An regional tsunami evacuation model based on practical disaster risk reduction activities

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Abstract

This study illustrates regional tsunami evacuation schemes and planning model from workshops, evacuation drills, and feedback questionnaires. Including cars as an option for tsunami evacuation may be effective in some areas. However, there could be a possibility that encouraging car use could result in heavy traffic. To be developed to ensure that all persons in a possible tsunami inundation area can immediately move to safety zones, strategical tsunami evacuation plan is needed. Minabe Town, Wakayama Prefecture, Japan, was chosen as the research area because it had repeatedly experienced devastating consequences by the earthquakes and tsunamis from the nearby Nankai Trough. Further, as the next Nankai Trough earthquake is expected in the early part of the twenty-first century, it is important for such areas to implement disaster risk reduction activities. So tsunami evacuation sites, risk perception problems, issues and measures for tsunami evacuation, evacuation drill objectives, and planning policies were discussed in the area. After each tsunami evacuation drill was conducted, questionnaires were carryed out for participants to measure evacuation activities. In the 2011 evacuation drill, it was found that the arrival time from the "long-distance area" to refuge in the safety zone was longer than for those from the "middle-distance area" or the "short-distance area". However, in the 2012 drills and 2013 drill, the arrival time for residents from the "middle-distance area" was longer than in the other areas. This was found to be partly because residents from the "long-distance area" tended to select buildings in the estimated inundation area as evacuation sites. It was also found that residents refuging on-foot required more time to reach safety zone than residents who used cars in the 2011 drill and motorbikes and bicycles in the 2012 drill. To examine the factors that affected arrival times, a quantification theory type-I was utilized. The results revealed that attribution of "long-distance area" required more time to reach safety zones and that using "cars" and "motorcycles and bicycles" as "evacuation methods," was more time than going "on-foot." For selecting "evacuation sites," residents who chose "buildings in the estimated inundation area" took less time to reach these sites than residents who selected sites "outside the estimated inundation area." "Age," "sex," and "year" were not found to be of significance. Tsunami evacuation scheme in Minabe Town that have 12 rules were developed and illustrated based on these results.

Keywords: Tsunami; Evacuation Drill; Workshop; Nankai Trough earthquake; Minabe Town

1. Introduction

This study illustrates regional tsunami evacuation schemes and planning model based on workshops, evacuation drills, and questionnaires.

The need for early warning tsunami evacuation systems was articulated in the Hyogo Framework for Action after the 2004 Indian Ocean earthquake and tsunami. However, for effective tsunami evacuation, resident evacuation perceptions are also very important.

After the Great East Japan earthquake occurred, around half the affected residents used cars for the tsunami evacuation, which resulted in many people being saved (Cabinet Office, 2011, Goto, Mikami, and Nakabayashi, 2012). However, the use of cars also caused traffic jams, which meant that some residents fell victim to the tsunami. Although the general evacuation rules in Japan specified that escaping on-foot is preferred, tsunami evacuation principles have now been changed to approve the use of cars. For some regional tsunami evacuation plans, adding the option of escaping by car could be effective. To enable all residents to arrive as quickly as possible to tsunami inundation safety zones after an massive earthquake, strategic regional tsunami evacuation plans are needed.

Community-based tsunami evacuation measures have been implemented in many regions (Jonients-Trisler and et al., 2005, Birkmann, Setiadi, and Gebert, 2008, Taubenböck and et al., 2009, Said and et al., 2011, Mikami, Takeuchi, and Shaw, 2009, Terumoto, 2012, Terumoto, 2015). However, regional community based tsunami evacuation models, especially in relation to the use of cars, have not been sufficiently developed.

2. Research area

2.1 Earthquake Characteristics in Research Area

Minabe Town, Wakayama Prefecture, Japan, was chosen as the research area (Fig.1). This area had repeatedly experienced devastating consequences by the earthquakes and tsunamis from the nearby Nankai Trough. Further, as the next Nankai Trough earthquake is expected in the early part of the twenty-first century, it is important for such areas to implement disaster risk reduction activities.

