

博 士 論 文

Multi-Scopic Evacuation Supporting System against Tsunami Disaster

:With Reference to the Great East Japan Earthquake in 2011

(行政規模に対応した津波災害避難計画支援システムの構築

: 東日本大震災の教訓から)

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Abstract

The Great East Japan Earthquake of March 11th, 2011 was distinct from the 1995 Kobe earthquake, especially in the causes of deaths. The former was characterized mainly by deaths due to drowning from the tsunami, while the latter was characterized by deaths due to structures that collapsed in the earthquake. The tsunamis also required evacuees to escape distances of over 15km, and the Evacuation Action Plan (EAP) had recommended walking mode as the only official mode of escape. This study analyzed the emergency escape mode and pattern of evacuation based on the questionnaire survey data collected by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan with 10,601 evacuees at shelters. The statistical results were derived from strategic designation of evacuation routes using the historical data. To illustrate the actual event during the disaster, I evaluated the situation using measures in terms of starting time of evacuation, evacuation distance and evacuation speed under the given geographical condition, population density, road network and time named EASY-LEE (Evacuation Action Supporting System-Leading Efficient Escaping) and STRONG-LEE (Shelter, Time, Road-Network, Geography-Leading Efficient Escaping). The results of such analysis were used as basis of appropriate recommendations for future decisions and political directions, such that the provision of a “needed more shelters” in hazardous prone area, “emergency parking area”, and assurance of “supporting car for evacuation” are some of the noted significant basic priorities which form the fundamental criteria for the evacuation route strategy. Residents living in Fukushima Prefecture did not have the advantage of escaping by walking. Iwate Prefecture had the advantage of car mode, but the EAP does not encourage this.

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Chapter 1 INTRODUCTION

1.1. BACK GROUND AND MOTIVATION

1.1.1. Background

A distinctive aspect of the disaster that struck Eastern Japan on March 11th 2011 was that 92.4% of the casualties were caused by drowning from the tsunami [NPA, 2011, MPD, 2012], whereas in the Kobe earthquake of 1995, fatalities were caused mainly by structures that collapsed in the ruinous shakes [NPA, 2011, DJPW, 2013]. This 2011 disaster has been broadcasted worldwide and has awakened us to the tremendous destructive power and threatening impact of tsunamis. The tragic events have gathered much attention and have opened way to research opportunities on topics related to evacuation and risk reduction from earthquakes as well as from tsunamis [Wegscheider et al. 2011, Charnkol et al. 2006, Limanond et al. 2011]. The central government of Japan, especially the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), has conducted surveys using formulated questionnaires to collect data on the condition of the actual evacuations for a period of six months after the disaster [MLIT, 2013]. Using the responses from 10,631 evacuees in the Tohoku area as primary data [ARIS, 2013], the authors were able to record data on individual evacuation time, distance, speed, mode share ratio and other general information.

In this disaster, evacuees were required to move long distances both horizontally and vertically in order to reach the shelters. They were required to evacuate not only from individual buildings, but also from entire cities or towns in order to evade the impending threats. It took around 30 minutes after the earthquake of magnitude 9.0 before the tsunamis inundated 600km of the eastern coastal line of the Japanese archipelago for as deep as 14km into the inland [JMA, 2013]. The emergency tsunami warnings allowed for an evacuation time of about 30 minutes to evacuate 14 kilometers

from their original site, which corresponds to an estimated velocity of 30km/h. In this case, the use of car mode would be the optimal, if not the only evacuation mode to reach safety.

The statistical results were derived from strategic designation of evacuation routes using historical data. To illustrate the actual event during the disaster, the authors evaluated the situation using the starting time of evacuation, evacuation distance and speed under the given geographical condition, population density and time. The results of the analysis were used as basis for recommendations regarding future decision-making and policy directions.

1.1.2. Motivation



Figure 1-1 Hazard Manual in Tokyo Metropolitan (BCCA, 2011)

In the Emergency Action Plans (EAP) documents, the main recommended mode for evacuation is walking because of serious congestions, uncertain road condition and/or the need for quick movement of emergency vehicles (MLIT, 2011, FEMA, 2011, NEMA, 2012). According to the hazard manual issued by the Tokyo Metropolitan government, the main mode for evacuation is walking, as shown in Figure 1-1, and this is basis for evacuation plans, disaster education and practice drills. Additionally, metropolitan cities have high population density, which cause serious congestions even in normal times. Given that there are so many other reasons why evacuees would not be able to effectively use a car, it seems rational to evacuate by foot. However, reality was different, as shown in Table 1-1. The mode ratio for evacuation after the earthquake in the cities was predominantly in car mode in the Tohoku area. In the case of Yamamoto, 94% of evacuees used car mode for evacuation. The average for all cities was 67%. In cities that were seriously struck by the disaster such as Rikuzentakata (63%), Otsuchi (57%), Onagawa (52%), and Ishinomaki (52%), the mode ratio for cars was lower than the average.

These results do not explain the main causes of the victims, but previous EAP have not covered these phenomena [MLIT, 2012, GIA, 2012, SBDG, 2013].

Table 1-1 Mode Ratio for Evacuation in Tohoku Area (Data: 復興支援調査アーカイブ , N=9,559)

Name	Car	Others	Name	Car	Others
Yamamoto	0.94	0.06	Rikuzentakata	0.63	0.37
Rifu	0.90	0.10	Tanohata	0.61	0.39
Iwaizumi	0.90	0.10	Hirono	0.59	0.41
Hirono	0.89	0.11	Minamisanriku	0.58	0.42
Shinchi	0.86	0.14	Kesennuma	0.58	0.42
Iwanuma	0.86	0.14	Yamada	0.57	0.43
Watari	0.81	0.19	Otsuchi	0.57	0.43
Kuji	0.79	0.21	Higashimatsushima	0.56	0.44
Minamisoma	0.78	0.22	Tagajo	0.54	0.46
Soma	0.78	0.22	Onagawa	0.52	0.48
Iwaki	0.75	0.25	Ishinomaki	0.52	0.48
Sendai	0.74	0.26	Shiogama	0.52	0.48
Natori	0.70	0.30	Miyako	0.49	0.51
Ofunato	0.69	0.31	Matsushima	0.41	0.59
Noda	0.64	0.36	Kamaishi	0.39	0.61
Shichigahama	0.64	0.36	Average	0.67	0.33

The differences between EAP and real evacuation behaviors can lead to problems when selecting the mode of evacuation because evacuation distance and congestions may be affected. The evacuation distance and congestion problems are often the main keys to solve the evacuation problems. So the phenomena based on the real evacuation behaviors should be discussed and the plans should be derived by real actions.

1.2. THE GREAT EAST JAPAN EARTHQUAKE IN 2011

1.2.1. Geographical Conditions: Rias and Plain Coastal Line

Tohoku area is the eastern part of Japan, composed of the Aomori, Iwate, Miyagi, Fukushima, and Ibaraki prefectures along a coastal line that is longer than 600km. Rias coast, or drowned coast, has complex and irregular shapes because of the depressed coast, strike slip fault motion, or sea level rises. Therefore, residential areas are located near the coast and are often surrounded by mountains. Small fishery is usually the main industry and the population is usually small. Some plain areas, which may have large agricultural land and some highly populated cities (e.g., Sendai City) are also located in this area. For better comparison of the geographical conditions, the tsunami damaged areas were divided into two parts: Rias areas and plain areas. The Rias areas contain Iwate and Miyagi prefectures, which have mountains near the residential areas and small fishery sectors in the lower lands. These areas are characterized by low population density and sites for the fishing industry, which have historically been recognized as areas that are vulnerable to tsunami (such as Minamisanriku, Onagawa, and Otsuchi). On the other hand, the plain areas are relatively wider areas allotted for agriculture, characterized by cities with comparatively higher population density (such as Sendai, Iwanuma, and Yamamoto). In the case of the Miyagi, the two conditions are mixed.

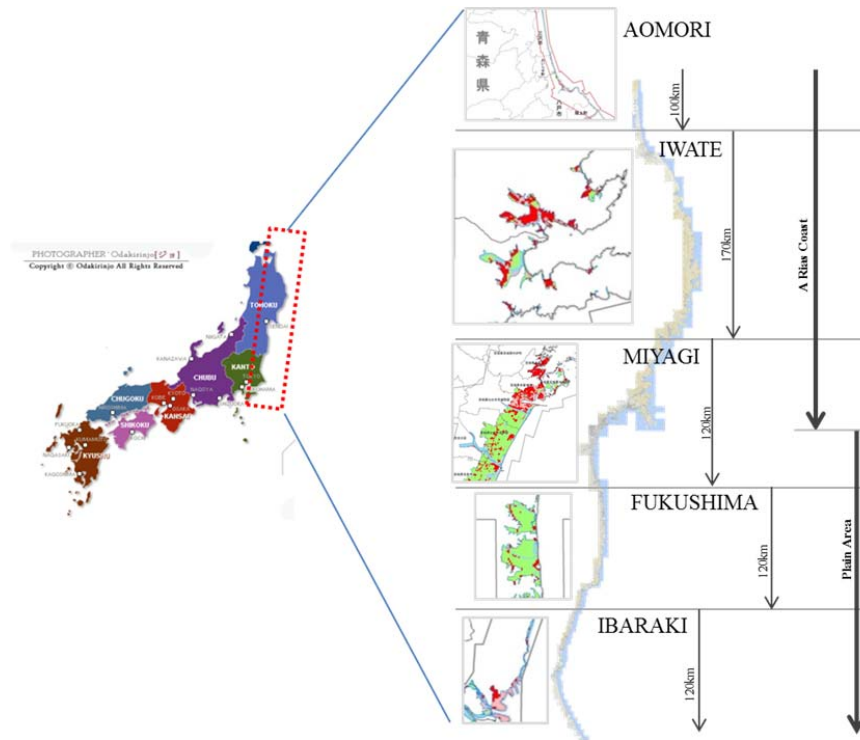


Figure 1-2 Geographical Conditions of Japan and Damaged Areas

1.2.2. Three Main Geographical Types

The main characteristic of the Rias coast is the complexity of its shape. These diverse geographical areas have been categorized in more detail into three geographical conditions following the damages from Tsunami. The total inundation area was 443km², and this is 6% of the area of damaged cities [MLIT, 2011].

Data from a total of 226 small towns were collected, and categorized based on the inundation area and the five different flooding characteristics. The linear shape (2%, 5 cases) is shown in Figure 1-3 and Kesennuma is exemplified. The residential areas of those cities are located along the line, so there is a sea in the front side and mountains on the back side. If citizens in these areas evacuate in a linear direction, they are still in the hazard area but they can find a safe area nearby because they can evacuate to the mountains. In the isolated shape (22%, 46 cases) such as Miyako,

the small residential area is surrounded by mountains and one or two main roads can be used for evacuation by car mode, but the mountains are very close from the hazard areas. In Kesennuma and Ofunato, Eruption/Duplex areas (1%, 3 cases) are also seen, which have unique landscapes and the Tsunami had attacked the small area from two or more directions. These areas are generally very vulnerable from the Tsunami. The waterside areas (48%, 109 cases) have a river in the residential area (Otsuchi).

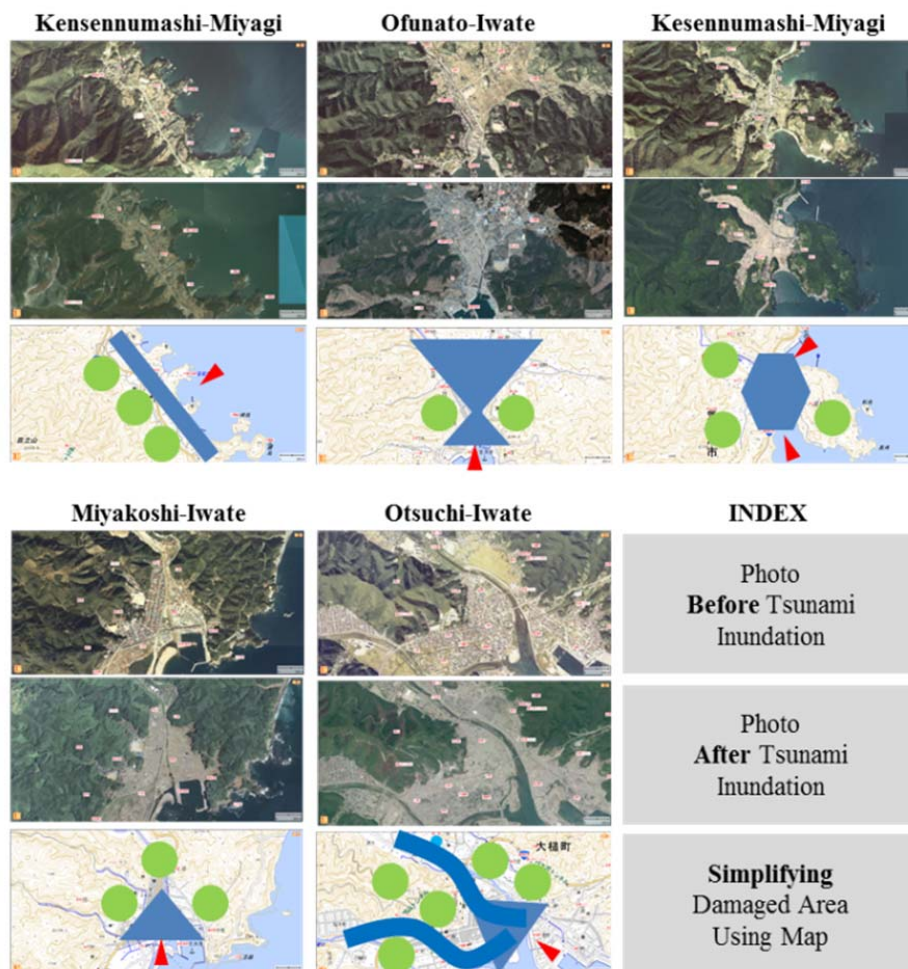


Figure 1-3 Five Main Different Geographical Conditions

Serious damages occurred in these areas because when the Tsunami attacked these areas, it followed the river side and the speed of inundation was faster than other areas. Therefore, these rivers brought about serious damage even when the height of the Tsunami was not much different from other areas. The plain areas (28%, 62 cases) had very wide inundation area because there are few mountains or high lands to slow or stop the tsunami. Therefore, the evacuation distance is longer than others.

1.2.3. Demographic Characteristics and Victims

Population and population densities are shown in Table 1-2 at the prefectural level and at the city level in Appendices B and C. Miyagi has the highest population density, while Iwate has the combination of lowest population density and highest average age. 27.2% of the citizen is more than 65years old, which is the highest among all prefectures in the Tohoku Area (see Appendix B).

Table 1-2 General Conditions of the Five Prefectures

Name of Prefecture	City Area (Km2) Damaged Area	Population Density (person/km2) Damaged Area	Population (person) Damaged Area	Age (Mean) Damaged Area
AOMORI	519	566	293,572	45
IWATE	4,876	56	270,998	50
MIYAGI	2,453	697	1,708,599	46
FUKUSHIMA	1,932	240	464,586	47
IBARAKI	1,444	667	963,792	45

* Calculated areas in prefecture contained only neighboring coastal cities

Shiogama city has the highest population density (3,318 people/km²) and Sendai city is the second highest (1,334 people/km²). In the case of Sendai city, only 18% of its citizens are over age 65. A total of 344,477 people tried to evacuate from the hazard areas and 18,926 people died. 92.4% of the deaths were caused by drowning and 65.2% of the victims were in their 60s or above. The problems pertaining to an aging society was prevalent in the Tohoku Area.

1.3. RESEARCH GOAL

1.3.1. Research Boundary and Concept

This research focuses on the congestion of walking mode and car mode in evacuating from earthquakes and Tsunamis, and comparing the level of infrastructure in the Tohoku Area. The research conducted a macroscopic comparison of the areas, assuming that the mode ratio for cars was more than 50%, and also identified specific regions where car mode was the main mode of evacuation. In the Tohoku area, the Tsunami disaster of 2011 is the main case, with data from the prefectural and city levels.

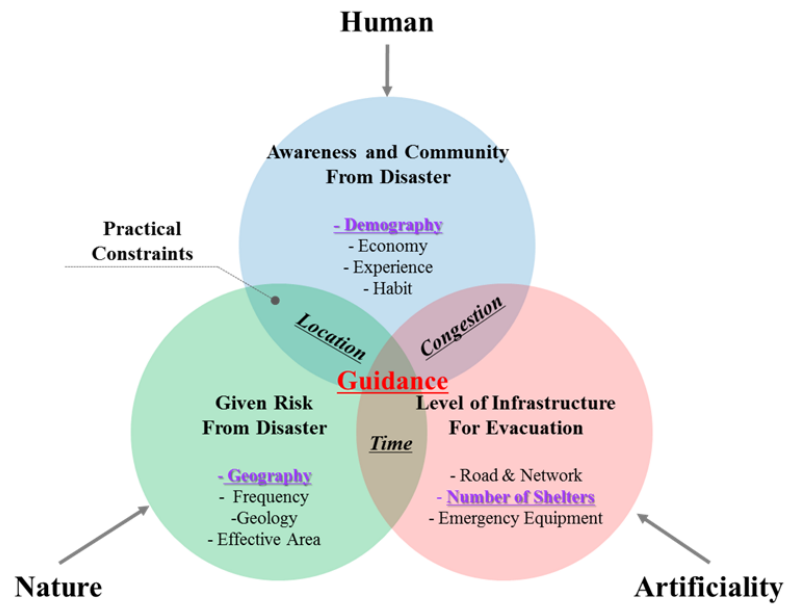


Figure 1-4 Basic Concepts for Research

“Human”, “Nature”, and “Artificiality” are the main components of the concept diagram shown in Figure 1-4. I assumed that demography is the main parameter for awareness and community in serious disasters, geography is a major component of given risk, and the number of refugees (shelters) represents the level of infrastructure in the area to cope with disasters. Based on these concepts, the “given risk” and “community” overlap with “location” problems because people live in the natural hazard areas. Road conditions and number of shelters (artificiality) affect evacuation speed and distance, and population is one of the main components to cause congestion with artificialities. Given risk from nature can be reduced by disaster prevention facilities, so infrastructure can increase the escaping time. Each of these problems was considered in Chapter 4, and a holistic discussion is in the concluding Chapter.

1.3.2. Given Data

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) collected data on individual evacuations immediately after the Tohoku earthquake of 2011. General information and average values for behaviors were calculated in reports and the Archive of Reconstruction Supporting Investigation (ARSI) web-GIS base. The preliminary results and raw data were obtained there. Demographical, geographical, and infrastructural data were collected from Statistics Bureau, Director-General for Policy, Planning & Statistically Research and Training Institute (SBDP) and the Geospatial Information Authority of Japan (GIA). Digital Japan Portal Web Site (DJPW) categorized land usage and the area damaged region. The height of Tsunamis and the approach time were reported in Japan Weather Association (JWA), and the location and number of shelters was obtained from the Disaster Prevention Information (DPI). Information on victims and the missing were collected by Metropolitan Police Department (MPD).

1.3.3. Practical Users

This research attempted to create evacuation guidance for planners, decision makers, and evacuees. In order to consider practical use, the results were divided into three levels: macroscopic, microscopic and nanoscopic. In order to further define the users of the results of this research, the given roles of government officers and community groups of citizens must be discussed. Each country and each society has different roles and needs, but Figure 1-5 shows one example for the Japanese government.

Conceptually, the central government needs macroscopic results using simple data in order to compare parts of the entire country because their focus is on the long term and at national scale (Figure 1-5, Figure 1-6). Local governments, on the other hand, focus on the short term but in more detail about practical options for their municipality. Post-disaster management, quick

response, rescue, allocation of logistics and recovery plans can be the main topics for each level of government.

However, the principle agents of evacuation are the individual citizens. Even if the government had an absolute and perfect evacuation plan, the citizens are the evacuees.. In this research, Nanoscopic guidance systems are suggested to help the evacuation of the community groups, including individual citizens on real road networks. This system can be applied to simulate the start of evacuation, mode changes and destination changes using smart phones or computer-based devices in the future.




	Central Government  <small>国土交通省</small> <small>Ministry of Land, Infrastructure, Transport and Tourism</small>	Prefecture Government  <small>福島県</small> <small>Fukushima Prefecture</small>	Local Government  <small>南相馬市</small> <small>Nanamiya City</small>	Community Group <small>自治会</small> <small>Individual EV Plan</small>
Concept	Simple Data			Complex Data
	Macroscopic			Microscopic
	Part of Whole			Whole Part
Attribute	General Plan Long Term	Conditional Plan Mid Term	Detail Plan Short Term	Survival Plan Temporary
Contents	Comparison Balancing Organizing .	Demography Economy Network .	Geography Infrastructure Land Use . .	Role Sharing Individual Ability Communication .

Figure 1-5 Given Roles and Needs for Evacuation Plan




Who	Central Government  国土交通省 Ministry of Land, Infrastructure, Transport and Tourism	Prefecture Government  福島県 Fukushima Prefecture	Local Government  南相馬市 Naraha City	Community Group 自治会 Individual EV Plan
When	Before Disaster (20~ Years Plan)	Before Disaster (10 Years Plan)	Before Disaster (1~3 Years Plan)	While Disaster (1 Hours Plan)
Where	In Office Covering County (Prefecture Unit)	In Office Covering Prefecture (City, Town Unit)	In and Out of Office On-the-spot (Each Facilities)	Near House Each Person (Role and action)
What	Deriving Direction	Mediation to applying	Practicality	Cooperation
Why	Considering Whole Matters in County	Reflecting Reality Based on the Situations	Reducing Victims Quick Response	One's Survival
How	Government Policy	Prefecture Policy Supporting City	Constructions Managements	Cooperation

Figure 1-6 Given Roles for Evacuation Planning

1.3.4. Objectives and Goal

The evacuation required in the Great East Japan Earthquake was not between two areas in the vicinity, but often across long distances from one city or metropolitan area to another. This research considered the guidance and supporting methods to develop evacuation plans for such long distance evacuations.

This research employed sophisticated modeling to relate real scenarios in finding the optimal solutions in a given network or site. For this, fundamental characteristics need to be extracted from the bulk of data about the actual situations as collected by MLIT.. This study utilized unique data containing detailed information on evacuation behavior. Basic statistical analyses were employed to understand the data and define the criteria for evacuation. This research attempted to derive solutions and proper recommendations for evacuation routes management based on observed problems.

First, the evacuation distances were long and the number of evacuees was very large both at the prefectural and municipal units. Special focus was given to average congestion, evacuation speed and the preparation time necessary for evacuation in accordance with macroscopic characteristics such as the level of infrastructure and the population density. Wide areas can be compared in one table (EAST-LEE: Emergency Action Supporting System – Leading Efficient Escaping).

Second, the parameters for macroscopic analysis were extended to incorporate variations in age groups, road ratio and given geographical conditions. In the microscopic analysis, 300 meters was employed as the standard minimum size of districts, leading to a new style hazard maps that can be used to determine emergency (quick response) roads and control points. Additionally, the observation results derived the buffer road, which is related to the absorbing evacuation traffics from hazard areas to safe areas.

Third, evacuation strategies for individual evacuees were suggested based on personal characteristics that were collected through questionnaires and personal travel behaviors. This research observed the self-safety phenomena for safety evacuation at individual levels.

1.3.5. Aim of this Research

Users can choose the guidance adopted for their objectives. Macroscopic guidance needs simple input (population density and average distance to shelters), so the results are also shown in one table. This can help a user in comparing the conditions and determining the principles. In nanoscopic guidance, specific and detail information are needed and therefore various results such as the location of shelters, evacuation roads and shelter supporters are shown along the different given conditions. Macroscopic guidance is shown in EASY-LEE (Evacuation Action Supporting sYstem-Leading Efficient Escaping) using simple input parameters and conceptual outputs. Nanoscopic one is applied in STRONG-LEE (Shelters, Time, ROad-network, Geography-Leading Efficient Escaping) included the road network and road capacity.

This research focuses on the earthquake and Tsunami disasters, but these results and concepts can be applied to other evacuation plans both for man-made and natural disasters. A discussion is included about Kochi city in the final chapter.

Chapter 2 **LITERATURE REVIEW**

2.1. EVACUATION MODELS IN TRANSPORTATION

2.1.1. Introduction

The congestion problems resulting from a simultaneous and sudden increase in the escaping population were analyzed in the discrete-space (cellular automata-based or lattice-based [Blue et al. 2001, Burstedde et al. 2001, Nagel 1998, Schadschneider 2001], route choice in the network, or queuing models [Løvås 1994, Yuhaski et al. 1989], space continuous as the social force and magnetic force model [Helbing et al. 1995, Okazaki 1979]. Related researches mainly focused on evacuation behaviors using walking mode. While walking mode is recommended as a mode of escape, car mode is often prohibited in order to give way for emergency vehicles during the emergency action plan [DPI (Disaster Prevention Information) 2011, FEMA (Federal Emergency Management Agency, 2011)]. However, several practical problems in using walking as the main evacuation mode were enumerated; walking is not always the optimal mode as proven in the case of the Great East Japan Earthquake.

2.1.1.1. Cumulative Evacuation Ratio

Conca et al (2012) accepted the ASET (Available Safe Escape Time), and MLIT (2012) showed the evacuation ratio along the time. The combination of these two concepts and the each session is defined as shown Figure 2-1. Normal session means the usual conditions, but after the sudden earthquake, in shock session, evacuees stay for a while and they need the time to decide whether they should evacuate or not. Some people start the escaping and more evacuees follow this to avoid the dangers in ignition session. In the maximum rate of increase in evacuees, I can find the breakpoint A. After this point, cumulative number of evacuees increase dramatically and this phenomena changes after the breakpoint B. In the spurt session, evacuees should effort to reach

the shelters as possible as they can because they do not have enough time to reach the shelters. However if the first wave of tsunami inundate a land, success and fail for evacuation can be divided by the point TI (Time of Inundation) .

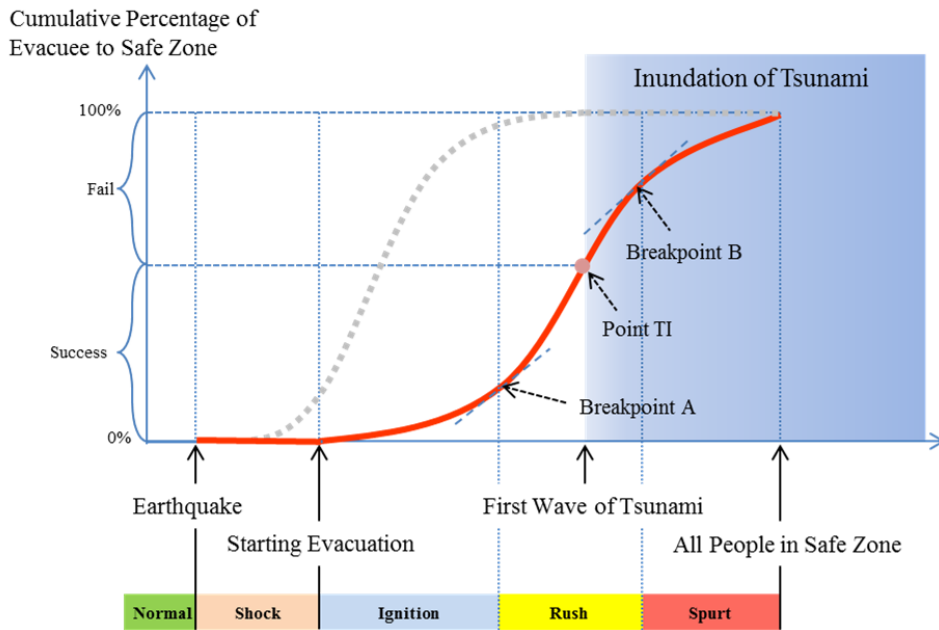


Figure 2-1 Cumulative Percentage of Successful Evacuation

In this case, the success ratio for evacuation can be increased by reducing shock and ignition sessions. Reducing shock means evacuees start the escaping faster than before and reducing ignition means breakpoint A occurs in early time. So stimulations to escaping in earlier time are the keys to save more people in given conditions.

2.1.1.2. Micro macro and nano scopic approaches

Actually the words macro, micro, and nanoscopic are based on unit of length. However I adopt this concept to simulation models and predict the basic model characteristics conceptually [PoszakTomas et al. 2007 Ni, 2010, Spek, 2006, Wong et al. 2011]. There are enough discussions for a long time to define the view of scopes, and Ni (2011) show simple criteria to define them. In his definition, the scopes can be divided by usages of three variables, x (longitudinal distance), y (latitudinal distance), t (unit time). In macroscopic scale, researches are connected with “concentrations of vehicles at location x and time t ” as an aggregation parameters of traffic flow in space, in mesoscopic scale, they interest in “distribution of a vehicle at location x and time t with speed v ”, while in the microscopic the longitudinal direction x and each lane derive the trajectories. If the longitudinal direction x and lateral y direction are considered simultaneously, he called picoscopic scale.

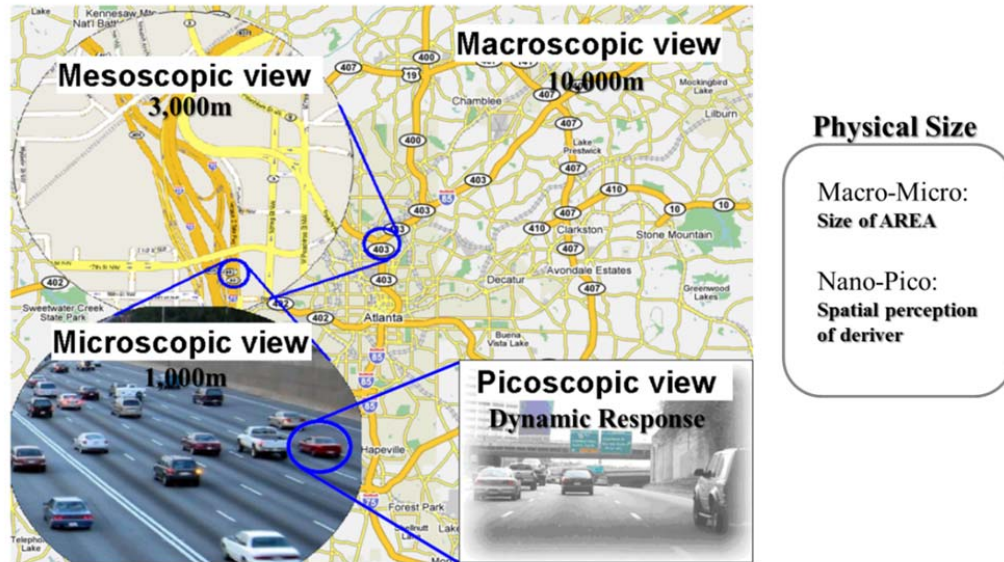


Figure 2-2 Physical Size of Multi-scope (Ni, 2011, reused figure)

However Morsink et al.(2008), Jaworski et al.(2012) and Ni(2010) showed the nanoscopic scale, and mentioned it is a man characteristics of nanomscopic scale that interacts among drivers and roads in the environment stimuli.

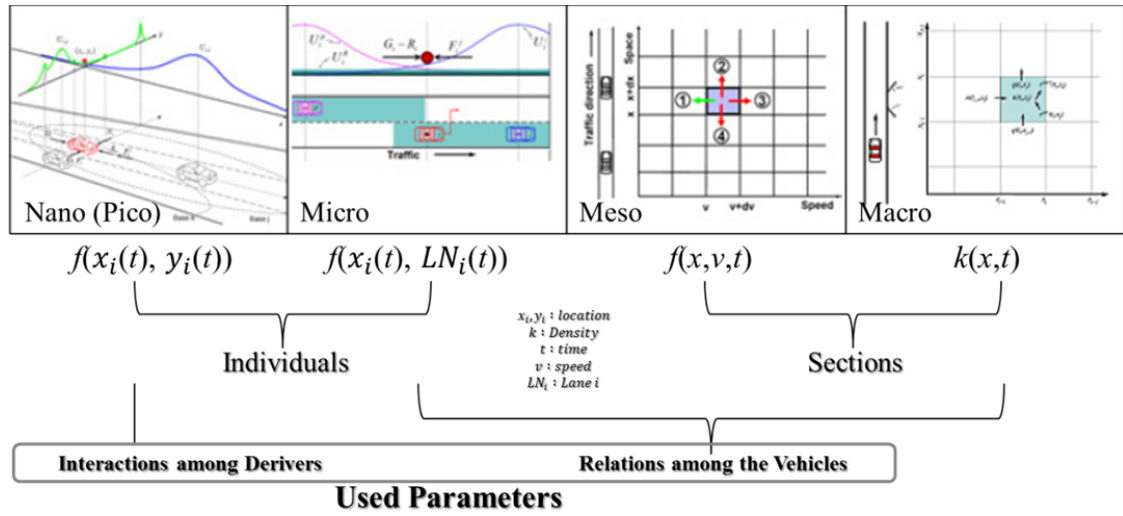


Figure 2-3 Considered Parameter of Multi-scope (Ni, 2011, reused figure)

2.1.2. Researches for Evacuation

Methods for numerical approaches such as agent-based and network-based models have been widely used. In the agent-based model, the evacuation movements are regarded as either crowd motion [Maury et al., 2011, Pan et al., 2007, Conca et al., 2012]. While particle motion [Helbing et al., 1995, Muramatsu et al., 1999] which could further been categorized into force model [Helbing et al., 1995, 2000, Oven et al., 2009, Hoogendoorn et al., 2003] or cell-based model [Muramatsu et al., 1999, Doheny et al., 1996, Klupfel, 2003]. Capacity [Zheng et al., 2010,

Madireddy et al., 2011] and queuing [Lovas, 1994] theories are also being applied in the network-based model.

Based on these approaches, researchers tried to calculate the evacuation time [Radwan et al., 1985, Lammel et al., 2008, Proulx, 1995], but evacuation behaviors under a serious disaster had shown different patterns of movement [Helbing et al., 2000, Sugimoto et al., 2003, Charnkol et al., 2006].

Furthermore, these evacuation behaviors might be very difficult to observe in a real situation due to some data constraints. As a result, fewer researches are using real evacuation data [Apatu et al., 2012, Galea et al., 2011, Yun et al., 2012] in finding the optimal or reasonable solution for evacuation.

Numerical approaches based on the empirical data or questionnaires derived the speed, capacity, and flow [Daamen, 2006, 2010, Blake, 2004, Peschl, 1971], but the Giovinazzi (2010) focused on the decision delay by the reliability to define the behavior.

Ball (2003) used the physical rule to show the relative behaviors among the person. While biological approaches, particle swarm [Reynolds, 1987, Kennedy, 1995, Bo, 2007, Kou, 2001] of ants and movement of mice [Saloma, 2003], were applied to explain the basic movement indirectly.

The researches about the panic movement, in psychological approach, were led by Quarantelli (2001) and Mawson (2005). Aguirre (1998) and Chertkoff (1999) mentioned panic behaviors of human in danger could lead more serious fatalities and damages than their normal behaviors. However Monh (2010) observed that fearness is can reduce the evacuation time as one of the emotional parameter.

Table 2-1 Research Topics

Simulation Approach	Agent-based model: Conca (2012), Wooldridge (2009), Hu (2012), Girod (2012), Aguirre (2011)	Group (Crowd) movement	Maury (2000), Pan (2007), Conca (2012), Wang (2012)	
		Particle movement	Force model	Helbing (1995), Helbing (2000), Oven (2009), Lakoba (2005) Hoogendoorn (2003), Helbing (2001), Helbing (2000), Ha (2012), Lo (2006), Pan (2006) Aguirre (2011), Bonabeau (2002), Antonini (2006), Sharma (2010)
			Lattice model, Cellular Automata	Muramatsu (1999), Doheny (1996), Kl"Nupfel (2003), Conca (2012), Minh (2010), Saloma (2003), Gwynne (2001), Oven(2009), Pelechano (2008), Tao (2009), Stella (2012), Helbing (2003)
	Network-based Model	capacity(travel function speed functions)	Zheng (2010), Madireddy (2011), Mark (2011), Wu (2010)	
		Queuing Model	Lovas (1994)	
		Two-stage	Yi (2007)	
	commercial simulator	Pelechano (2008)		
	Numerical Approach	Empirical or Questionnaire Approach	Speed	Daamen (2006), Blake (2004)
Capacity			Daamen (2010), Peschl (1971)	
Decision Delay by reliability			Giovinazzi (2010)	
Others	Physical	Ball (2003)		
	Biological	Particle Swarm	Reynolds (1987), Kennedy (1995), Bo(2007), Kou (2001)	
		mice	Saloma (2003)	
Panic Approach	psychological Approach	Quarantelli(2001), Mawson (2005), Quarantelli (1954), Drury (2007), Girod (2012), Drury (2007), Fahy (2009), Aguirre (1998), Minh (2010), Chertkoff (1999), Illera (2010)		

Huang et al (2012) interested in the humanitarian for post-prevention plan. In this research, it was combined with an efficacy (the extent to which the goals of quick and sufficient distribution), and equity (the extent to which all recipients receive comparable service). The aim of this research is to balancing plans. However Pu et al (2005) showed current evacuation system to support evacuation. This research is the focused on the information; automatic detection system, alarm system, emergency lighting and so on. It mainly discussed how to collect data real time and how to distribute them for the supporting evacuation. In the research of Madireddy (2011) reviewed an agent based model for evacuation traffic management and controlling.

2.2. EVACUATION GUIDANCE AND PLAN

In the current EAP as well as in the official guidance, individual car mode is prohibited and walking is usually the only accepted mode for evacuation. Some of the reasons stated include the possibility of serious congestion, uncertainty in the road condition, and the need for rapid movement of emergency vehicles [DPI (Disaster Prevention Information), FEMA (Federal Emergency Management Agency), NEMA (National Emergency Management Agency)]. The recommendation for keeping the roads open to emergency vehicles is expressed in a succinct phrase: “Do not drive.”

Table 2-2 Emergency Action Plan (EAP) for Individual Evacuee(Summary)

Prepare Manual for Earthquake	Prepare Manual for Tsunami
<p><u>During an Earthquake</u></p> <ul style="list-style-type: none"> - Take COVER by getting under a sturdy table or furniture. - HOLD ON cover until the shaking stops. - STAY INSIDE until the shaking stops - If it is safe, GO OUTSIDE. - FIRE ALARMS may TURN ON. [Conditioned Reflex] - DO NOT use the elevators. 	<p><u>After the Earthquake, Before the Tsunami</u></p> <ul style="list-style-type: none"> - IMMEDIATELY MOVE to your local tsunami shelter area - If there are no routes, move to HIGHER ground A MILE inland - If you are already in a safe location, STAY there - Move on FOOT when possible. - DO NOT DRIVE - Keep roads open and clear for emergency vehicles
<p>Ministry of Land, Infrastructure, Transport and Tourism in Japan (国土交通省) 2011</p> <p>Federal Emergency Management Agency U.S. Department of Homeland Security (FEMA) 2011</p> <p>National Emergency Management Agency in Korea (소방방재청) 2012</p>	

Basically, the walking mode is considered for main mode for evacuation. In the high populated area, metropolitan city, it could be acceptable plan because the traffic congestions are normally observed in daily life. However, in the rural area, the phenomena of traffic congestion have different aspect from the city area. This is the research about the guidance for evacuation, so it is needed to satisfy the different situation as a practical manual.

Chapter 3 BEHAVIORS OF EVACUEES

3.1. DATA SOURCE

Ever since the disaster of 2011, MLIT has worked to examine what happened between September to December 2011. One of these reports is the “Survey Report of Reconstructing Method for the Damaged Cities by the Tsunami Disaster (2012),” which contains data on people’s awareness about Tsunami and evacuation behaviors to utilize for various plans related to reconstruction, evacuation, positioning of shelters and driving evacuation strategies [MLIT, 2012]. The survey items include all trip-chains containing destination choice, mode choice, route choice, travel time, travel distance and reasons for each choice [Archive of Reconstruction Supporting Investigation (ARIS), 2012]. Disaster awareness and the acquisition of information were also announced in this report. A total of 10,601 people were probed and 20,429 trip-chains (total of 30,727 trips) were sampled from citizens who were in the hazard area during the disaster (details in Table 3-1).

Table 3-1 Total Number of Samples

Total Trip (30,727: 100%)						
Evacuation Trip (13,288: 43%)						No Evacuation (17,439: 57%)
Endangered Trip (11,968: 39%)			Safe Trip (1,320: 4%)			
Waking (5,820: 19%)	Bicycle (435: 1%)	Car (5,713: 19%)	Waking (506: 2%)	Bicycle (44: 0%)	Car (770: 3%)	

Table 3-2 shows the name of the city, the ID, and the Code. A total of 49 cities were collected by MLIT in 2011, and each city was categorized into three types (plain area, waterside area and isolation area)

Table 3-2 City Code and Types

ID	Code	Type	Name	ID	Code	Type	Name
102	22071	3	Misawa	315	42111	1	Iwanuma
104	22039	2	Hachinohe	316	43613	1	Watari
105	24465	3	Hashikami	317	43621	1	Yamamoto
201	35076	3	Hirono	320	41009	1	Sendai
202	32077	2	Kuji	401	75612	1	Shinchi
203	35033	3	Noda	402	72095	1	Souma
205	34843	3	Tanohata	403	72125	1	Minamisouma
206	34835	3	Iwaizumi	409	75418	1	Hirono
207	32026	3	Miyako	410	72044	1	Iwaki
208	34827	3	Yamada	501	82155	1	Kitaibaraki
209	34614	2	Otsuchi	502	82147	1	Takahagi
210	32115	2	Kamaishi	503	82023	1	Hitachi
211	32034	2	Ofunato	504	83411	1	Tokai
212	32107	2	Rikuzentakada	505	82210	1	Hitachinaka
301	42056	2	Kesennuma	506	82015	1	Mito
302	46060	2	Minamisanriku	507	83097	1	Oarai
303	42145	2	Higashimatsushima	508	82341	1	Hokota
304	45811	3	Onagawa	509	82228	1	Kashima
305	42021	2	Ishinomaki	510	82325	1	Kamisu
306	44016	1	Matsushima	601	122025	1	Tyoshi
307	44067	1	Rifu	602	122157	1	Asahi
308	42030	1	Shiogama	603	122351	1	Sosa
309	44041	1	Shichigahama	604	124109	1	Yokoshibahikari
310	42099	1	Tagajyo	610	124214	1	Ichinomiya
314	42072	1	Natori	Type: 1-Plain ,2-Waterside, 3-Isolation			

The samples were collected in the damaged areas, but the sources of the data may be unbalanced due to the varying population sizes in the Tohoku Area. Approximately 50% of the data was collected in Miyagi prefecture, whereas only few cases were considered in Ibaraki and Aomori prefecture, mainly because Miyagi prefecture was struck by the disaster at scale. In this research,

the aggregated data was rescaled by sample size and population density, and labeled as the expending value.

$$\text{Expending Value} = \frac{\text{Answers (EA.)}}{\text{Sample Size(EA.)}} \times \frac{\text{Population (person)}}{\text{Area (km}^2\text{)}}$$

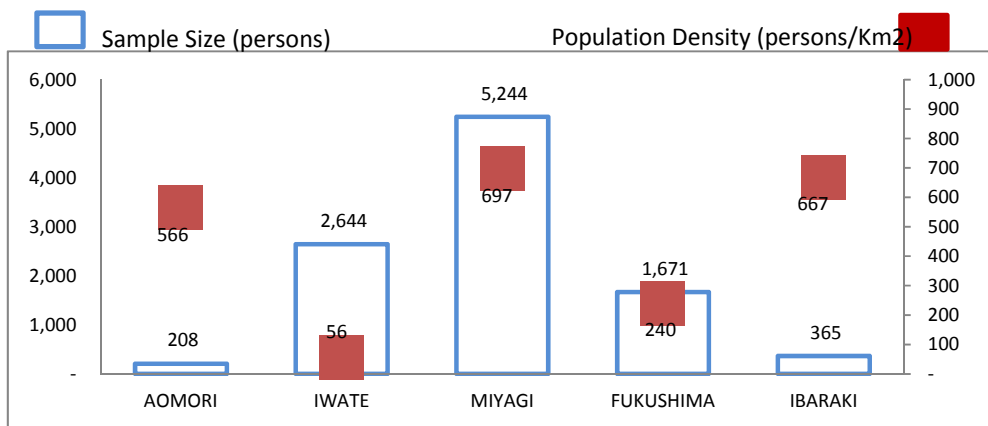


Figure 3-1 Sample Size and Population Density

3.1.1. Maps and Topography

In Section 1.2.2, geographical conditions were discussed and five categories of damaged areas were derived. The five areas were then organized based on two axes: level water friendliness and configuration of land with respect to mountains. Low water friendliness means that the residential area is very close to mountains or safe high areas and high water friendliness means that the inundation speed is very fast because of a river nearby or multidirectional tsunami inundation. The locked configuration is based on the number of roads connecting the hazard areas to the safe areas.

