in 2019 from illness unrelated to the Natech, so the participants comprised 26 individuals (22 households). The community disaster prevention organization asked all 26 vulnerable people to complete the survey. Of these, 18 agreed to participate (8 had moved out the prefecture). The final sample comprised 69% of all vulnerable people and 73% of all vulnerable households in the district.

Participants were 8 men and 10 women (average age at the time of the flood: 84.3 years). Of participants, 1 lived alone; 9 lived with family members (2 lived together; 8 lived in a

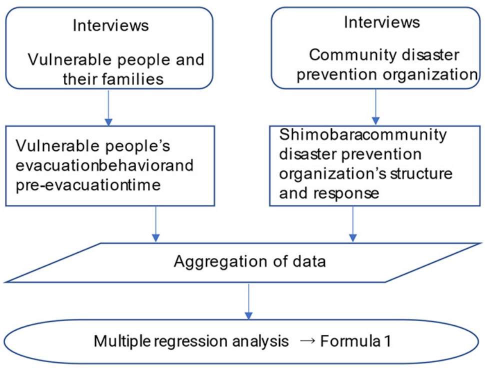


Figure 2.
Flowchart of methodology

household of ≥3 people, of which 2 lived in one household). Seven respondents were able to walk independently in normal circumstances, seven used a cane, two used a rollator and two required assistance. One respondent lived alone and required no special care; three required assistance in daily life; four had long-term care need certification; one had an incurable disease; and one had no long-term care need certification but had visual impairment. The remaining persons required assistance because of their age.

There were 90 interview questions, including items related to evacuation behaviors and routes, home damage, injures and pre-flood situations or preparation for future disasters. Participants were asked to chart their movements from evacuation start points to shelters (using a residential map), identify factors affecting evacuation decisions and describe evacuation methods and times.

Pairs of researchers conducted face-to-face interviews with each vulnerable person and their family. The community disaster prevention organization arranged the interviews. Questions were based on questionnaire responses provided before the interview. Each interview was approximately 2 h and focused on evacuation behaviors, the explosion and pre-evacuation time.

4.2 Interviews with community disaster prevention organization members

On April 24, 2019 and January 23, 2020, we conducted interviews with members of the Shimobara community disaster prevention organization regarding their door-to-door visits to advise residents when to evacuate.

4.3 Analysis of variables affecting pre-evacuation time

We used multiple regression analysis to identify variables that affected pre-evacuation time. This method is appropriate for simultaneously examining the positive and negative effects of several variables. To avoid multicollinearity, we restricted the analysis to the six variables that had the greatest effect on pre-evacuation time in a preliminary multiple regression analysis. We then generated a formula to conduct a multiple regression analysis (Section 5.6).

5. Findings

5.1 Shimobara community disaster prevention organization structure and response

5.1.1 Structure and plan up to the 2018 Japan floods. Shimobara District contained 357 people (110 households) in 2018. The Shimobara community disaster prevention organization was formed in 2012. The organization established bylaws, an organization chart, disaster prevention map, disaster prevention plan, household registry, vulnerable people registry and a disaster prevention tool and equipment registry. The disaster prevention plan guided evacuations and presented evacuation plans by block. The organization conducted evacuation drills with residents every year from 2012 in the town's Ginkgo Square, fulfilling its promise to "act to protect lives".

5.1.2 Response to the 2018 Japan floods. The community disaster prevention organization held its first meeting about the heavy rains at 4:00 p.m., July 6, 2018, to discuss the steps to be taken in the event of landslides or inundations. The senior members then inspected the rising water levels of three local rivers: the Takahashi and Shinpon rivers, located in the district, and the Oda River, which runs through the adjacent town, Mabi, in Kurashiki City. The organization held a second meeting at 9:00 p.m. The rising level of the Shinpon River, which runs along the area's east side, caused the greatest concern. Members decided to urge all households to evacuate vertically. Subsequently, the senior members patrolled the area to urge vertical evacuation using a loudspeaker installed on a light truck.

At 11:35 p.m., inundation caused a steam explosion at the district's aluminum factory, resulting in fires, damage to homes and shrapnel injuries. All 16 houses in this study were damaged by the explosion. The explosion injured seven people, two of who immediately sought medical attention (one was transported to hospital in an ambulance). At the time of the explosion, the closest participant was approximately 150 m from the epicenter; the furthest was approximately 1,030 m.