Seismic hazard assessment results of Nankai Trough earthquakes are shown in Table 1 (Wakayama Prefecture, 2014). Fig.2 shows a simulation result of tsunami inundation area after Nankai Trough megathrust earthquake (Minabe Town, 2014). In Table 1, the seismic intensity scale in Minabe Town is estimated to be in the upper six (JMA seismic intensity scale). So, after the earthquake occurred, many buildings, roads, and facilities may collapse by strong ground motions. There could be also landslides in mountainous areas, resulting in major casualties. There are also possibilities that many persons are injured by these collapsed facilities. In that

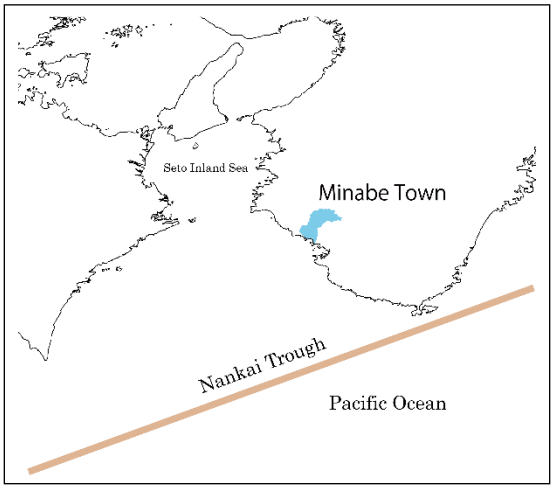


Fig.1 – Location of Minabe Town

circumstances, residents must seek refuge to any safety zone.

In both cases, the tsunami arrival times were at estimated approximately 15–20 minutes, indicating that the lead time after the earthquake is less than in the Tohoku coastal area affected by the Great East Japan earthquake. Further, as the distance to the tsunami safety zones in some coastal area districts in Minabe Town is longer than one kilometer, it may be difficult for some people to evacuate to safety zone by on-foot before the arrival of the tsunami.