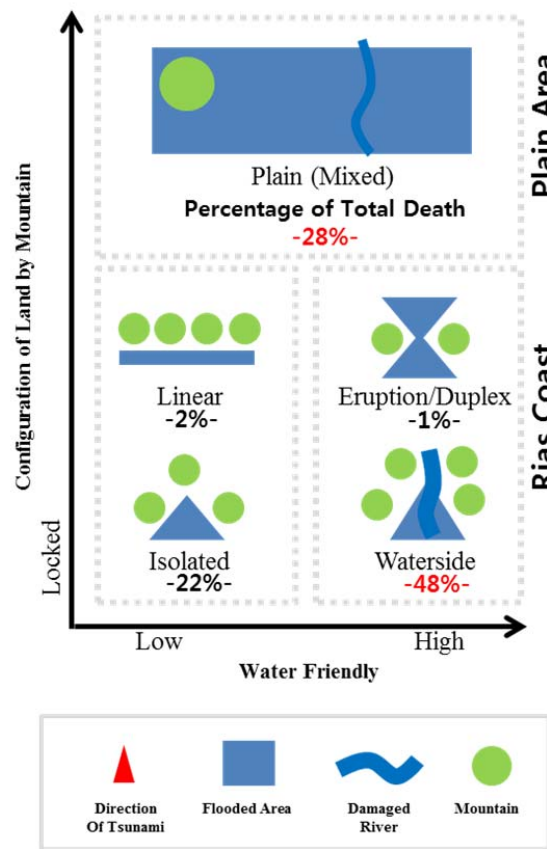


Figure 3-2 Three Divisions of Geographical Condition

The isolation areas that contain linear shapes and isolation shapes have few road connections to safe areas but are close to mountains (less than 500m) as in the case of Yamada (Figure 3-3). Waterside areas containing Eruption/duplex and waterside shapes have similar road connections with the isolation areas (e.g., Otsuchi) but the safe areas and mountains are far from the hazard areas (more than 500m). In the plain areas where the inundation area is wide, evacuees sometimes need to evacuate more than 5km.



Figure 3-3 Three Main Different Geographical Conditions

The criteria of 500m will be discussed in Section 4.2.1.5. The median speed of walking is 2.73km/h and the median evacuation time is 10 minutes. The average evacuation distance for 50% of the citizens is 464m. In this research, these three conditions are discussed to compare the different geographical situations. The details of each city are shown in appendix A.

3.1.2. Questionnaires and Answer Sheets

The number of people who immediately thought after the earthquake that a tsunami would come is shown in Figure 3-4. Approximately 70% of the people in the isolation areas recognized that a tsunami will come, but 63% of respondents in the plain area did not foresee a tsunami attack. These differences may be explained by the historical experiences and geographical situations of the cities, since the isolation areas are located at lower elevations and areas such as the Sanriku area and Rikuzentakata city have been damaged by tsunamis many times in their history.

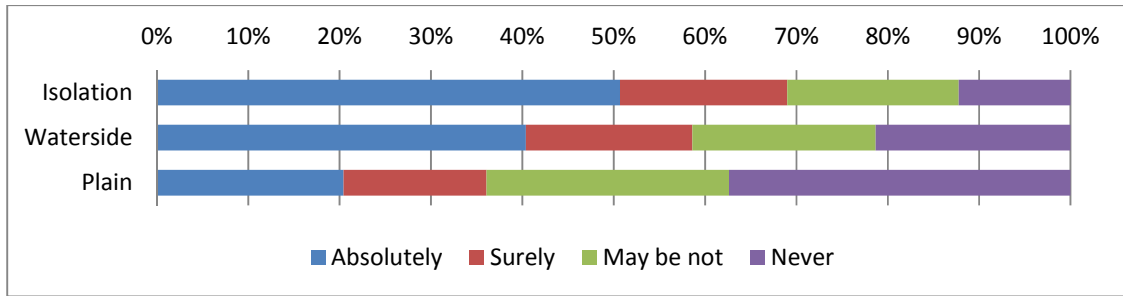


Figure 3-4 Did you think Tsunami will Come? (N=9,368)

Of the 3,758 respondents that immediately foresaw a tsunami, Figure 3-5 shows how these respondents came to think that a tsunami will be approaching. In the isolation and waterside areas, 78% of citizen knew from prior knowledge or experience, but 34% of citizens were not worried about the tsunami attacks until official warnings or warnings from neighbors. Official warnings were the sources of awareness in 13% of the respondents. In total, 66% of the respondents foresaw the tsunami dangers from their own knowledge or experience.

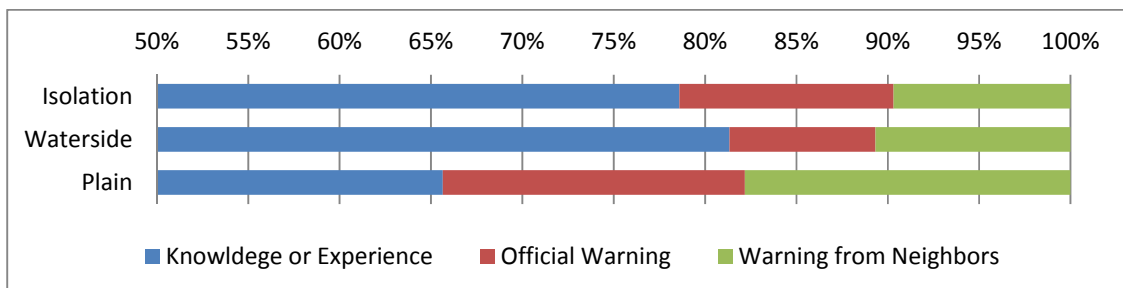


Figure 3-5 Why Did You Think Tsunami will Come? (N=3,758)

Of the 3,147 people who did not think that a tsunami would come, 92% of the respondents believed so based on their own knowledge or experience, as shown in Figure 3-6.

This suggests that in such hazardous situation, people's knowledge and experience play an important role, and therefore disaster education and preparation may be important in building awareness of evacuate.

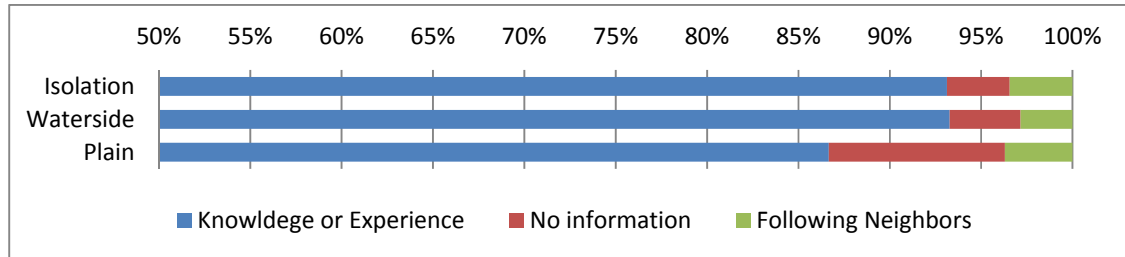


Figure 3-6 Why Did You Think Tsunami Will NOT Come? (N=3,147)

Figure 3-7 shows the initial actions (multiple responses permitted) that respondents took immediately after the earthquake. The results show that people tried to contact family and neighbors rather than to immediately prepare for escaping. Only 20% of citizens in the hazardous areas thought that they need to escape from the tsunami disaster, but more than 20% of the respondents attempted to get information from sources of media and neighbors. 13% of the respondents did not think about evacuating and began cleaning their houses.

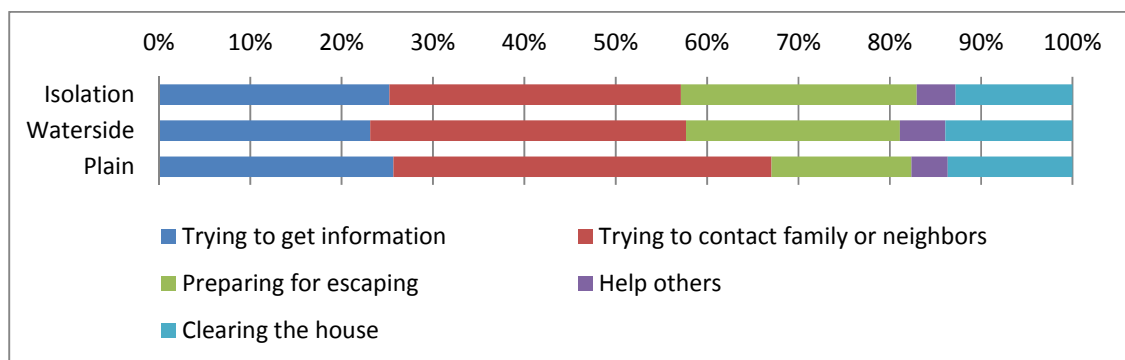


Figure 3-7 What Did You Do After Shaking? (N=16,713)

Broadcasting, loud-speaker-vehicles, loud-speaker-alarms, and individual messages by visiting are used by local governments to warn residents and manage disaster risks. However, 50% of the respondents claim that they either did not receive an official warning or have forgotten whether they had or not. Because tsunami attacks happen shortly after earthquakes, it is very hard to receive additional warning messages of the tsunami risks.

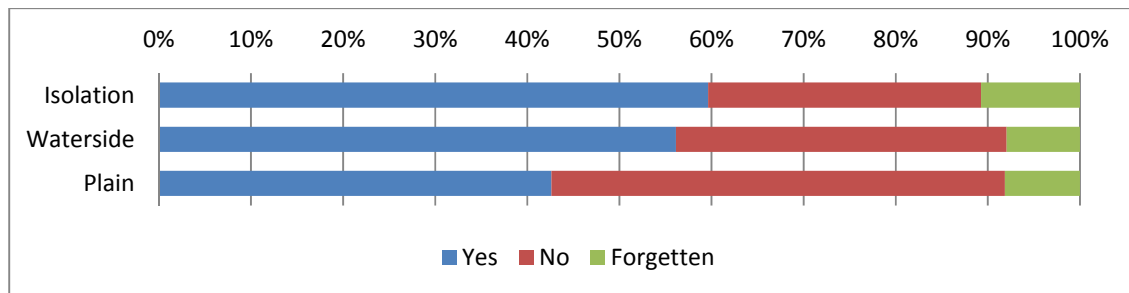


Figure 3-8 Did You Hear the Warnings (N=9,353)

Most of the citizens obtain disaster information from the media, including TV, Radio and messengers. The second source is family and neighbors. Therefore, it might be important to keep media functional without electric power or special networks because the earthquakes can destroy power plants and life lines.

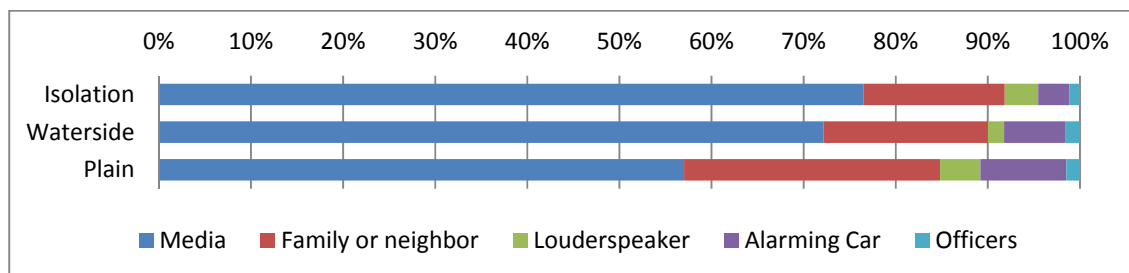


Figure 3-9 How Did You Get the Information? (N=6,153)

Evacuees answered that the most helpful information was media, but 18% of the respondents think that any additional information could have provided extra help in their evacuations. In the isolation and waterside areas, the importance of loudspeakers was greater than in the plain areas because these areas are located in small areas surrounded by the mountains.

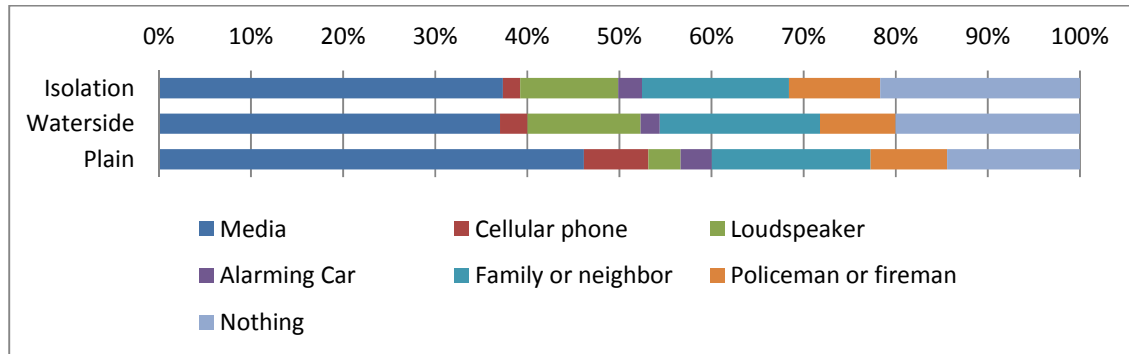


Figure 3-10 What Sources Were Useful for Your Evacuation? (N= 13,408)

Approximately 20% of citizen did not follow the escaping order from officers, and 8% thought that they did not need to evacuate from their location, as shown in Figure 3-11. On the other hand, 65% of the respondents said that they would absolutely follow officers' orders, and 10% surely. These result shows that people will follow official recommendations.

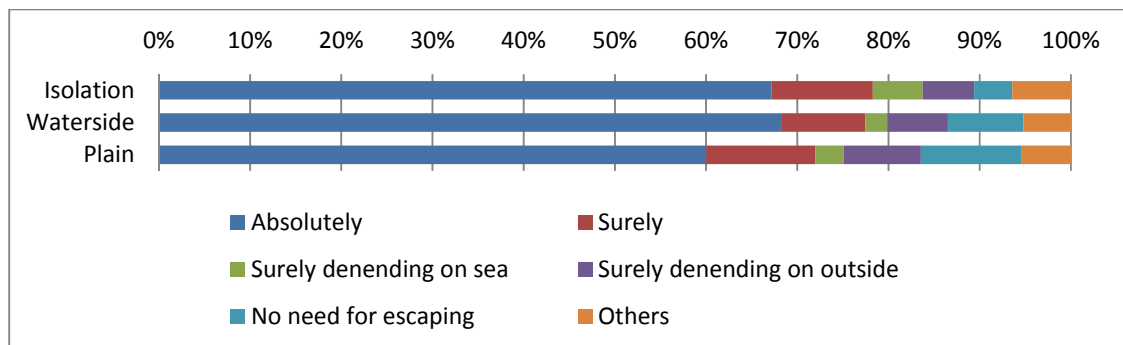


Figure 3-11 When You Get The Escaping Order from Officer, Do You Try to Escape Evacuate? (N=3,392)

Figure 3-12 shows the 272 respondents who did not start evacuating even though there were evacuation orders from officers and they knew the risks of the tsunami. Approximately 40% of the evacuees stayed in order to fulfill their responsibilities, such as at command centers to announce disaster information or to support evacuation. The second most frequent answer as illness of the body, and the third most frequent answer was to wait for children.

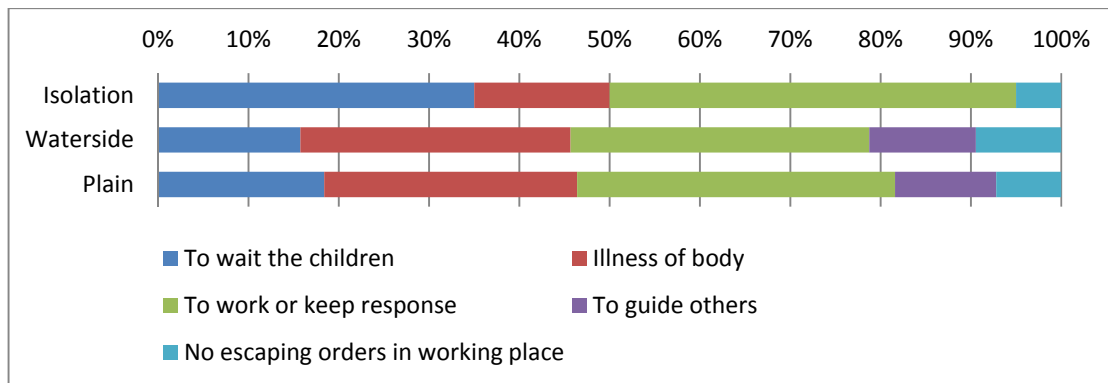


Figure 3-12 Why You Could Not Evacuate from Tsunami? (N=272)

Figure 3-13 shows the reasons why evacuees who chose car mode decided to do so. More than 30% of the respondents used car mode to evacuate with their family. The second most frequent answer was that they thought there would not be enough time to access shelters by foot. The answers are related to the previous questions about not escaping from the tsunami. The evacuees wanted to evacuate with their family, and as a result some did not evacuate immediately, and others chose car mode for evacuation.

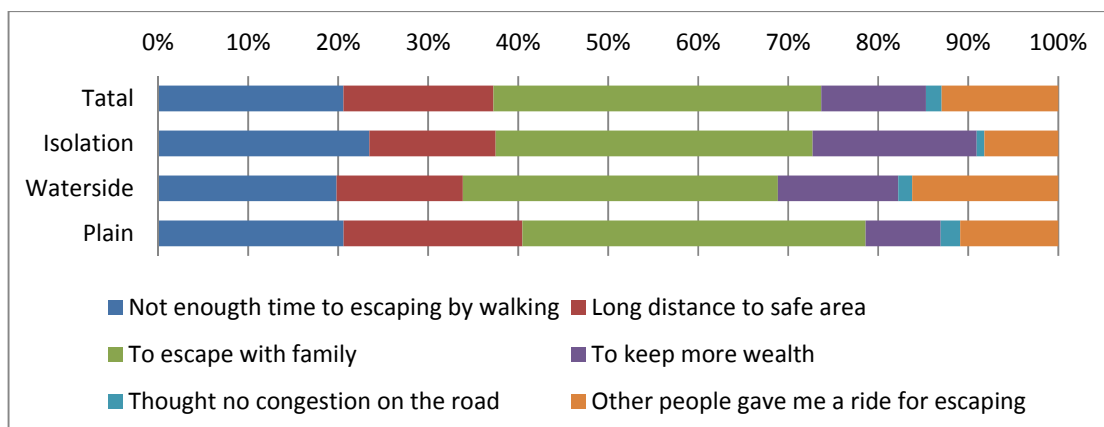


Figure 3-13 Why Did You Choose the Car Mode for Evacuation? (N=4,254)

Approximately 75% of the respondents knew at the time of the earthquake where the nearest shelter was from their position (Figure 3-14). However, only 50% of the evacuees were able to reach the closest shelter (Figure 3-15). Of the respondents that were not able to reach the closest shelter, 1,759 answers were selected. Their reasons were similar to the reasons why they choose the car mode (e.g., they wanted to evacuate with family or neighbors 20% of total) (Figure 3-16).

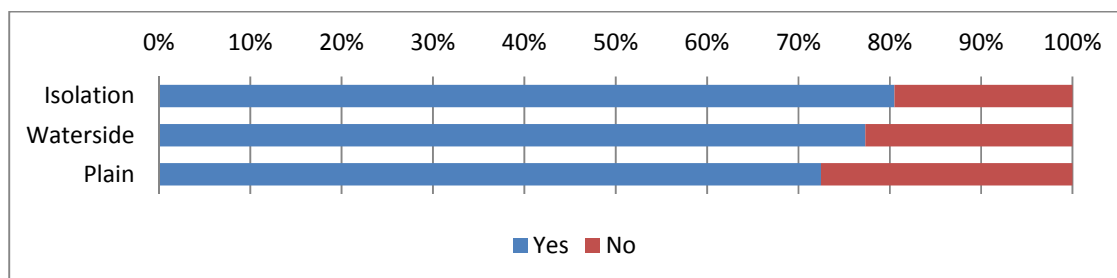


Figure 3-14 Did You Know Where Is the Nearest Shelter? (N=9,344)

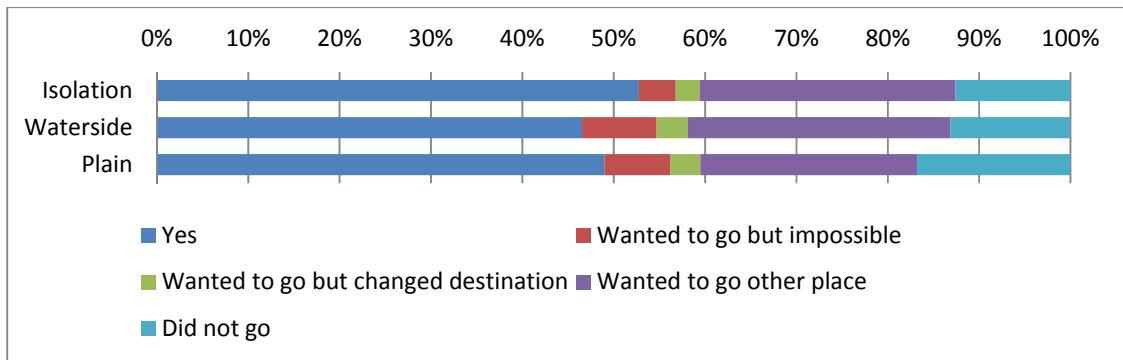


Figure 3-15 Did You Go to the Closest Shelter? (N=7,052)

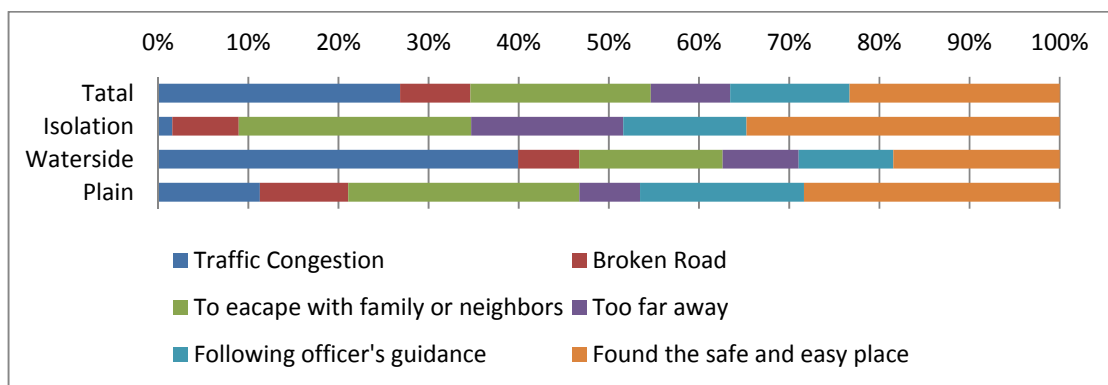


Figure 3-16 Why You Did Not Go to the Nearest Shelter? (N=1,759)

It can be seen from these results that wanting to be with and evacuate with family was a major driver for people's actions immediately after the earthquake.

3.1.3. Statistics on Victims

The victims in the damaged area at the municipal level are shown in Table 3-3. The city with the highest ratio of dead and missing people per population was Onagawa, followed by Otsuchi.

Table 3-3 The Current Extent of Damage (DPI, JMA, GIA, NPA, collected on July 25th 2011)

Name of City	Population Density(Per./km2)	Ratio (Death+Missing)/Population (%)
Onagawa	152	8.53
Otsuchi	76	8.22
Rikuzentakata	100	7.48
Minamisanriku	106	4.79
Yamada	71	3.98
Yamamoto	261	3.57
Higashimatsushima	421	2.52
Kamaishi	90	2.40
Ishinomaki	289	2.26
Kesennuma	221	1.71
Natori	731	1.26
Shinchi	179	1.19
Soma	191	1.15
Ofunato	126	1.05
Tanohata	25	1.01
Miyako	47	0.89
Watari	477	0.81
Minamisoma	178	0.76
Noda	57	0.58
Iwanuma	724	0.34
Iwaki	278	0.10
Matsushima	279	0.09
Iwaizumi	11	0.08
Hirono	93	0.04
Rifu	755	0.03
Kuji	59	0.02

3.1.4. The Collected and Used Data

3.1.4.1. Concepts

According to statistics by MLIT, 344,477 people evacuated to shelters, and 18,926 people either died, of which 92.5% died by drowning. This research took 10,601 evacuees as the sample, and it was assumed that their general behaviors resemble that of the 18,926 victims (Figure 3-17).

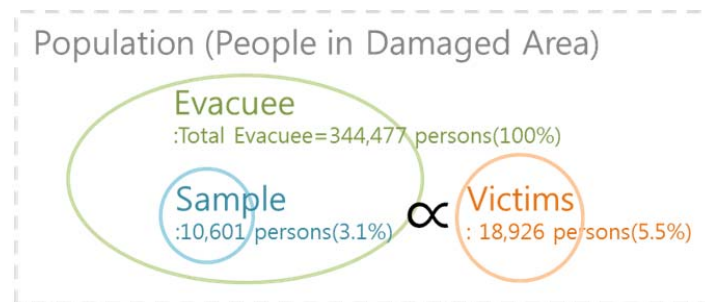


Figure 3-17 Assumption of Evacuation Behavior

Of the 10,601 samples, 2,167 evacuees who were nearly washed away by the tsunami were selected as a sample of people whose behaviors are almost identical to those who could not survive the tsunami

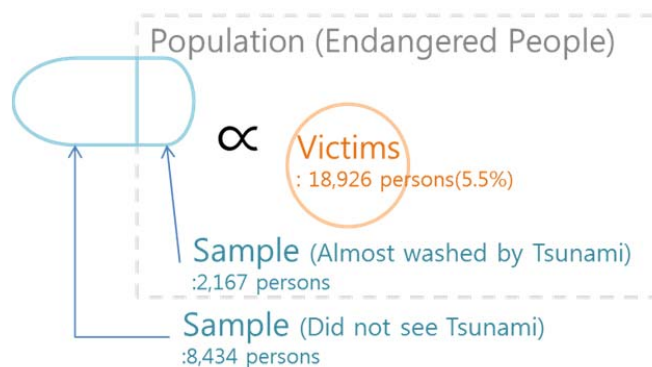


Figure 3-18 Assumption of Victims Behavior

3.1.4.2. Characteristics of Samples

The main large city among damaged areas in Tohoku is Sendai city, which has a large population, high population density and is located in the plain area. The average population density in the plain area is approximately 630 people per square kilometer, which is considerably higher than in the isolation and waterside areas. .

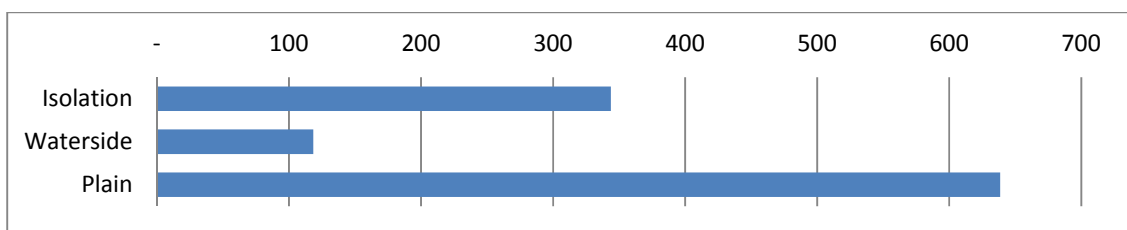


Figure 3-19 Population Density in Damaged Area (N=10,601)

The percentage of residents who are older than 65 was approximately 20%. The population density is lower in waterside areas, which are usually composed of small fishery ports and residential areas. These areas are often surrounded by mountains, but the distance to higher grounds is farther than 1.5km on average.

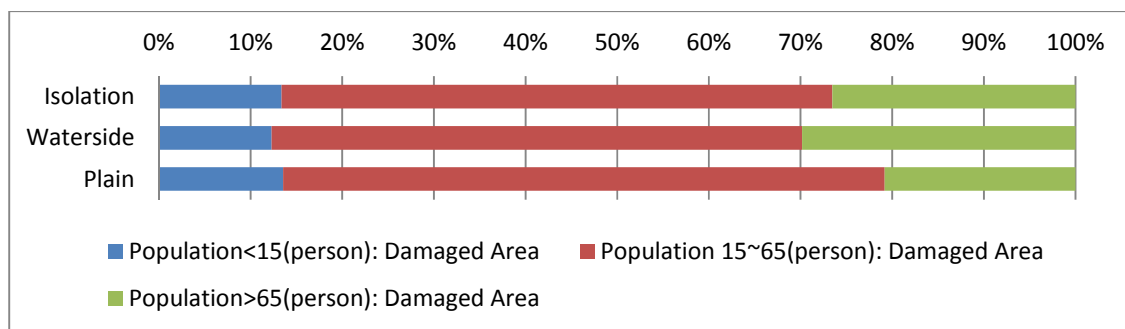


Figure 3-20 Portion of Age in Damaged Area (N=10,601)

3.2. DATA DESCRIPTION

3.2.1. Descriptive Analysis

The results of the survey conducted by [ARSI, 2011, MLIT, 2011] show that the average mode share ratio for cars was 65%, and 68% of evacuees in their 30s used cars mode for evacuation. Approximately 51% of car users did not experience any problems when evacuating by driving. The main reasons for delays in escaping among car users (29%) were broken signals (12.5%) and traffic jams (11.7%). The main reasons for using car mode were to evacuate with family (57.6% in Rias areas¹, 56.8% in Plain areas², multi-reply) and the distance of refuge to safe areas (50.4% Rias in areas, 54.8% Plain in areas). Given the geographical conditions and the distance to safe areas, many evacuees used cars because they thought that they would not be able to reach safety by foot and also feared being alone [ARSI, 2011].

¹ Rias areas have complicated geography are surrounded by mountain, and sometimes have rivers and deltas.

² Plain areas are often far from areas of high altitude

3.2.2. Population and Total Evacuees

More than 95% of the victims were older than 15 and 55% of them were older than 65. This shows that the elderly experienced serious problems in evacuating from the Tsunami. It must also be noted that the death toll in the isolation areas where higher grounds (i.e., safe areas) are relatively close by (1.5km on average) was higher than others. In other words, the difficulties of evacuating are related not only to the evacuation distance but also to other factors [ARSI, 2011].

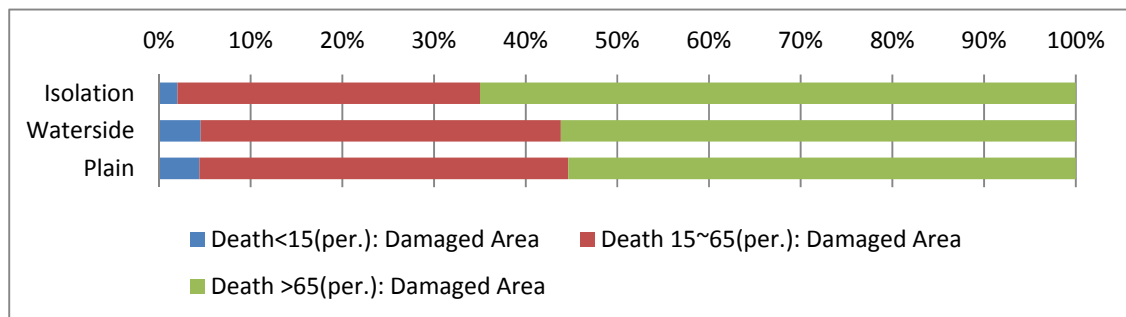


Figure 3-21 Portion of Death on Age in Damaged Area

3.2.3. Evacuation Starting Time

It was found that the bicycle mode was the fastest mode of evacuation. Car mode, as shown in Table 3-4, was faster than walking. These differences are related to the preparation time needed for the chosen mode. The median Evacuation Starting Time (EST) of walking mode was 28min, while the tsunami reached shore in approximately 30min. [ARSI, 2011, DBDG, 2012]. Thus, about half of the evacuees who chose walking mode were at risk. The mode ratio for cars was 94% in Yamamoto city. Shelters are far from the residential areas and safe areas were scarce in the vicinity because of the city is in the plain area [ARSI, 2011, JMA, 2011, GIA, 2011].

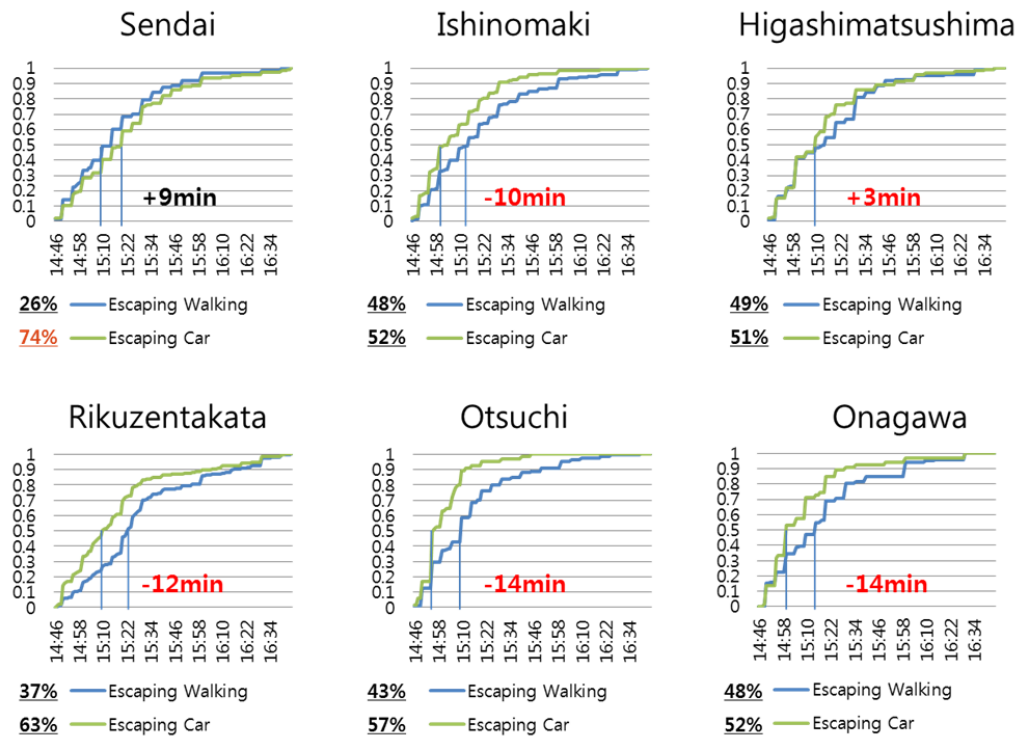


Figure 3-22 Cumulative Relative Frequency of Evacuation Starting Time

The EST for cars was faster than walking, despite the fact that car mode requires additional time such as for warming up. The EST results include not only the time needed for deciding on the choice of mode but also for deciding whether or not to evacuate. In fact, 35% of respondents initially did not think that the tsunami would reach their residential area [ARSI, 2011].

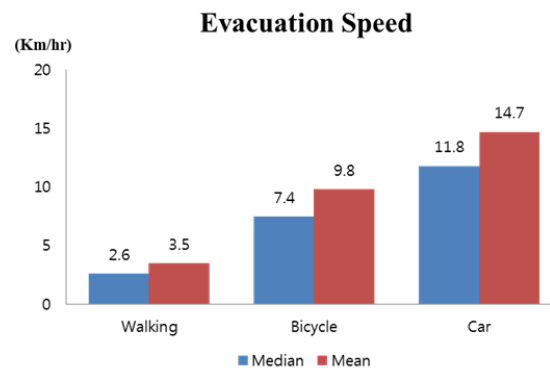
The average population density of the Tohoku area is not very high, at an average of $544p/km^2$ [SBDG, 2012]. Therefore, car mode is generally preferred if available. In the EST model, an initial value of 5min was assumed for walking, 10min. for bicycle and 15min. for car.

Table 3-4 Evacuation Starting Time for Each Mode (N=11,968)

Mode	25%	50%	75%	95%	Samples ³
Walking	13 min.	28 min.	47 min.	98 min.	6,326 Trips
Bicycle	5 min.	13 min.	36 min.	84 min.	479 Trips
Car	8 min.	18 min.	39 min.	85 min.	6,483 Trips

3.2.4. Evacuation Speed

Car speed was five times faster than walking mode, as shown in the average Evacuation Speed (ES) in Figure 3-23. However, the cars' average actual speed of 14.7km/h was slower than the design speed of 60km/h under normal conditions. This shows that serious congestions and damaged roads affected the evacuation.



Median < Mean

Figure 3-23 Average of Evacuation Speed (N=11,968)

³Original data was collected by [MLIT, 2012] and reported in [ARSI, 2011]. In this paper, 29 cities were selected and the average values of each mode were calculated from the 13,288 evacuations that were recorded in Tohoku, Japan: Yamamoto, Rikuzentakata, Rifu, Tanohata, Iwa-imi, Hirono, Minamisanriku, Shinchi, Kesennuma, Iwanuma, Yamada, Watari, Otuchi, Kuji, Higashimatsushima, Minamisoma, Tagajo, Soma, Onagawa, Iwaki, Ishinomaki, Sendai, Shio-gama, Natori, Miyako, Ofunato, Matsushima, Noda, Kamaishi.

The average speeds for walking and bicycle were 2.6km/h and 9.8km/h in the model used. The variation in speed may have been caused by geographical conditions rather than the population density [LEE et al. 2009]. Therefore, the maximum and minimum speeds were assumed to have the same value as the average. It was assumed that bicycles followed the same logic. However, different speeds were used for car mode among the various population densities because while geographical conditions do not affect the speed of cars, delays or jamming may be caused based on the population density [LEE et al. 2009].

Table 3-5 Evacuation Speed for Each Mode (N=11,968)

	Walking	Bicycle	Car
Ave.	2.6km/h	9.8 km/h	14.7 km/h
Var./Ave.	3.6	7.6	8.7
Sample	6,326Trips	479Trips	6,483Trips
Max. (Assumption)	2.6km/h	9.8 km/h	50km/h ⁴
Min. (Assumption)	2.6km/h	9.8 km/h	2.6km/h ⁵

Therefore, a speed-density curve as shown in equation (3.1) was derived. The population density is P_i (Population density i , p/km^2) and the speed of the car is $v_{P_i,C}$ (Car speed, when P_i , v_{P_i} , km/h). The curve is defined by three points: minimum speed – population ($1000p/km^2$), average speed – population ($544p/km^2$)⁶, and maximum speed –population ($1 p/km^2$).

$$v_{P_i,C} = \alpha e^{-\beta P_i} \quad (3.1)$$

⁴95% of cars had a speed of less than 50km/h [ARSI, 2011].

⁵It was assumed that the minimum car speed was faster than the average walking speed.

⁶ Average population density collected from city level data was $544p/km^2$

3.2.5. Evacuation Speed and Road Ratio

Evacuation speed is affected by the road infrastructure and demand (e.g., road width, connection and traffic volume). The capacity of roads is one of the important components in calculating the speed of each mode in each session. In this research, only the road ratio (Area is divided by Road Length, τ) was used, which can be applied with ease so that the input can be kept simple in order to compare wide effective areas simultaneously.

Speed variation among the cities is shown in Figure 3-24. When the road ratio is higher, the velocity is also faster. These relationships are combined and the equation (3.2) is applied in this model. The calculated parameters are in the equation. (3.3) ($R^2=0.67$, $N=34$).

$$v_{P_i,C} = \alpha e^{-\beta P_i} + \delta \tau \quad (3.2)$$

$$v_{P_i,C} = 118e^{-0.004P_i} - 1.43\tau \quad (3.3)$$

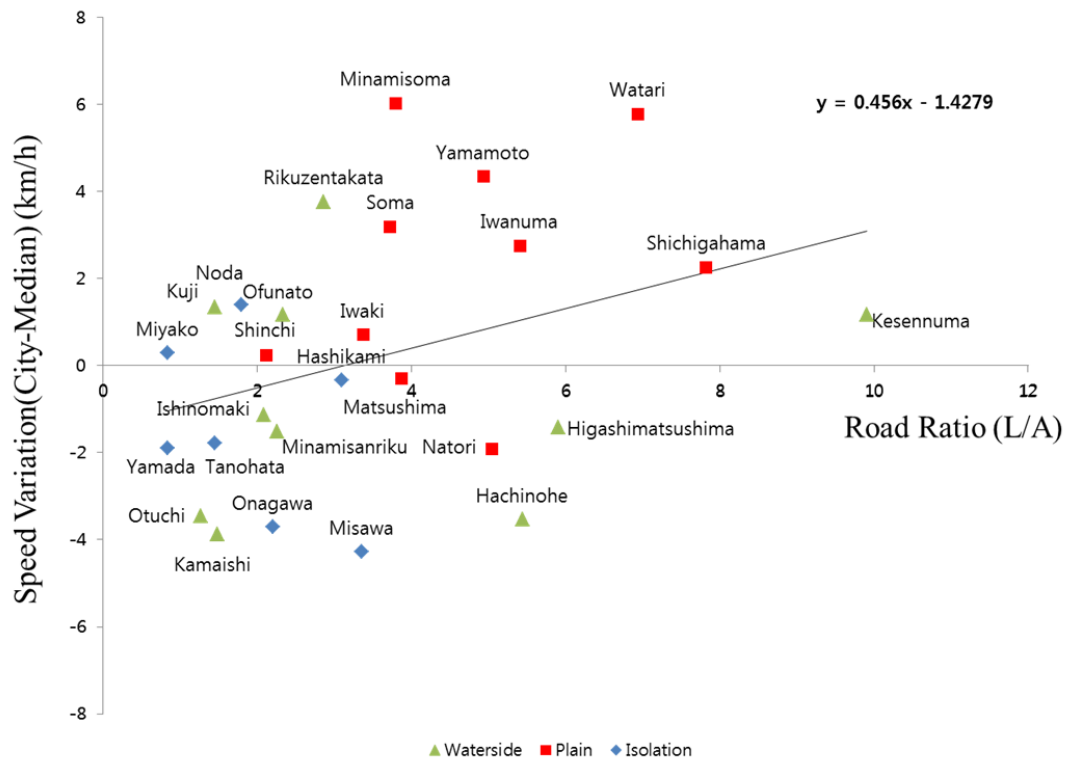


Figure 3-24 Speed Variation among the City (N=11,968)

3.2.6. Evacuation Distance

The distribution of Evacuation Distance (ED) for each mode is shown in Table 3-6. More than 50% of evacuees who used car mode travelled more than 1,600m to find safe areas, while 95% of evacuees who used walking mode found safe areas within 1,500m. 50% of evacuees who chose walking mode moved less than 300m, while only 5% of the evacuees within the 250m distance moved by car [ARSI, 2011]. Based on these results, the maximum evacuation distance for walking mode was derived at 1,500m.

Table 3-6 Evacuation Distance for Each Mode (N=13,288)

Cumulative Relative Frequency	Walking	Bicycle	Car
95%	1500m	5300m	7600m
75%	600m	1700m	3300m
50%	300m	900m	1600m
25%	200m	500m	800m
5%	100m	100m	300m
Trips	6,326Trips	479Trips	6,483Trips

The evacuation distance can be categorized into three types according to the age group. The moving distance of people in their 20s and 30s is longer than those in their 40s to 60s. Those who are older than 70 have the shortest distance. The evacuation distance in the plain areas is longer than in other areas because by definition there are few mountains and obstacles. Additionally, because safe shelters and higher grounds are not nearby, longer evacuation distance is natural.

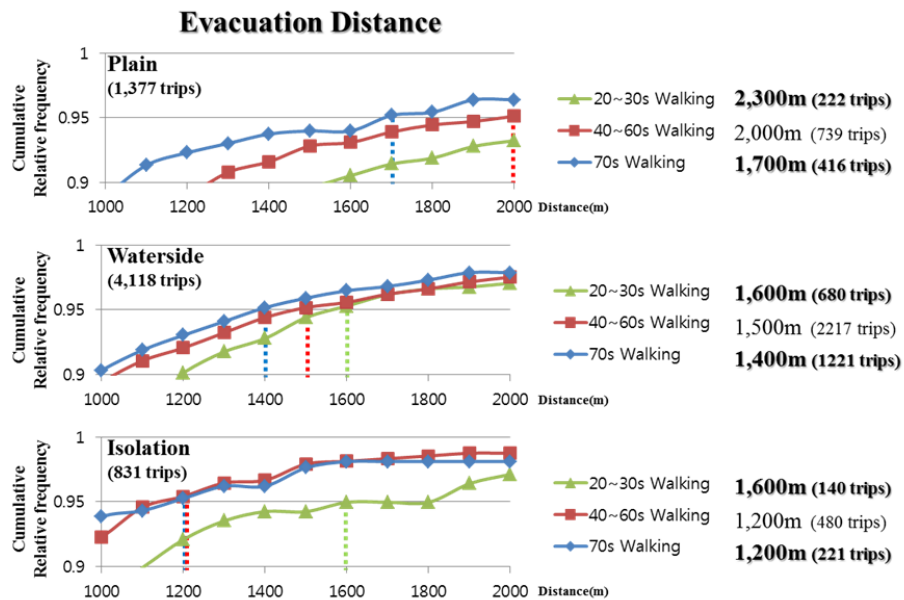


Figure 3-25 Evacuation Distance of Walking, Age Boundary (N=6,336)

In the isolation area, the walking distance is shorter than others (relative frequency is 0.95 for 1200m). These areas are surrounded by mountains and the residential areas are small, and therefore people can reach safe higher grounds within 1000m.

3.2.7. Evacuation Distance and Distribution

In order to interpret the details of ED, the cumulative relative frequency of each mode is sorted on the moving distance line. The three lines in Figure 3-26 are walking, bicycle, and car. Log lines are applied in order to define the CED-CDF (Cumulative Evacuation Distance - Cumulative Distribution Function) and the results were estimated for 11,968 samples. In the case of car, 5% of evacuees moved more than 7800m, while 95% of bicycle evacuees moved within 4900m. Here, the Maximum Evacuation Distance of walking (MEDw) is set to 1500m, Maximum Evacuation Distance of bicycle (MEDb) to 4900m, and Maximum Evacuation Distance of car (MEDc) to 7800m.