At 00:34 a.m. on July 7, 2018, the organization received a call from Soja City disaster control headquarters, advising the issuance of an evacuation order to all residents because of the risk of a secondary explosion. Around that time, residents evacuated using their own cars or buses arranged by the fire department. Block leaders confirmed all household evacuations by approximately 4:30 a.m. and reported to the community disaster prevention organization headquarters. At approximately 7:00 a.m., the left bank of the Suemasa River broke, flooding Shimobara District. The water was up to 3 m deep.

From approximately midnight on July 6 to the early morning of July 7, 2018, when heavy rain hit the district, block leaders visited all households, including those of vulnerable people, in all seven blocks (some households had already evacuated by this time). Block leaders urged evacuation in the Higashinakamura block and the adjacent Hinoshiri block. Table 1 shows the residential composition based on the community disaster prevention organization chart and household and vulnerable people registry. Because the organization had seven leaders for each block, this multilayered structure relieved the headquarters of some responsibilities and ensured that the organization acted strategically.

When the heavy rain occurred, the Shimobara community disaster prevention organization had only been established for 6 years. Nevertheless, the organization had created a multilayered structure to respond to disasters and was able to respond appropriately. The organization officials and block leaders successfully monitored and visited all households.

5.2 Evacuation behavior of vulnerable people

The evacuation behaviors on July 6 and 7, 2018, involved vertical evacuation to second floors and horizontal evacuation from the district. Of the 16 households in this study, 10 evacuated horizontally and 6 evacuated vertically (37.5%) but were subsequently evacuated horizontally. All households evacuated, so the evacuation rate of vulnerable people who completed the survey was 100% and there were no casualties.

The 18 vulnerable people horizontally evacuated as follows: 9 walked to the home entrance by themselves, 6 walked with assistance, 2 used a cane and 1 used a rollator. A total of 8 walked by themselves from their doors to a vehicle, 8 walked with assistance, 1

Table 1. Number of households, residents, and vulnerable people on each block in Shimobara district (July 2018 heavy rain event)

Shimobara District				
		Residents		
Block	Households	Vulnerable people	Non-vulnerable people	Total
Hinoshiri	16	1	44	45
Higashiyamane	15	2	47	49
Higashinakamura	20	4	54	58
Nishinakamura	18	6	62	68
Nakayamane	14	5	44	49
Nishiyamane	6	4	13	17
Maeba	21	7	64	71
Total	110	29	328	357

used a cane and 1 used a rollator. When leaving the house, 14 people evacuated with family, 3 had assistance from people other than family and 1 was alone.

5.3 Factors affecting horizontal evacuation decisions

Six participants evacuated because of the sound of the aluminum factory explosion, five because of recommendations from relatives, four because of recommendation from the community disaster prevention organization, two because of police recommendations, two because of neighbors' recommendations, one because of an administrative radio broadcast on disaster prevention and one because of river levels (multiple answers allowed). No participants responded because of evacuation information (e.g. an advisory), but it is possible that this information was conveyed through third parties.

A total of 16 households participated in this survey. Households 5 and 12 each contained two vulnerable people.

The number of horizontal evacuations substantially increased after the explosion. Six individuals heard the community disaster prevention organization's announcement to evacuate at 9:00 p.m. on July 6.

Murakami and Honoki (2019) and Ushiyama *et al.* (2012) found that the most frequent reason for evacuation was awareness of a rise in water levels. In contrast, the present findings show that only one household evacuated because of a rise in river levels. Most residents in Shimobara, Arii and Oyama districts evacuated because of evacuation recommendations. In Shimobara and Arii, the factory explosion was the factor that most affected evacuation decisions.

5.4 Time of evacuation

Figure 3 shows the relationship between the number of households who completed vertical and horizontal evacuations (per cent) and the accumulated precipitation. Six vulnerable people evacuated vertically. Most (five) vertical evacuations occurred between 11:00 p.m. and 11:59 p.m. on July 6. All vulnerable people in this study evacuated the district by 3:00 a.m. on July 7.

5.5 Relationship between pre-evacuation time and main evacuation method

Seven individuals used relatives' cars, five used private cars, two walked and then used the bus arranged by the fire department, one used a neighbor's car and one was taken to hospital in an ambulance. The pre-evacuation time of the 11 individuals who used evacuation methods other than private cars was 150–190 min (standard deviation: 15.59).

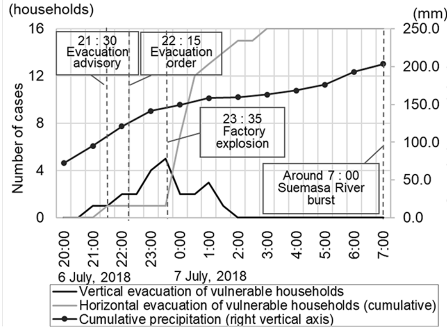


Figure. 3. Relationship between vertical and horizontal evacuation completion (cumulative) and cumulative precipitation

The pre-evacuation time of the five individuals who used their own cars was 20–330 min (standard deviation: 104.96); four individuals took over 200 min.