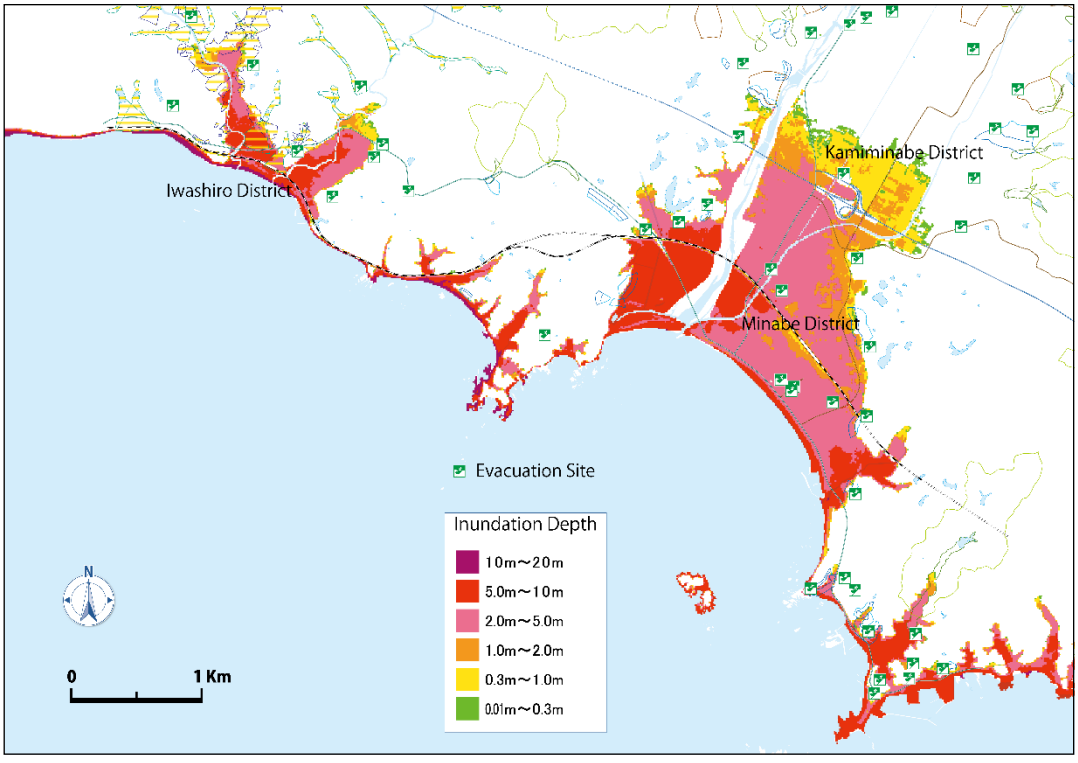


Fig.2 – Estimated tsunami inundation area map in Minabe Town

Table 1 – Results of earthquake damage estimation

Item	Nankai Trough earthquake	
	Tokai-Tonankai-Nankai earthquake (Mw 8.7)	Nankai Trough megathurust earthquake (Mw 9.1)
Seismic intensity(JMA seismic intensity scale)	7	7
Tsunami height	Max:7 m, Mean:6 m	Max:14 m, Mean:12 m
Tsunami arrival time	23 minutes	3 m:14 minutes, 10 m : 24 minutes
Tsunami inundation area	80 ha	450 ha
Collapsed buildings caused by seismic motions	2,400	2,000
Collapsed buildings caused by tsunamis	72	2,100
Collapsed buildings caused by fire spread	190	71
Human damages	Death toll: 270 Injured: 200	Death toll: 3,900 Injured: 230

Population: 13,700, Total buildings: 8,100, Square: 12,026 ha

2.2 Outlines in Minabe Town

There are 22 resident associations and disaster risk reduction groups in Minabe Town's tsunami inundation area and these communities are closely united. Table 2 shows the numbers of populations and households in the area. The number of people who would find it difficult to evacuate by themselves is based on the questionnaire results from representatives in these districts in 2012.

3. Tsunami Evacuation Plan Examination Process

Tsunami evacuation drills and workshop series were conducted since 2011 in the coastal area of Minabe Town. Fig.3 shows the outline of planning process.

Residents of four associations that had been selected as model districts took part in the workshop series in 2011. In these workshops, tsunami evacuation sites, risk perception problems, issues and measures for tsunami evacuation, evacuation drill objectives, and planning policies were discussed. A basic tsunami evacuation framework for Minabe Town was developed based on the results of these workshops in February, 2012.

From 2012, these measures have been discussed by the residents in the disaster risk reduction groups. Tsunami evacuation drills and the results of these drills were especially important themes. Tsunami evacuation drills have been generally conducted once a year with the aim of improving resident abilities and the verifying steps of the measures. The main evacuation issues were extracted through these discussions and are shown in

Table 2 – Populations and households of the coastal area of Minabe Town

Night-time population	11,740
Day-time population	6,751
Households	4,137
The number of People who would find it difficult to take refuge	640

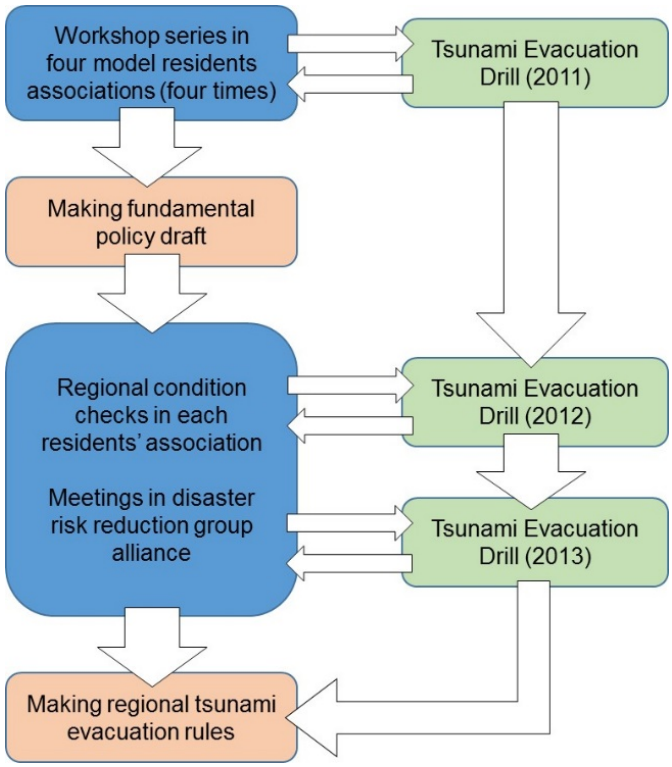


Fig.3 – The examination process of tsunami evacuation measures

Table 3–Abstracted main content for regional tsunami evacuation problems in workshop series discussion