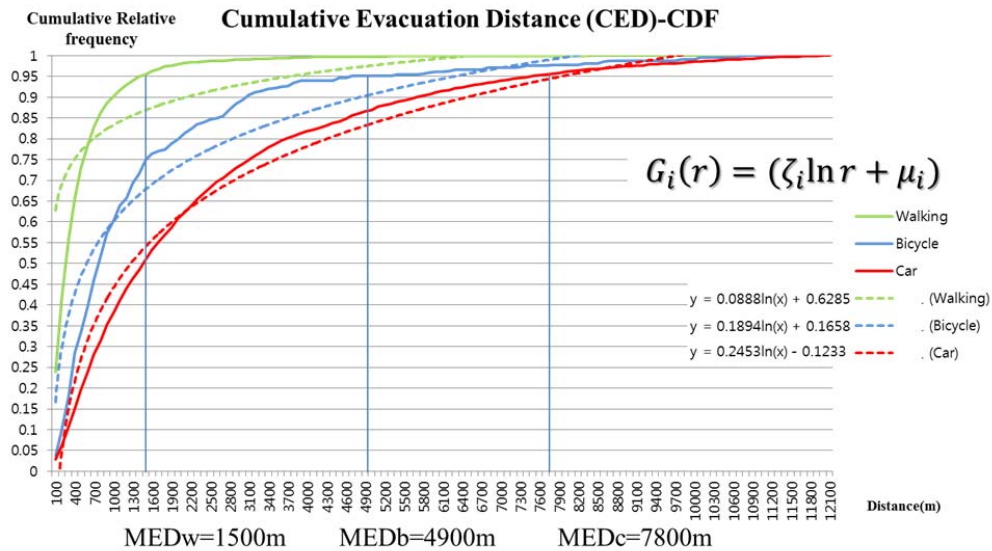


Figure 3-26 Cumulative Relative Frequency of Evacuation Distance (N=11,968)

Chapter 4 **METHODOLOGY OF EASY-LEE CHART**

4.1. DERIVING THE EASY CHART

4.1.1. Effective Parameters

In this research, special focus was given to the macroscopic effects that traffic congestions may have on evacuation. The first parameter is population density (p/km^2), combined with the population and area of each region. The population includes various aspects such as the complexity of community groups in high density areas or the fact that areas with lower population density have smaller financial support from the government. These implicit characteristics may lead to various disadvantages (e.g. insufficient infrastructure, lack of alternative roads). Although the population density cannot explain everything, it is a useful parameter to explain various characteristics of a given society.

The second parameter is the distance to shelters (i.e., average distance to official refuge). Evacuation speed, time, and distance can be considered intuitively, but the speed and time may vary and are also difficult to measure. The average distance to shelters was used to calculate the number of refugees divided by the area.

4.1.2. Notations of Parameters

P_i : Population density i ,

t_0 : Tsunami warning Time

t_w : Evacuation starting time for walking mode

t_b : Evacuation starting time for bicycle mode

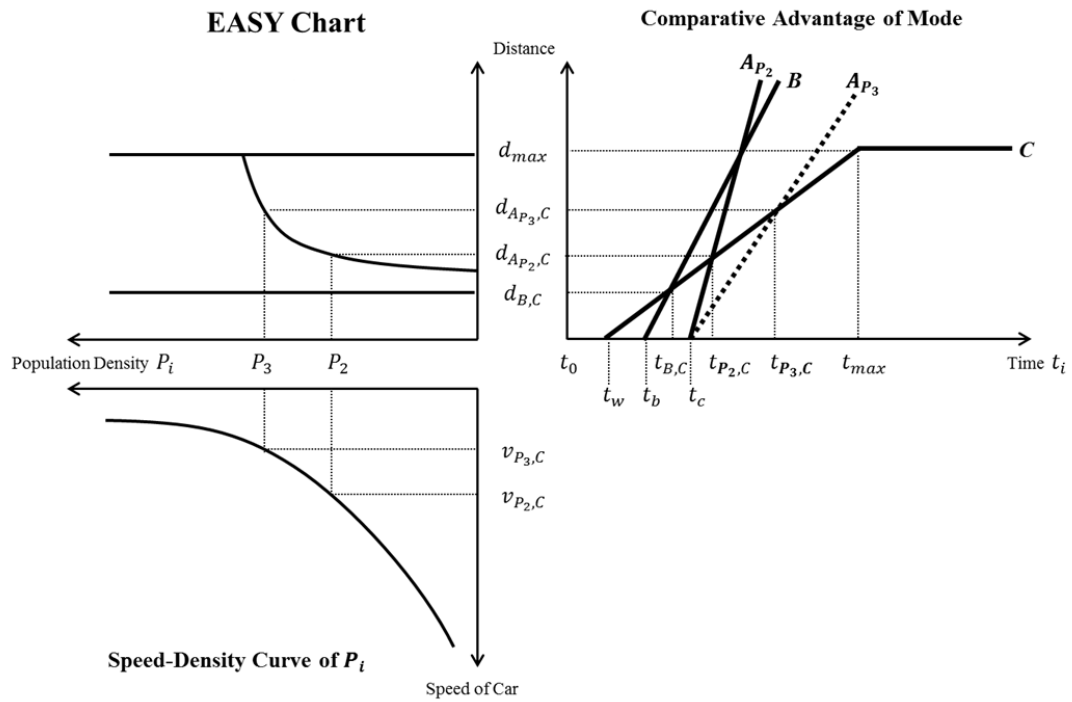


Figure 4-1 Population, Evacuation Distance, and Speed of Mode in EASY Chart

t_c : Evacuation starting time for car mode

$t_{B,C}$: Crossing of time line B and C

$t_{P_i,C}$: Crossing of time line A_{P_i} and C

t_{max} : Maximum duration for walking mode before tsunami inundation

$v_{P_i,C}$: Car speed, when P_i

v_{P_i} : Walking speed

v_b : Bicycle speed

d_{max} : Maximum distance for walking mode

A_{P_i} : Time space line for Car mode, when v_{P_i}

B : Time space line for bicycle mode

C : Time space line for walking mode

$d_{B,C}$: Crossing distance between line B and C

$d_{A_{P_i},C}$: Crossing distance between line A_{P_i} and C

4.1.3. The Best Distance and Maximum Distance to Evacuate Using Walking Mode in CAM (Comparative Advantage Modes)

The evacuee can reach a shelter with ease if it is located close to the original location, but it would be impossible if the shelter is too far away. In this chapter, time-space diagrams are derived to define the Comparative Advantage Modes (CAM), along with the best distance and maximum distance for walking mode. Line C (equation (4.1)) is the walking distance under the conditional time. Line B (equation (4.2)) is for bicycle mode in Fig. 1. In EST (Section 3.2.3), t_w is calculated at 5 min., t_b at 10min, t_c at 15min.

$$C(t_i) = \begin{cases} 0, & t_i \leq t_w \\ v_w(t_i - t_w), & t_{max} \geq t_i > t_w, \\ d_{max}, & t_{max} < t_i \end{cases} \quad for\ 0 < i < \infty \quad (4.1)$$

$$B(t_i) = \begin{cases} 0, & t_i \leq t_b \\ v_b(t_i - t_b), & t_i > t_b \end{cases} \quad for\ 0 < i < \infty \quad (4.2)$$

When the distance to the shelter is $d_{B,C}$ (equation (4.3)), CAM shifts from C to B at time, $t_{b,c}$. If the distance to the shelter is shorter than $d_{B,C}$, evacuees can reach this distance by walking mode at $t_{B,C}$ because 50% of evacuees using walking mode were able to begin evacuating at time t_w . While bicycle mode is faster than walking mode, evacuees using bicycle mode were only able to begin evacuating at time t_B .

$$d_{B,C} = C(t_{B,C}) = B(t_{B,C}), \quad \text{for } t_B < t_{B,C} < t_{max} \quad (4.3)$$

The maximum EDS d_{max} for walking (Section 3.2.4) was derived based on the walking distance for the small group of evacuees (5% of all evacuees) who walked more than 1,500m. However, $t_{B,C}$ is out of boundary from t_B to t_{max} , and $d_{B,C}$ cannot be derived because $t_{B,C}$ is not defined. In this case, equation (4.4) can be used instead of equation (4.3).

$$d_{max} = \begin{cases} 0, & t_{B,C} \leq t_w \\ v_w(t_{B,C} - t_w), & t_{B,C} > t_w \end{cases} \quad (4.4)$$

Equations (4.3, 4.4) include the maximum evacuation time (MET), or how much time evacuees can use for evacuation.

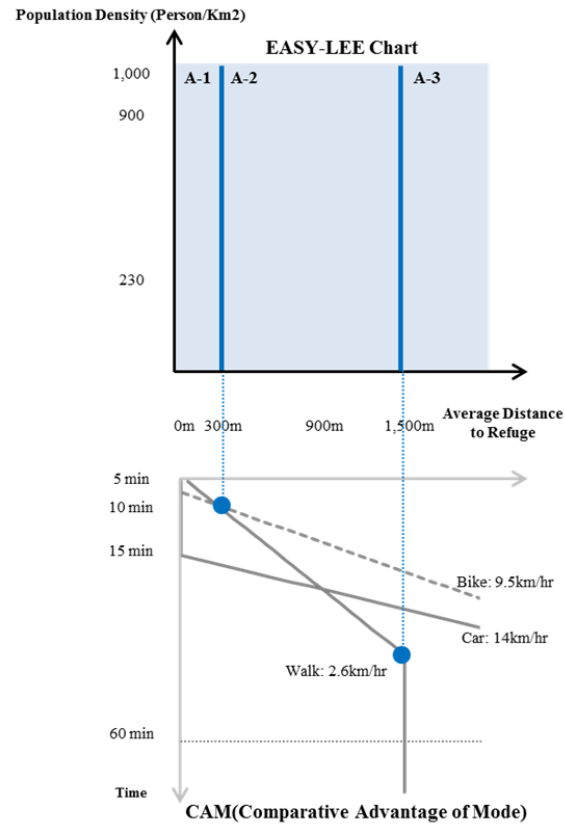


Figure 4-2 Comparative Advantage of Mode and EASY-LEE Chart

As shown in Figure 4-2, the EASY-LEE chart is divided into three parts: A-1, A-2, and A-3. A-1 has an advantage over walking because the preparation time is shorter. However, the people in A-3 cannot reach distances of more than d_{max} (MEDw). In these cases, car mode has the comparative advantage due to longer evacuation distances.

4.1.4. Evacuation Speed Variation along the Population

Line A_{P_i} , equation (4.5), is the moving distance for car mode when the population density is P_i , and the speed is $v_{P_i,C}$, for $t_i > t_c$. The speed of the car, $v_{P_i,C}$, is calculated by equation (3.3); $v_{P_i,C}$ has various values for different P_i . The speed decreases when P_i increases in equation (3.3).

$$A_{P_i}(t_i) = \begin{cases} 0, & t_i \leq t_c \\ v_{P_i,C}(t_i - t_c), & t_i > t_c \end{cases} \quad \text{for } 0 < i < \infty \quad (4.5)$$

When the distance to the shelter is $d_{A_{P_i},C}$, equation (4.6), CAM shifts from C to A_{P_i} at population density, P_i . When the distance to the shelter is more than $d_{A_{P_i},C}$, car mode is faster than walking mode at population density P_i .

$$d_{A_{P_i},C} = C(t_{P_i,C}) = A_{P_i}(t_{P_i,C}), \quad \text{for } t_c < t_{P_i,C} < t_{max} \quad (4.6)$$

The CAM between A_{P_i} and B is not the only crossing point. For each population density P_i , the speed for car mode differs, when $d_{B,C}$ has one crossing point. However, if $t_{B,C}$ is out of boundary from t_c to t_{max} , then equation (4.7) and $d_{A_{P_i},C}$ can be affected by MET.

$$d_{A_{P_i},C} = d_{B,C} \quad (4.7)$$

Further, three types of distances are defined.

The first is $d_{B,C}$. Walking mode has an advantage at distances shorter than $d_{B,C}$. For distances longer than $d_{B,C}$, bicycle mode or car mode have an advantage. However, because t_{max} is very short, evacuees cannot reach the shelter even if they can walk more than 1,500m. If assumptions are made for EST and ESM ($t_w=5min$, $t_b=10min$, $v_w=2.6km/h$, $v_b=9.8km/h$ in Sections 3.2.1-3), $t_{B,C}$ is 11.8min and $d_{B,C}$ is 295m. Considering these parameters, walking mode has an advantage at distances that are less than 295m. The second type of distance is d_{max} , which satisfies the boundary condition ($t_B < t_{B,C} < t_{max}$), and d_{max} is 1,500m. The third type of distance is $d_{A_{P_i},C}$. When the population density is fixed at $P_i=500p/km^2$ and EST at $t_c=15min$ as shown in Section 3.2.3, $v_{500,C}$ is 12.6 km/h, $t_{500,C}$ is 17.8min and $d_{A_{500},C}$ is 546.4m.

The division line between B-1 and B-2 is $P_i = d_{A_{P_i},C}$, which is the set of $d_{A_{P_i},C}$ along the various P_i (EC: Equilibrium Curve). Each element has the same CAM for walking and car mode to reach distance $d_{A_{P_i},C}$ in Figure 4-3. For car mode, it is assumed that higher population density causes slower car speed.

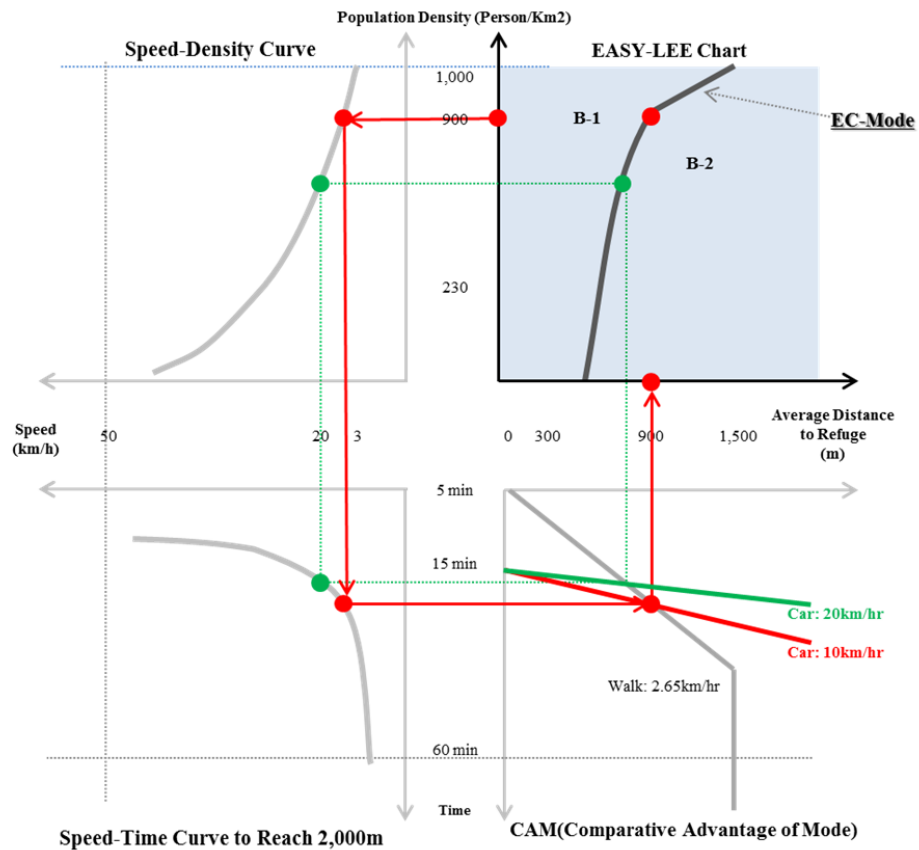


Figure 4-3 EC (Equilibrium Curve) of Mode along the Different Speed affected by Population Density

4.1.5. Equilibrium Curve for the Demand and Availability of Road

Demand and supply are concepts that are widely used to deal with changes under conflicting conditions. The intersection point of the demand curve and the supply curve is usually interpreted as the optimal values. Here the total distance necessary (length) for evacuation is defined, along with the calculated road distance (length) used by evacuees in the case of the Tohoku area.

4.1.5.1. Notations of Parameters

a : TND-Total Needed Distance (per*km/km²)

b : TAD-Total Available Distance (per*km/km²)

r : Average Distance to Refuge

P : Population Density (per/km²)

TND a : Set of same a under \forall_P, \forall_r (per*km/km²)

TAD b : Set of $h(r)/r$, while $b = \int h(r, V, U, F, R) d(r)$ under \forall_P (per*km/km²)

V_i : Velocity of Mode i ($i=w, b, c$)

F_i : Relative Frequency of Mode i ($i=w, b, c$)

R_i : Mode Ratio of Mode i ($i=w, b, c$)

T_{max} : Maximum Time for Evacuation

$U_{r,i}$: Time Unit per Distance at r for of Mode i ($i=w, b, c$)

$I_{r,i}$: Travel Time to r of Mode i ($i=w, b, c$)

τ : Road Ratio, t : Time (min.)

$\alpha_i, \beta_i, \gamma_i, \delta_i, \zeta_i, \mu_i$: Parameters of Mode i ($i=w, b, c$)

w : Walking, b : Bicycle, c : Car

4.1.5.2. Total Needed Distance for Evacuation

Total Needed Distance (TND) is a concept similar to the indifference curve, which is derived as summation of evacuation distances. For example, if the average distance to refuge is 500m in the case of population density of 1,000 people per square kilometer, and the total distance needed for evacuation is 500km, then the distance needed for evacuation of 833 people is 600m as shown in Figure 4-4. The TND₅₀₀ curve can be drawn with blue, red, green, and purple dots as shown in Figure 4-4. The TND₆₀₀ curve also can be found in the same way. Finally, these curves can be expressed as the relationship between the population density (P) and the average distance to refuge (r), as shown in equation (4.8).

$$P = \frac{a}{r} \quad (4.8)$$

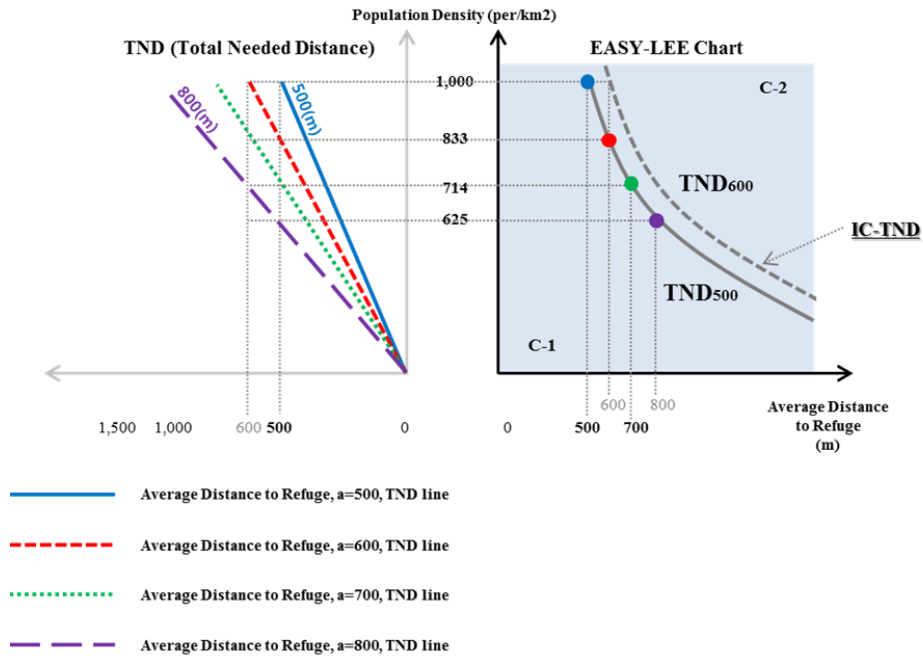


Figure 4-4 Total Needed Distance for Evacuation

4.1.5.3. Distribution of Evacuation Distance

In order to calculate the used distance (length) for evacuation, the distribution of evacuation distances of evacuees is derived from the Cumulative Evacuation Distance – Cumulative Distribution Function (CED-CDF) shown in Figure 3-26. The Probability Distribution Function (PDF) of Evacuation Distance is calculated by the differentiation of CDF ($G_i(r)' = F_i$) and the three different parameters for car, bicycle, and walking modes were derived by the equation in Figure 3-26.

Three different distributions were assumed for the three modes but the distributions of evacuation distance within the same mode were assumed to have the same distribution. F_w is the PDF of evacuation distance in walking mode. The shape of the distribution is shown in Figure 4-5, where the probability initially increases as the distance increases because evacuees have to move to

refuge and 50% of evacuees walked to refuge within 300m. Therefore, the probability decreases after 300m in the case of walking mode.

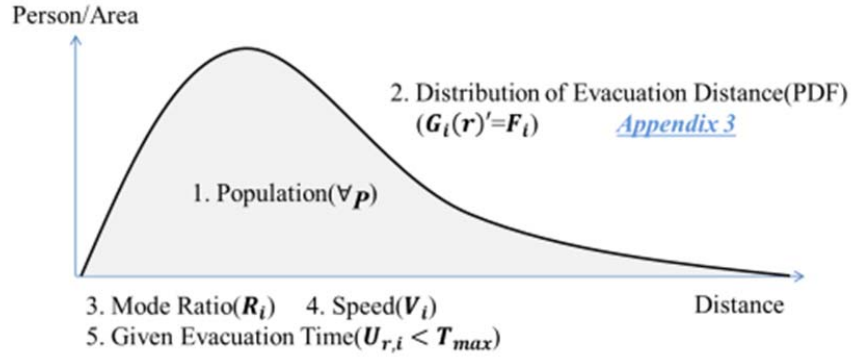


Figure 4-5 Distribution of Evacuation Distance of Evacuees

4.1.5.4. Total Available Distance for Evacuation

The Total Available Distance (TAD) for evacuation takes into consideration the speed of each mode (V_i), given population density (P_i), mode ratio (R_i), and relative frequencies of each mode (F_i) based on the travel time to distance r (meter) of each mode ($I_{r,i}$). For all distance r , TAD is modeled by equation (4.9). This equation was calculated using the numerical method, and this derived curve is the supply curve, which is the cumulative distance of road distance used by evacuees at population density (P_i).

$$b=\forall_P \int_0^r \left(\sum_{i=w,b,c} V_i U_{r,i} F_i R_i \right) dr \quad (4.9)$$

$$V_i = \alpha_i e^{\beta_i \forall_P} + \delta_i \tau ,$$

$$U_{r,i} = \begin{cases} V_i^{-1}, & I_{r,i} < T_{max} \\ 0, & I_{r,i} \geq T_{max} \end{cases}$$

$$I_{r,i} = \int_0^r \frac{1}{V_i} dr ,$$

$$F_i = G_i(r)' = (\zeta_i \ln r + \mu_i)',$$

$$R_i = \text{Given from field data}$$

Equation (3.3) is used for the speed of each mode (V_i). As the population density increases, the moving speed decreases. Higher road ratio leads to higher speed. This research assumed the population density from 1 to 2,000 (people/km²) using integers. The average mode ratios (R_i) were determined from ARSI (2012), in which car mode was 55%, bicycle mode was 1%, and walking mode was 44%. However, the mode ratio was also applied on a case-by-case basis when the real mode ratio was available depending on the analyzing size. For example, the total average was used at the prefectural level, while the average of groups of cities with the same geographical condition was used at the municipal level, and the average for each city was used for the 500m mesh level.

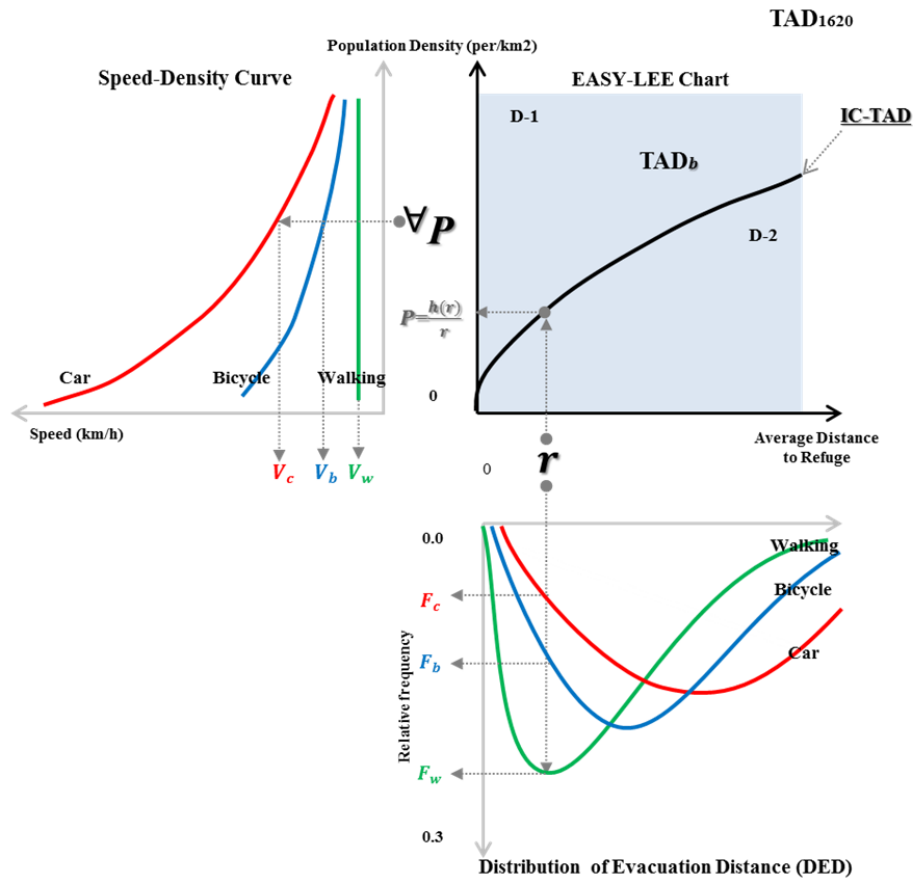


Figure 4-6 Total Available Distance on the Speed Variation, Mode Ratio, and Distribution of Evacuation Distance

Each speed (V_i) of the modes were derived from the speed-density curve, while the population density ($\forall P$) and the mode ratio (R_i) were decided from field data. In order to calculate the moving distance, the distribution of evacuation distance (F_i) was used, as shown in Figure 3-26.

4.1.5.5. Equilibrium Curve

$TNDa$ means that the total evacuation distance at any population density is a (per.*km/km²), and b is the total useable distance for evacuees, $TADb$, for any population density. The intersecting

point of these two curve is the equilibrium ($a=b$). This is the same point as the intersecting point of the demand and supply of road usage for evacuation at any population density.

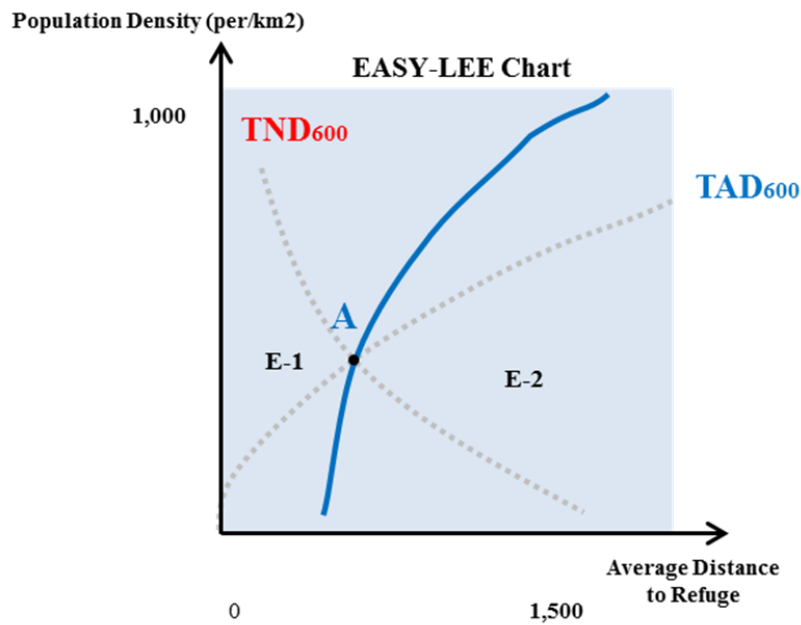


Figure 4-7 Equilibrium Curve from Demand and Supply

The set of these and the equilibrium points, called the equilibrium curve, can be derived from any combination of $TNDa$ and $TADb$. The equilibrium point, A, from TND_{600} and TAD_{600} is shown in Figure 4-7. The equilibrium curve divides the EASY-LEE chart into E-1 and E-2. In E-1, $TNDa$ is larger than $TNDb$. In other words, the demand for evacuation roads is higher than the supply. If the road demand for evacuees is larger than the supply, serious congestion may be caused. In order to solve the congestion problem, it is better to use walking mode for evacuation because walking mode does not cause serious congestion, and the benefits of walking mode may be larger than driving under congested conditions.

4.1.6. Combining Conditions and EASY-LEE Chart

The Comparative advantage of mode (CAM) (Figure 4-2), the Equilibrium Curve of Mode (ECM) along the different speed affected by population Density (Figure 4-3) and the Equilibrium Curve from Demand and Supply (ECDS) (Figure 4-7) can all be expressed in one chart. This result is a special case of the EASY-LEE chart, based on the average value of collected data as in Figure 4-8.

Sessions I and II are divided from the CAM line. Walking mode is the best mode because the evacuation distance is less than 300m and the other modes require preparation time for evacuation. Therefore, in session I, evacuees can most quickly reach the shelter using walking mode. Sessions II and III are divided by the ECM for different speeds. In Sessions I and II, walking mode has an advantage for the same distance, while car mode has an advantage in Session III.

The ECDS divides Sessions III and IV. While the demand was larger than supply in Sessions I, II, and III, the supply is larger than demand in Session IV. Session III can be referred to as the “dilemma session” because car mode is the fastest mode, but since the demand is high, congestions occur readily as more and more people decide to use car mode. The last line is divided vertically at 1,500m, which is the maximum distance in walking mode for the smaller of 95% of the walking distance for evacuees or the walkable distance inundation by the tsunami. For distances of more than d_{max} , car mode does not always have a CAM, but there are no other options. Demand is higher in session VI and lower in session V, but walking mode is not viable in either of the Sessions due to the far distance.

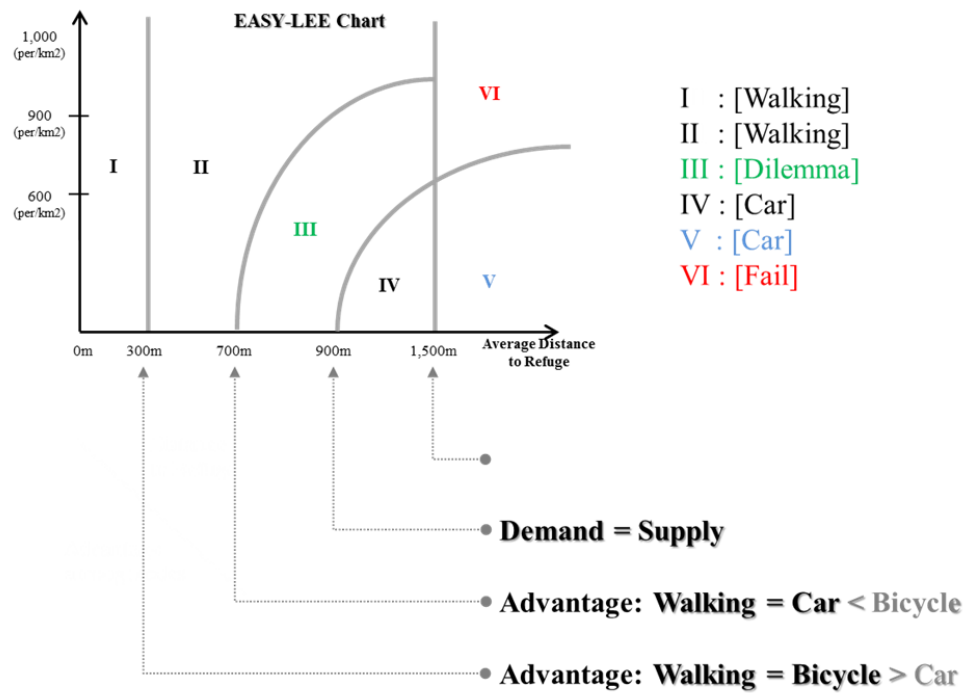


Figure 4-8 Combining of EASY-LEE Chart

4.2. FLEXIBLE APPLICATION OF PARAMETERS

One of main indices in the EASY-LEE method is CAM (Figure 4-2), which provides insight into the various sessions (Figure 4-8). In order to apply this method to more detailed regions and prospective areas, it is necessary to demonstrate the flexibility using various parameters. Below are some examples that illustrate the flexibility of the EASY-LEE method.

4.2.1. Geographical Differences of Maximum Evacuation Distance

This research has been dealing with three different geographical conditions: isolation, waterside, and plain (Figures 3-2, 3-3, 4-9). These differences led to three different maximum distances of evacuation for walking mode. 95% of evacuees finished escaping within 1.5km, and thus this

distance is considered to be the maximum distance in the plain and waterside areas. In some other areas, evacuees can reach safer, higher grounds in less than 1.0km. Therefore, in these areas the maximum distance of evacuation can be defined by the geographical condition shown in Figure 4-9.

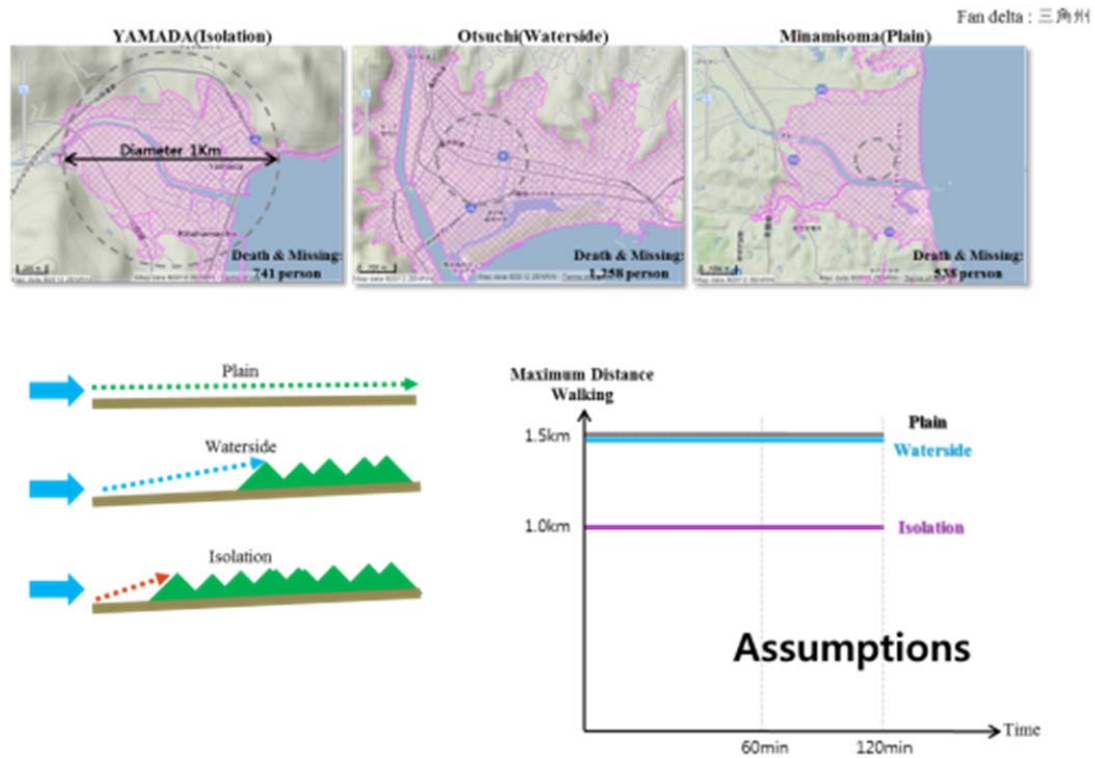


Figure 4-9 Assumptions of Maximum Evacuation Distance

4.2.2. EST and ED in Walking Mode for Various Age Categories

Age of evacuees may have a significant effect on the results of the EASY-LEE method. The CAM lines can vary as shown in Figure 4-10. Different evacuation starting times, evacuation speeds and maximum evacuation distances at the same time were applied for various age groups. The dotted line shows the worst case among different age categories. For example, in the isolation area, almost all evacuees immediately began evacuating after the earthquake because they had

knowledge and experience about the tsunami and understood the dangers (bottom left in Figure 4-10). 95% of evacuees in age group 20s~30s moved less than 2.3km in the plain areas because there were less obstacles and it was easier than other geographical conditions to move by walking mode (top left in Figure 4-10). In a similar way, the different ages, evacuation starting times, speeds and maximum distances can be applied in CAM and used for flexible relationships in the multi-level analysis.

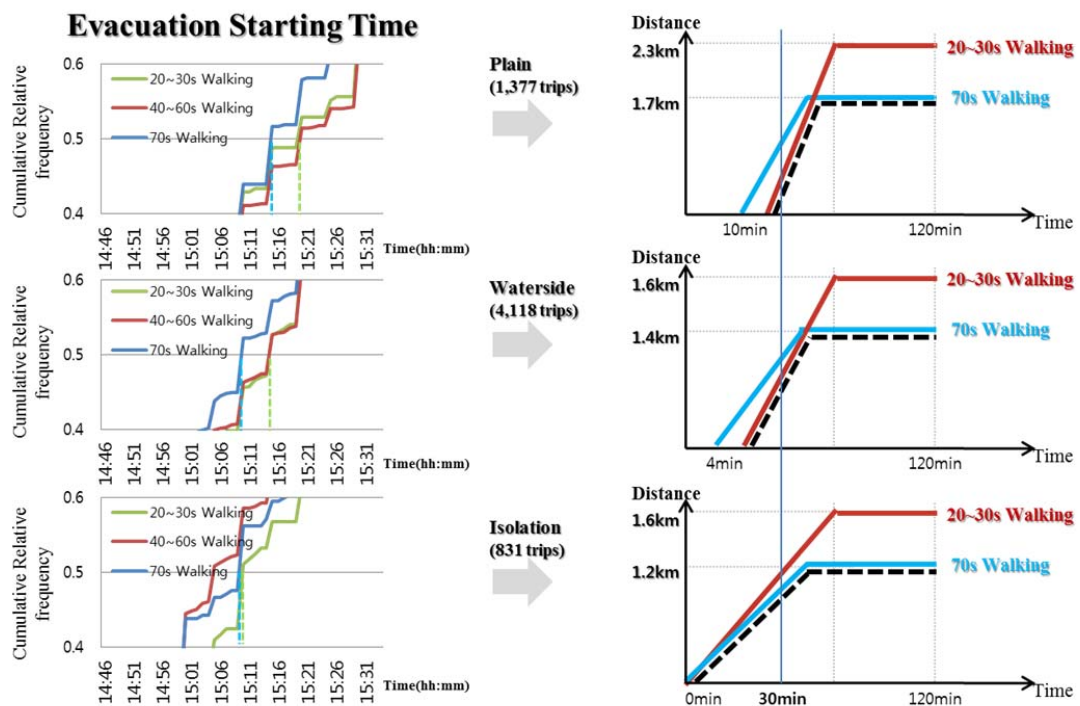


Figure 4-10 Evacuation Starting Time (N=11,968)

4.2.3. Changing Barrier on Speed Variation

Car speed is one of the most important parameters for car mode, and the barriers can change in the EASY-LEE chart. From the data [ARSI, 2012], the average speed in car mode was 14.7km/h, and this value is first applied in order to derive the EASY-LEE chart. The barriers may change

when different car speeds are used and the average speed is increased to more than 20.6m/h (increase of 140%), when there is no dilemma because if an evacuee has the advantage in car mode, there are less issues in using car mode. Since the speed decreases by 20%, the session almost changes to Session II, where walking mode is the optimal mode.

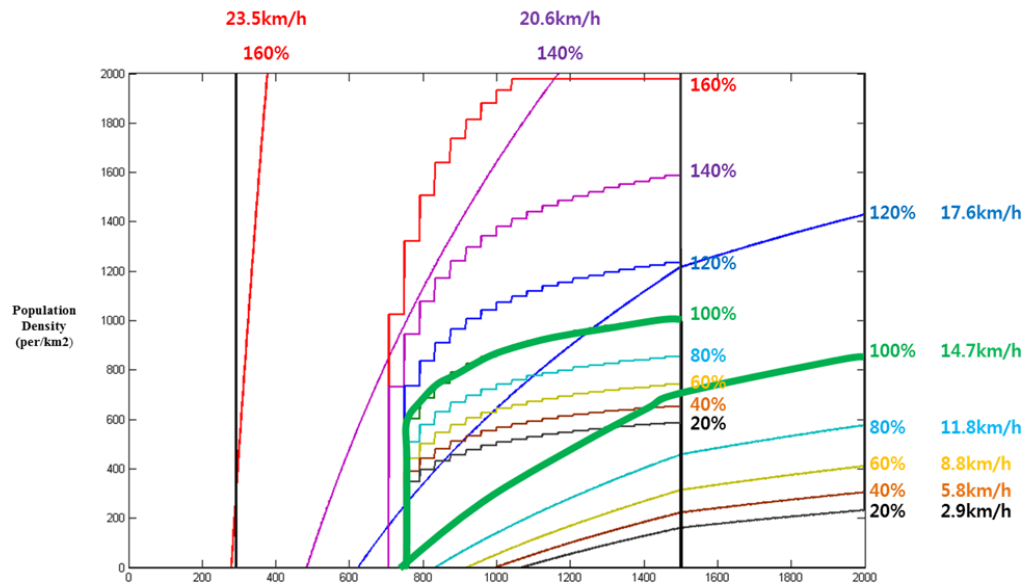


Figure 4-11 Speed Variation and Change of Lines

4.2.4. Changing Barriers for Tsunami Approaching Time

The next parameter for flexibility is the Tsunami Approach Time (TAT). Each place has a different tsunami inundation time. Therefore, TAT can be applied in the CAM level as shown in Figure 4-12. Even though the EASY-LEE method is used for the same place, the lines can be changed by TAT. The vertical line, which is the maximum evacuation distance in walking mode (Figure 4-12), moves to the left side of the chart and Sessions II ~ V change to VI. In this case, it

is very difficult to evacuate by walking and thus this area needs more temporary shelters. In summary, the special characteristics of each prefecture or city can be flexibly taken into account.

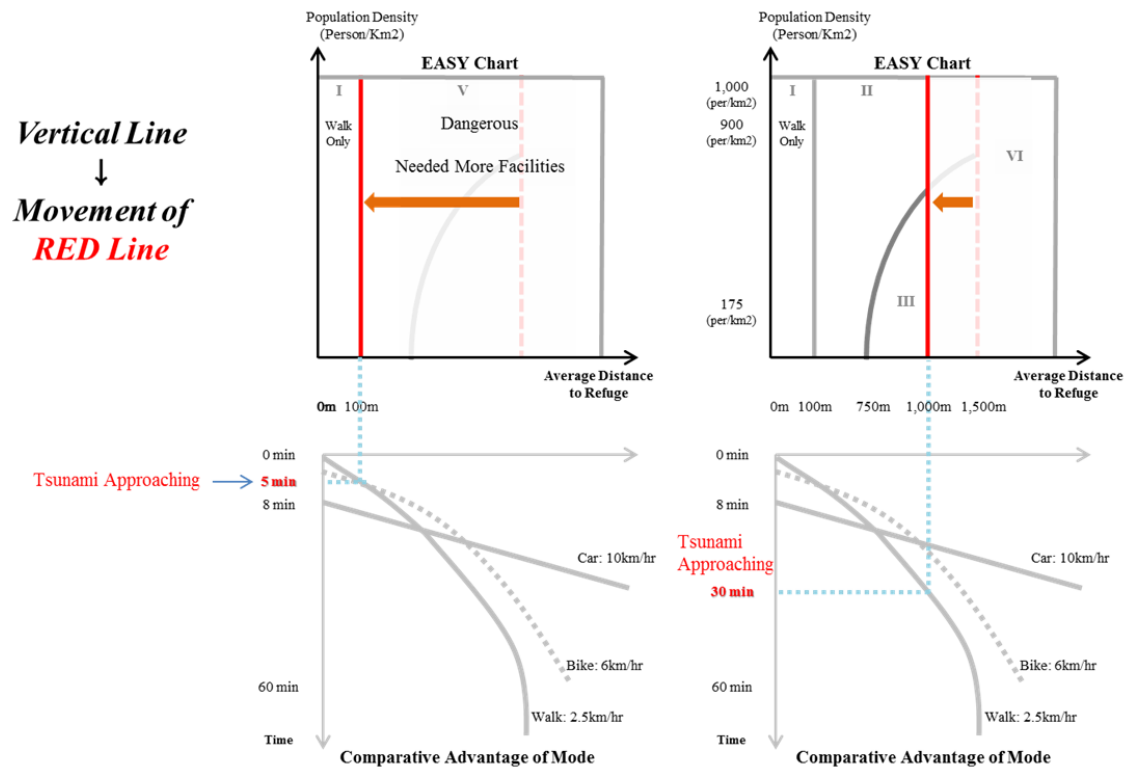


Figure 4-12 Session Changes along the Tsunami Attached Time

4.3. FLEXIBLE APPLICATION

4.3.1. Prefectural Level (Macroscopic)

The six sessions are shown in the EASY-LEE chart in detail in Figure 4-13 (the cities located in the coastal area are shown on the chart). Considering the average distance to official shelters and the average values of parameters, Aomori is in Session II, Ibaraki, Miyagi and Fukushima in Session III, and Iwate is in Session V.