Next, we conducted a one-way analysis of variance to test whether the association between pre-evacuation time and the main evacuation method was significant. The F ratio was 24.452 (>2.587), indicating a significant association.

Only immediate family members used private cars to evacuate. The use of other relatives' cars, walking, buses, neighbors' cars and ambulances involve people other than immediate family members, which probably affected the pre-evacuation time.

5.6 Variables that affected evacuation time

We conducted a multiple regression analysis with pre-evacuation time as the objective variable and the six variables that may have affected pre-evacuation time as explanatory variables. We focused on the 18 vulnerable people (rather than the 16 households) and analyzed the effect of the six variables (*a*–*f* in Formula 1).

A sample of 18 was not ideal for this analysis, but this was a survey of all vulnerable people in Shimobara District. As mentioned in Section 3.2, there was only one neighboring residential community (in Mabi Town, Kurashiki City). However, relationships differed between the community disaster prevention organization, Kurashiki City municipal government and residents. In addition, the evacuation order and advisory were issued at different times. Therefore, samples from other districts were not included.

In the formula below, pre-evacuation time is defined as (minutes) = evacuation start time − the time when the evacuation advisory was issued (i.e. July 6, 9:30 p.m.).

$$Y = 236.861 + 26.437a - 8.330b - 38.417c - 5.250d - 72.504e + 106.598f \text{ (Formula 1)}$$

a = Level of independence in daily living (point)
b = Index of disaster experience (point)
c = Number of information sources known per person: evacuation advisory, heavy rain emergency warning, evacuation order (urgent)
d = Number of people who visited the household to facilitate evacuation
e = Evacuation decision triggered by the explosion sound (decided to evacuate because of the explosion sound: 1; other reasons: 0)
f = Injuries from the explosion (injured: 1, others: 0)

The level of independence in daily living (*a*) was evaluated according to a ranking system for the independence of people with special needs or older people in performing daily living activities (Table 2) (Ministry of Health, Labour and Welfare, Government of Japan, 2018), which focuses on movement status. Higher scores on this measure indicate lower levels of independence. We evaluated the participants' ability to live independently using Table 2.

The index of experiencing either disasters or accounts of disasters (*b*) was developed from the seven previous flood events in Shimobara District (1893, 1945, 1954, 1972, 1976, 1985 and 2011) as follows:

No experience and no accounts told, 0; accounts told by family members or friends, 1; experienced a disaster but no damage, 2; damage to a portion of the house, 3; serious damage to the house, 4; family members injured or killed, 5.

The total scores for the seven flood events were evaluated in terms of the frequency and intensity of disaster experiences.

The average pre-evacuation time calculated using Formula 1 was 186.6 min. Three variables were significant at $p < 0.05$ and showed an effect at $t \geq 2$ and were categorized as interference with early evacuation and facilitating early evacuation.

In terms of pre-evacuation time, the variable that most interfered with early evacuation was injuries from the explosion (t = 4.048, late evacuation when injured). The variables that facilitated early evacuation, in descending order of effect, were the number of times residents were made aware of the issuance of an evacuation advisory, heavy rain emergency warning and evacuation order (urgent) (t = −3.505, greater awareness was associated with earlier evacuation) and the disaster experience index (t = −2.642, greater experience of previous disasters or damage was associated with earlier evacuation). In other words, the explosion sound accelerated the evacuation of non-injured people (variable e), whereas injury from the explosion significantly delayed evacuation for injured individuals (variable f).

The values of the six variables a–f were substituted into Formula 1 for all subjects to confirm the results. The pre-evacuation times obtained were correct. Therefore, we concluded that Formula 1 was a valid equation for calculating the pre-evacuation time.

5.7 Estimation of pre-evacuation time assuming no factory explosion

We estimated the pre-evacuation time assuming no factory explosion using Formula 1. We set two variables related to the explosion (e: evacuation decision triggered by the explosion sound and f: injuries from the explosion) to 0. Because all 18 vulnerable people experienced explosion-related damage to their homes, home damage was not used as a variable in this case.