Selecting between seeking refuge outside the estimated tsunami inundation area or seeking refuge in an evacuation building in the estimated inundation area may be difficult in an emergency.
In an emergency, resident may not be able to perceive the tsunami arrival time and elapsed time after the occurrence of an massive earthquake.
There is a possibility that residents may have little idea about the tsunami inundation spread image in this area.
Estimated tsunami occurrences after Nankai Trough megathurust earthquake may bias resident perception of the tsunami hazard.
Reservoir(s) in mountain areas near evacuation sites may collapse because of strong ground motions or the consequent aftershocks.
Residents in some districts intended to take refuge in clusters when the tsunami evacuation drills were implemented.
There are some difficult stairs on some evacuation routes.
Valuable evacuation time may be taken up gathering emergency situation information after an earthquake occurs.

Table 3. Tsunami evacuation rules were developed based on these results.

4. Tsunami Evacuation Drill Results

4.1 Framework for the Drills

Fig – 4 Scenes of tsunami evacuation drills

Table 4 – Outline of each tsunami evacuation drill

	2011	2012 (Iwashiro District)	2012(Minabe and Kamiminabe district)	2013
Time	08:00, 4th, Dec., (Sun)	15:00, 22nd, Nov., (Th)	09:00, 25th, Nov., (Sun)	08:00, 24th, Nov., (Sun)
Assumed situations	Tsunami warning	Nankai Trough megathrust earthquake（M9.1） Seismic Intensity: 7	Nankai Trough megathrust earthquake（M9.1） Seismic Intensity: 7	Nankai Trough megathrust earthquake（M9.1） Seismic Intensity: 7
Weather	Fine	Cloudy	Fine	Fine
Participants and percentage	3814 persons, 31.8%	241 persons, 23.0%	3342 persons, 30.8%	3605 persons, 30.7%
Questionnaire implementation sites	11 sites	5 sites	15 sites	25 sites(Iwashiro district; 8, Minabe and Kamiminabe district; 17)
Collected questionnaires	567	89	704	852

Table 4 shows the content of the tsunami evacuation drills. The 2011 tsunami evacuation drill was implemented on the fourth of December in the coastal districts in the estimated tsunami inundation area. Drills in 2012 were conducted in cooperation with elementary schools in each elementary school district. In the Iwashiro elementary school district, as the drill was when the elementary school students were going to school, they had to select an evacuation site by themselves. The 2012 evacuation drill in Minabe and Kamiminabe elementary school districts were conducted at same time. In 2013, the drill was implemented in all districts. Photos of the tsunami evacuation drills are shown in Fig.4.

4.2 Survey Methods

After each tsunami evacuation drill, when the participants arrived at evacuation sites, questionnaires were carried out at some sites. Therefore, not all participants were targeted for questionaires. The arrival time was noted by the staff.

5. Results

5.1 Evacuation drill arrival time results

The aggregate results for the resident living areas, evacuation routes, and the evacuation sites for each evacuation drill are shown in Fig.5. These areas are distinguished by the distance to outside the estimated inundation area with the “long-distance area” being over 1 km, the “middle-distance area” being 750 m–1 km, and the “short-distance area” being under 750 meters. Evacuation methods were by on-foot, motorbike/motor scooter or bicycle, and car. The evacuation sites are divided into those inside the estimated inundation area and those outside the estimated inundation area.

In Fig.5, people of over 15 minutes are found in each attribute, although tsunami arrivals in both Nankai Trough earthquake assessments are approximately 15-20 minutes. These results indicate that some people may not reach an evacuation site in the lead time after a Nankai Trough earthquake.

5.2 Comparative Analyses

Table 5 shows the means, standard divisions, and the results of one-way analysis of variance for each year. Tukey’s HSD test was used for multiple comparisons, with the significance level set at five percent.

In the 2011 evacuation drill, residents from the “long-distance area” took longer to arrive at the evacuation sites than residents from the “middle-distance area” and “short-distance area.” However, in the 2012 drills and the 2013 drill, residents from the “middle-distance area” took longer to arrive at the evacuation sites than residents from the other areas. This result was partly because many residents from the “long-distance area” chose to evacuate to buildings inside the estimated inundation area. Foot evacuees were found to need more time to reach evacuation sites that those who chose to use a car in the 2011 drill, and those who chose to use a motorbike/scooter or a bicycle in the Minabe and Kamiminabe 2012 drills.