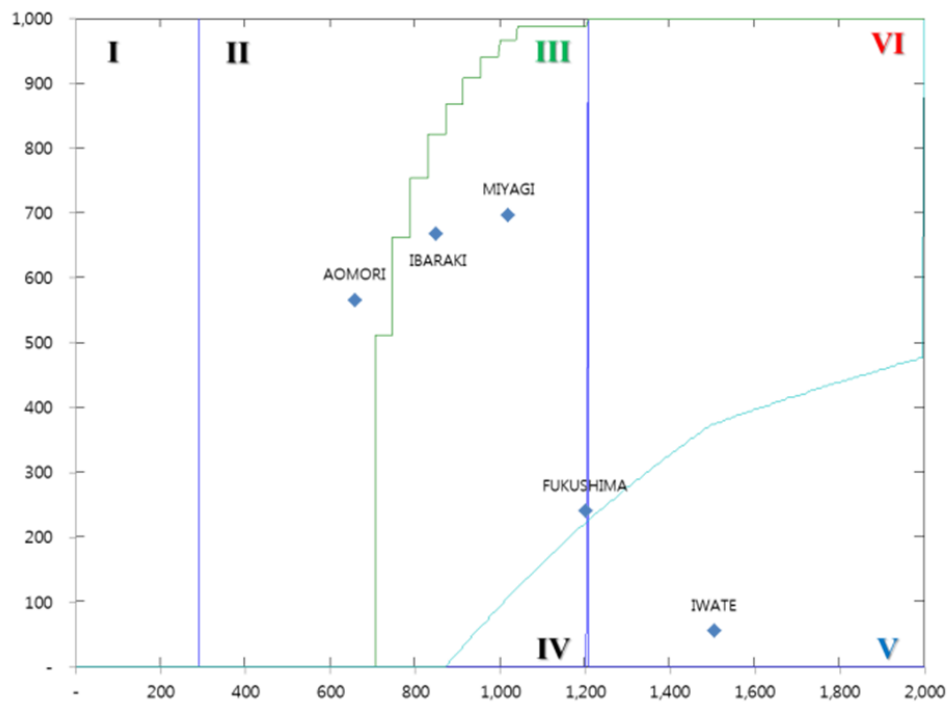


Figure 4-13 Results on Prefecture Level (Prefecture in Coastal Area Only)

The six sessions may be able to be separated into three main part categories: A, B and C for further simplicity. Session A contains Sessions I and II, where walking mode is the recommended mode. Session B is the dilemma category that includes Session III. Session C covers the Sessions IV ~ VI, where car mode is the recommended mode.

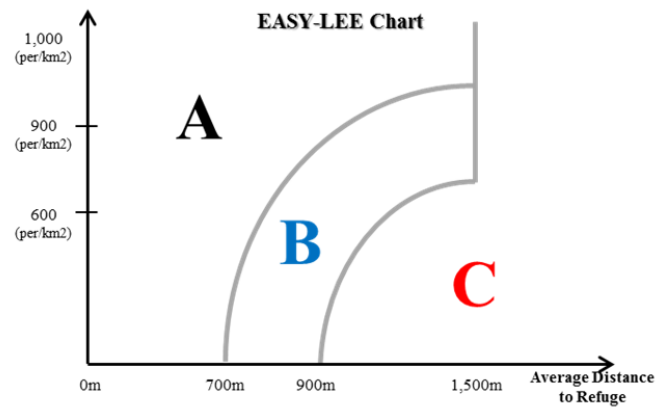


Figure 4-14 Three Part on Macroscopic Level

In addition to the macroscopic comparison at the prefectural level, microscopic analysis is necessary to thoroughly explain the results because the main object of the comparison at the prefecture level is for the central government to be able to make holistic recommendations at the national level (see Figure 1-5, 1-6).



[S: Safe area]

Figure 4-15 Results at the District Level (500 Mesh Data)

4.3.2. City and District Level (Microscopic)

The six sessions can also be applied at the municipal level. The results of the EASY-LEE method with the 500 mesh data (district level) can distinguish the hazardous areas from the safe areas in one map (Figure 4-16). The map shows areas that can be categorized as Sessions V and VI, where more shelters are necessary because accessing shelters by foot is very difficult, and in Session VI, congestion may also rule out the car mode. High grounds and official shelters were also considered at the macroscopic level, so that the residents who live in hazardous areas can evacuate to higher and safer areas.

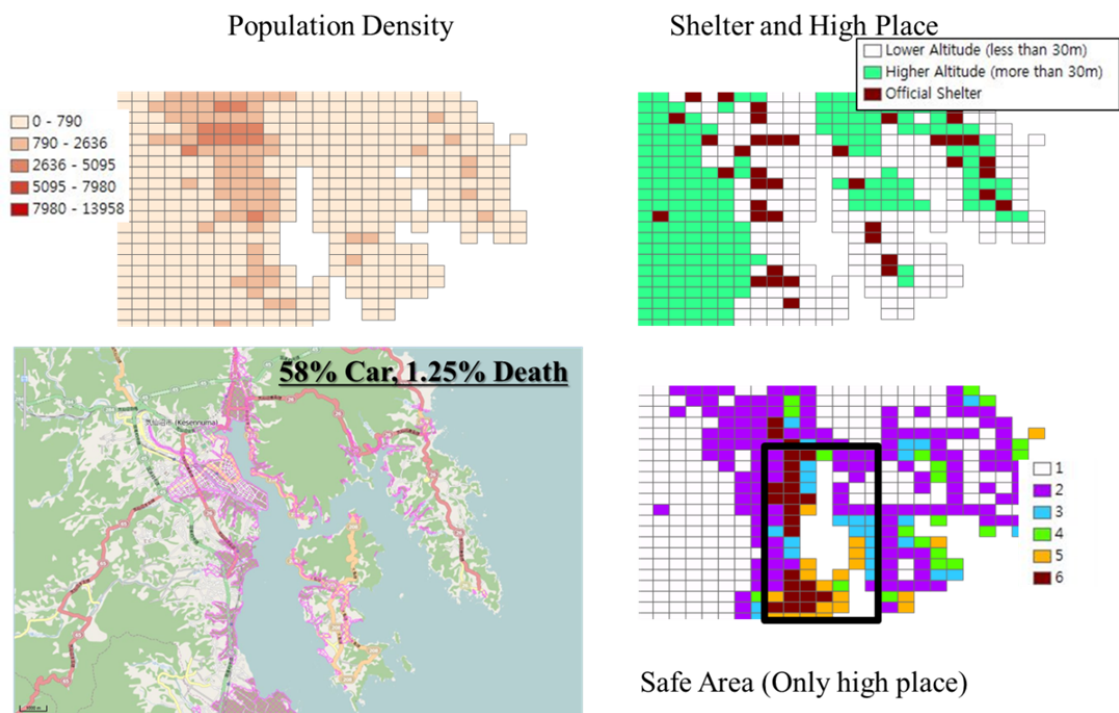


Figure 4-16 Kesennuma City (500 Mesh Data)

Chapter 5 CHARACTERISTICS OF EASY-LEE

5.1. CHARACTERISTICS OF THE SESSIONS

5.1.1. SESSION I (Walking is optimal)

In Session I, walking mode has the greatest CAM for the first 295m, as shown in Figure 3-26. When the evacuation distance is shorter than 295m, fewer people use car mode. Less than 15% of the evacuees used car mode, as shown in Figure 3-26. In Session I, walking was the primary mode of evacuation regardless of the population density. If the population density is very low, evacuees can choose any mode because congestion is negligible.

5.1.2. SESSION II (Walking is faster than Car)

In Session II, walking mode is a CAM over car mode. If evacuees use car mode, serious congestions may be expected due to the high population density. Furthermore, the distance to shelters is shorter than 1,500m, and thus walking is a viable option. In this case, it is recommended that evacuees walk instead of driving to evade congestions and give way for emergency vehicles.

Table 5-1 Characteristics of Sessions on EASY-LEE Table

Advantage Evacuation Mode	Less than 300m	300m~1500m		More than 1500m	
	Demand > Supply	Demand < Supply		Demand > Supply	
Walk>Car	I	II	-	-	-
Walk<Car	-	III	IV	V	VI

5.1.3. SESSION III (Dilemma- Strict Controlling Needed)

In Session III, car mode has an advantage to reach the same shelter, based on the distance and CAM. However, demand is higher than supply for evacuation roads, which means that although cars have an advantage as an evacuation mode up until a certain degree, if the mode ratio for cars exceeds 60%, congestion becomes serious and evacuees may fail to evacuate. Therefore, evacuation managers should control the mode ratios, so that the use of car mode can be controlled.

5.1.4. SESSION IV (Mobility for Car Supported)

In Session IV, car mode is the CAM, mainly because the supply is higher than the demand. This session is characterized by lower population density and the distance to shelters is less than 1,500m. The number of cars is not high, and thus congestion would not adversely limit driving speed. This area could allow evacuees to freely choose their preferred evacuation mode. Additionally, it is important to take into consideration the safety of evacuation routes to high altitudes in order to survive from tsunamis.

5.1.5. SESSION V (More Shelters Needed for Walking)

Many problems are cited for Session V and VI. It may be difficult to reach shelters by foot, and thus evacuees might consider the use of car mode. However, road conditions may not guarantee safety after a strong earthquake, and the high population density may cause serious traffic congestions. It is strongly recommended that provisions be implemented for more facilities and infrastructure that could serve as temporary shelters.

5.1.6. SESSION VI (Most Dangerous Area)

Session VI has similar characteristics with Session V, but is more dangerous because of the high population density and the higher demand for evacuation roads. Therefore, this session is the most difficult to evacuate by car due to congestions and the most difficult to escape by foot due to the long distance.

5.2. EVACUATION SPEED AND DISTANCE

The difference in Evacuation Speed among the various walking modes is insignificant. For car mode, Session II (9.3km/h) is significantly slower than others. Session III (63%) has a larger mode share for cars than Session II (57%), implying that fewer evacuees used cars because of the low speed due to factors such as congestion. This can be supported by the survey in which respondents answered regarding “Problems to access the shelters” and “Reason not to go to the nearest shelter”. Session II has the highest proportion of “Overcapacity in accessing the shelters (65%)” and “Found easy place because evacuees can not to go to the nearest shelter (59%)”. Session III shows that the car mode is a CAM but the demand is higher for evacuation roads.

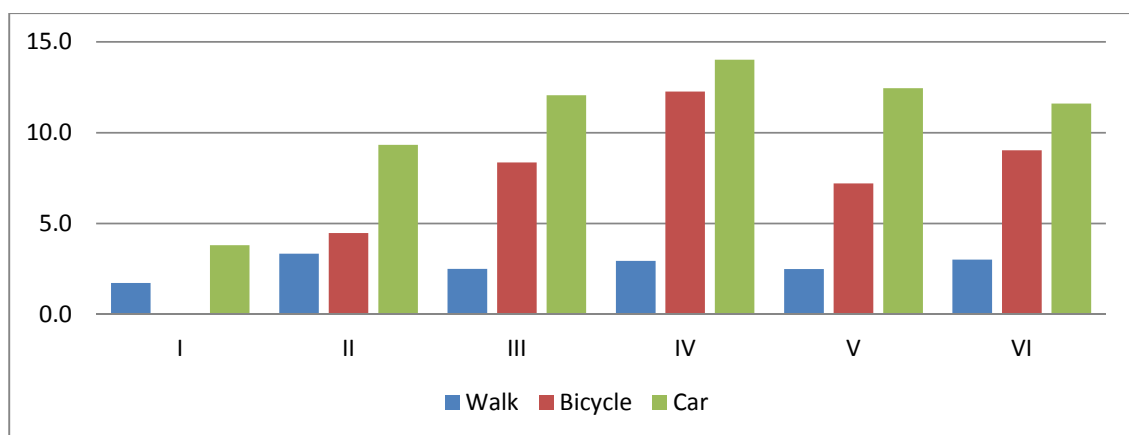


Figure 5-1 Evacuation Speed of Each Session (N=11,968)

Sessions V and VI do not have options other than car mode. Evacuees in these sessions felt that distance was a problem in accessing shelters by car mode, and thus answers such as “Reasons for Car use” and “Problems to access the shelters” can be seen. Sessions V and VI have a high proportion of answers that note “Lack of Time and Long Distance (78%, 70%)” and “Long Distance and Difficult Accessibility (69%, 66%)”. The mode share ratios are different between Session IV (car: 64%) and VI (walking: 55%), showing that there is a great advantage in using car mode in Session IV because evacuees can move longer distances (Evacuation distance: 2,402m) at the fastest speed of cars (Evacuation Speed: 13.1km/h) at the lowest congestion (Serious congestion: 9%). Additionally, Sessions I and VI show serious congestion (II: 22%, VI: 39%) that is significantly larger than Session IV’s (9%).

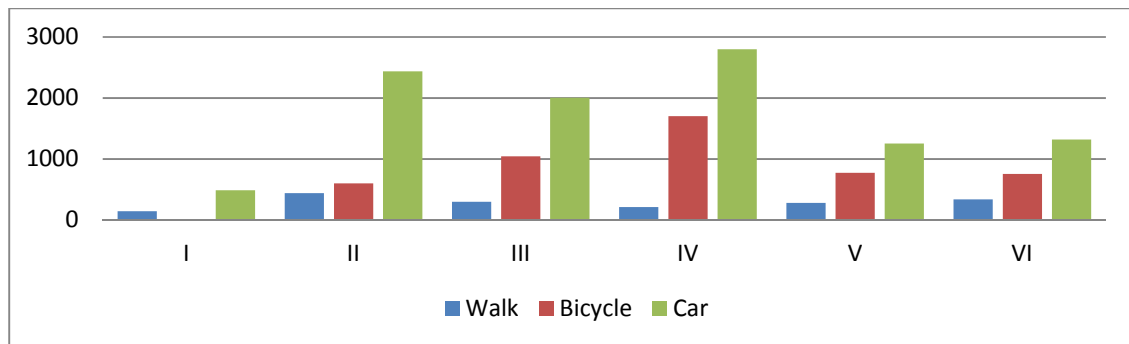


Figure 5-2 Evacuation Distance of Each Session (N=11,968)

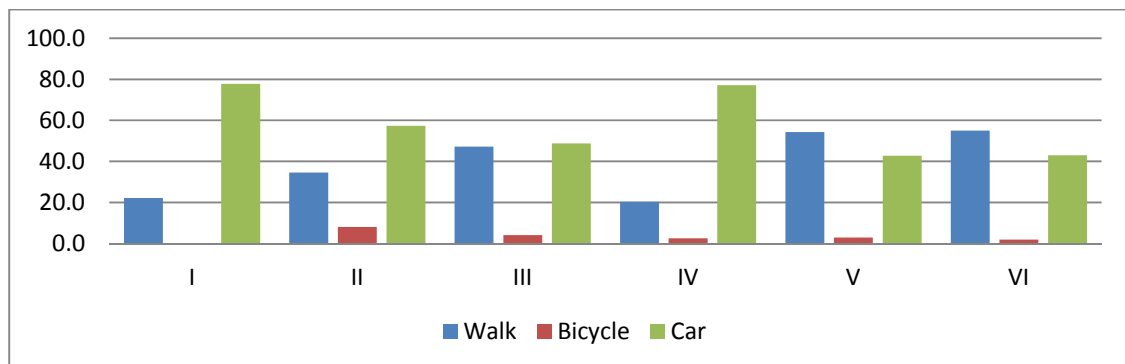


Figure 5-3 Evacuation Mode of Each Session (N=11,968)

Finally, if the mode share ratio for cars increases, Session II faces serious congestion problems (Overcapacity; 65%, serious congestion: 22%). The highest proportion of car mode (63%) was seen in Session IV, but at the same time, this session was characterized by the highest speed of cars (13.1km/h), the longest distance travelled (2,402m) and least congestion (9%). Session VI had the smallest proportion of evacuees using car mode (only 43%), and was characterized by long distances to shelters (39%) and most serious congestion (39%). Further, the evacuation distance on foot (309m) was longer than Session IV (255m). In the case of Session I, evacuees wanted to use car mode for “keeping asset (23%)” and “escaping with family (57%)”. Evacuees in Session I had the flexibility to choose their evacuation mode because of the shorter evacuation distance (walking: 144m, car: 490m) and the highest portion for car mode (78%).

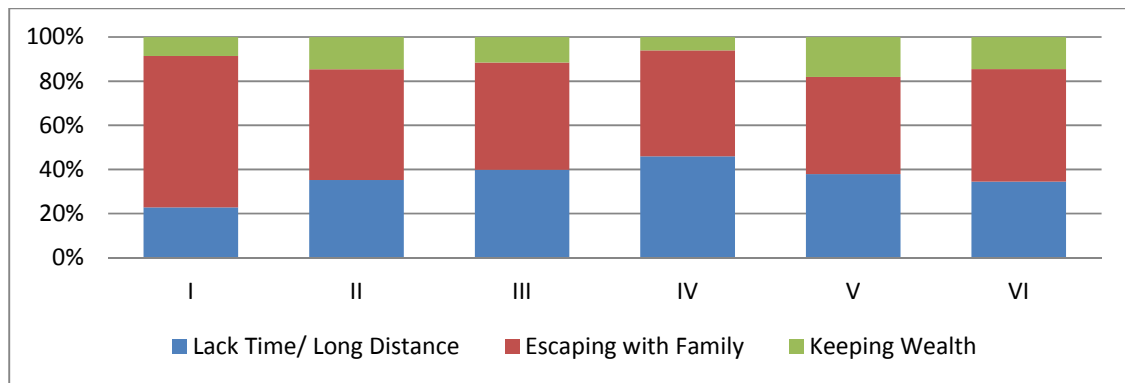


Figure 5-4 Reasons of Car Use in Each Session (N=11,968)

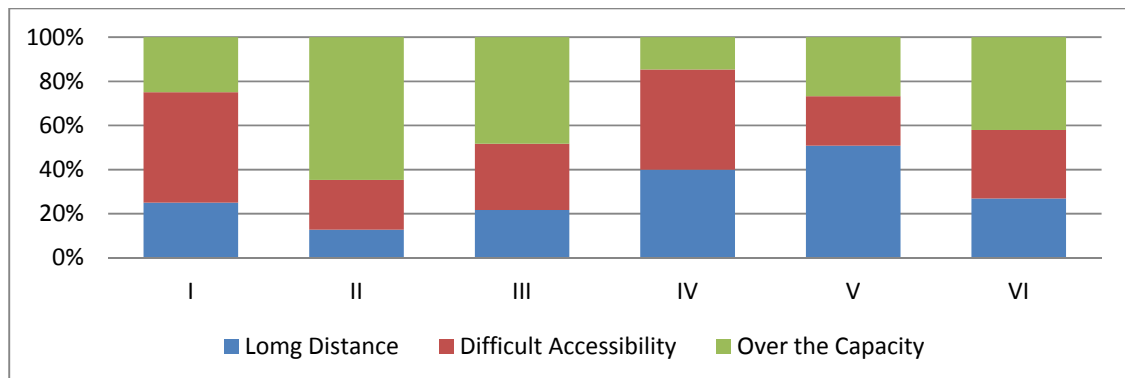


Figure 5-5 Problems to Access the Shelters (N=11,968)

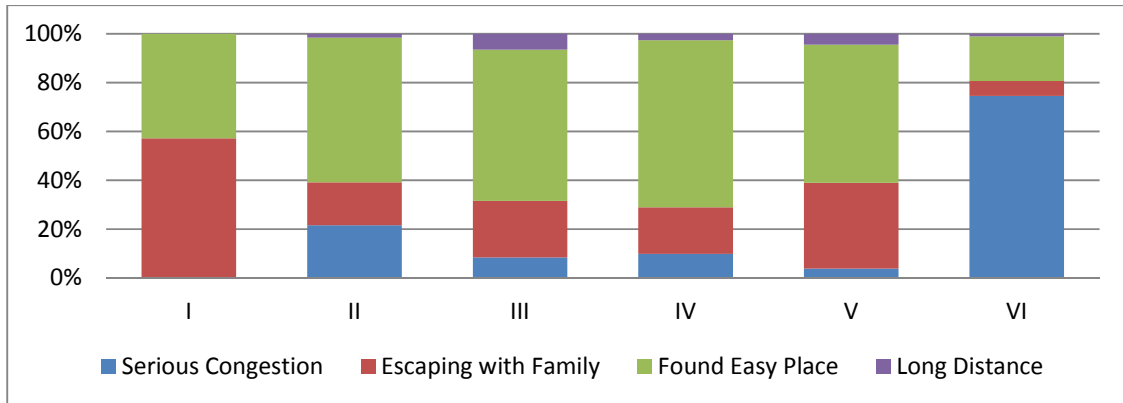


Figure 5-6 Reasons Not to Go to the Nearest Shelter (N=11,968)

In the EASY-LEE Chart, six groups are set based on the different population densities and the distances to refuge areas. Table 5-2 shows the parameters considered and their relations.

Table 5-2 Parameters in EASY Chart

	Demography: Population Density	Infrastructure Distance to Shelters
Evacuation Starting Time	Constant for Each Mode	-
Evacuation Speed	Constant for Walking, Bicycle Variable for Car	Over the Maximum Distance Walking Speed, 0
Evacuation Maximum distance	-	Walking has Maximum Distance
Distribution of Evacuation Distance	Constant for each age	Official & Temporal Refuges

Chapter 6 MULTI-SCOPIC USAGE OF EASY-LEE CHART

6.1. EASY CHART IN MACROSCOPIC POINT OF VIEW

In this research, an attempt was made to formulate a general guidance for evacuation based on the given conditions of refuge and population density, as well as the traffic mode and travel distance. A general recommendation can be made for refuge plans and the preferred mode of escape. Using the EASY-LEE Chart, the characteristics of evacuation in various cities were compared. This can serve as a useful means to understand the given condition of infrastructure as well as the tendencies and travel behaviours at a macroscopic level.

Table 6-1 Evacuation Speed, Disatance, and Mode Ratio on Macroscopic Level

	Evacuation Speed (km/h)			Evacuation Distance (m)			Evacuation Mode (%)		
case	Walk (6,326 trips)	Bicycle (479 trips)	Car (6,483 trips)	Walk	Bicycle	Car	Walk	Bicycle	Car
All	2.6	7.4	11.8	300	884	1718	47.6	3.6	48.8
A	3.3	4.5	9.3	441	600	2435	34.5	8.1	57.4
B	2.5	8.4	12.1	296	1042	2005	47.2	4.1	48.7
C	2.8	9.5	12.7	277	1077	1790	43.2	2.5	54.3

6.2. EASY CHART IN MESOSCOPIC POINT OF VIEW

Each city in the Tohoku area is located in the EASY-LEE Chart based on population density and the average distance to shelters; Session 1: Rifu, Session 2: Natori, Matsushima, Hachinoge, Session 3: Iwanuma, Watari, Iwaki, Minamisoma, Ishinomaki, Minamisanriku, Kamaishi, Yamamoto, Shinchi, Session 4: Soma, Rikuzentakata, Ofunato, Kuji, Otuchi, Noda, Yamada, Tanohata, Miyako, Onagawa, Misawa, Kesennuma, and the characteristics of each session are shown in Figure 6-1. For example, in the case of Session 1, shelters are closer than 295m. Only one city (Rifu) belongs to this session, so the other sessions II ~ IV will be compared in this chapter.



I: Rifu

II: Natori, Matsushima, Hachinohe

III: Iwanuma, Watari, Iwaki, Minamisoma, Ishinomaki, Minamisanriku, Kamaishi

IV: Yamamoto, Shinchi

V: Soma, Rikuzentakata, Ofunato, Kuji, Otuchi, Noda, Yamada, Tanohata, Miyako

VI: Onagawa, Misawa, Kesennuma

Figure 6-1 Results on Each City Level

6.3. EASY CHART IN MICROSCOPIC POINT OF VIEW

In this research, I applied this method in the restrict level, 500mesh data. To define the ID, I arrayed number in the first layer shown in Figurer 6-2, 6-3. The shelters(2), safe area(1), and sea(3) were let by three different number. Population density was recalculated by the person per square kilometer. Here are two kinds of different equation to derive the evacuation distances in EASY-LEE method. In the macroscopic level, city level, prefecture level, I used only the total number of refuges which were listed by a government officially based on the total area of unit. However I used the Pythagoras' theorem to calculate the evacuation distance among the centers of the mesh rectangulars.

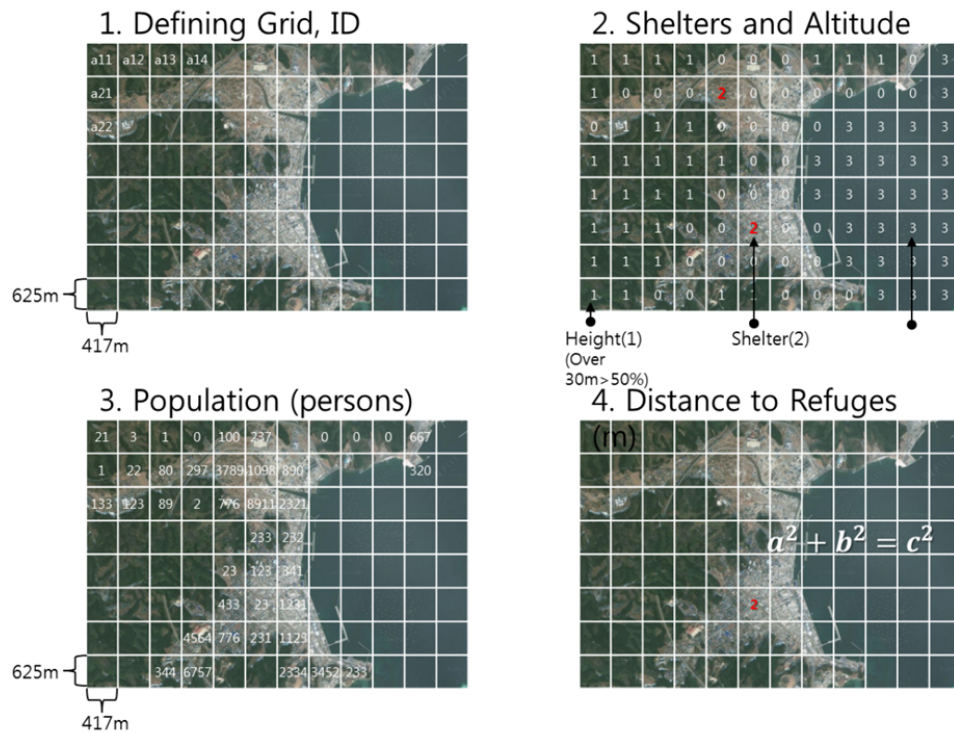


Figure 6-2 Data Collection for District Level

Data structure and the sources are shown in Figure 6-3, the data were collected as below.

- POP DATA:

<http://e-stat.go.jp/SG2/eStatGIS/page/download.html#>

- LANDUSE ATTRIBUTE:

<http://nlftp.mlit.go.jp/ksj/gml/codelist/LandUseCd-09.html>

- BOUNDARY CODE:

http://www.dictator.co.jp/i/i_jis/i_jis_00.html#39

- TSUNAMI INFO:

<http://fukkou.csis.u-tokyo.ac.jp>

- CORDINATE TRANSFER:

<http://asp.ncm-git.co.jp/QuickConvert/Address.aspx>,

<http://newspat.csis.u-tokyo.ac.jp/geocode-cgi/geocode.cgi?action=start>

<http://ktgis.net/gcode/geocoding.html>

- SHELTER INFO

<http://www.kokuminhogo.go.jp/hinan/index.html>

- Local Government

IWATE http://www.kokuminhogo.go.jp/pdf/hinan_iwate.pdf

MIYAGI http://www.kokuminhogo.go.jp/pdf/hinan_miyagi.pdf

FUKUSHIMA http://www.kokuminhogo.go.jp/pdf/hinan_fukushima.pdf

SHIZUOKA http://www.kokuminhogo.go.jp/pdf/hinan_shizuoka.pdf

KOCHI http://www.kokuminhogo.go.jp/pdf/hinan_kochi.pdf

- MESH INFO

<http://www.stat.go.jp/data/mesh/pdf/gaiyo1.pdf>

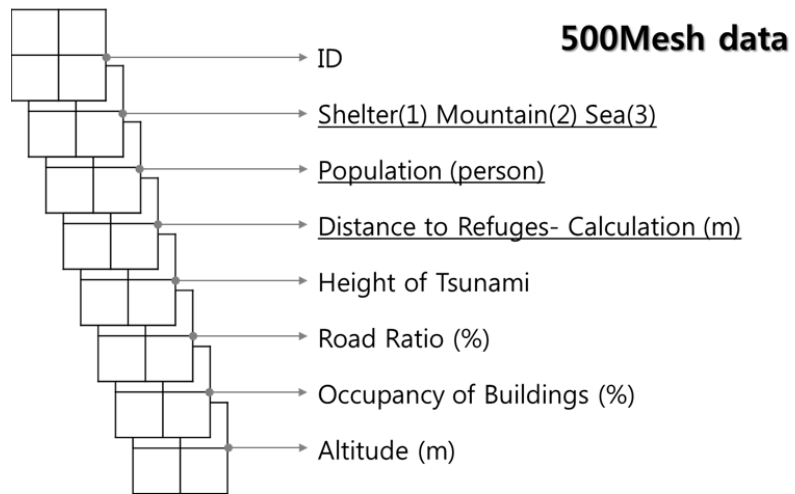


Figure 6-3 Data Structure

Chapter 7 STRONG-LEE METHOD

7.1. DETAIL CONCEPT FOR EVACUATION PLAN

In the EASY-LEE method, real road networks are not considered in the sessions. Instead, hazard information is provided for managers about dangerous areas and the advantages and disadvantages of each site or group. However, road networks are cores to designing evacuation routes and plans. Evacuation route should be assigned based on the existing roads and connections, congestion of sections, evacuation distance and road reliability. By overlaying road networks on EASY-LEE charts, insight can be obtained regarding the positioning for shelters, monitoring points for controlling, accessibility of car mode, and isolated area (Figure 7-1).

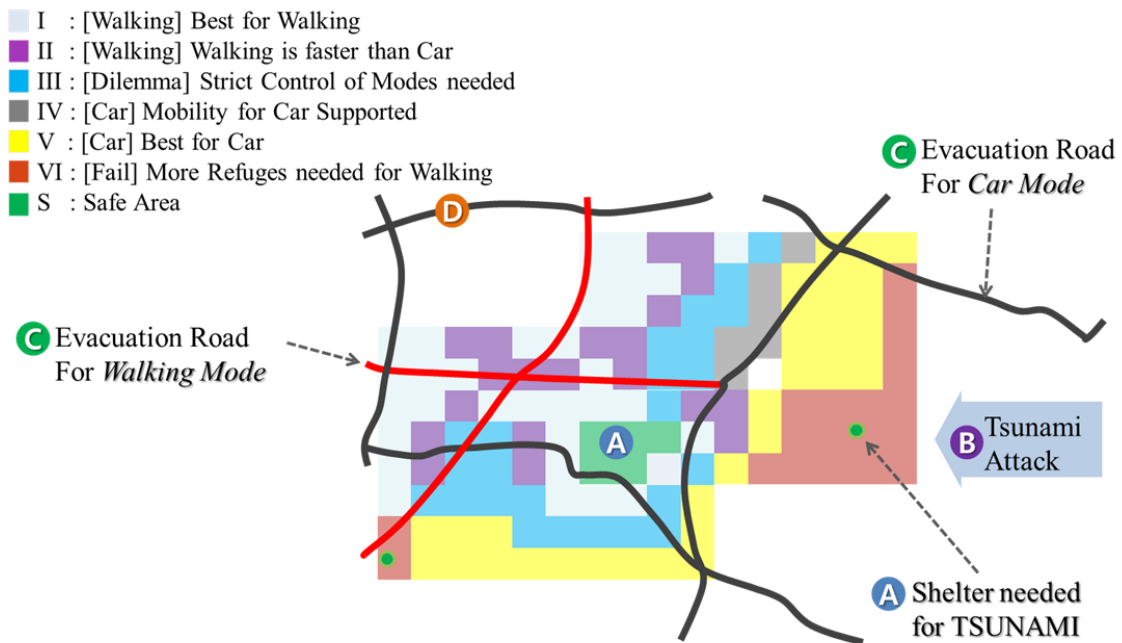


Figure 7-1 Concepts of STRONG-LEE Method

7.2. CASE STUDY OF KOCHI CITY

In order to exemplify the use case of the STRONG-LEE method, this research applied the method to Kochi City in Kochi Prefecture, Japan. This city is considered to be one of the most dangerous areas when a serious earthquake occurs. Tsunamis are forecasted to reach more than 12km in depth toward the inland at a width of 6km width, as shown in Figure 7-2.

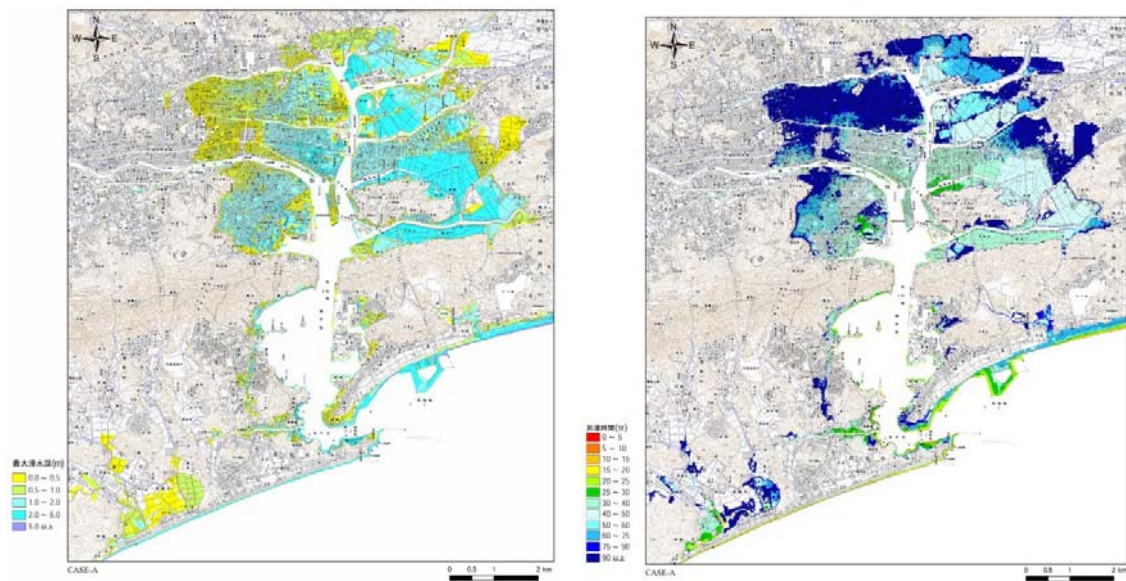


Figure 7-2 Expected Inundation Area: Hazard Map Left - hight of Tsunami, Right - inundation time (Kochi Prefecture, 2013)

7.2.1. Given Condition of Geography and Population Density

Kochi City is located in the southern part of Kochi prefecture. The Central business district is located in the inland area, which is far (6km~14km) from the coast as shown in Figure 7-4. However, the elevation of the residential areas is low, and thus the tsunami disaster is expected to reach the center of the city. Furthermore, due to the mountains that block the view to the coast, the residents of Kochi City may not observe the tsunami from the city (Figure 7-3).

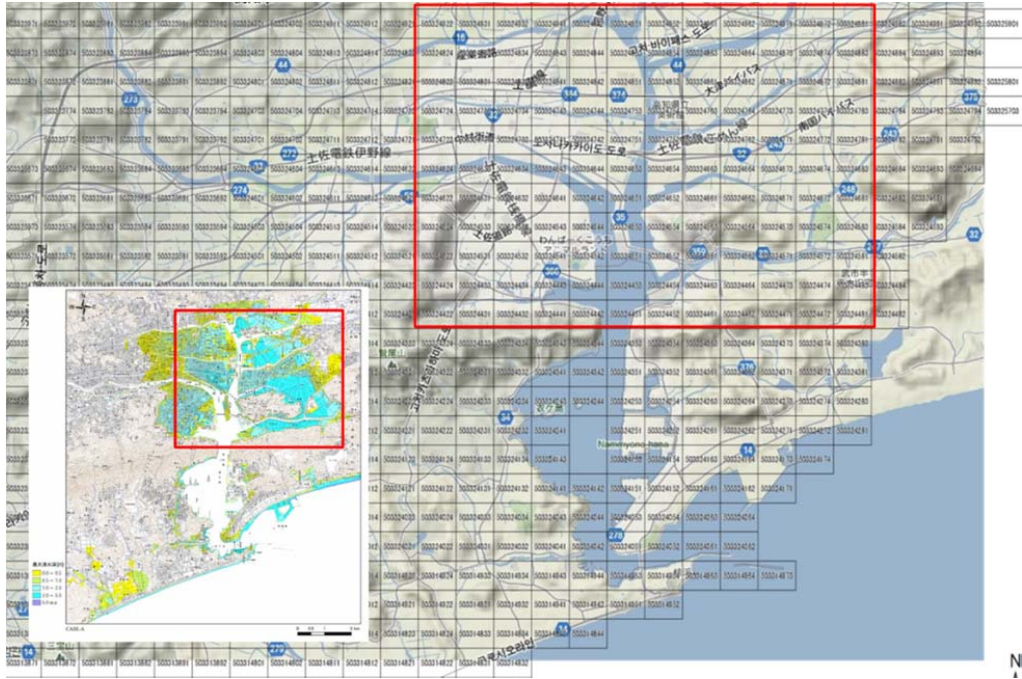


Figure 7-3 Kochi City in Kochi Prefecture

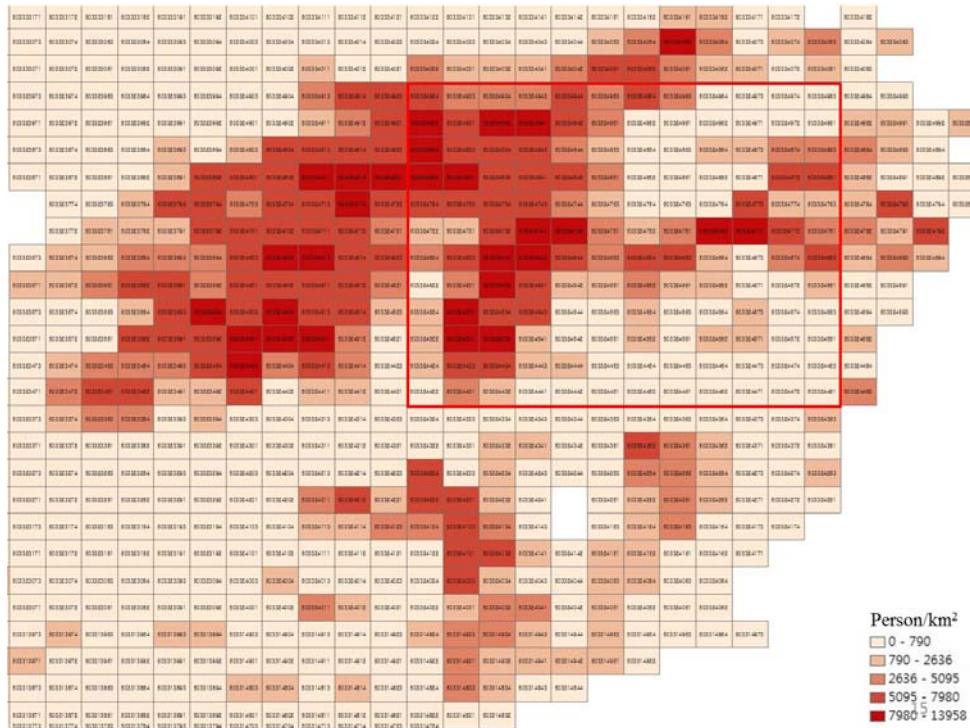


Figure 7-4 Population Density in 500 Mesh

7.2.2. High Place, and Officially Assigned Refuges

The wide plain area is surrounded by mountains, and official shelters are located in the populated areas in the west. In the western area, residents can access shelters within 500m. The areas shown within the red rectangular marking in Figure 7-5 are the most dangerous because higher grounds are too far to reach by foot. The areas shown in white have low elevations (less than 30m on average), while the areas shown in green have higher elevations (more than 30m, average), and the areas shown in brown have official shelters in Figure.

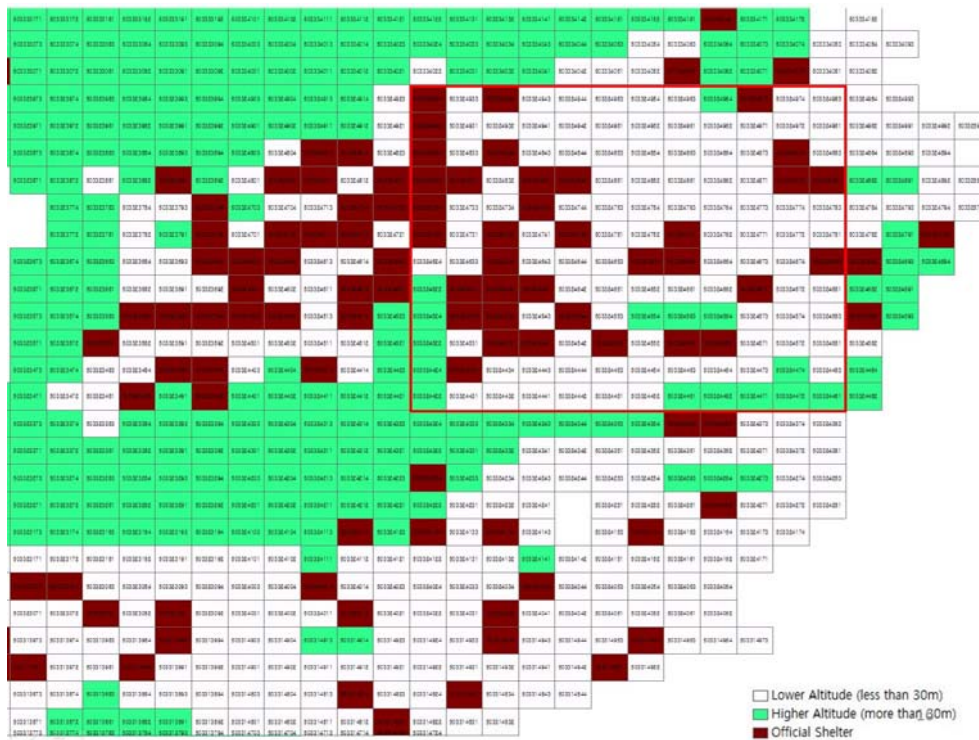


Figure 7-5 Location of Shelters and Safe Areas in 500 Mesh

7.3. DERIVING A RESULT FROM EASY-LEE

In order to define the EASY-LEE method, the population density and the distance to shelters must be obtained from each cell. The evacuation distance is calculated as the distance between

the center of the cell using the Pythagorean theorem. The population density follows the 500 mesh data from eStatGIS (2013). Coloring each cell, the following startling results emerge: (1) Sessions I and II are mainly in highly populated areas, (2) Session VI is in the high populated area, (3) Sessions V and VI are mostly in the low populated areas, and (4) is the dilemma area.

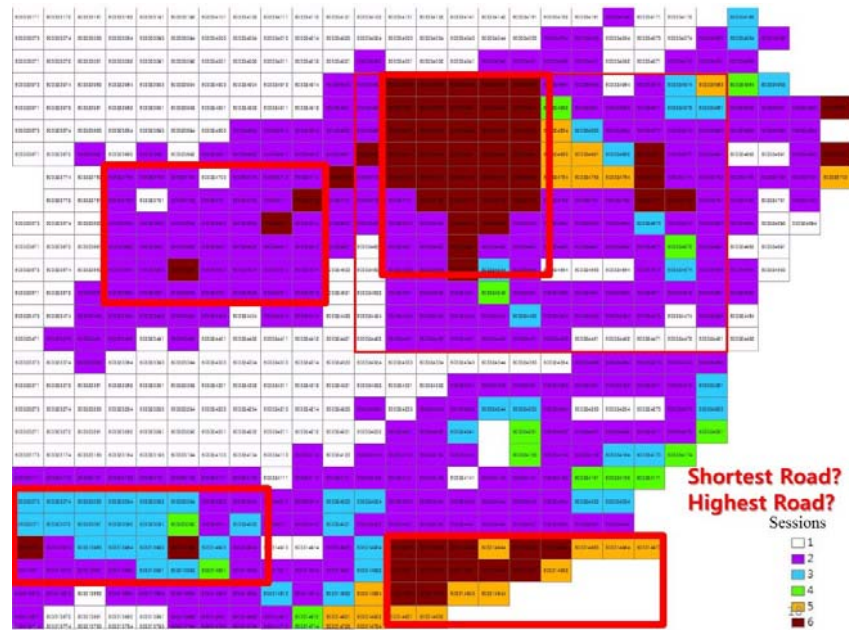


Figure 7-6 Result of EASY-LEE Method in 500 Mesh

(1) is in the western part of Kochi City where evacuees can reach shelters on foot because the shelters usually in residential areas. (2) is in the central highly populated areas, where there are fewer shelters and the distance to higher grounds is far. In this case, it is very difficult to evacuate because the high population density causes serious traffic congestion for car mode and the evacuation distance is very far for walking mode. (3) and (4) are located in the rural and coastal areas with lower population density.

7.4. ROAD NETWORK FOR WALKING AND CAR MODE

The core of the STRONG-LEE method is the evacuation distance is calculated on the real road network from the cell base mesh data field. To find the shortest path, origin and destination of cell assumed the center of each cell, and the routes were started from the nearest. Any road can be used for walking mode, but there are restricts for car mode to use the network. Roads which were less than 6m width or only for the pedestrian cannot be used for car mode. One-way and roundabout were also considered to let the direction of car movements. Two routes were assigned for the shortest path from ID 503324761 to ID 503324563 in Figure 7-7 and green route is for the walking mode and the other purple route is for car mode. As a result, (1) the shortest path for walking mode is referenced by all network links, however, (2) the shortest path for car mode contains selected roads which are available for car users. So moving distance (1) is shorter than or equals to moving distance (2), shown in Figure 7-12.