The average pre-evacuation time assuming no factory explosion was 167.5 min, 19.1 min less than the actual average of 186.6 min taken by participants before starting to evacuate. This is because evacuation decisions triggered by the sound of the explosion contributed to shortening pre-evacuation time; however, explosion-related injuries had a greater negative effect, and therefore extended the pre-evacuation time. In other words, if the factory explosion had not occurred, then seven vulnerable people would not have been injured and there would have been no fires or damage to homes. Thus, the average pre-evacuation time would have been 19.1 min shorter.

Independence in daily living	Rank J	People with some type of disability able to live at home independently and go outside the home on their own. 1. Able to go outside the home alone and use public transportation 2. Able to go outside the home and visit neighbors
House-bound	Rank A	People who can live independently at home, but cannot leave the home without assistance 1. Able to go outside with assistance and spend most of the day out of bed 2. Unable to go out frequently and spend the day in and out of bed
Bed-bound	Rank B	People who require some sort of assistance at home and spend most of the time in bed, but can maintain a sitting position 1. Able to get in a wheelchair and get out of bed to eat and go to the toilet 2. Able to get into a wheelchair with assistance
	Rank C	People who spend all day in bed and require assistance with using the toilet, eating, and changing clothes 1. Able to roll over on their own 2. Can no longer roll over on their own

The use of assistive devices or self-help devices was allowed when evaluating the degree of independence.

Note: The following scoring was used for analysis: J1 = 1 point, J2 = 2 points, A1 = 3 points, A2 = 4 points, B1 = 5 points, B2 = 6 points, C1 = 7 points, C2 = 8 points
Source: (Ministry of Health, Labour and Welfare, Government of Japan, 2018)

Table 2. Level of independence of people with special needs or older people in performing daily living activities

6. Discussion

There were several similarities and differences between the present findings and previous findings from studies evaluating evacuation behaviors and factors affecting evacuation decisions.

6.1 Awareness of evacuation information

Baker's (1991) findings that most residents aware of two or more evacuation advisories/orders evacuated successfully during a hurricane are consistent with our own results, which showed that residents who were aware of the evacuation information evacuated at an early stage. Regarding the use of evacuation simulations to predict evacuation rates, Kakimoto and Yamada (2013) argue that evacuation rates would be approximately 1.4 times higher if all households could monitor river status and receive an evacuation advisory. However, these previous studies do not mention vulnerable people.

Murakami and Honoki (2019) concluded that the evacuation rate was higher among individuals aware of both the flood evacuation advisory and order. Therefore, previous and present findings suggest that direct communication of evacuation advisories and orders to residents reduces casualties and should be a standard strategy in future disasters.

6.2 Effect of the explosion sound on evacuation decisions

The findings show that (in descending order of frequency) the sound of the factory explosion, recommendations from relatives and recommendations from the community disaster prevention organization affected evacuation decisions. This indicates that the flood-related explosion increased residents' concerns about further explosions, prompting their evacuation decisions. Similarly, Murakami and Honoki (2019) and Ushiyama *et al.* (2012) reported that the most frequent reason for evacuation was awareness of a rise in water levels, although they did not investigate the evacuation of vulnerable people. For future disasters, therefore, strategies are needed to encourage evacuation when no external signs are visible.

6.3 Effectiveness and risks of household visits by community disaster prevention organization

Although household visits by the community disaster prevention organization were effective during the heavy rains, future evacuation plans must take into account that organization member visits to all households are only possible and effective if there is sufficient time. Members may be at risk if they time such visits incorrectly.

6.4 Limitations

A major study limitation was the relatively small sample. However, we targeted all vulnerable people living in one district at the time. We examined both vulnerable people's evacuation behavior and community responses during the Natech, which have not been investigated in previous studies.

7. Conclusions

This study presents insights into the evacuation behavior of vulnerable people during the 2018 Japan floods in Shimobara District, Soja City, Okayama Prefecture. There were no casualties because all 18 people from 16 households evacuated their homes in time.

There were three major findings. First, the factors that had the most positive effect on evacuation decisions were the sound of the factory explosion, recommendations from relatives and recommendations from the community disaster prevention organization. Explosion-related injuries had the greatest negative effect on early evacuation.

Second, using the multiple regression analysis results, we created a formula to predict pre-evacuation time. We estimated the pre-evacuation time (assuming no explosion) as 19.1 min shorter than the actual time.

Third, we found that the Shimobara community disaster prevention organization's disaster response includes a vulnerable people registry, visits to all 110 local households (including those of vulnerable people) and a multilayered approach that enables the organization to monitor all households.

Because this event involved both flood damage and explosion-related damage, it highlights the need to understand how hazardous materials stored in areas susceptible to flooding can cause damage and lead to a Natech. We plan to share these findings with the Shimobara community disaster prevention organization and the community's vulnerable people.

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