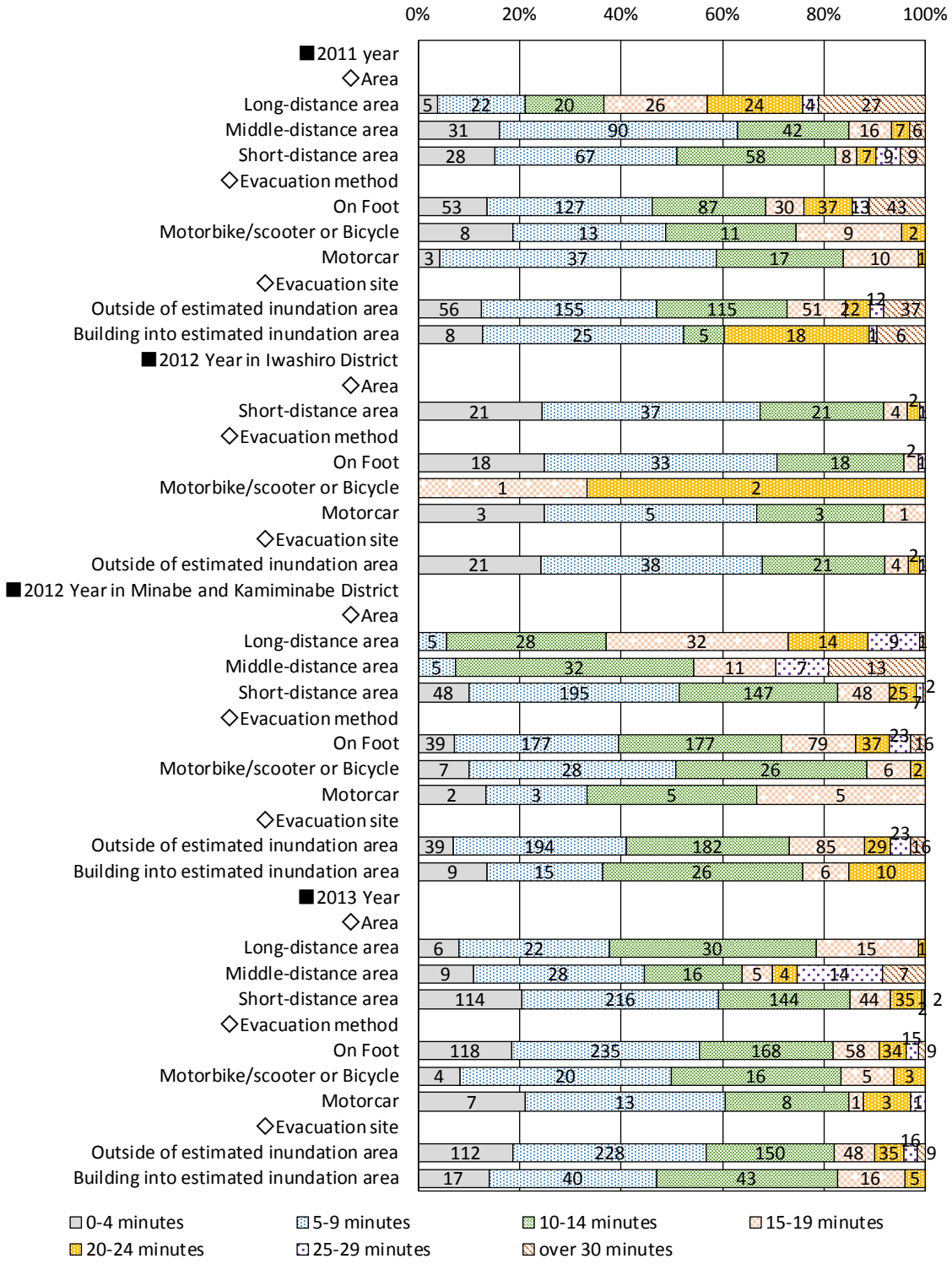


Fig.5 – Aggeregate arrival times results

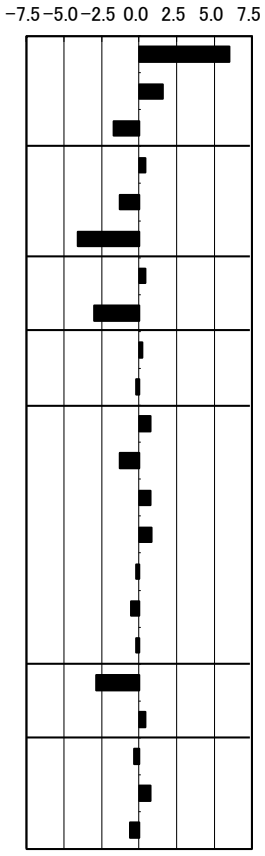
5.3 Arrival Time Factors

To find the factors that affected arrival times, quantification theory type-I was utilized and the items in Table 5 used to explain the variables. Fig.6 shows the results of the analyses.

Table 5 – Arrival times and comparative evaluation

Item	2011	2012 in Iwashiro District	2012 in Minabe and Kamiminabe District	2013
Mean(S.D)	11.9 (9.1)	7.3 (4.8)	11.7 (6.5)	9.2 (6.2)
Area	Middle, Short< Long	-	Short< Long, Middle	Short, Long< Middle
Evacuation method	Car < On-Foot	n.s.	Motorbike/scooter or Bicycle <On-Foot	n.s.
Evacuation site	n.s.	-	n.s.	n.s.
Sex	n.s.	n.s.	n.s.	n.s.
Age	n.s.	n.s.	n.s.	n.s.

Item	Category	Frequency	Score	Range	Partial correlation coefficient
Area	Long-distance area	270	6.00	7.70	0.35
	Middle-distance area	315	1.55		
	Short-distance area	1243	-1.69		
Evacuation method	On foot	1560	0.44	4.48	0.17
	Motorbike/scooter or Bicycle	146	-1.29		
	Car	122	-4.04		
Evacuation site	Building into estimated inundation area	1596	0.43	3.41	0.16
	Outside of estimated inundation area	232	-2.98		
Sex	Male	797	0.23	0.41	0.03
	Female	1031	-0.18		
Age	under 20	88	0.78	2.13	0.09
	21-30	48	-1.30		
	31-40	216	0.73		
	41-50	280	0.83		
	51-60	419	-0.19		
	61-70	463	-0.57		
	over 71	314	-0.17		
District	Iwashiro	227	-2.85	3.26	0.16
	Minabe and Kamiminabe	1601	0.40		
Year	2011	432	-0.31	1.38	0.09
	2012	703	0.78		
	2013	693	-0.60		



Multiple Correlation Cofficient 0.43

Fig.6 – The result of mathematical quantification theory type-I