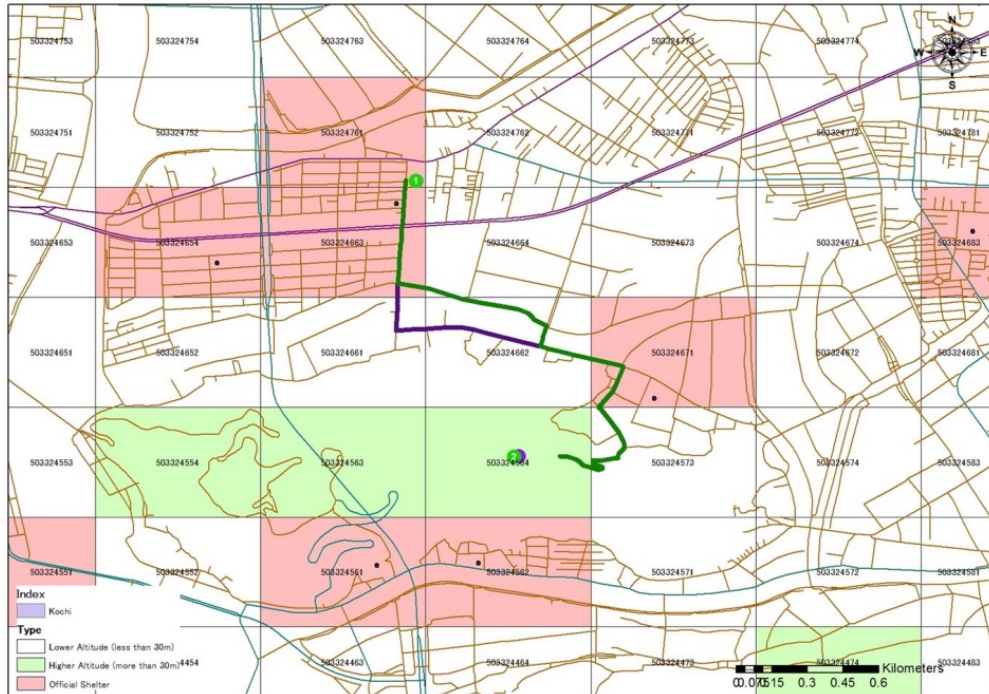


Figure 7-7 The Shortest Path of Walking and Car Mode in 500 Mesh

7.5. DERIVING A RESULT FROM STRONG-LEE

The shortest path for car evacuation is shown in Figure 7-8, and it shows the effective area of each shelter. Some shelters have wide range of effective area and those were marked by red stars in Figure 7-9 (safe shelter). Routes of the shortest path of cars are overlapping in the some routes and those are marked by green solid lines (shortest path by car). These lines are the shortest path for many evacuees and it can be prospected congested routes. The black stars were selected among the bridges in Kochi city. These bridges make important connections and if these have problems to path, disconnected, many evacuees can be isolated in hazard area or their evacuation distance will be increase dramatically. Here I found three points of STRONG-LEE method, (1) popular shelters based on the shortest path, red stars, (2) popular routes, green lines, and (3) important connection, bridges, black stars.

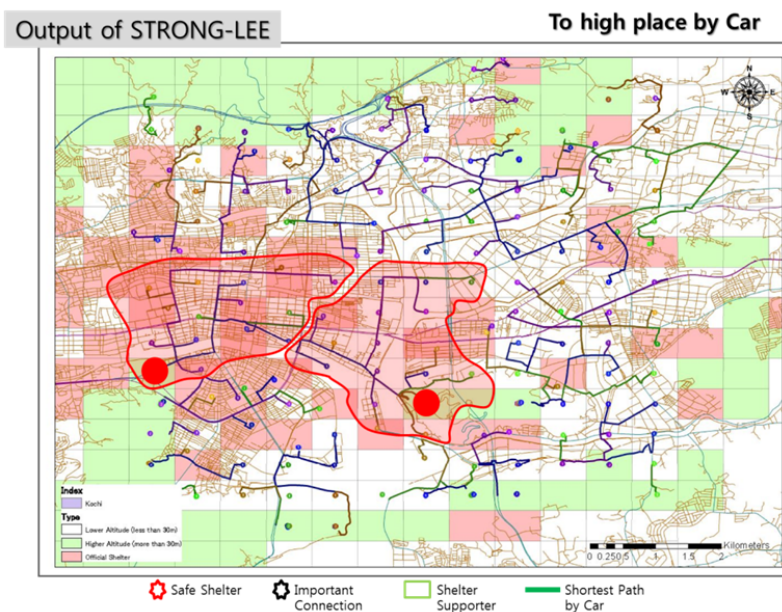


Figure 7-8 The Shortest Path to Reach the Nearest Safe Area by Car Mode

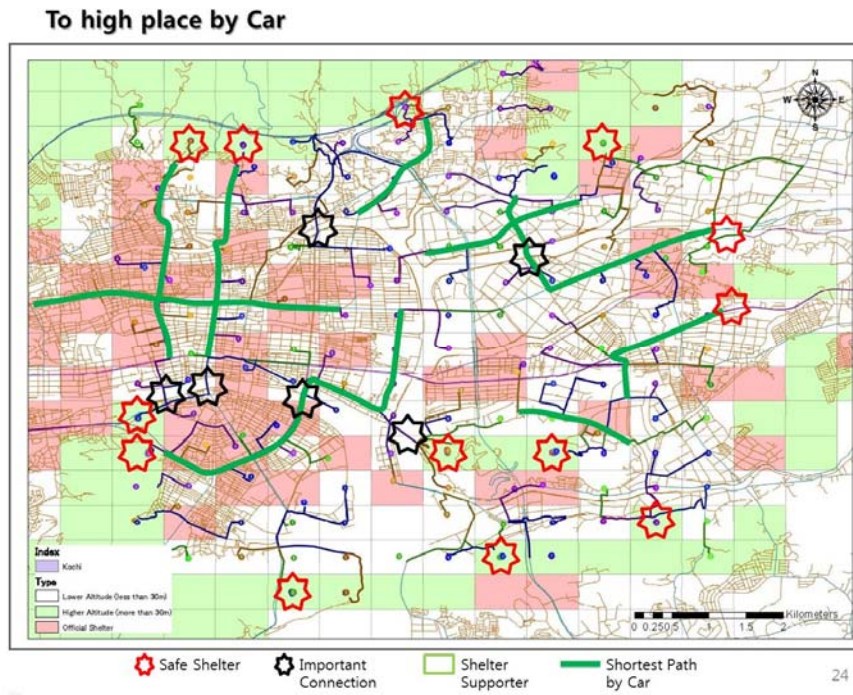


Figure 7-9 Results of STRONG-LEE Method (Map Base)

Figure 7-9 can be overlapped to photo of Kochi city shown in Figure 7-10, and those markings indicate the shelters in higher place, congested road for path, and bridges.

Here I decided the evacuation routes for car mode, but it is needed to consider the parking zone for evacuation mode. To complete the plan for the car evacuation to the high place, I supposed the parking area, called shelter supporter, near the evacuation points. Normal shelters did not consider the car evacuation, but it takes too much time to prepare new space for parking in the developed urbanized area. So, car parking near the shelter and car evacuation should be designed at the same time. If the place has wide space, play ground in school or parking area in a hospital, it can support the parking problems, when evacuees use the car mode to reach the safe shelters. These places shown in Figure 7-10 can be a control points of evacuation plan to guide and divide the traffic flows or assigning of volumes.

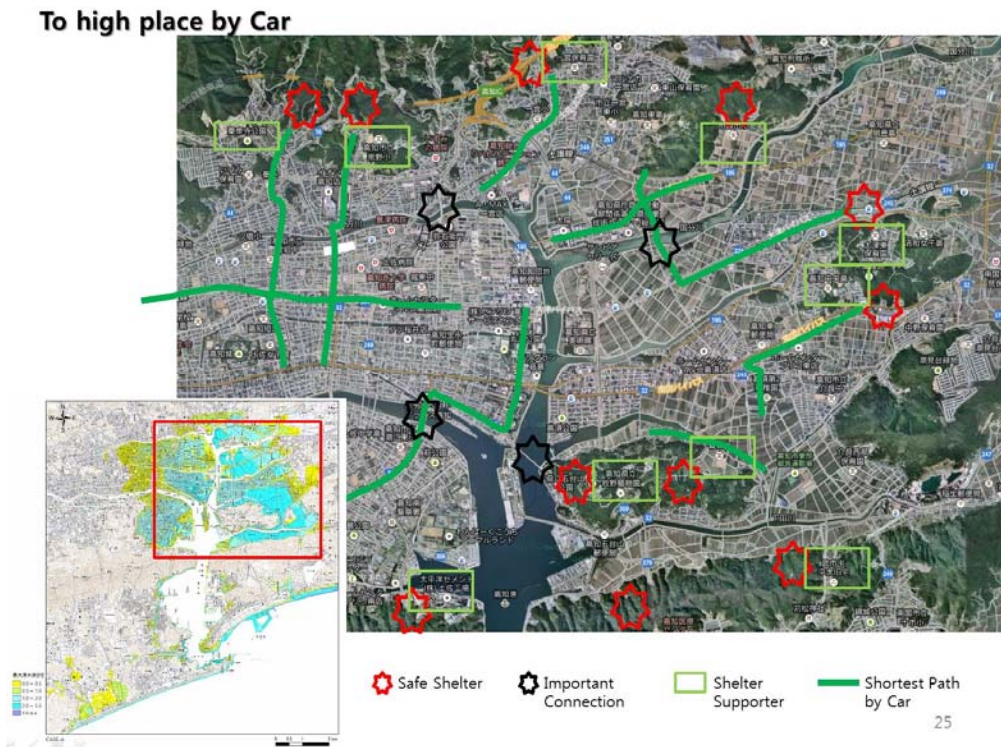


Figure 7-10 Results of STRONG-LEE Method (Photo Base)

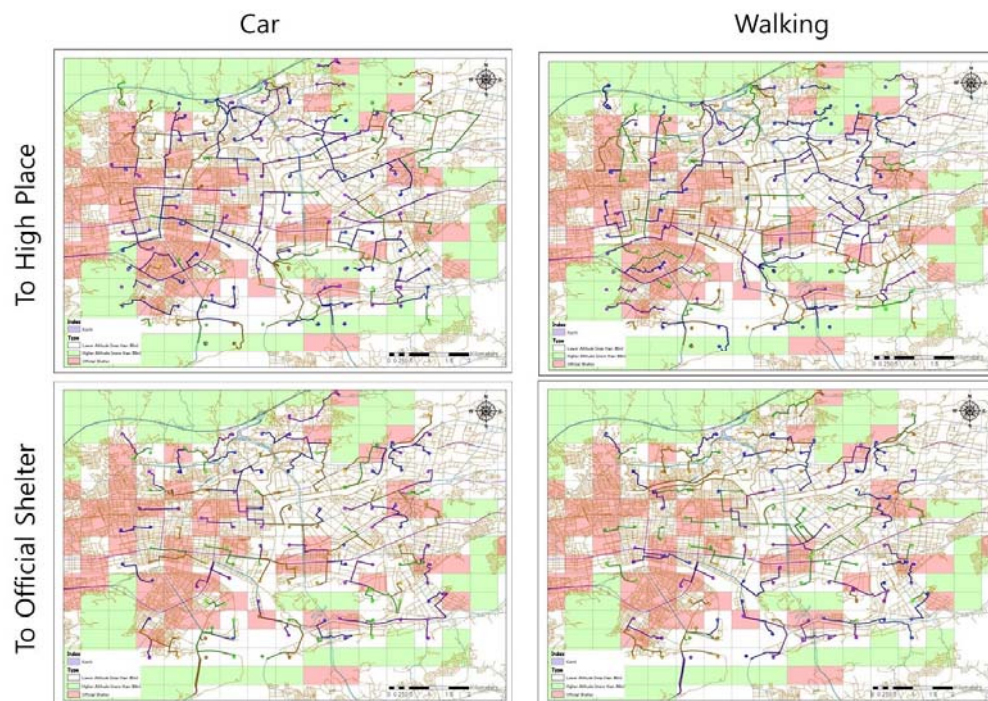


Figure 7-11 Results of Four Cases of STRONG-LEE Method (Map Base)

The brief results of STRONG-LEE are shown in Figure 7-11. Routes for walking and car mode were divided, and I assumed the destination of evacuation “to official shelter” and “to high place”. Main modes for discussion are walking and car; there were less cases of bicycle and bike evacuation (less than 1%; ARIS, 2012).

Average evacuation distance of car mode to safe areas, officially designed shelter or high place, are shown in Figure 7-12. If evacuees make destination to shelters rather than high place, average distance is shorter. However if evacuees escape to high place, these distances increase because the center of urbanized city is plat area and far from the mountain.

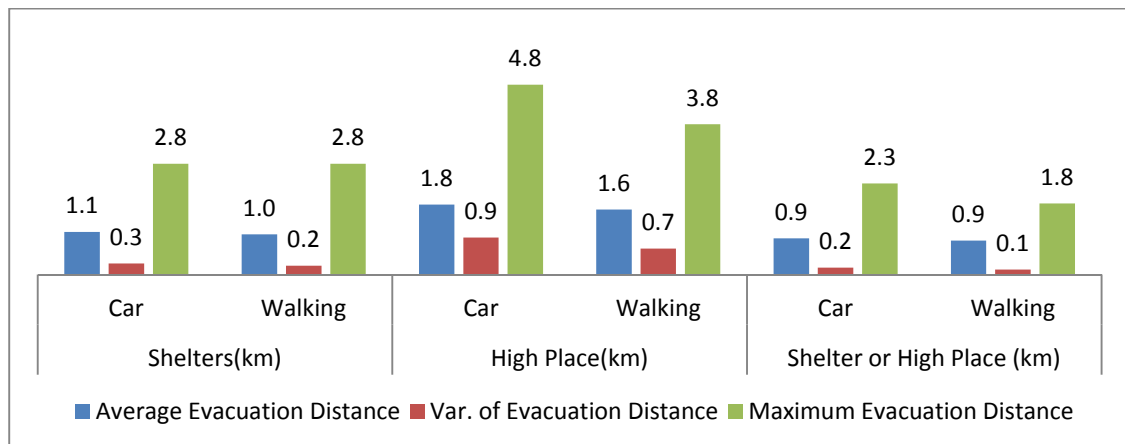


Figure 7-12 Evacuation Distance in Kochi City (STRONG-LEE)

Chapter 8 CASE STUDY

8.1. GEOGRAPHICAL CONDITION

For better comparison on the geographical conditions, the tsunami damaged areas were divided into two parts: Rias areas and plain areas. The Rias areas contain IWATE and MIYAGI prefectures, which have mountains near the residential areas and small fishery sectors in the lower lands. These areas are characterized by low population density and sites of fishing industry, which were historically recognized as areas that are vulnerable to tsunami (such as Minamisanriku, Onagawa, and Otsuchi). On the other hand, the plain areas are of relatively wider areas allotted for agricultural farm, characterized by cities with comparatively higher population density (such as Sendai, Iwanuma, and Yamamoto) than others [LEE et al. 2013].

Here, three cities from Tohoku, Japan, were chosen as samples for the comparison of evacuation behavior: Iwanuma, Yamamoto and Otsuchi. Iwanuma (61km²) and Yamamoto (64km²) were planned area in terms of urban planning, and the regions are located in plain areas, whereas Otsuchi (201km²) is located in a Rias area, which was reported as one of the serious damaged areas. Other cities are a mixture of high and low density areas, or plain and Rias areas together. These three cities were chosen using the observed comparable characteristics such as similarity in size and road length but of different population densities. The basic information of Iwanuma, Yamamoto, and Otsuchi is shown in Table 8-1.

Table 8-1 General Information for the Three Cities [LEE et al 2013]

	Otsuchi	Iwanuma	Yamamoto
Geography ¹⁾	Rias	Plain	Plain
Population (person) ²⁾	15,276	44,187	16,704
Area (km ²) ³⁾	201	61	64
Planned Area (km ²) ⁴⁾	30	61	64
Population/Planned Area (person/ km ²)	509	724	261
Type ⁵⁾	City	City	Rural
Number of Shelter ⁶⁾	37	14	11
Road Length (m) ⁷⁾	254.8	329.8	315.5
Height of tsunami (m) ⁸⁾	12.6	8.8	N/A

¹⁾ Ministry of Land, Infrastructure, Transport and Tourism, ²⁾ Statistics Bureau, Director-General for Policy, Planning & Statistically Research and Training Institute, ³⁾ Geospatial Information Authority of Japan, ⁴⁾ Digital Japan Portal Web Site, ⁵⁾ Archive of Reconstruction Supporting Investigation, ⁶⁾ Disaster Prevention Information, ⁷⁾ Ministry of Land Infrastructure, Transport and Tourism, ⁸⁾ Japan Weather Association

8.2. EVACUATION STARTING TIME

The citizens living in the Rias area (Otsuchi) were found to have evacuated earlier than those in the plain areas shown in Figure 8-1. Around 50% of the evacuees in Otsuchi who evacuated on foot started within 25 minutes after the earthquake, while those in plain areas of Yamamoto started to evacuate within 40 minutes. In Yamamoto, for the rest 50% people who evacuated on foot, it might have slower to use car mode. The median EST (Evacuation Starting Time) value of car mode in the Rias area is 22 minutes faster than that of the plain areas (paired t-test, $t=-14.650$, $p=0.000$). The EST between walking and car mode showed that car mode is faster than walking mode in Otsuchi and Yamamoto but there was no significant difference (paired t-test, $t=-1.852$, $p=0.072$) in Iwanuma. Moreover, it is also safe to say that the EST in the plain areas is later than that of the Rias area (paired t-test, $t=18.462$, $p=0.000$).

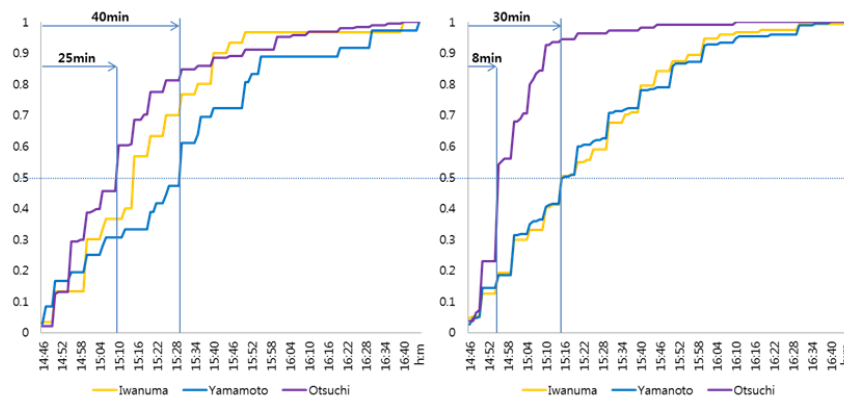


Figure 8-1 Cumulative Relative Frequency of Evacuation Starting Time for Walking (Left) and Car Mode (Right): Iwanuma (N=134trips), Yamamoto (N=238trips), Otsuchi (N=397trips)

8.3. EVACUATION DISTANCE

Figure 8-2 shows the distribution of ED (Evacuation distance) in the three cities. The average ED of walking and car are 321m and 2.3km, respectively. In the ED of walking mode, 95% of people walked to shelters in less than 1.5km, while 50% of them reached their evacuation destination in less than 300m. It may show the maximum and the median value of ED when they evacuate on foot.

Using the car mode, the plain area (Iwanuma and Yamamoto) movements were measured to be three times longer (3km) than the Rias area (Otsuchi) when comparing the median. The differences among lines show that the variations of walking mode are smaller than the car mode. This is accounted to the difference in the limitations of human level of physical capacity. The case of car mode does not have limitations on distance, so evacuees can easily direct to their preferred destinations. In the case of car mode, ED of plain area is longer than ED of Rias area as observed from the distance.

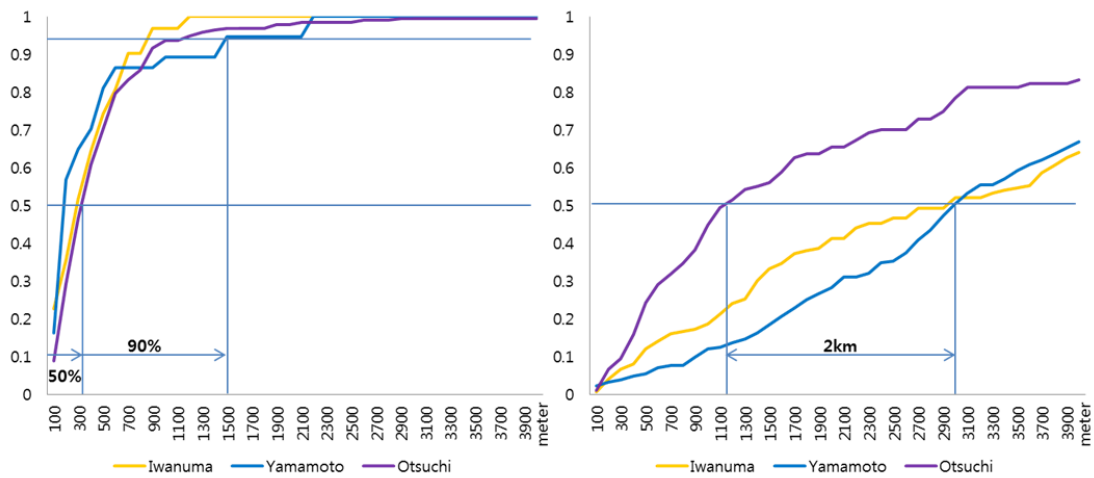


Figure 8-2 Cumulative Relative Frequency of Evacuation Distance for Walking (Left) and Car Mode (Right): Iwanuma (N=134trips), Yamamoto (N=238trips), Otsuchi (N=397trips)

8.4. EVACUATION SPEED

The average ES (Evacuation Speed) of walking and car mode are 2.5km/h and 14km/h, respectively, in these areas as shown in Figure 8-3. By analyzing the 5-minutes interval data, it was found that the average ES of walking mode did not exceed 8km/h. The ES of car mode is found to be in the upper range of 8km/h boundary. These show that evacuees who used car mode with a speed not less than 8km/h had successfully escaped. As a matter of course, the average ES of car is higher than the average ES of walking. Moreover, the plain area (Yamamoto) is faster than Rias area (Otsuchi) and urban area (Iwanuma). It means that Yamamoto (plain and rural area) faced fewer congestion problems in the walking mode due to the fewer numbers of people in the area and that they were able to keep their own speed in flat lands. The ES of car mode was found to be the fastest among the cities for the same reasons. However, the maximum average ES of car mode did not exceed the 20km/h and the average ES of walking mode shows constant average speed, while the average ES of car mode was decreasing over time. While the numbers of evacuees have increased in time, the ES of walking is not greatly affected by the number of other

evacuees. But in the case of car mode is affected by other factors such as the road conditions. Finally, I can observe a relatively lower speed and shorter distance in Otsuchi (Rias and urban area).

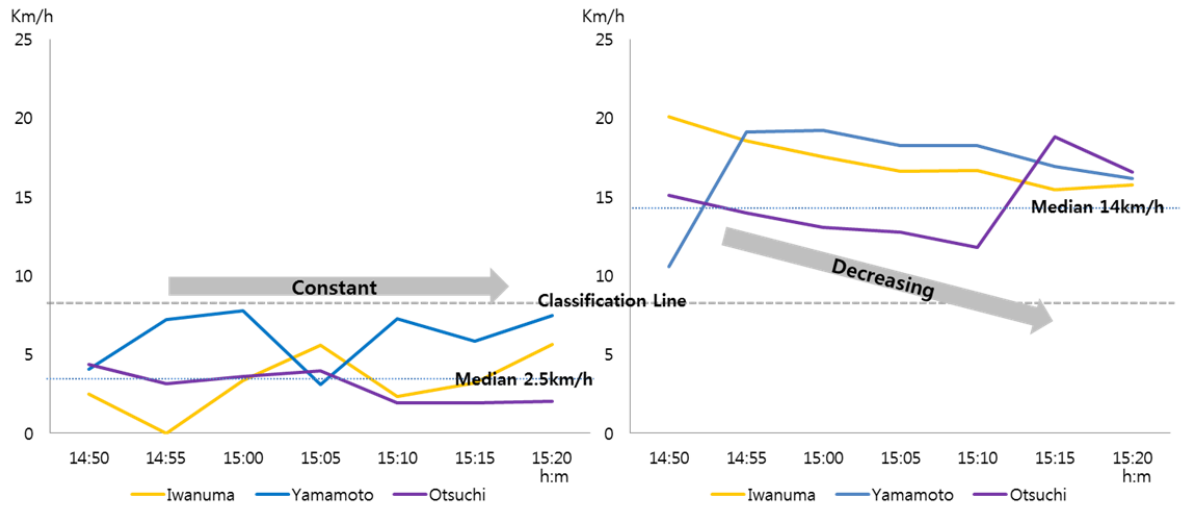


Figure 8-3 Evacuation Average Speed: Walking (Left) and Car Mode (Right): Every 5minutes

8.5. RESULTS OF THE QUESTIONNAIRES

The several results of the questionnaires were summarized to capture the actual scenario during the evacuation. It contains the written statement of emotions and thoughts of evacuees in deciding their actions during the tsunami disaster. One of the interesting questions was, “What made you (the evacuees) decide to use the car mode for evacuation?” as one important source of information to understand the evacuees’ tendency to prefer the car mode. Another question is, “What were the problems you encountered before you reached your shelters?” as I could find the main problems as the evacuees approached their shelters. Lastly, “What are the reasons for preferring shelters other than that of the nearest from your places of residence?” explains the main

reasons why some evacuees changed their destinations and the possibility of finding the temporal shelters before the inundation of the tsunami.

8.5.1. Why Did You Use The Car Mode for Evacuation?

In Figure 8-4, the answer of “Time/distance” links to the reasons related to the lack of evacuation time, long distance, and difficulty in reaching the areas on foot, while the answer of “together” explains that the evacuees wanted to meet their families or tried to save their assets before they decided to start their evacuations. ED of the plain areas is longer than that of the Rias area in Figure 8-2, and it may affect the mode share ratio of car. The “Time/distance” has a bigger portion in the plain areas (Iwanuma and Yamamoto) than in the Rias area (Otsuchi). Evacuees responded that the shelter is very far and that they have no options but to use the car mode. In the Rias area, on the other hand, evacuees tried to reach for their families.

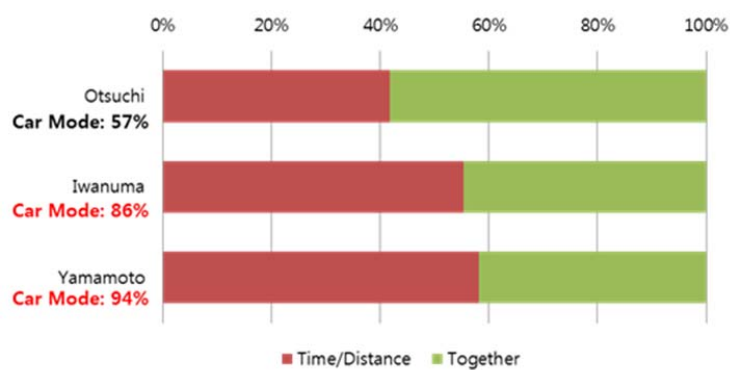


Figure 8-4 Answer for “Why did you use the car mode for evacuation?”

8.5.2. What Were The Problems When You Access The Shelters?

In Figure 8-5, the problem on “Accessibility” means evacuees had troubles from the ground geography, route search, dangerous roads and collapsed shelters in approaching the shelters, while “Capacity” contains information on traffic congestions and number of persons to stay. The problems on capacity occurred in almost all three areas and modes in approaching the shelters. In particular, the modes in Iwanuma (urban and plain area) have problems of over capacity because a high number of evacuees in urban area used car mode (86%) in addition to the serious congestion due to high population density in waking. In Otsuchi (urban and Rias area) the main problem was on the accessibility for walking because this area is the mountainous Rias area with complex and narrow roads. Otsuchi has accessibility problems for walking due to its natural geographical condition. The main problems in Yamamoto (rural and plain area) on the contrary are the accessibility on car mode, because 94% of the evacuees chose the car mode for evacuation, while the physical distance to shelter is comparatively longer.

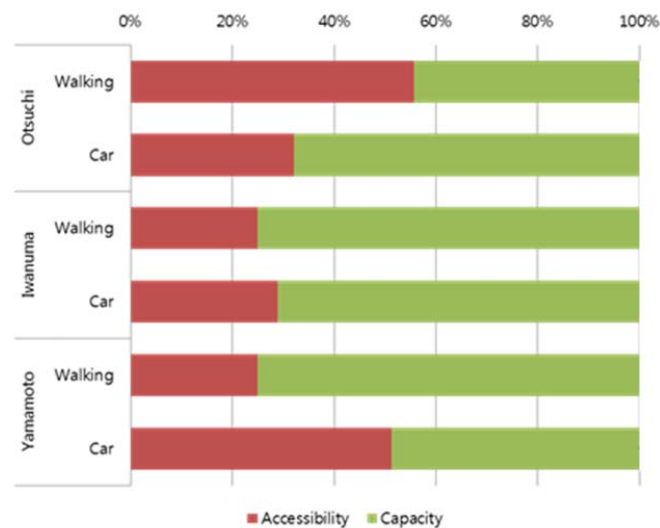


Figure 8-5 Answer for “What were the problems when you access the shelters?”

8.5.3. Why Didn't You Go To The Nearest Shelter?

Some evacuees were found to be preferring shelters other than that of nearer from them. In this disaster, Otsuchi (urban and Rias area) is one of the most seriously damaged cities; 8.22% of citizen died or are still missing. One of the main reasons in changing route instead of insisting for nearest path was “to contact family (walking 22%; car 38%) in this area. While in Iwanuma (urban and plain area) they changed their destinations because of the congestions (walking 18%; car 13%), more active escaping behavior was observed in finding the shelter than in the case of Otsuchi. Even though the evacuees in Iwanuma had to change their destination or route, the death ratio is lower than that of the other cases. In Figure 9-6, “Congestion” means that the access road has exceeded its capacity resulting to delays along the road. “Easy place” refers to the location of evacuees who were able to found safe area, and “family” shows effort in trying to reach for their family members and to evacuate together.

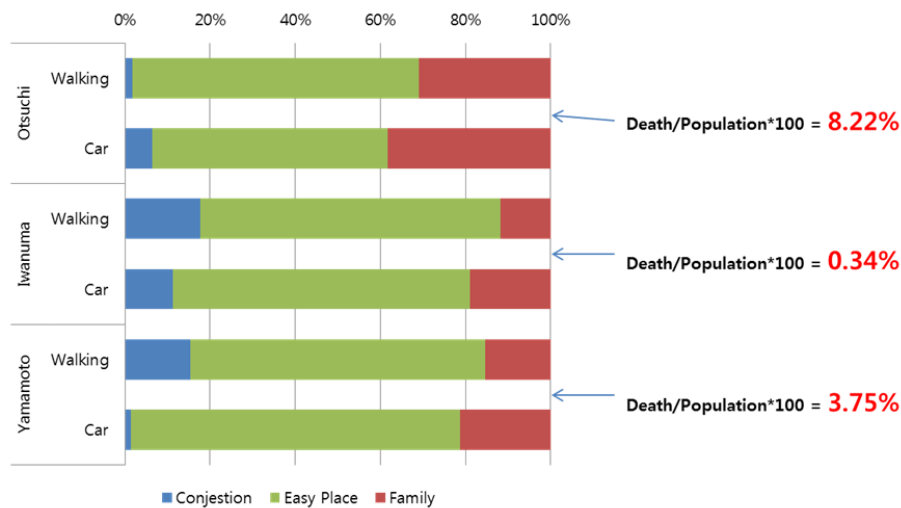


Figure 8-6 Answer for “Why you did not go to the nearest shelter?” The number of death: National Police Agency (NPA), Metropolitan Police Department (MPD)

8.5.4. Summary

Geographically, the Rias area is higher than the plain areas. The EST of Rias was faster than in the plain areas. Yamamoto has lower population density and EST was found to be the fastest in Otsuchi. However this area shows the highest death ratio among the three cities. Although 94% of evacuees used the car mode for evacuation in Yamamoto, its ES is faster than Otsuchi. Serious damage occurred in Otsuchi (Death Ratio: 8.22%) and only 57% of the evacuees used car mode in this area. The summary for these comparisons are shown in Table 8-2.

Table 8-2 Characteristics Summary of Three Cities (LEE et al. 2013)

Contents	Otsuchi (Rias)		Iwanuma (Plain)		Yamamoto (Plain)	
	Walking	Car	Walking	Car	Walking	Car
Geography	High		Low		Low	
Density	High		High		Low	
Evacuation Starting Time (50%)	Fast	Fast	Middle	Slow	Low	Slow
Evacuation Distance (50%)	Same	Short	Same	Long	Same	Long
Speed Variation	Constant	Decreasing	Constant	Decreasing	Constant	Decreasing
Median Speed	Slow	Slow	Fast	Fast	Fast	Fast
Median Distance	Same	Long	Same	Long	Same	Short
Reason Using Car Mode is Traffic Problems	Low		High		High	
Reason changing shelter is to evacuate with family	High		Low		Low	
Death Ratio	High (8.22%)		Low (0.34%)		Middle (3.75%)	
Mode Ratio of Car Mode	Low (57%)		High (86%)		High (94%)	

8.5.5. EST and Geographical Conditions

Citizens in Otsuchi started evacuation earlier than the other two areas and the difference of EST is almost 22 minutes in the car mode for 50% of the evacuees as shown in Figure 8-1. In this case, Otsuchi was already historically known to be a tsunami-prone area as shown from the records (1960, 1933, and 1896) even before the Tohoku earthquake incident which led to serious damages in 2011. The MLIT report (2012) shows that the 64.7% of citizens in Rias areas predicted that “Tsunami will come”, while 60.6% of citizens in plain areas otherwise predicted, “Tsunami will NOT come”. For the same height of tsunami which had reached the Tohoku area, there was fewer evacuation roads in Rias area than in the plain areas (Otsuchi: Area 201km², Load Length 254.8km; Iwanuma: Area 61km², Load Length 329.8km; Yamamoto: Area 64km², Load Length 435.5km, in Table 8-1). This inadequacy of evacuation roads can lead to more serious traffic congestions and citizens already might have understood this situation. It might force the citizens in Otsuchi to start evacuation earlier.

8.5.6. Shelter Choices and Evacuation with Family

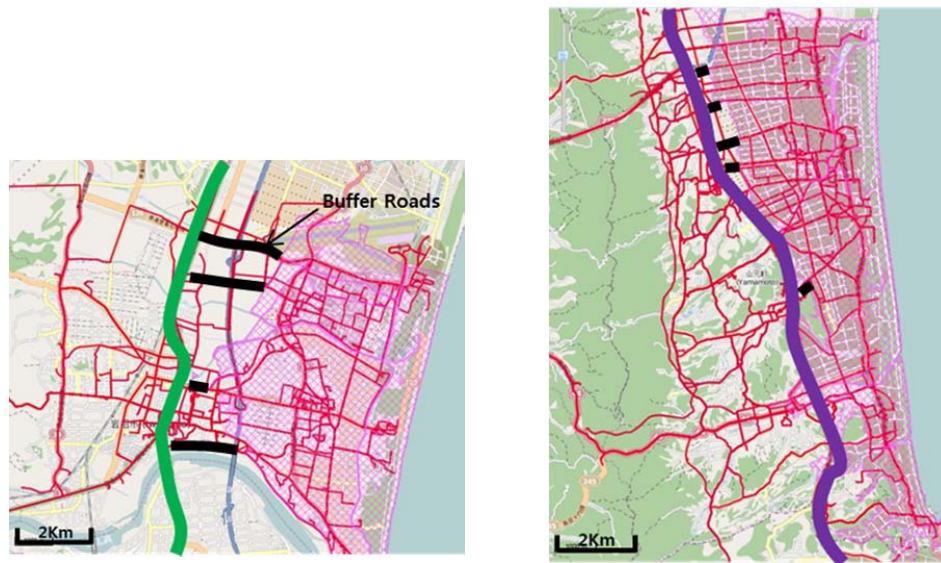
The maximum distance of walking mode is less than 1.5km as shown in Figure 8-2 and this seems to be a physical ability for human. Although walking had some accessibility problem (39%, Figure 8-5), still 51% of the evacuees decided to derive in order to reach their families shown in Figure 8-4. Moreover, 57% of the evacuees in Otsuchi used the car mode to escape with families as shown in Figure 8-4, wherein 31% of them did not go to the nearest shelters as shown in Figure 8-6. As a result, these behaviors generated higher death ratio (8.22%, Table 8-2). Even though citizens in Otsuchi started evacuation in earlier time, they had slower ES (Table 8-2) due to the lack of evacuation roads and negligence to seek their nearest shelters to escape together. As a result, if an evacuee is alone, it seems better to evacuate alone.

8.5.7. Congestion and Death Ratio

In Iwanuma, citizens faced the congestion (capacity) problems when they accessed their shelters (walking: 76%, car: 63%, Figure 8-5). Around 17% (walking: 18%, car: 16%, Figure 8-6) of them changed their destinations from the nearest shelters to others which are relatively farther due to these congestion problems. In the case of Yamamoto, citizens had capacity problems on their personal human levels to access their shelters (walking: 76%, car: 50%, Figure 8-5) and congestion problems (walking: 16%, car: 2%, Figure 8-6) for car mode. These congestions were observed in national routes near the hazard area (KSP, 2013, Chunichi, 2011). However these two cities show a ten times difference in their death ratios (Iwanuma: 0.34%, Yamamoto: 3.76%, Figure 8-6). This difference can be viewed in the map below. The congestion lines in Figure 8-7(b) of Iwanuma (National Route 4), are observed outside the tsunami inundation area, while Yamamoto in Figure 8-7(c), shows congestion mainly inside the hazard area. Both in Iwanuma and Yamamoto long congested lines were observed in the National Route 6, but these queues were in the hazard areas only in the case of Yamamoto. It yields more victims in the same plain area and the similar size of land.



(a) Otsuchi



(b) Iwanuma



(c) Yamamoto

Figure 8-7 Evacuation Route (MLIT 2013) and Congested National Highways (LEE et al. 2013)

8.5.8. Congested Lines and Inundation Areas

When citizen evacuated from the tsunami, they had to move along a direction perpendicular to costal lines to avoid immediate risks from the tsunami wave shown in Figure 8-7. The evacuees tried to access the main roads or national routes that connect to safer places. The congested lines

observed in the parallel roads from coastal line in Figure 8-7 (b), (c): National Route 4 and National Route 6. This is because; the evacuating cars were coming from every corner of the city area, which resulted to over congestion. However the locations of these two national routes are different, in Iwanuma this road is longer distance from the inundation area than Yamamoto's. Even though evacuees are locked in a congested line, if particular roads are located in a safe area away from tsunami, there is a high possibility to save lives. However, the ES cannot guarantee safety. The roads between the national routes and hazard area could be served as "buffer roads" which could absorb the evacuating trips to safe area. So it could effectively save the evacuees.

8.6. FINDINGS

I discussed evacuation behaviors based on the MLIT data. These three cities showed the significance of the provisions for an evacuation route and evacuation distance. In deciding for the evacuation route, two issues are necessary to be considered. First, "evacuees who derived might be faced to serious dangers, when the congestion occurred in the hazard area", "evacuation time can be increase when evacuees want to meet the family", and "the evacuees who walked have to consider their physical strength during evacuation and reduce the evacuation distance and time", so evacuees have to consider "self-safety" while they are escaping. The second point is, "the evacuation route should have enough buffer roads to move additional cars from the hazard area to safe area" and "these buffer roads are located in a direction perpendicular to coastal lines to prevent the expected dangers."

Furthermore, the following conclusions were realized. It is safer to use the safe roads than take risks in using the uncongested roads for the purpose of evacuation using the car mode, a buffer road could absorb the evacuation traffics, and evacuees who aim to escape with their families usually do not use the nearest shelter. Additionally, the relationships between national highway

and buffer road should be clarified in the future work. To know the capacity drops or absorbing volume of traffics in the buffer road, more detail cases, changes of traffic parameters (speed, density and flow), should be collected and discussed in the microscopic point of view to lead the optimal car evacuation strategies. The other hand, self-safety could be research issues not only education and practice drill for prevention and evacuation but also evacuation crowd and self-organized evacuation models.

Chapter 9 DISSION AND CONCLUSION

9.1. WHO WOULD BENEFIT FROM USING CAR MODE?

From a macroscopic point of view, higher population density and longer evacuation distance lead to serious congestion. If the evacuation distance is too long, evacuees could fail to evacuate from the hazardous areas. This research derived the EASY-LEE Chart to compare the different conditions of facilities and population, categorizing them into four sessions.

Sessions I and II do not benefit from using car mode for evacuation. Therefore, it is recommended in these sessions to identify the shortest pedestrian route for easy evacuation. Strategies to reduce the mode ratio for car use are necessary in Session II.

In Session VI, serious congestion could result from the high population density, and none of the enumerated modes are able to provide full security and assurance. Therefore, it is recommended that provisions are implemented for temporary refuges and shelters. Although there are no alternatives to car mode and car mode does not guarantee safety, the use of car mode should not be prohibited.

In Session IV, the mode ratio for cars was higher than others, congestions were limited and high driving speeds were reported. Therefore, this session has the largest advantage among all sessions in using car mode. When designing evacuation routes in session IV, the safest route (e.g., higher roads) and the shortest path should be carefully considered in order to cope with the long distance.

In the case of Yamamoto, the mode ratio for cars is 0.94, as shown in Table 1-1. This the highest place where evacuees used car mode for evacuation. Here, more than 90% of the residential area is categorized as Session V (Figure 9-1). In Yamamoto, the evacuation distance is very far and

the population density is low, so the benefit of car mode is high, and the actual usage of car mode was among the highest of all cities.

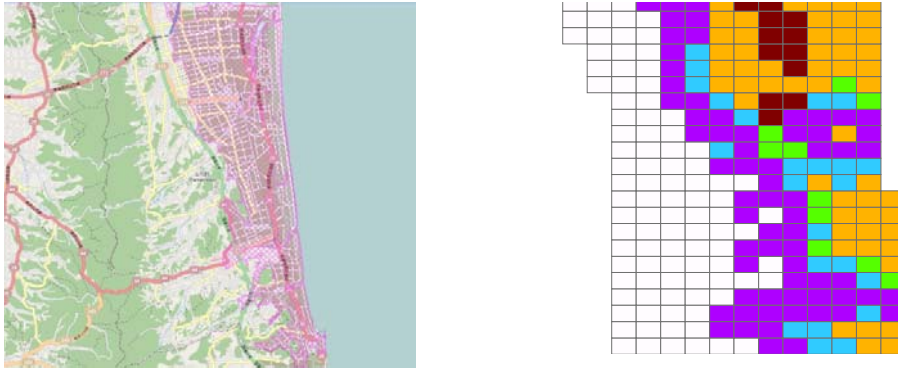


Figure 9-1 Car Mode and Residential Area in Session V and VI (Yamamoto)

9.2. ADVANTAGE OF EASY-LEE CHART

From a macroscopic point of view, this research is limited to the use of specified variables using available data. In order to understand the panic at the time of evacuation, attempts were made to contain relationships among the modes using CAM and basic abilities of modes (maximum and average values). The input parameters (population density and the average distance to shelter) and the output (Session I~VI) were simplified and shown in one chart. This can assist in devising the

general guidance when planning the renewal or reinforcement strategies, and also to understand the given transportation systems at the time of disasters. It can also be used for government officers to design evacuation plans.

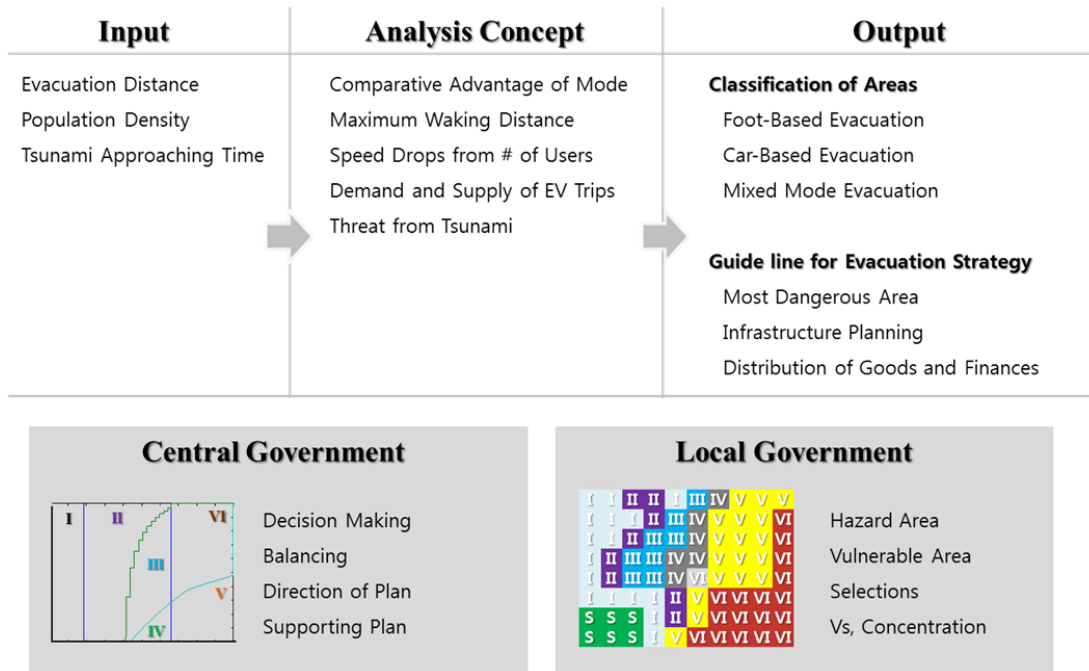


Figure 9-2 Discussion for EASY-LEE Method

9.3. ADVANTAGE OF STRONG-LEE CHART

To derive exact plans for evacuation route, shelter location, reinforcement of road, real network was used to STRONG-LEE method. This method combined the free size of mesh data and road, which shows the characteristics of each area and usable road for each mode based on the quickest path. Conceptual capacity of shelter and road are simulated in the map, and important link and

junction can be shown in the map. When I focus on the car evacuation, the places for shelter supporters especially emergency parking area can be selected near the evacuation point for car routes and path. Official control points of policemen and evacuation guiders also can be assigned based on these routes.