The most important item was “Area.” Residents coming from the “Long-distance area” took longer to arrive. The second important item was “the evacuation method.” Arrival times for people using a “Car” and “motorbike/scooter or Bicycle” were shorter than for those arriving “On-foot.” In “Evacuation site,” the arrival times for residents who selected “buildings in the estimated inundation area” tended to be shorter than for residents who selected “Outside the estimated inundation area.” “Age,” “Sex,” and “Year” were not statistically significant in this analysis.

6. Discussion

The Tsunami evacuation scheme in Minabe Town was based on the results of assessments of Nankai Trough earthquakes, the workshop series, the tsunami evacuation drills, and the questionnaires. Table 6 shows the tsunami evacuation rules in coastal area of Minabe Town. These frames had 12 rule items.

The objective of the tsunami evacuation strategies in Minabe Town is to ensure that no residents stay in the estimated tsunami inundation area in 10–15 minutes after a huge earthquake strikes. These rules were developed in an attempt to decrease human losses after an huge earthquake occurrence, so were not designed to restrict resident action. These were also not directly intended to target improvements in resident risk perception.

Rules 1 and 2 focus on basic evacuation attitudes. Heading outside the estimated inundation area is encouraged, and steps for taking refuge inside the estimated inundation area building in an emergency are described. These rules are based on the limited time available between the earthquake occurrence and the tsunami arrival, and the risks of evacuating to buildings in the estimated tsunami inundation area that may be surrounded by tsunami (see Table 1 and Fig. 2).

Rule 3 focuses on the evacuation route, and warns to move away from rivers and the seaside as soon as possible. This rule was developed as it was noticed that during the evacuation drills, some residents went along river sides and across the bridges. Rule 4 describes what needs to be done for people requiring assistance. Rule 5 focuses on the evacuation activities and is related to precautionary safety confirmations (see Table 3).

Table 6 – contents of tsunami evacuation rules (1)

Rules	Points
1 Evacuate to outside the estimated inundation area up to 10–15 minutes after the earthquake.	·Do not be particular about local government designated site. Highly elevated places such as mountain areas are recommended for evacuation. ·You can meet family members and neighborhood residents after the evacuation. ·When evacuating, pay attention to possible landslides.
2 Don't use evacuation buildings easily in the estimated inundation area.	·However, if unable to arrive in an outside safety zone within 10–15 minutes after the earthquake, evacuate to a high building. ·If selecting a building in the estimated inundation area, it is not necessary to go only to the local government designated buildings. High buildings and reinforced concrete buildings are recommended.
3 When evacuating, take care to leave the estimated tsunami inundation area.	·When you noticed seismic motions, remember the lessons from previous Nankai Trough earthquakes. ·Do not pass by rivers or the seaside. The first selection is to leave the estimated tsunami inundation area as soon as possible. ·Do not go across and along the Minabe river because of the risk of an upstream river tsunami.
4 Communities in residents' association are regarded as a unit for these evacuation rules and planning. Supports for people requiring assistance during a disaster must be examined in each district.	·Support rules, systems, and roles for people requiring assistance should be arranged in each district. ·When these rules are examined, consider the different circumstances such as day or night, and weekdays or holidays. ·These support rules should be reported to the local government. ·The local government must manage the evacuation rules based on each district's rules.
5 When a massive earthquake strikes, do not immediately implement safety confirmations, such as roll calls. Do not gather and evacuate with many residents to decrease evacuation time.	·Do not decide only a singular evacuation site in advance. Have many options of evacuation sites and buildings. ·Residents can check confirmation of the safety of residents after the emergency evacuations.

Table 6 – contents of tsunami evacuation rules (2)

Rules	Points
6 Motorbikes/scooters and Bicycles are recommended for the evacuation.	·When using a motorbike/scooter or bicycle, pay attention to foot-evacuees. ·Avoid areas where traffic jams may occur.
7 Using a car for evacuation may be permitted depending on the conditions. Use recommended evacuation roads and sites for the evacuation.	·Decide on the evacuation route and method based on the damage and the number of injured person(s) after the earthquake strikes. ·If car(s) encounter damaged structures, act according to circumstances; e.g. Leave the vehicle. ·When drivers arrive at an evacuation site, move the car forward as much as possible to allow for following vehicles. ·When evacuating by car, use decided routes so as not to interrupt foot evacuees.
8 Residents in long distance districts seeking to evacuate outside the estimated inundation area are permitted to use cars.	·Residents in these districts should evacuate on-foot, or by motorbike/scooter or bicycle as much as possible. ·Decrease the use of cars by using the same car for several residents by deciding on which cars to take before an earthquake occurs. ·Report the number of cars to be used for the evacuation to the local government office.
9 People requiring assistance, injured people, and their supporters are permitted to use cars in all districts.	·Decrease the use of cars by using the same car for several residents by deciding on which cars to take before an earthquake occurs. ·Report the number of cars to be used for the evacuation to the local government office. ·To avoid the emergency responses such as for injured person(s), implement prepared disaster risk reduction activities.
10 Estimated tsunami arrival time is informed by count-down after the major warning announcement based on the anticipated tsunami arrival time.	·Warnings for the last ten minutes and the last five minutes before the anticipated tsunami arrival time are announced from local government broadcast system. ·When the warning is given in the last five minutes, stop response activities, and evacuate to the nearest evacuation site.
11 After an massive earthquake occurs, you may not follow strictly these rules. Act according to the circumstances for saving your live(s).	
12 These contents are verified based on results of annual tsunami evacuation drills.	