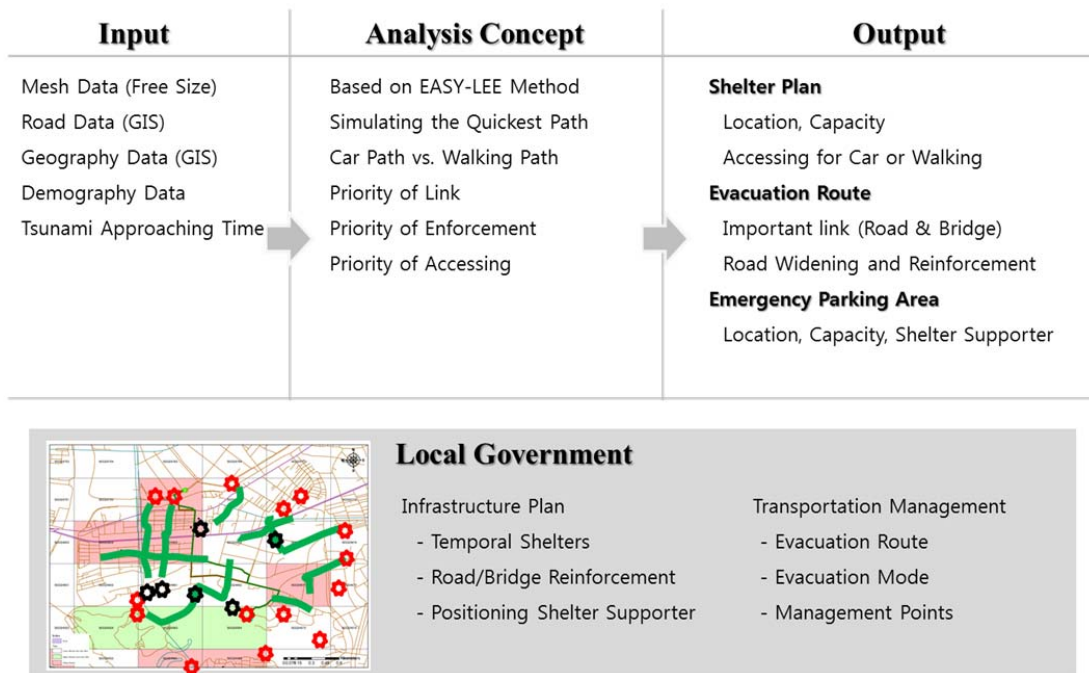


Figure 9-3 Discussion for STRONG-LEE Method

9.4. Application Process

In order to derive the detailed evacuation plan, the EASY-LEE method can be used to classify the areas according to the different evacuation modes using general information, evacuation distance, population density, and Tsunami approach time. This classification can easily identify the most dangerous areas and the highest congested areas. Based on these classifications, the road network is applied in order to determine the exact evacuation route and mode in the STRONG-LEE method. This method shows the evacuation route as the shortest path lines of EASY-LEE, and

also supports the feedback on EASY-LEE. While EASY-LEE method defines the characteristics of wider area, STRONG-LEE method gives an detail information of main evacuation routes on the road network.

The size of the unit is flexible for any objective. In this research, 500 mesh data was used as the smallest unit, but this is a limitation of the available data, not the analytical method.

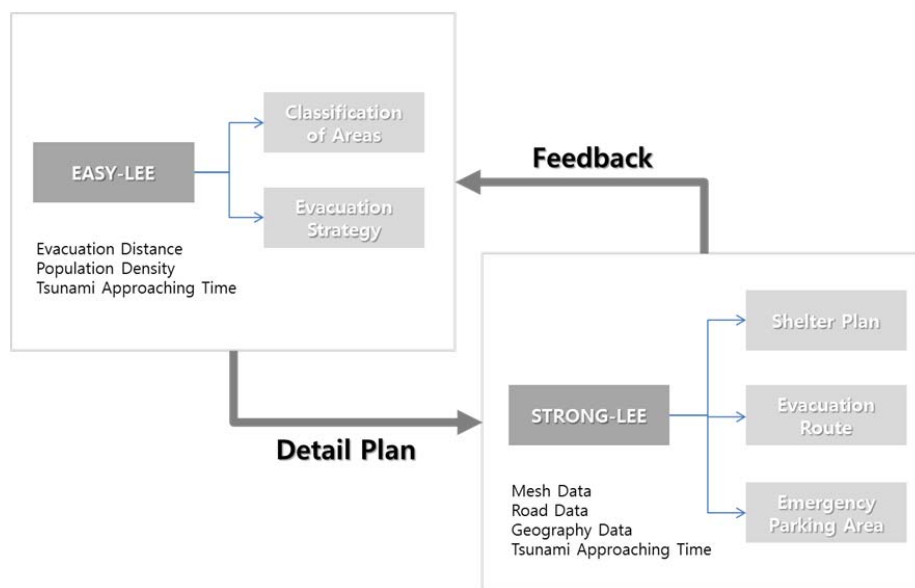


Figure 9-4 Detail Plan and Feedback Process

9.5. Evaluation of the Model

9.5.1. LIMITATIONS

The EASY-LEE method has some limitations when applied. For example, this research was only able to use average values to derive the sessions. The sessions can vary and results yielded may differ depending on these average values. If this chart is to be applied to smaller regions, it is recommended to carefully consider the use of average values. The EASY-LEE method only

reflects special cases and partially considers MET, EST, EDS and ESM as ideal conditions for the purpose of comparison. Moreover, the chart has to consider justifiable situations and specific values when applied to smaller regions. The EASY-LEE Chart could be modified to incorporate real scenarios that consider geographical differences and a full population spectrum. Future researches should also include these cases as well as variations in speed (walking and bicycle modes) and the conditional mode ratio.

The other limitation is that the reactions of evacuees were not considered. The evacuation manuals for citizen who lived in the hazardous area did not recommend car mode for evacuation. However, approximately 60% of evacuees chose car mode. This research did not discuss the effects that giving information may have on the person when choosing their mode of evacuation. In future researches, the reactions of evacuees when informed of a specific strategy should be taken into account. The conclusion of this research does not contain a detail discussion on who knew the recommendations for evacuation planning and who the most sensitive evacuees were.

9.5.2. FLEXIBILITY OF THE METHOD

While the exact inundation time of the tsunamis is unknown, MET can be predicted in order to devise a more reasonable EASY-LEE method. If one region has 5min MET, people do not have alternatives modes of evacuation. They should walk or run to a shelter or safe area, and the distances might be within 100m. Otherwise, many people could fail to evacuate. In this case, the EASY-LEE method should be separated into two parts that will show Sessions I (Best for walking mode) and IV (dangerous, need more facilities) because $d_{B,C}=d_{A_P,C}$ in equation (4.3). Each city and area has a different expected MET, so this line will vary depending on the prediction of time at the macroscopic level.

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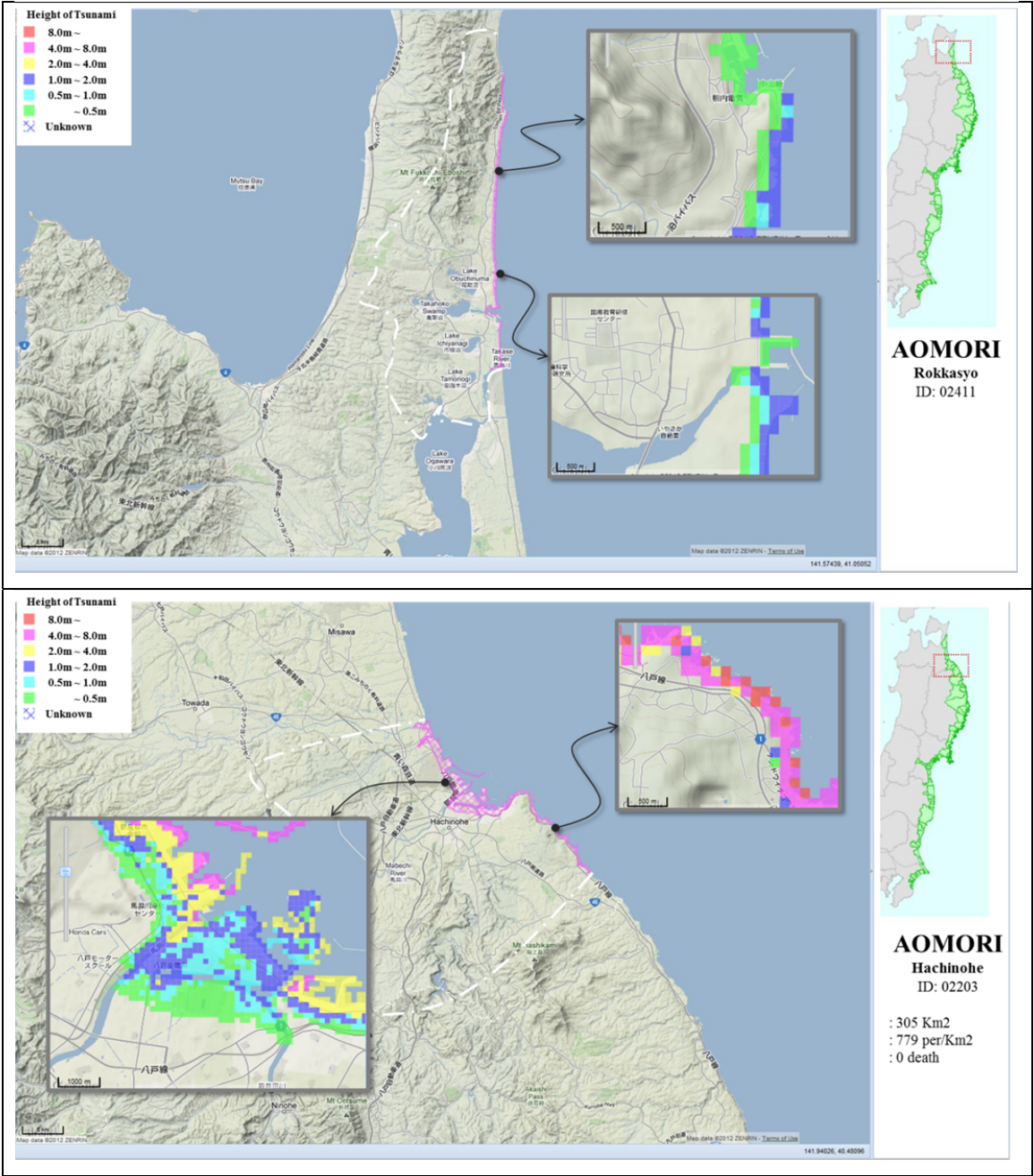
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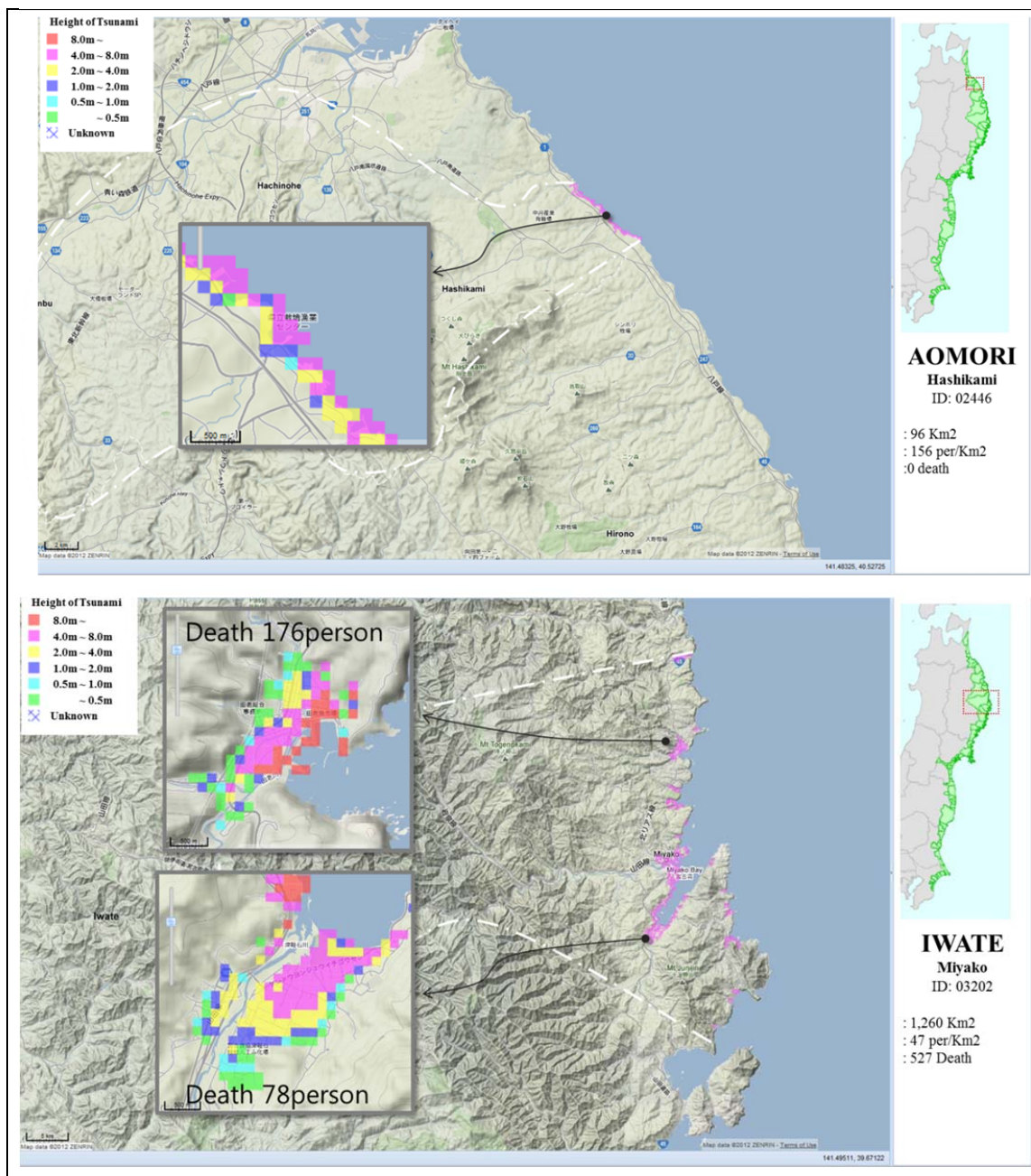
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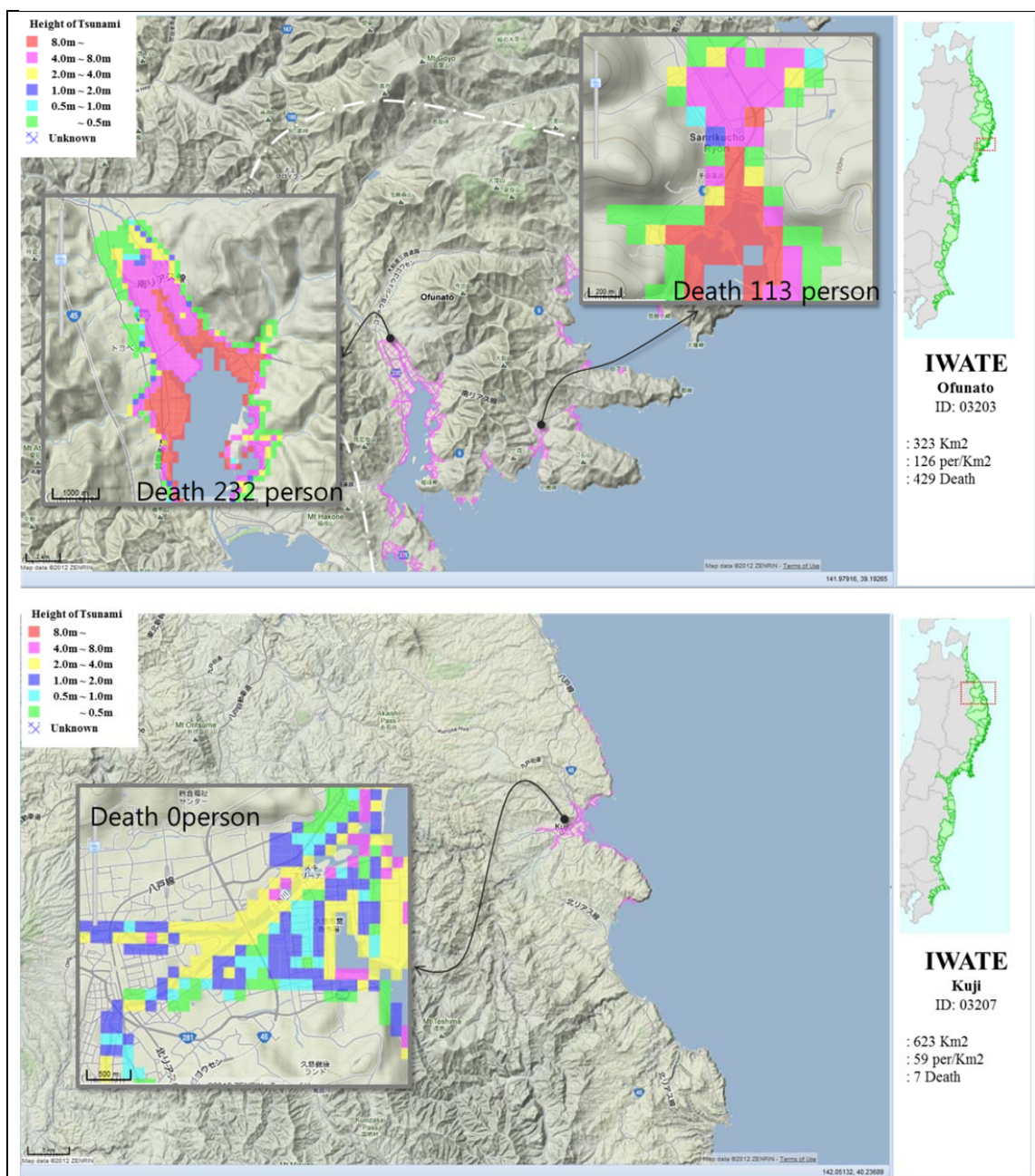
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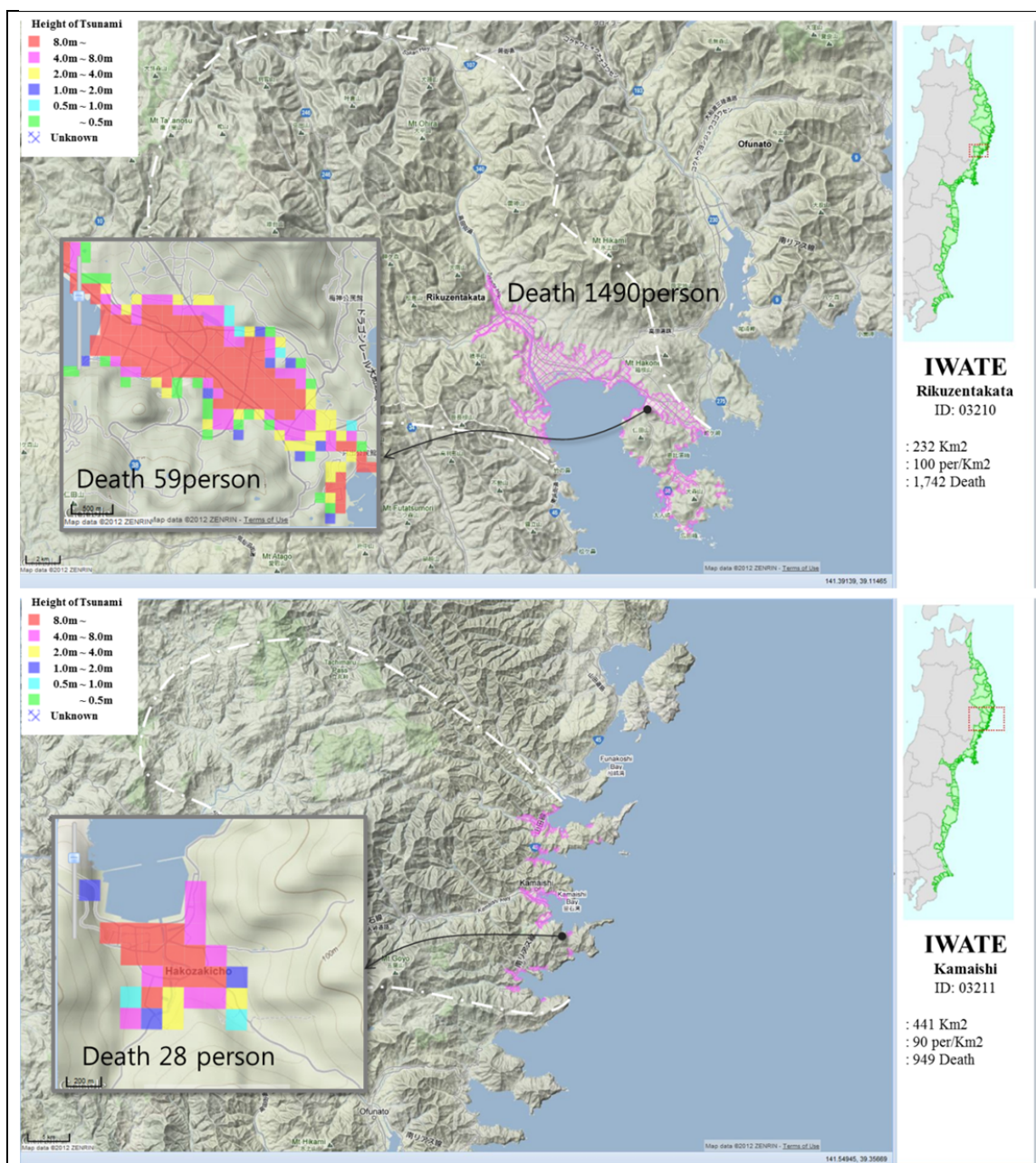
Appendix

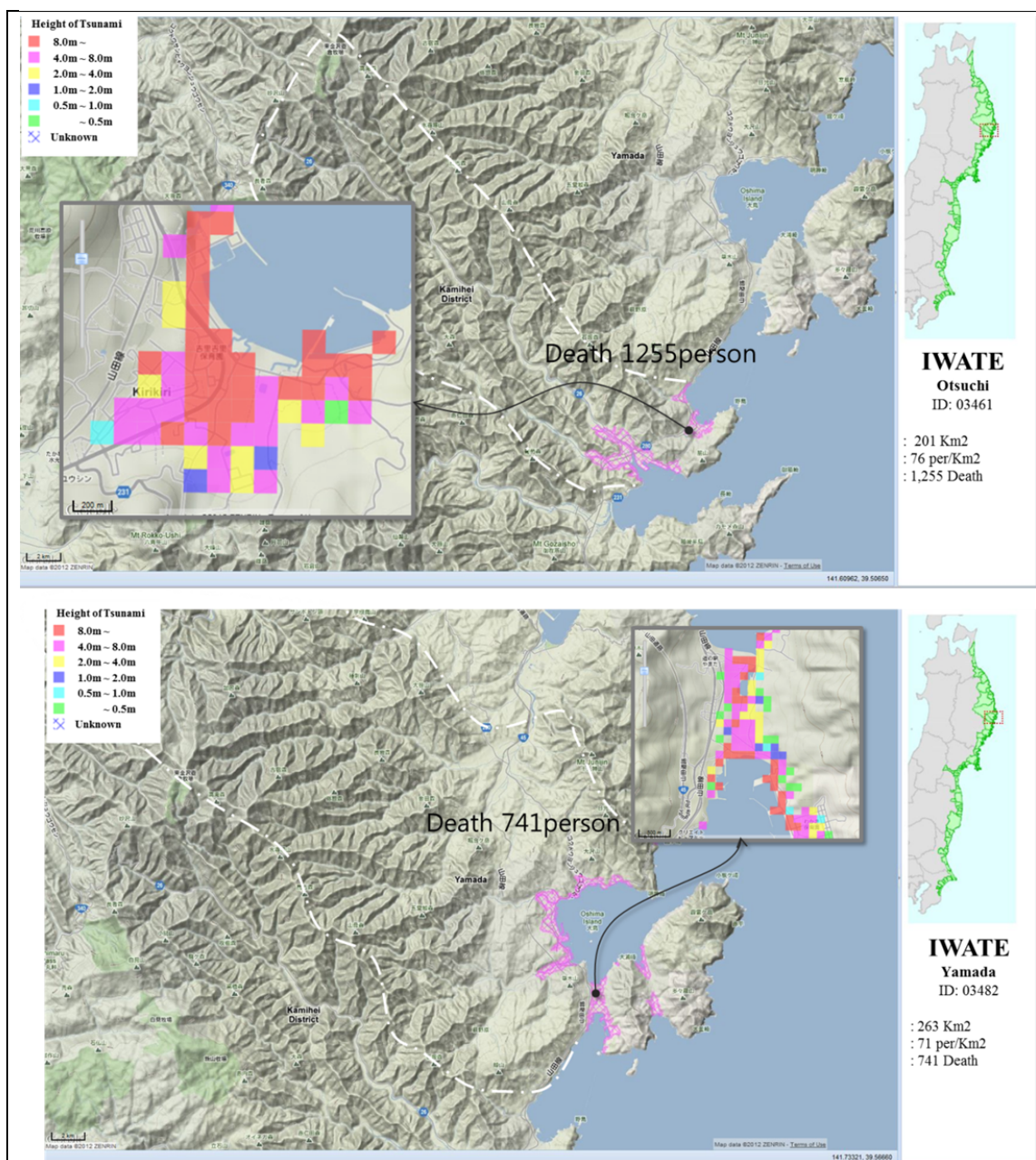
A. Geographical conditions

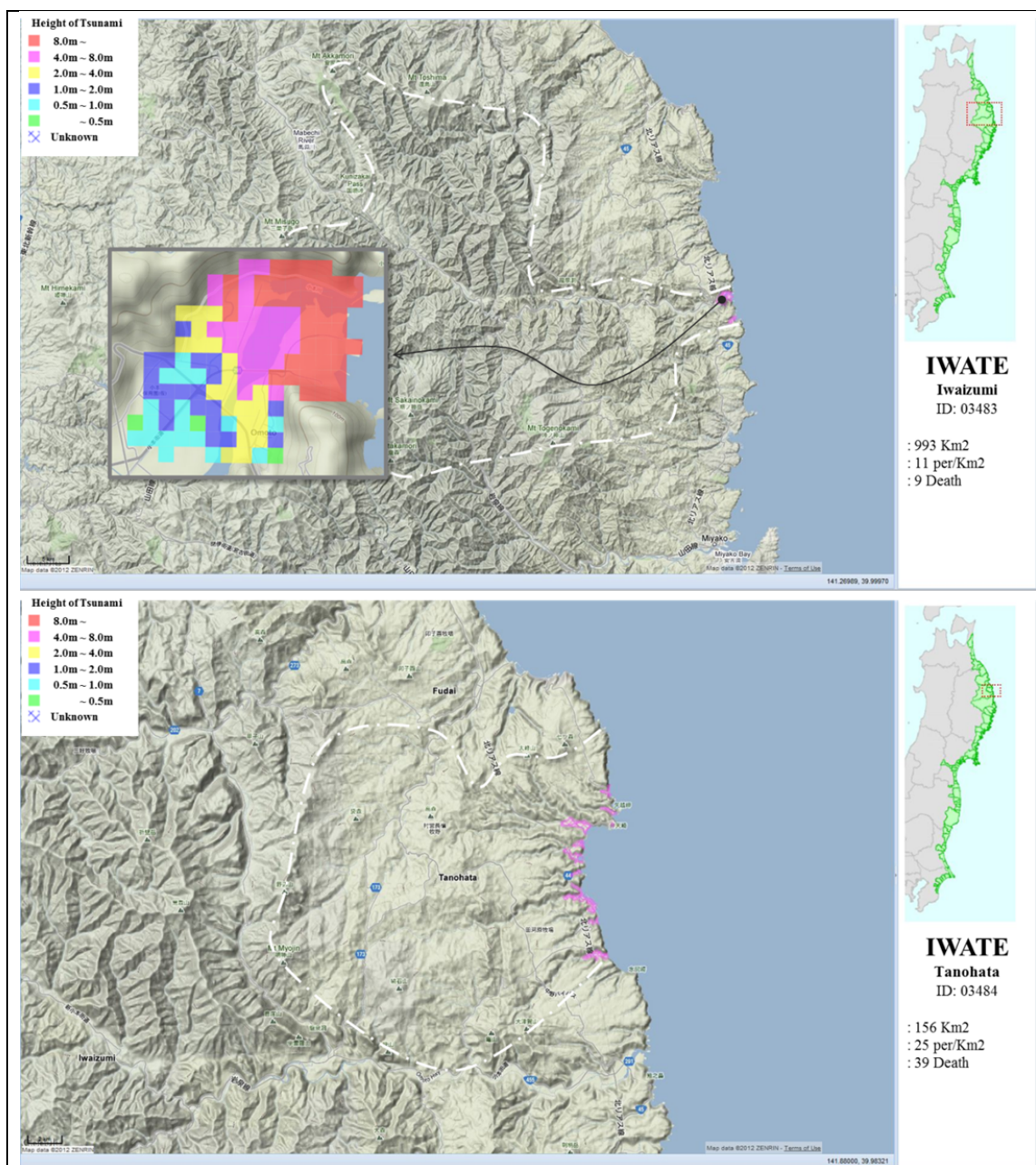


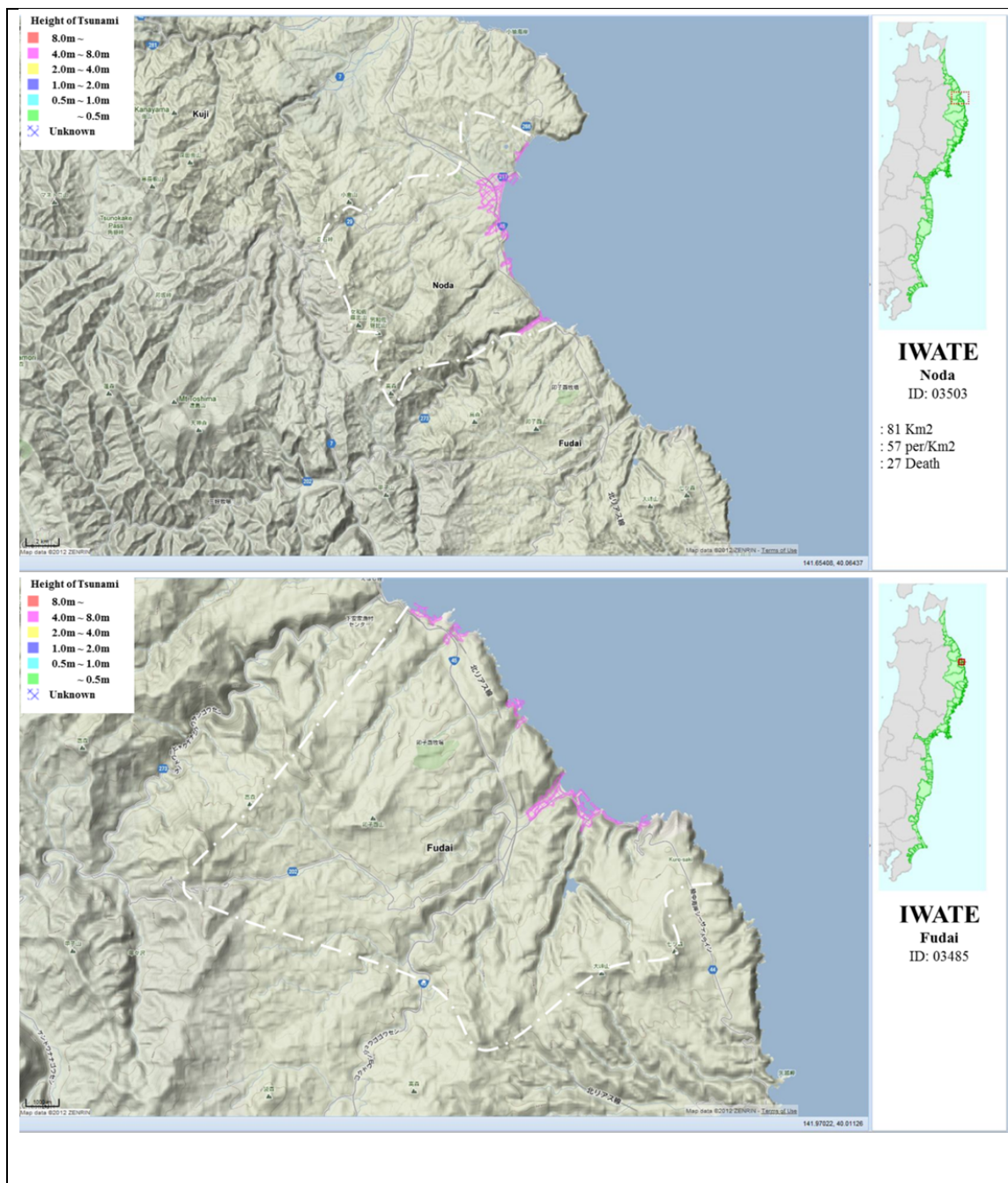


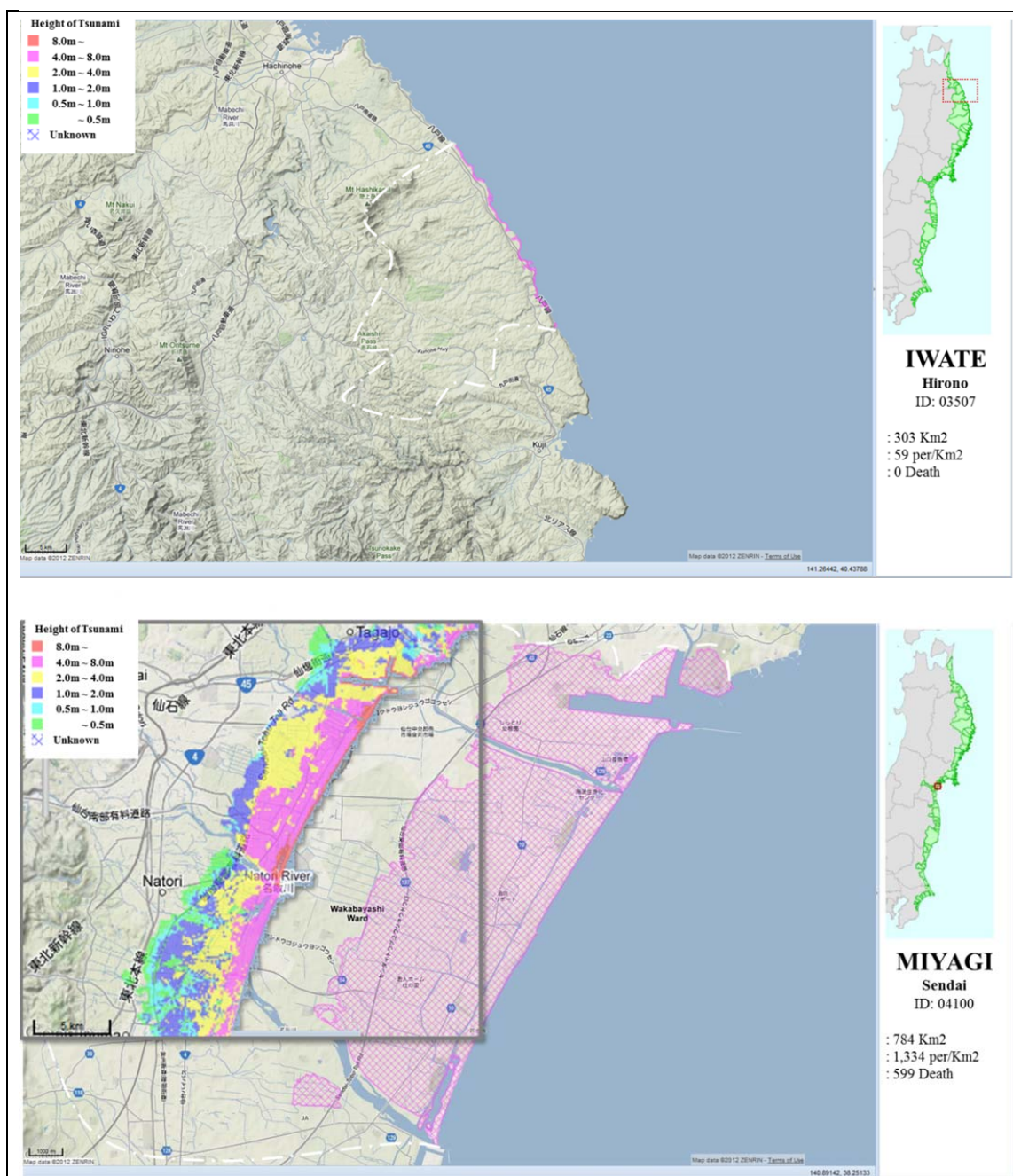


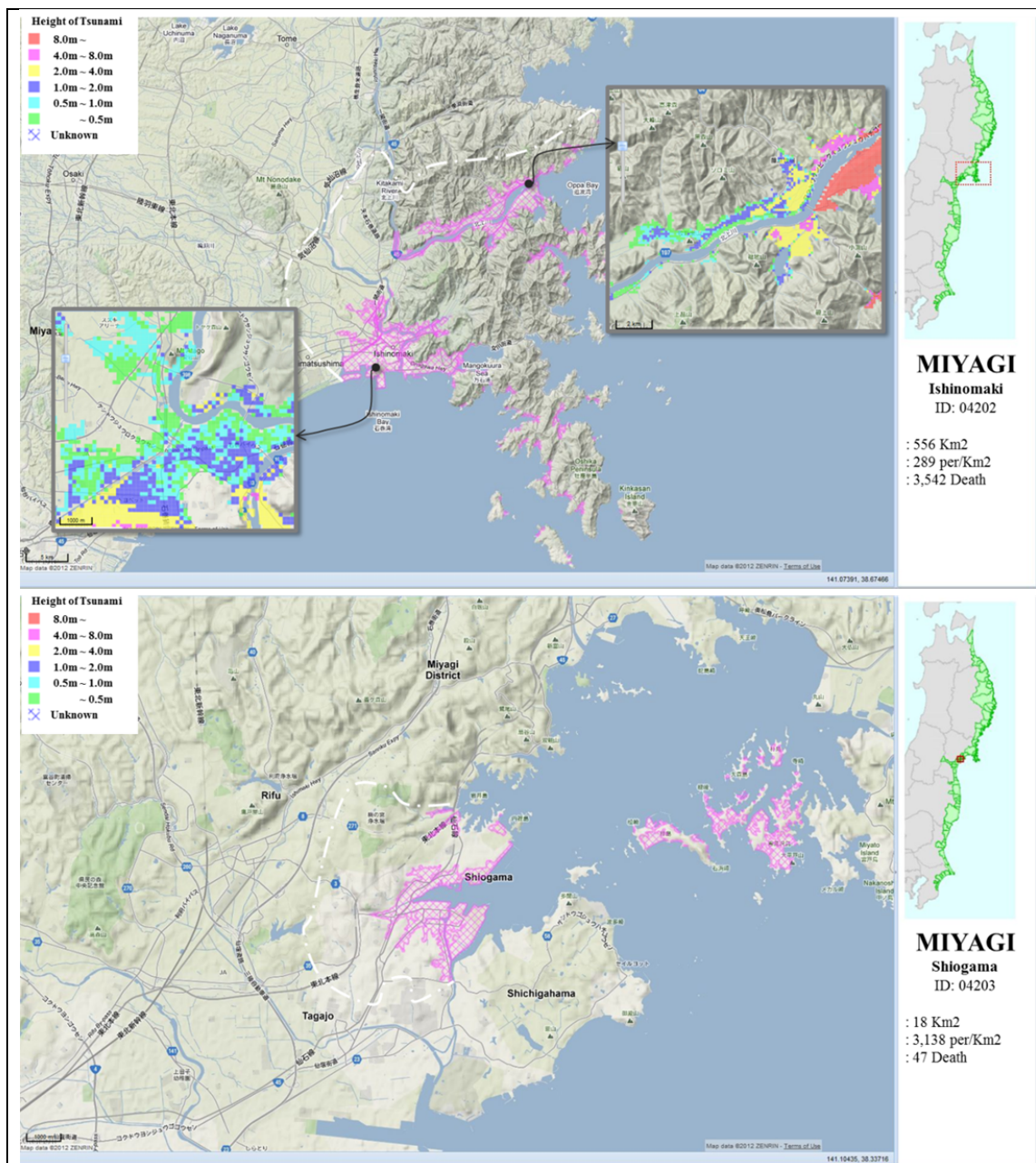


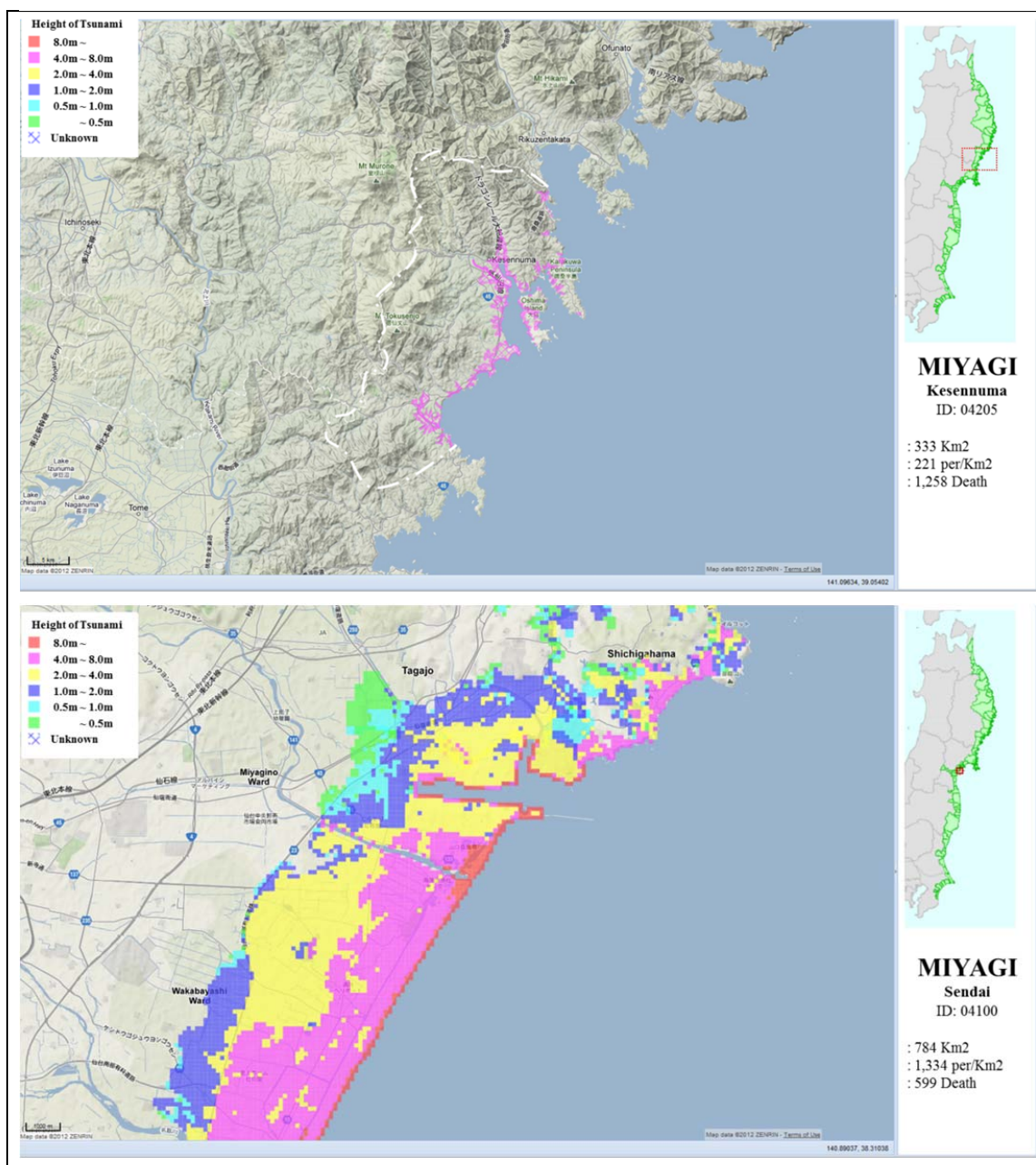


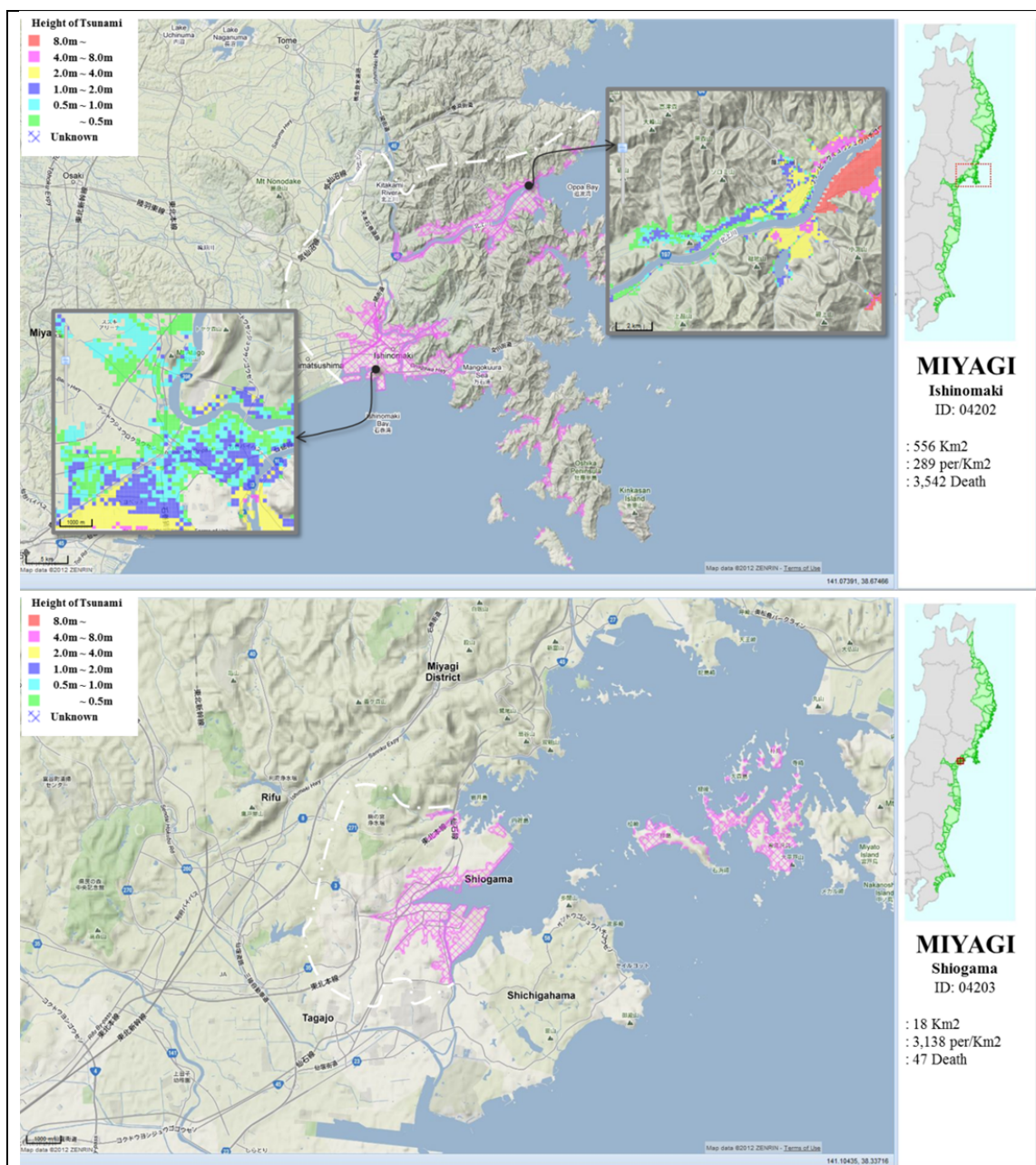


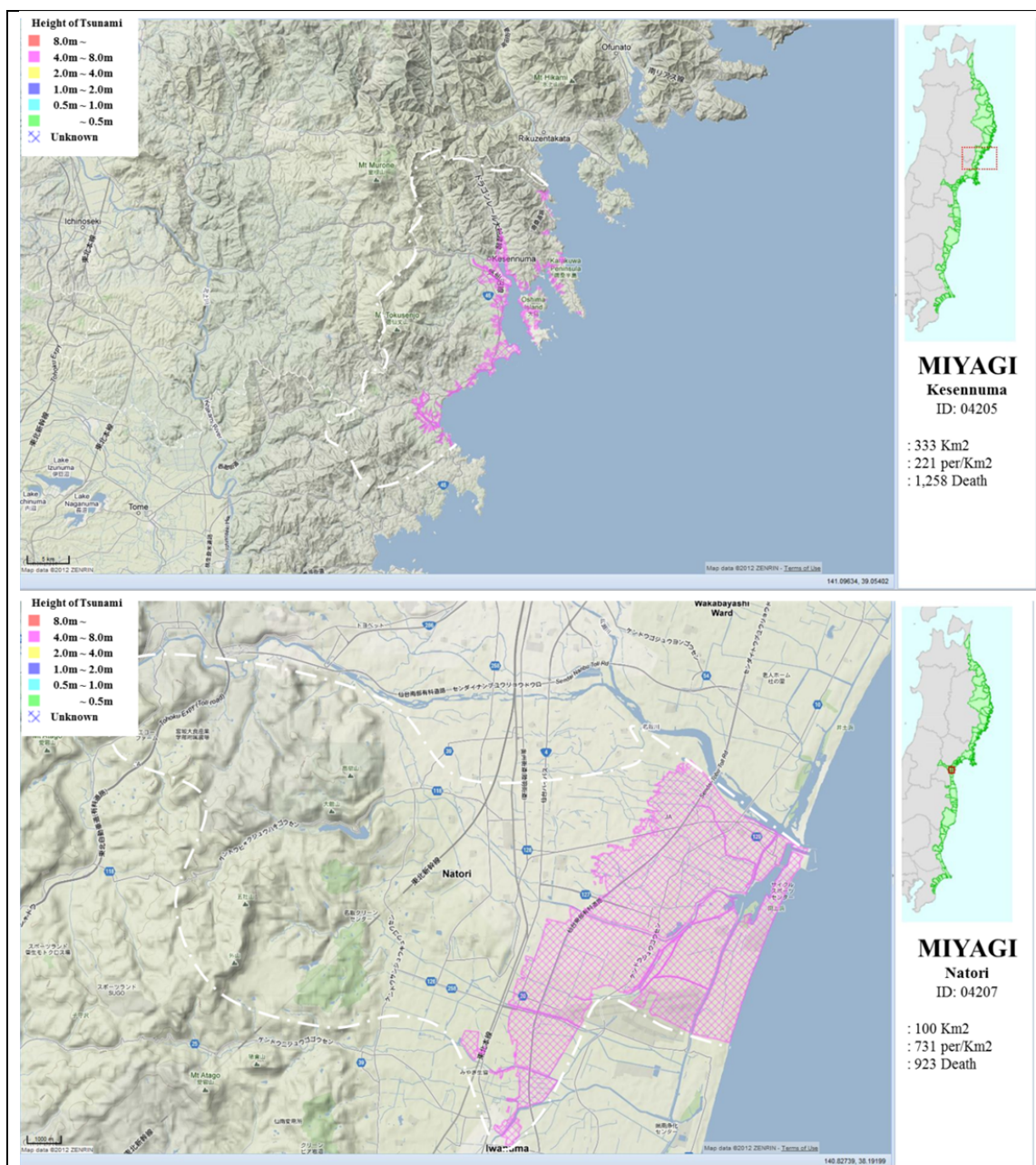


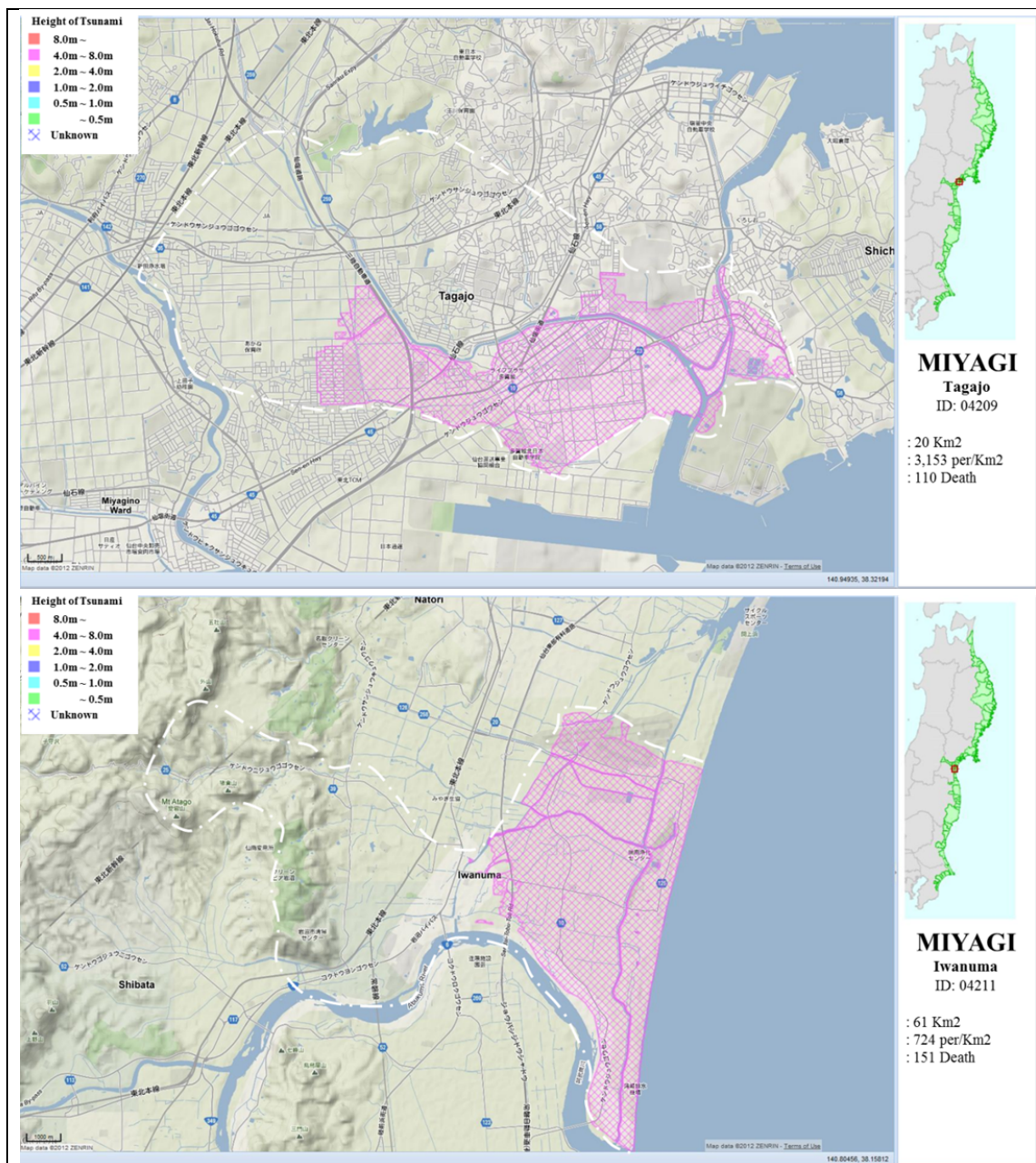


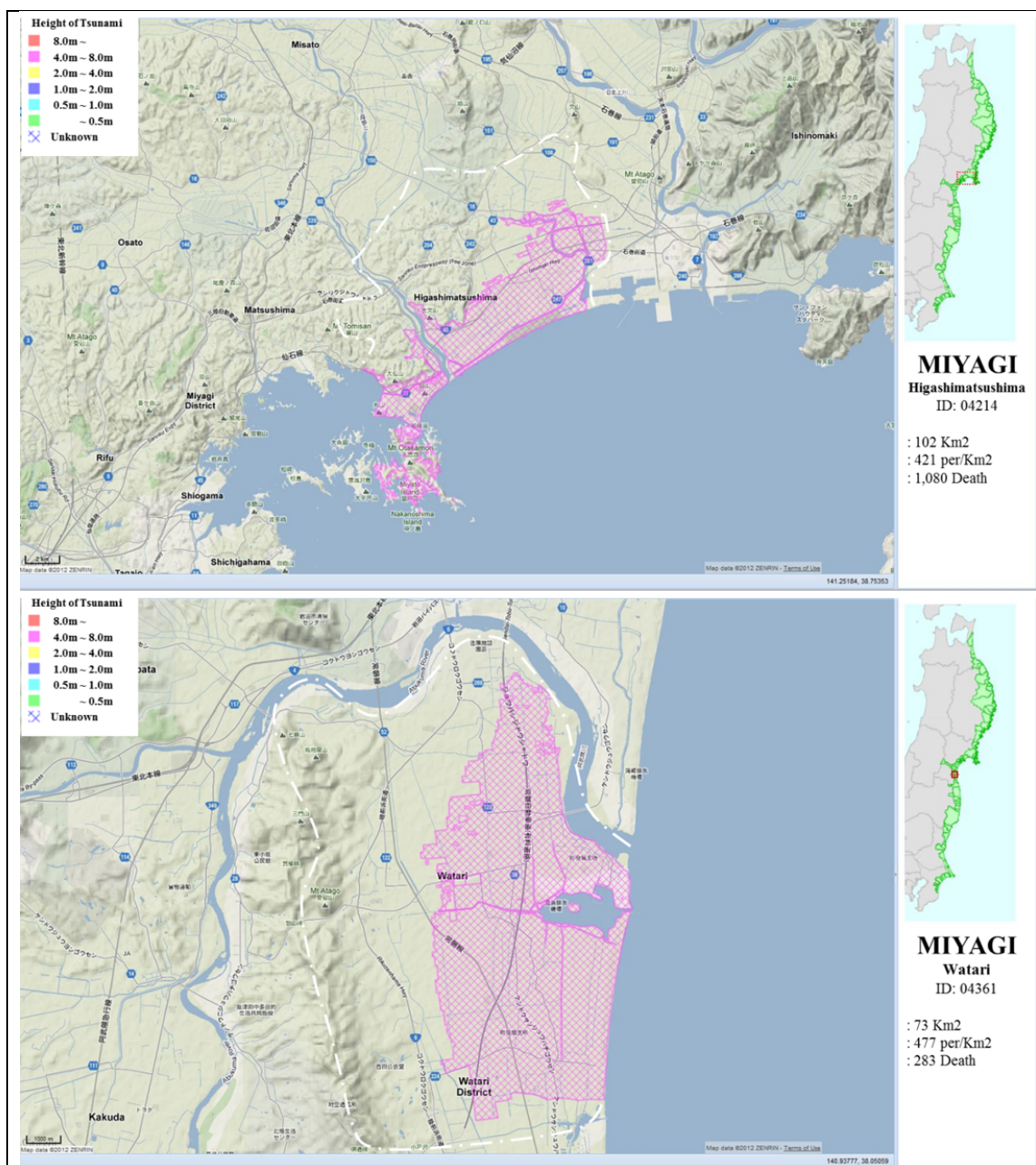


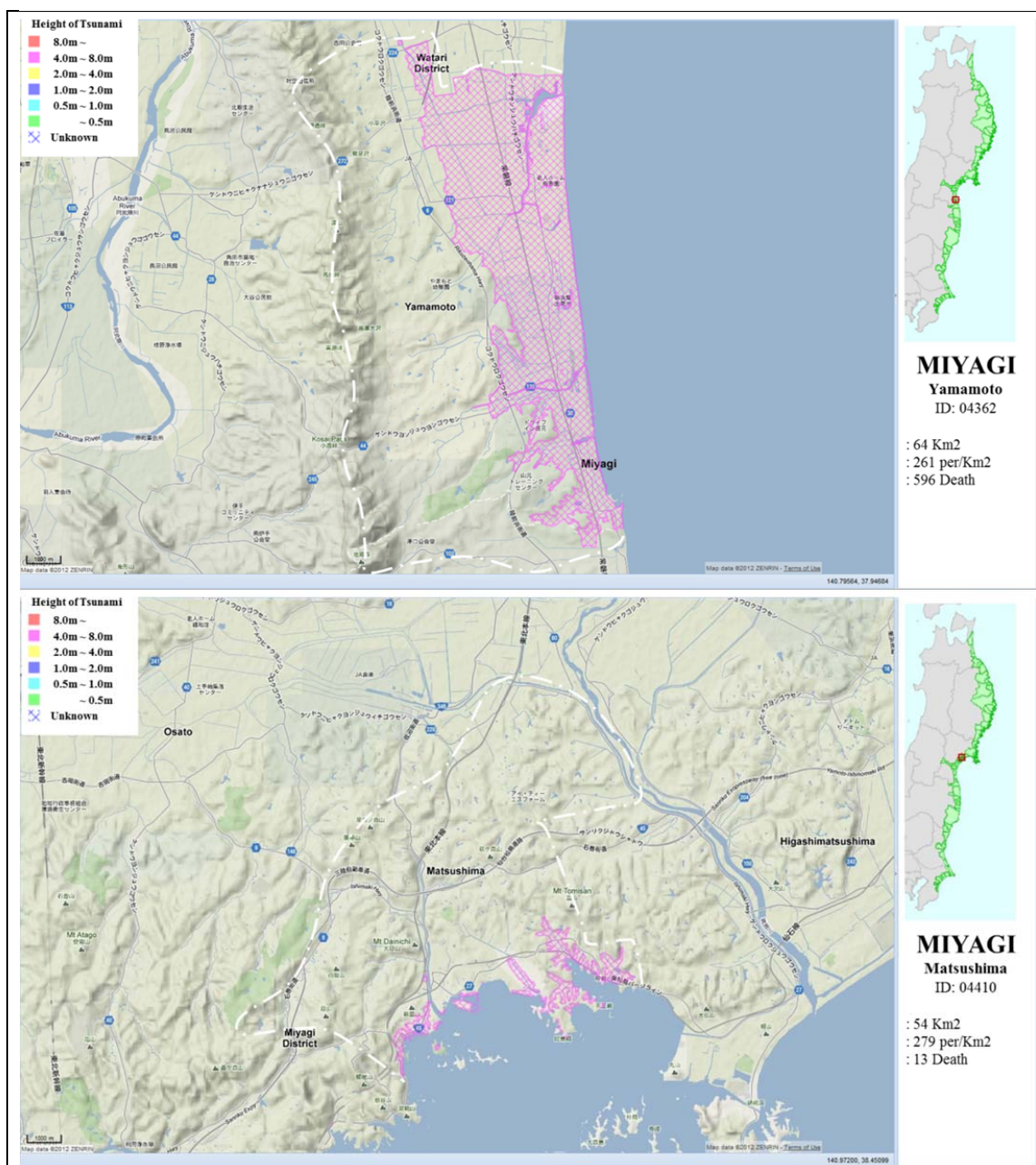


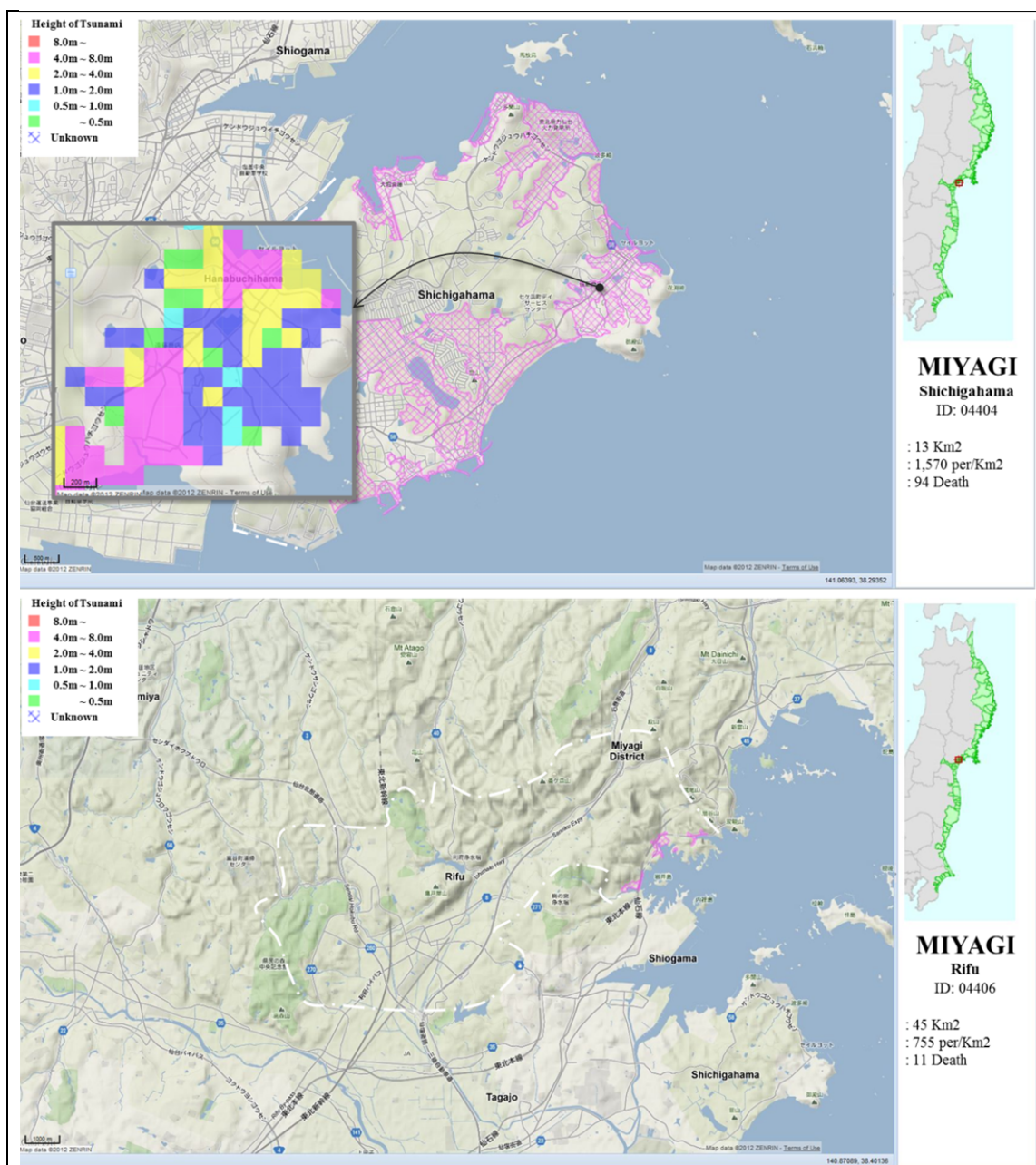


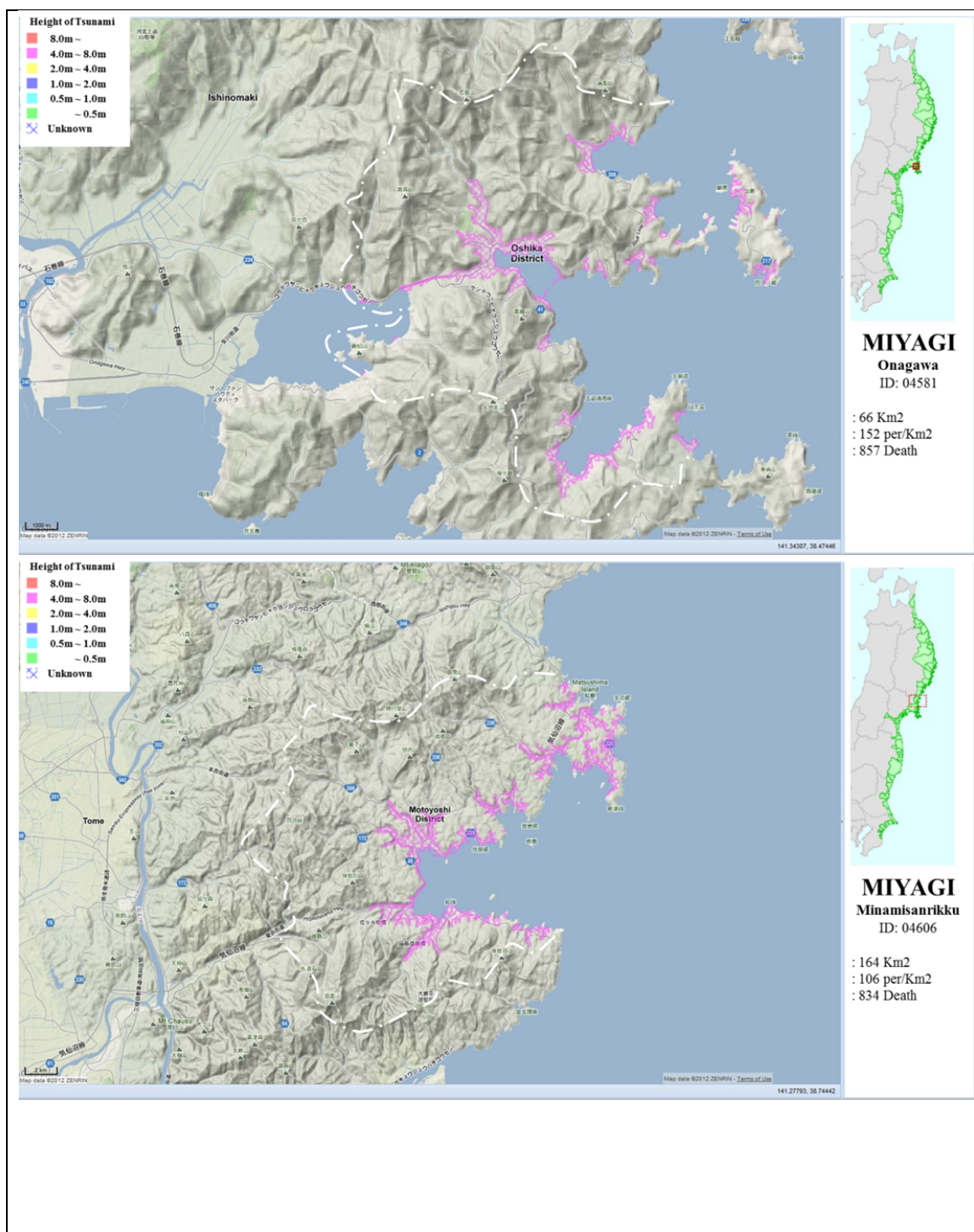


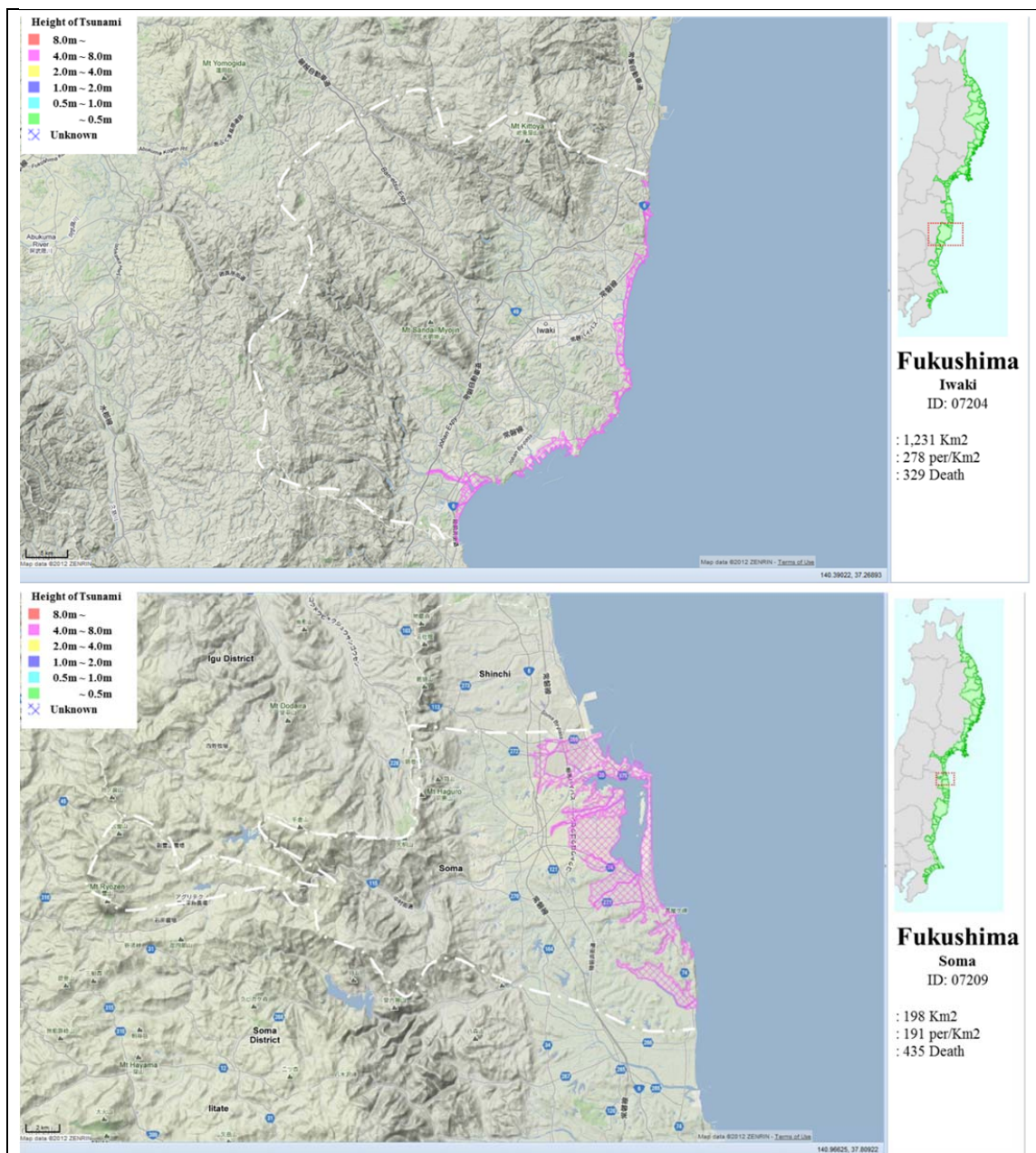


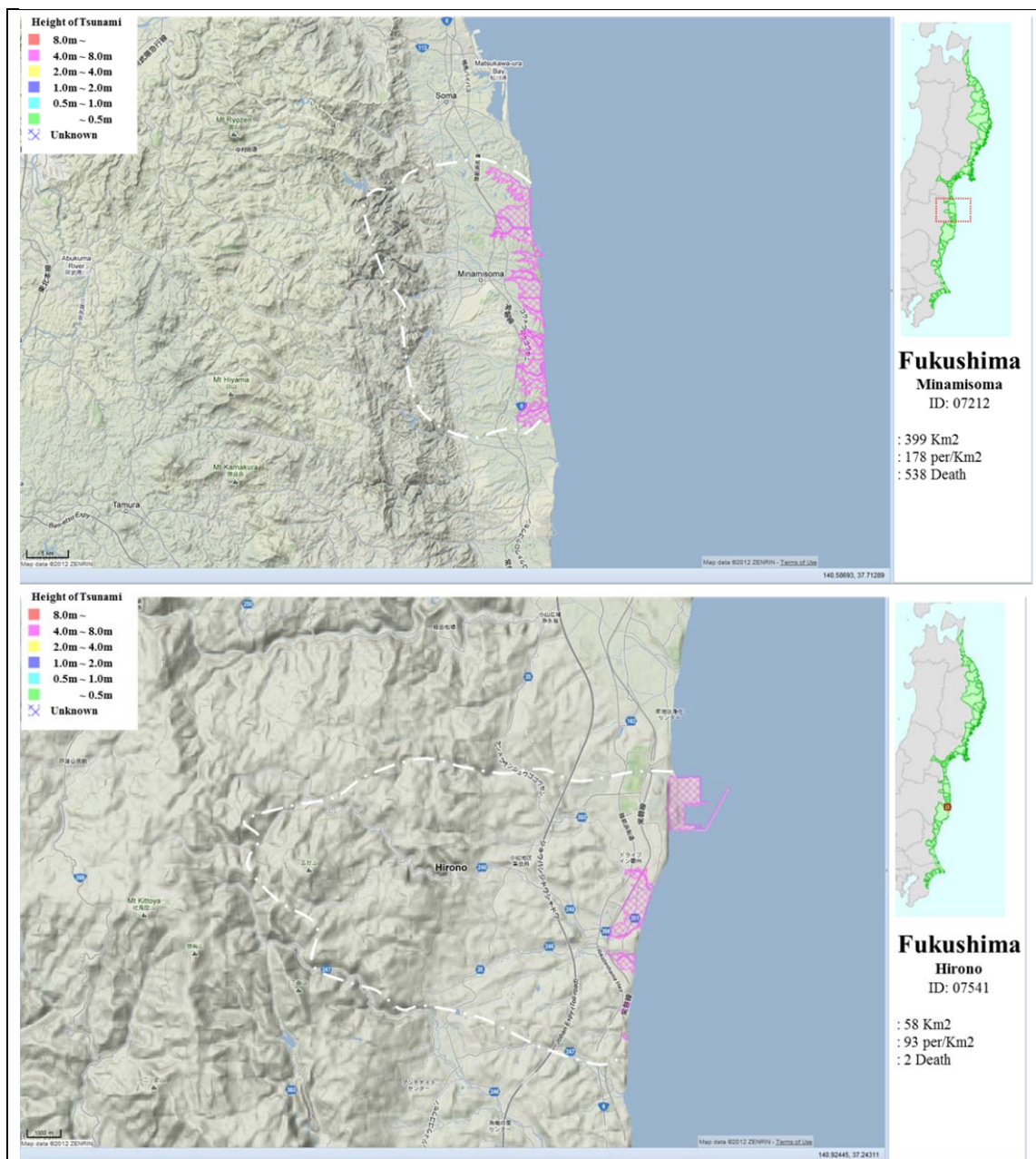


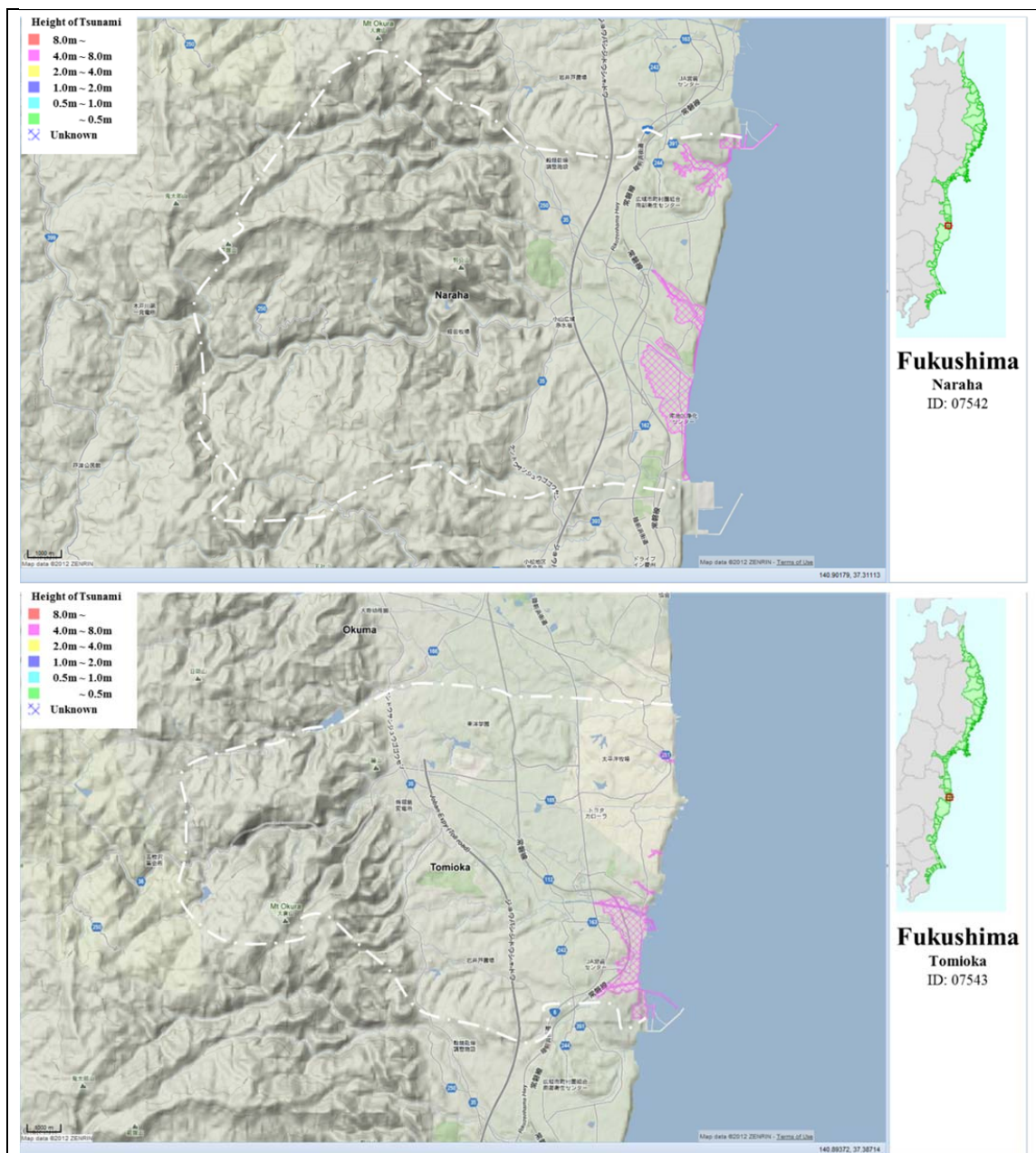


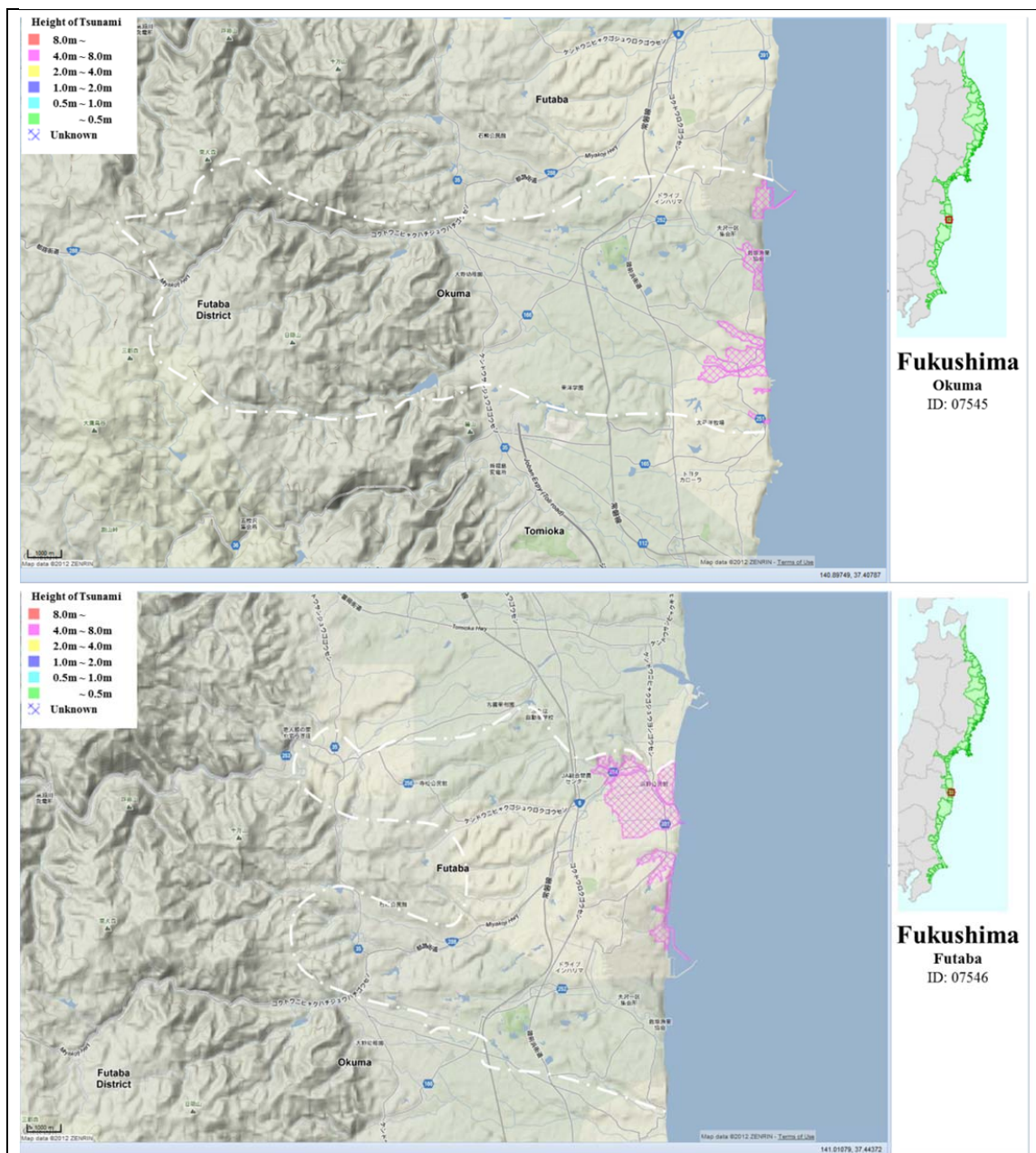


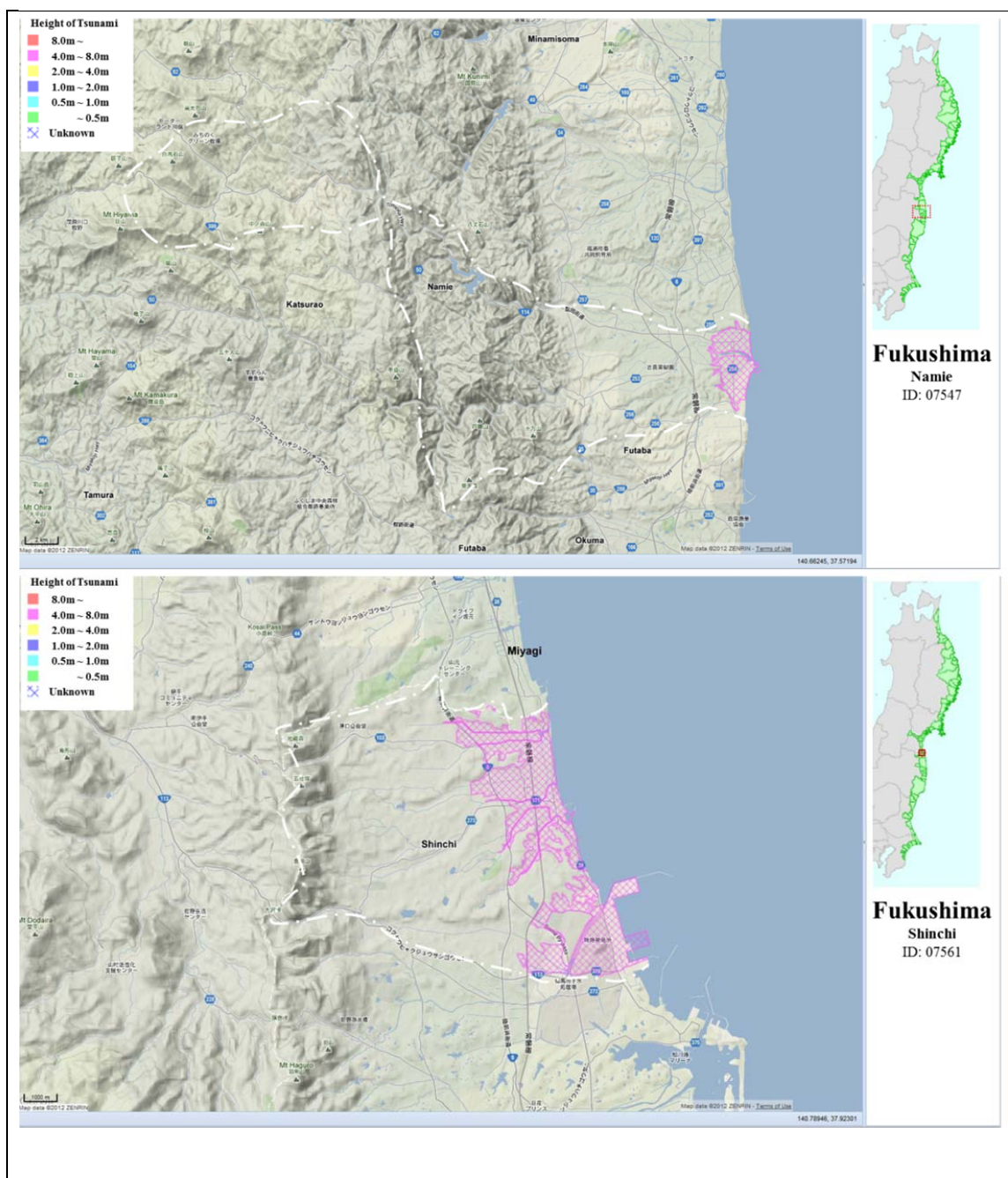












B. Demography and industry

Name	Area (Km2)	Population Density(Per./km2)	Population (person)	Age (Mean)	Age (Median)
AOMORI	9644.54	142.4	1373339	47	49
IWATE	15278.89	87.1	1330147	47	50
MIYAGI	7285.76	322.3	2348165	45	45
FUKUSHIMA	13782.76	147.2	2029064	46	48
IBARAKI	6095.72	487.2	2969770	45	45
Name	Area(Km2): Damaged Area	Population Density(Per./km2): Damaged Area	Population(person): Damaged Area	Age(Mean): Damaged Area	Age(Median): Damaged Area
AOMORI	519	566	293,572	45	46
IWATE	4,876	56	270,998	50	54
MIYAGI	2,453	697	1,708,599	46	48
FUKUSHIMA	1,932	240	464,586	47	49
IBARAKI	1,444	667	963,792	45	46
Hachinohe	305	779	237,615	46	47
Misawa	120	344	41,258	43	43
Hashikami	94	156	14,699	45	47
Miyako	1,260	47	59,430	50	53
Ofunato	323	126	40,737	49	52
Kuji	623	59	36,872	47	49
Rikuzentakata	232	100	23,300	51	55
Kamaishi	441	90	39,574	52	56
Otuchi	201	76	15,276	51	55
Yamada	263	71	18,617	50	54
Iwaizumi	993	11	10,804	53	58
Tanohata	156	25	3,843	52	56
Noda	81	57	4,632	49	52
Hirono	303	59	17,913	49	53
Sendai	784	1334	1,045,986	42	41
Ishinomaki	556	289	160,826	47	50
Shiogama	18	3138	56,490	48	50
Kesennuma	333	221	73,489	50	53
Natori	100	731	73,134	42	42
Tagajo	20	3153	63,060	42	41
Iwanuma	61	724	44,187	43	42
Higashimatsushima	102	421	42,903	45	46
Watarai	73	477	34,845	46	48
Yamamoto	64	261	16,704	51	55
Matsushima	54	279	15,085	50	53
Shichigahama	13	1570	20,416	44	46
Rifu	45	755	33,994	41	42
Onagawa	66	152	10,051	51	55
Minamisanriku	164	106	17,429	49	52
Iwaki	1,231	278	342,249	46	48
Soma	198	191	37,817	46	48
Minamisoma	399	178	70,878	47	50
Shinchi	46	179	8,224	48	51