Rules 6, 7, 8, and 9 focus evacuation methods. There is a possibility that some routes may be damaged or destroyed in the strong ground motions and subsequent aftershocks. As motorbikes/scooters and bicycles are faster than going on-foot, and smaller than a car, rule 6 recommends their use. Rule 7 focuses on the evacuation sites and routes when using a car to evacuate. Detailed car use rules are shown in Fig.7. In Fig.7, a car evacuation site is defined as a place at ground level such as a parking lot at a hotel, and the car evacuation areas being large spaces such as around farms. In the car evacuation areas, drivers may bring the car anyplace. This rule outlines the necessity to anticipate possible traffic jam areas and also stresses the need to consider those people who are evacuating on-foot along major roads. Rules 8 and 9 give recommendations as to which people can use cars in an evacuation, which were based on the results of the evacuation drills and the specific regional conditions.

Rule 10 relates to the information to be given by the local government office after a massive earthquake, which was based on the results of the workshop series discussions (see Table 3). A countdown warning is applied for the information which is designed to assist evacuees when deciding on where to go and when to cease response activities.

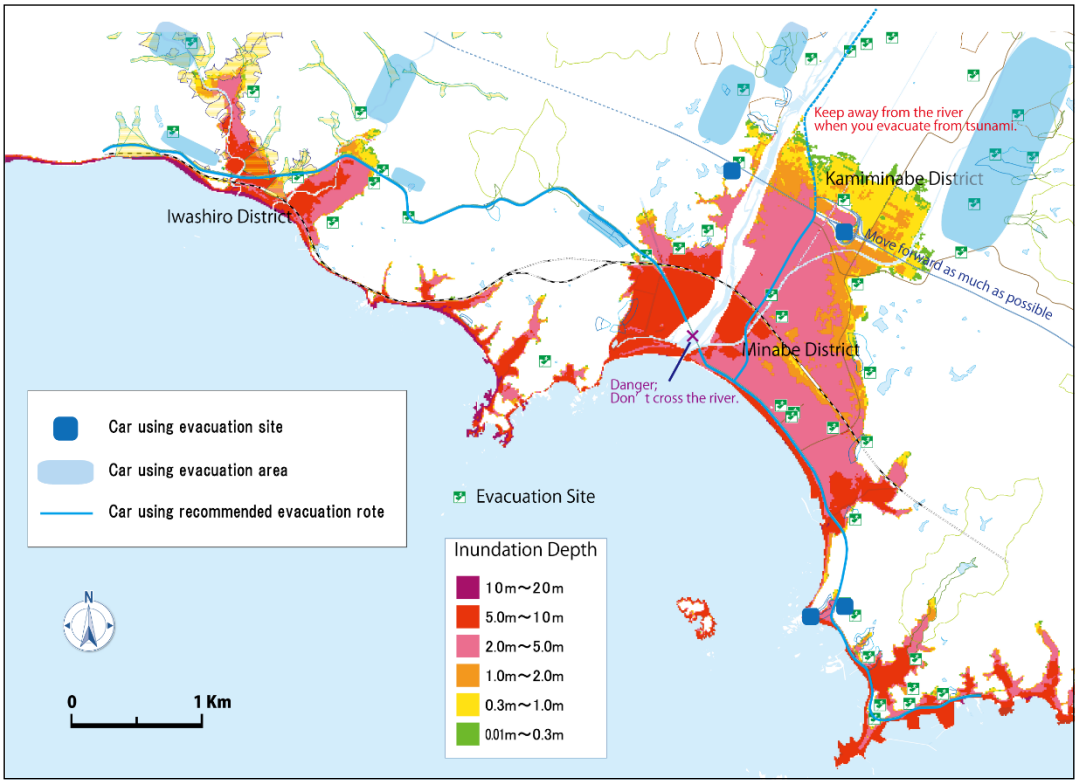


Fig.7 – Car using rule map

Rules 11 and 12 are focused on the flexibility in the scheme.

However, while these rules cover the general evacuation in the area, they do not cover the support systems for people who may require assistance. Therefore, further analysis and examination are needed.

7. Conclusion

In areas where the anticipated tsunami arrival time is short, it is important to not only increase the risk perceptions of the residents, but also to develop common regional rules for tsunami evacuation. These rules must consider areal situations and reality, and construct frameworks that are agreed up on by the residents.

The regional rules framework developed in this study could be utilized as the basis for rules developments in other areas. Improving this model to include support services and unfolding it to another area are the subjects for future practices and studies.

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