Name	Population<15(person)	Population 15~65(person)	Population>65(person)
AOMORI	171,842	843,587	352,768
IWATE	168,804	795,780	360,498
MIYAGI	308,201	1,501,638	520,794
FUKUSHIMA	276,069	1,236,458	504,451
IBARAKI	399,638	1,891,701	665,065
Name	Population<15(person): Damaged Area	Population 15~65(person): Damaged Area	Population>65(person): Damaged Area
AOMORI	40,236	185,646	66,600
IWATE	32,915	152,287	85,650
MIYAGI	225,134	1,113,358	354,235
FUKUSHIMA	63,495	281,950	117,399
IBARAKI	135,330	607,776	214,341
Hachinohe	31,926	149,842	55,030
Misawa	6,475	26,191	8,381
Hashikami	1,835	9,613	3,189
Miyako	7,230	33,792	18,363
Ofunato	4,834	23,259	12,552
Kuji	5,211	21,943	9,718
Rikuzentakata	2,732	12,441	8,125
Kamaishi	4,436	21,359	13,772
Otuchi	1,749	8,579	4,948
Yamada	2,329	10,361	5,927
Iwaizumi	1,121	5,599	4,084
Tanohata	455	2,087	1,301
Noda	526	2,713	1,393
Hirono	2,292	10,154	5,467
Sendai	136,832	703,379	191,722
Ishinomaki	20,214	96,297	43,747
Shiogama	6,437	34,476	15,493
Kesennuma	8,746	42,004	22,600
Natori	11,147	47,815	13,945
Tagajo	9,453	41,769	11,531
Iwanuma	6,691	28,729	8,723
Higashimatsushima	6,181	26,751	9,932
Watari	4,654	21,776	8,078
Yamamoto	1,691	9,729	5,284
Matsushima	1,510	8,920	4,654
Shichigahama	2,880	13,132	4,400
Rifu	5,483	22,934	5,526
Onagawa	1,057	5,616	3,362
Minamisanriku	2,158	10,031	5,238
Iwaki	46,776	208,667	85,510
Soma	5,187	22,832	9,577
Minamisoma	9,649	42,196	18,809
Shinchi	1,118	4,890	2,215

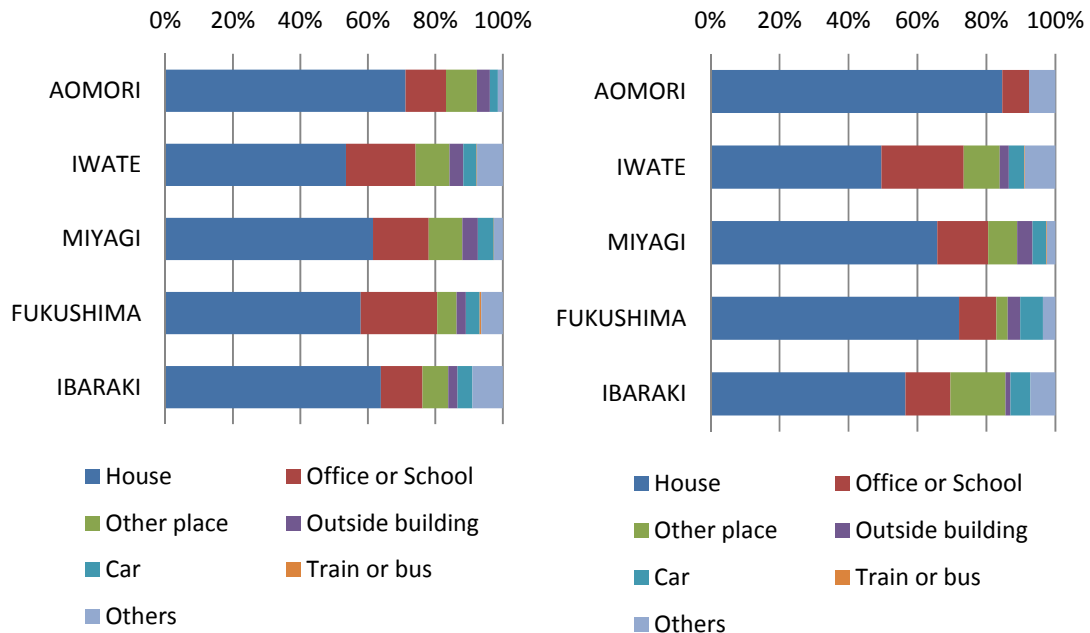
Name	Total Household	Houehold (alone)	Houehold (alone) %
AOMORI	511,427	141,070	28
IWATE	482,845	132,370	27
MIYAGI	900,352	281,354	31
FUKUSHIMA	719,441	188,617	26
IBARAKI	1,086,715	279,780	26
Name	Total Household	Houehold (alone)	Houehold (alone) %
AOMORI	511,427	141,070	28
IWATE	482,845	132,370	27
MIYAGI	900,352	281,354	31
FUKUSHIMA	719,441	188,617	26
IBARAKI	1,086,715	279,780	26
Hachinohe	91,726	25,504	28
Misawa	16,142	5,025	31
Hashikami	5,698	1,823	32
Miyako	22,440	6,146	27
Ofunato	14,798	4,082	28
Kuji	13,984	3,878	28
Rikuzentakata	7,767	1,602	21
Kamaishi	16,070	4,762	30
Otuchi	5,679	1,392	25
Yamada	6,596	1,491	23
Iwaizumi	4,350	1,317	30
Tanohata	1,301	268	21
Noda	1,575	295	19
Hirono	6,112	1,320	22
Sendai	464,640	188,567	41
Ishinomaki	57,796	14,509	25
Shiogama	20,363	4,500	22
Kesennuma	25,399	5,685	22
Natori	25,092	5,089	20
Tagajo	24,047	6,859	29
Iwanuma	15,495	3,535	23
Higashimatsushima	13,982	2,563	18
Watari	10,894	1,491	14
Yamamoto	5,222	907	17
Matsushima	5,126	1,018	20
Shichigahama	6,413	852	13
Rifu	10,808	1,392	13
Onagawa	3,937	1,231	31
Minamisanriku	5,288	949	18
Iwaki	128,480	33,775	26
Soma	13,211	3,646	28
Minamisoma	23,523	5,361	23
Shinchi	2,460	373	15

Name	First Industry(person)	Second Industry(person)	Third Industry(person)
AOMORI	81,042	127,978	413,318
IWATE	76,003	153,479	393,167
MIYAGI	53,219	234,210	746,752
FUKUSHIMA	71,428	272,417	560,520
IBARAKI	82,873	401,004	863,268
Name	First Industry(person): Damaged Area	Second Industry(person): Damaged Area	Third Industry(person): Damaged Area
AOMORI	6,069	30,444	94,768
IWATE	14,757	33,710	70,917
MIYAGI	23,991	144,409	571,879
FUKUSHIMA	9,765	64,821	128,915
IBARAKI	21,187	127,051	277,112
Hachinohe	3,926	24,456	77,412
Misawa	1,496	4,014	13,601
Hashikami	647	1,974	3,755
Miyako	2,548	6,486	16,534
Ofunato	1,982	5,449	11,214
Kuji	1,596	4,524	10,135
Rikuzentakata	1,602	3,013	5,972
Kamaishi	1,191	4,986	10,712
Otuchi	519	2,368	3,782
Yamada	1,545	2,373	4,406
Iwaizumi	1,286	1,067	2,543
Tanohata	467	489	815
Noda	364	615	1,073
Hirono	1,657	2,340	3,731
Sendai	4,005	67,162	372,941
Ishinomaki	6,282	20,850	43,158
Shiogama	251	5,887	18,576
Kesennuma	3,128	8,398	20,077
Natori	1,439	7,184	23,659
Tagajo	326	6,028	22,099
Iwanuma	688	5,545	14,232
Higashimatsushima	1,819	5,054	13,012
Watari	1,509	4,813	9,691
Yamamoto	841	2,332	4,171
Matsushima	385	1,364	5,093
Shichigahama	304	2,418	6,564
Rifu	335	3,468	12,041
Onagawa	747	1,594	2,566
Minamisanriku	1,932	2,312	3,999
Iwaki	4,736	46,002	96,852
Soma	1,722	5,689	9,406
Minamisoma	2,679	10,900	19,034
Shinchi	514	1,347	2,011

C. Road Ratio and Shelter Density

Name	Road Length/Area (km/km ²)	Num. of Shelter/Area (EA/km ²)	Name	Road Length/Area (km/km ²)	Num. of Shelter/Area (EA/km ²)
Hachinohe	5.44	0.79	Kesennuma	3.97	0.26
Misawa	3.35	0.22	Natori	5.04	0.30
Hashikami	3.09	0.35	Tagajo	9.43	1.15
Miyako	0.83	0.07	Iwanuma	5.41	0.23
Ofunato	2.33	0.16	Higashimatsushima	5.90	0.17
Kuji	1.45	0.08	Watari	6.93	0.27
Rikuzentakata	2.86	0.20	Yamamoto	4.93	0.17
Kamaishi	1.48	0.26	Matsushima	3.87	0.65
Otuchi	1.27	0.18	Shichigahama	7.82	1.85
Yamada	0.84	0.08	Rifu	5.07	1.98
Iwaizumi	0.54	0.05	Onagawa	2.20	0.24
Tanohata	1.45	0.10	Minamisanriku	2.25	0.15
Noda	1.79	0.09	Iwaki	3.37	0.19
Hirono	2.08	0.18	Soma	3.72	0.08
Sendai	4.37	N/A	Minamisoma	3.79	0.15
Ishinomaki	4.25	0.33	Shinchi	4.64	0.15
Shiogama	9.91	1.00	Average	3.81	0.37

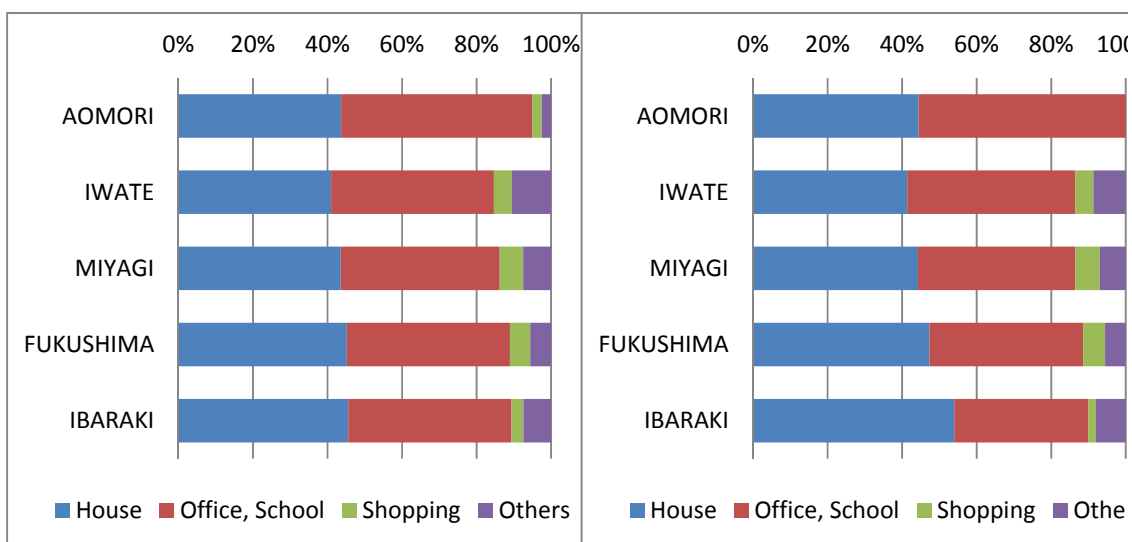
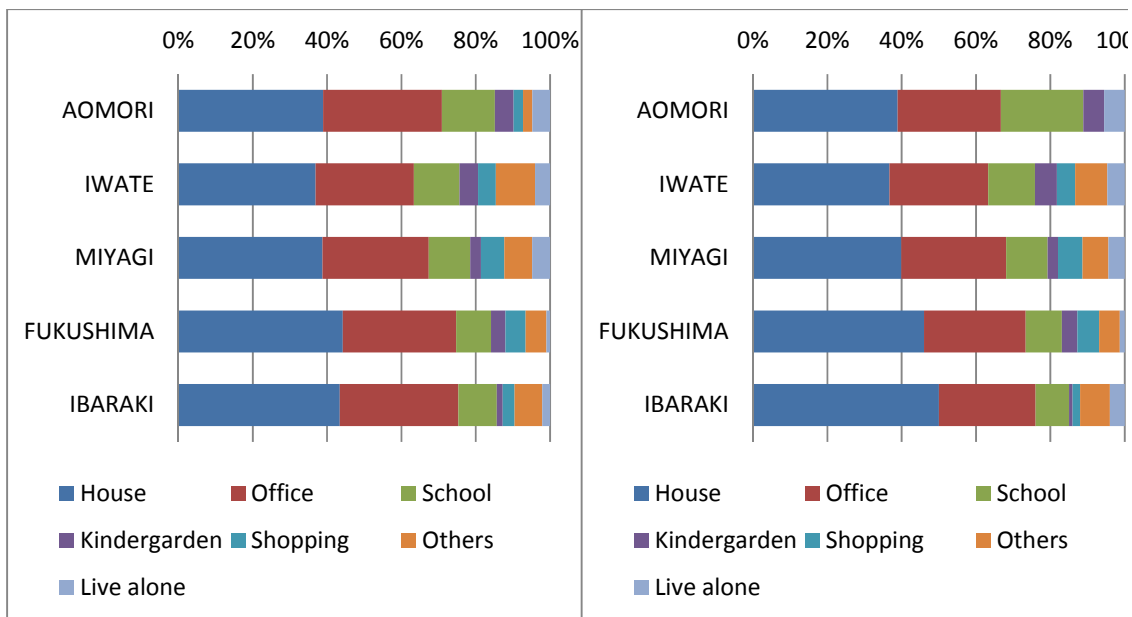
D. Summary of Questionnaire (Left: all, Right: Indangered Evacuees)



Total N=10,132

N=2,167

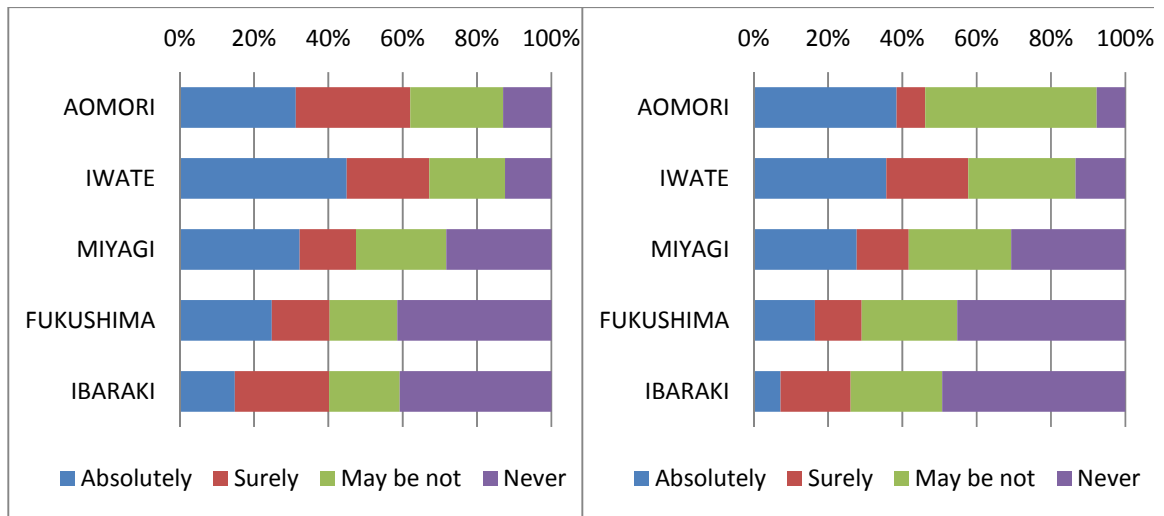
The places when the earthquake occurred



Total N=10,132

N=2,167

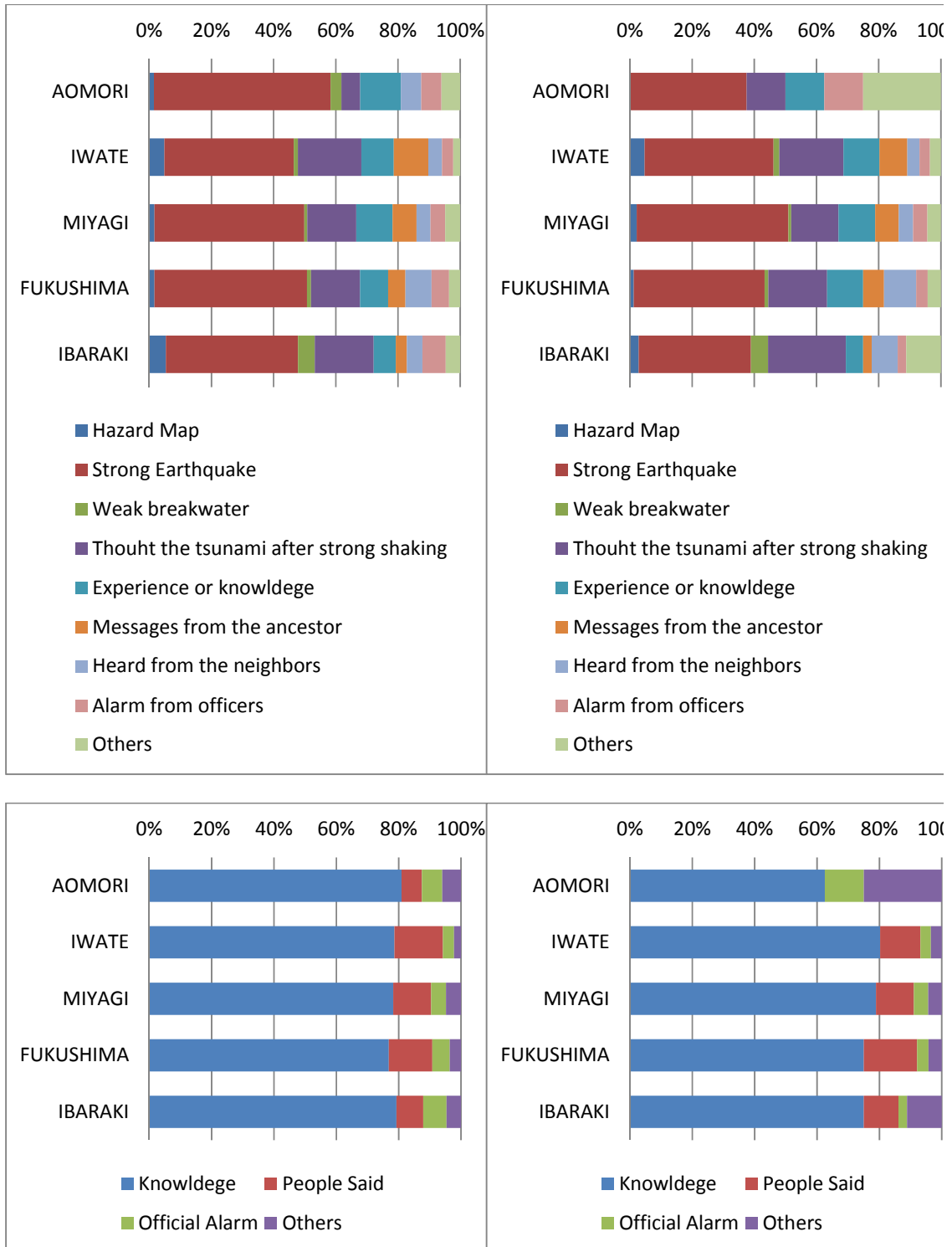
The places of Family when the earthquake occurred



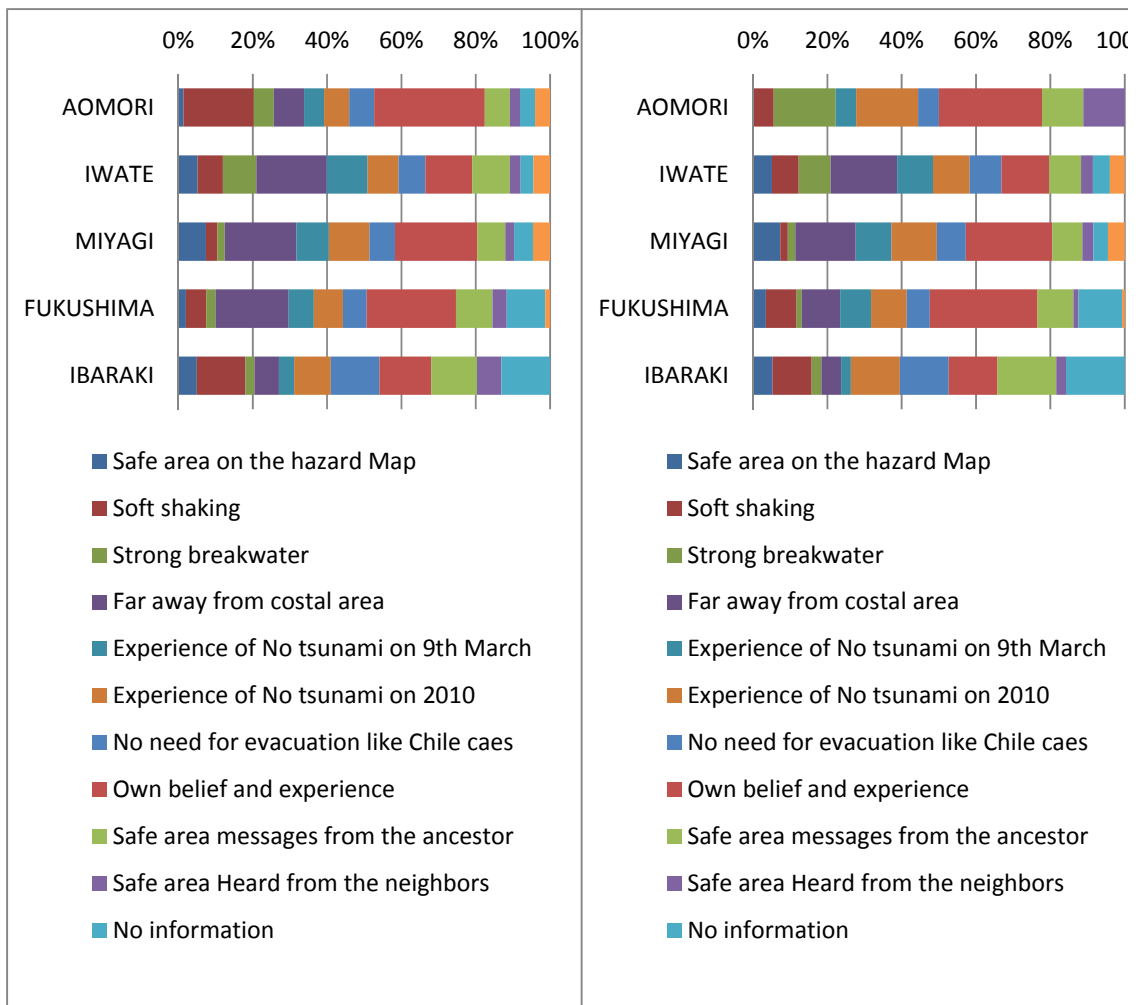
Total N=10,132

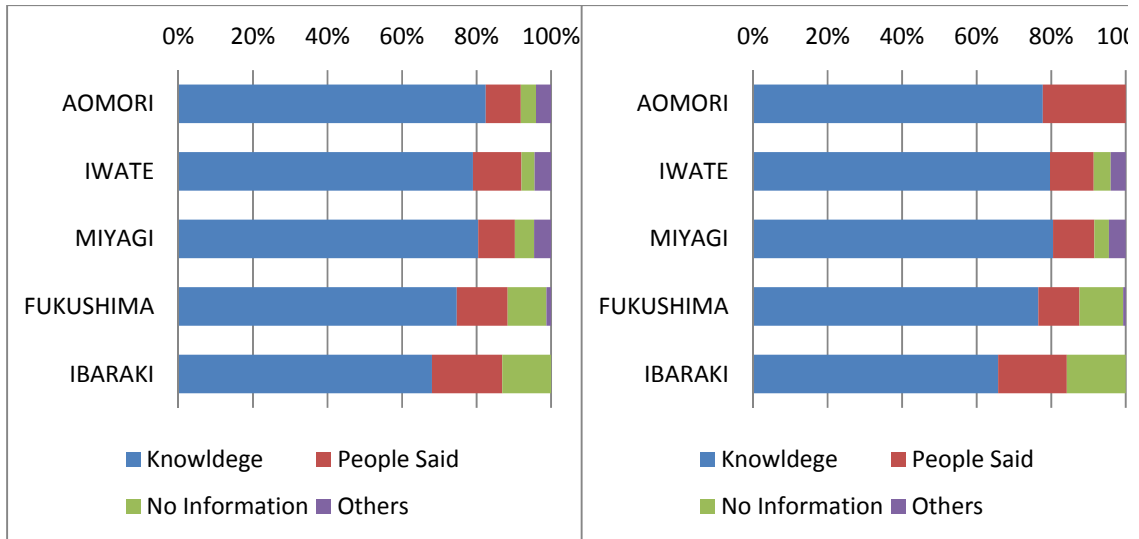
N=2,167

Belief, Tsunami comes, before the Tsunami Warning

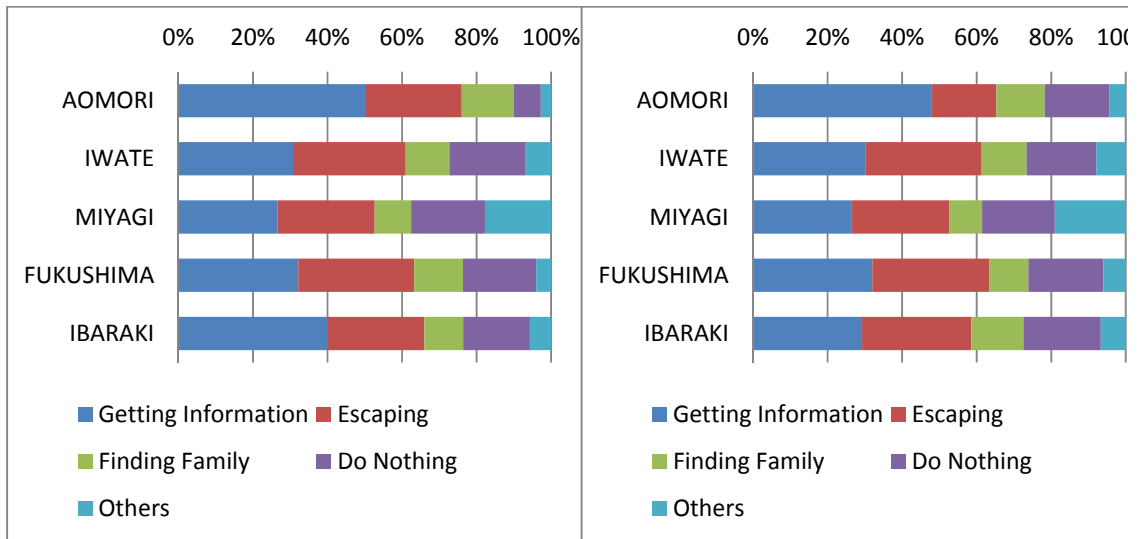
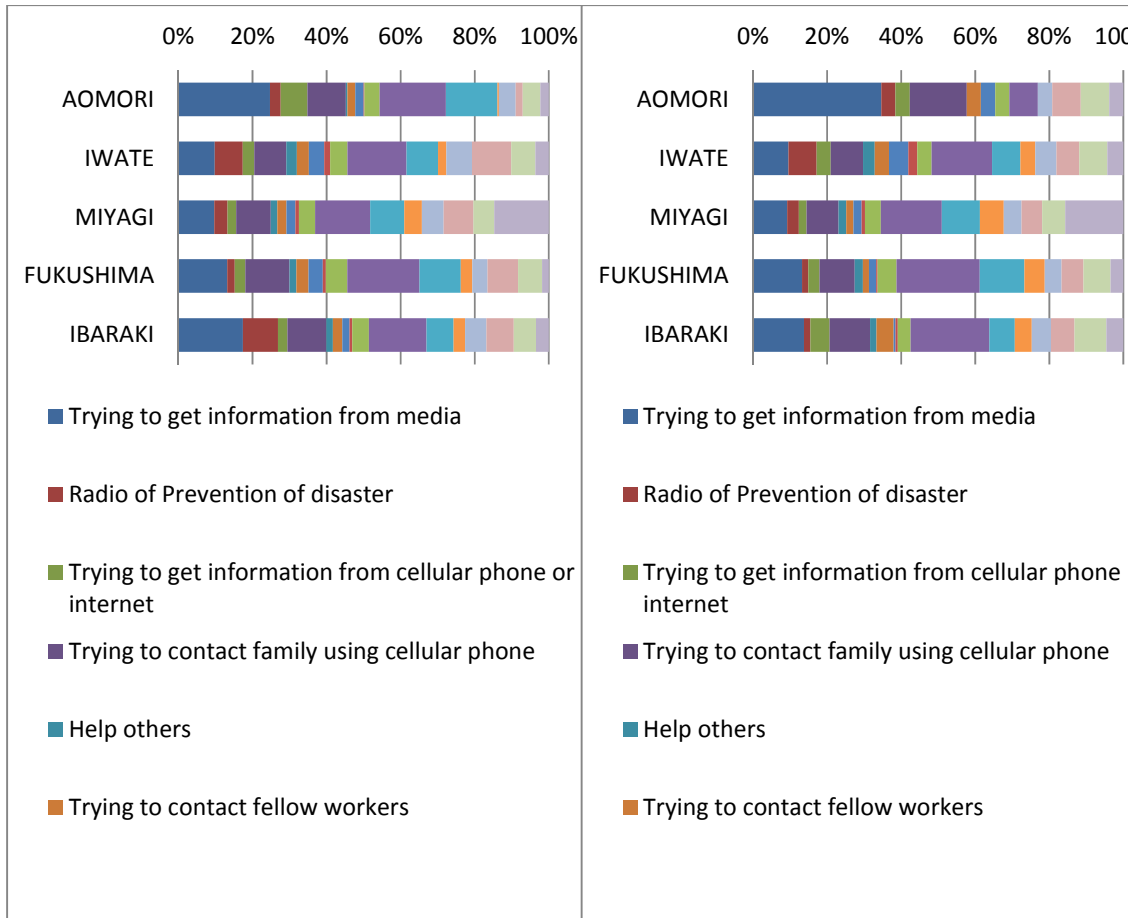


The reason why the Tsunami will come





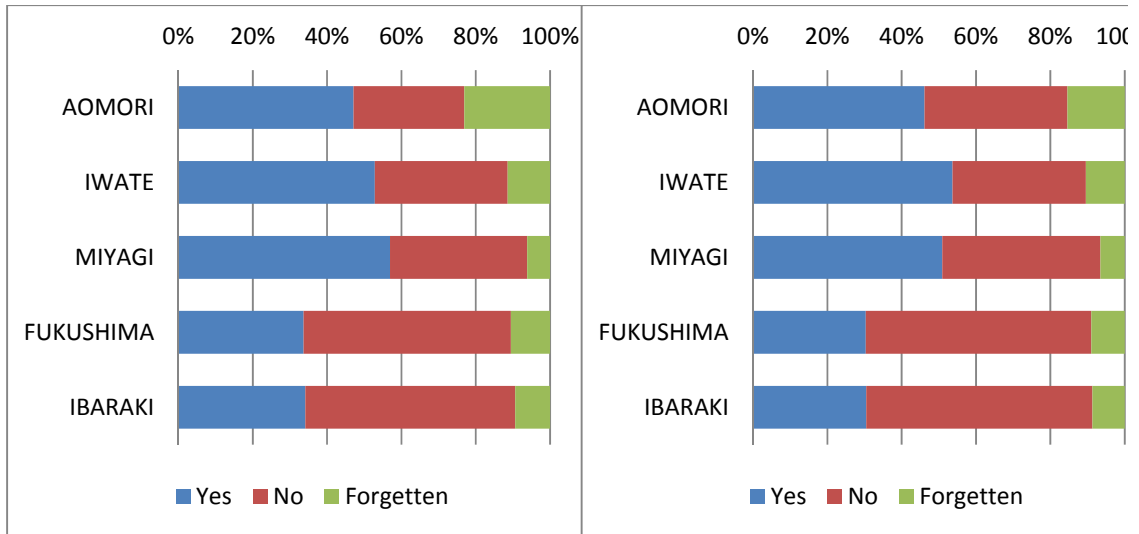
The reason why the Tsunami will NOT come



Total N=10,132

N=2,167

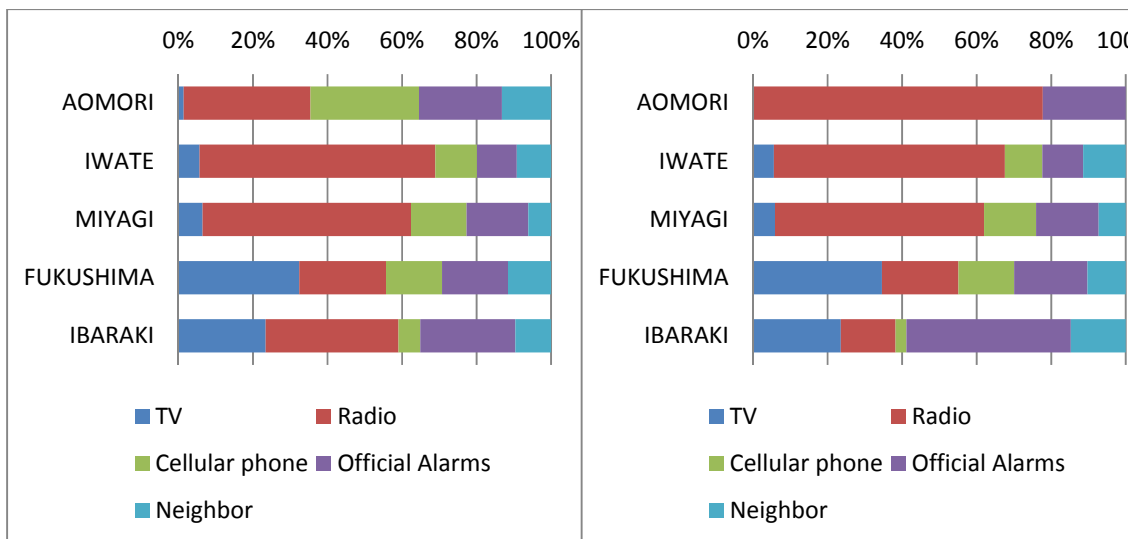
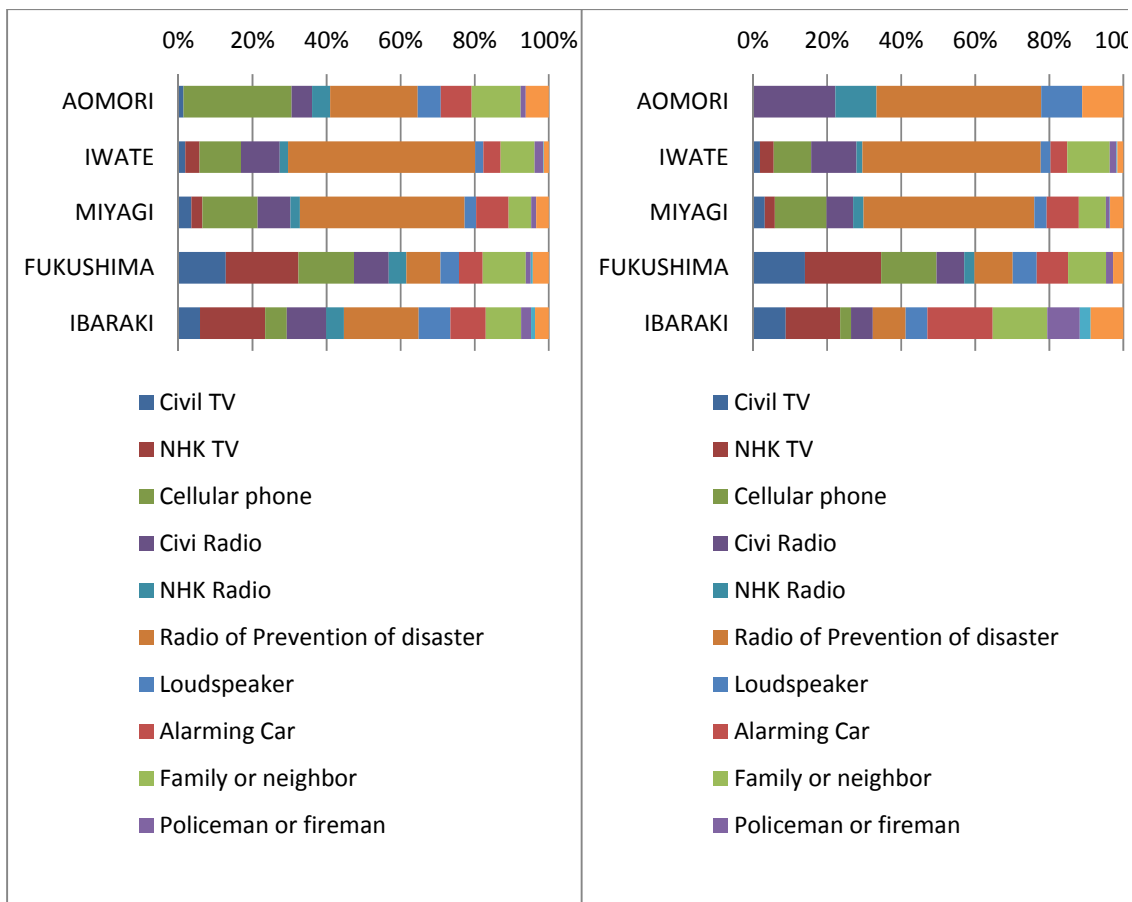
Actions just after shaking



Total N=10,132

N=2,167

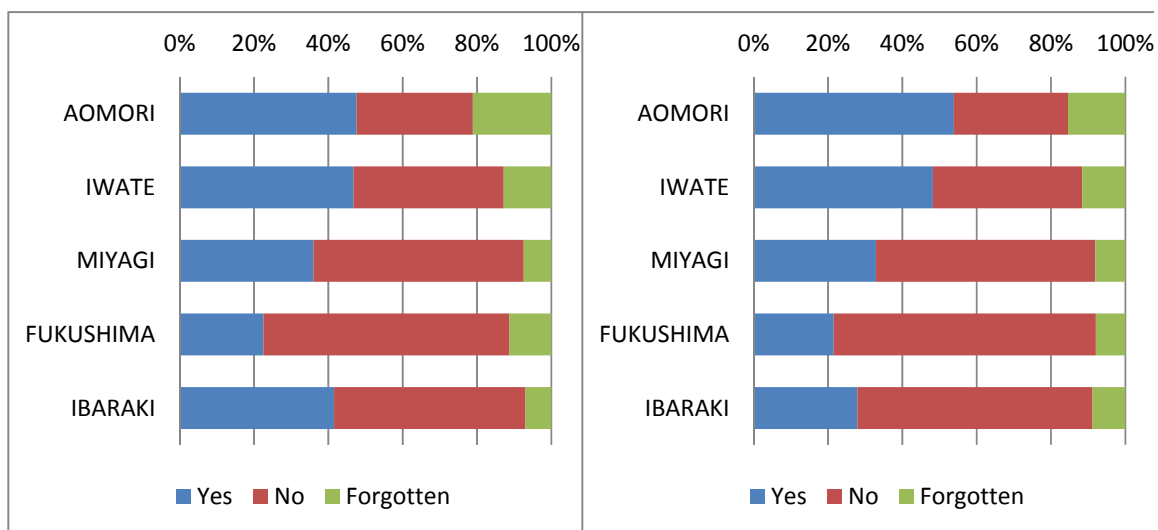
Catching the Tsunami Warning Sound



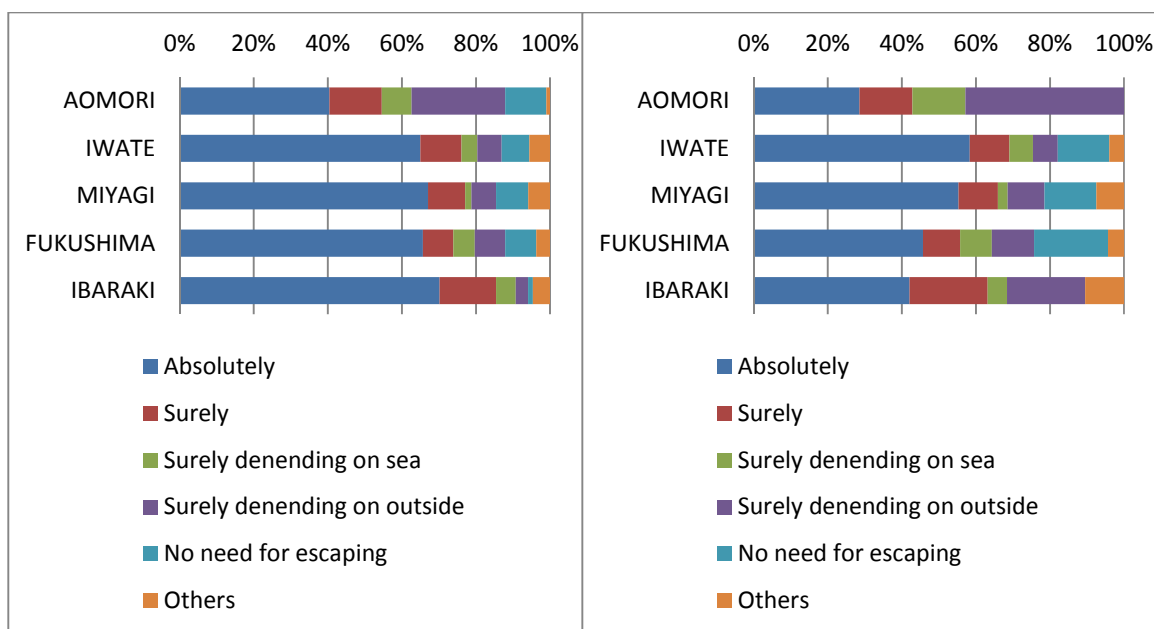
Total N=10,132

N=2,167

Getting Tsunami warning Information



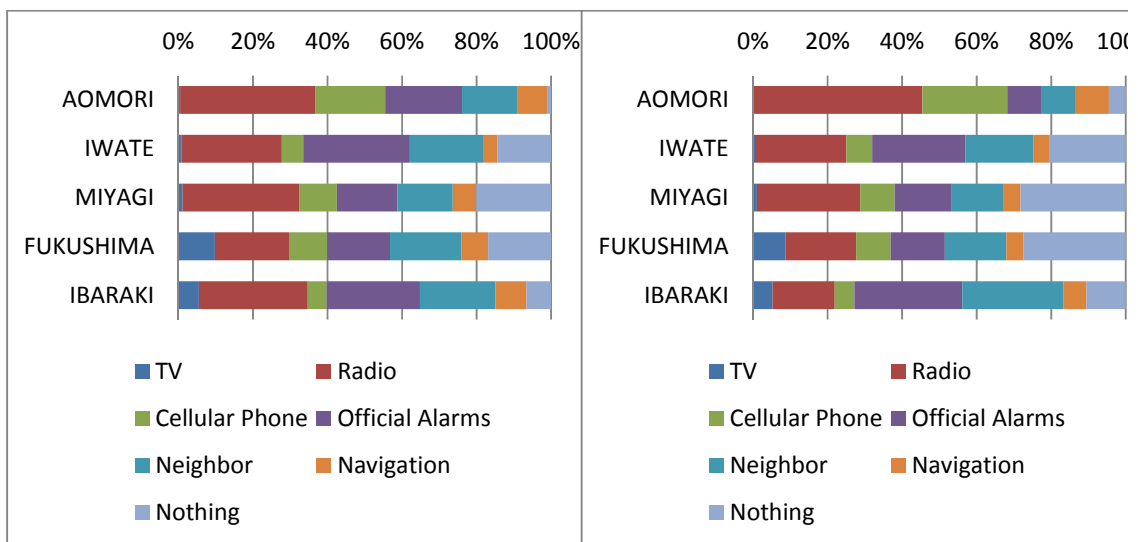
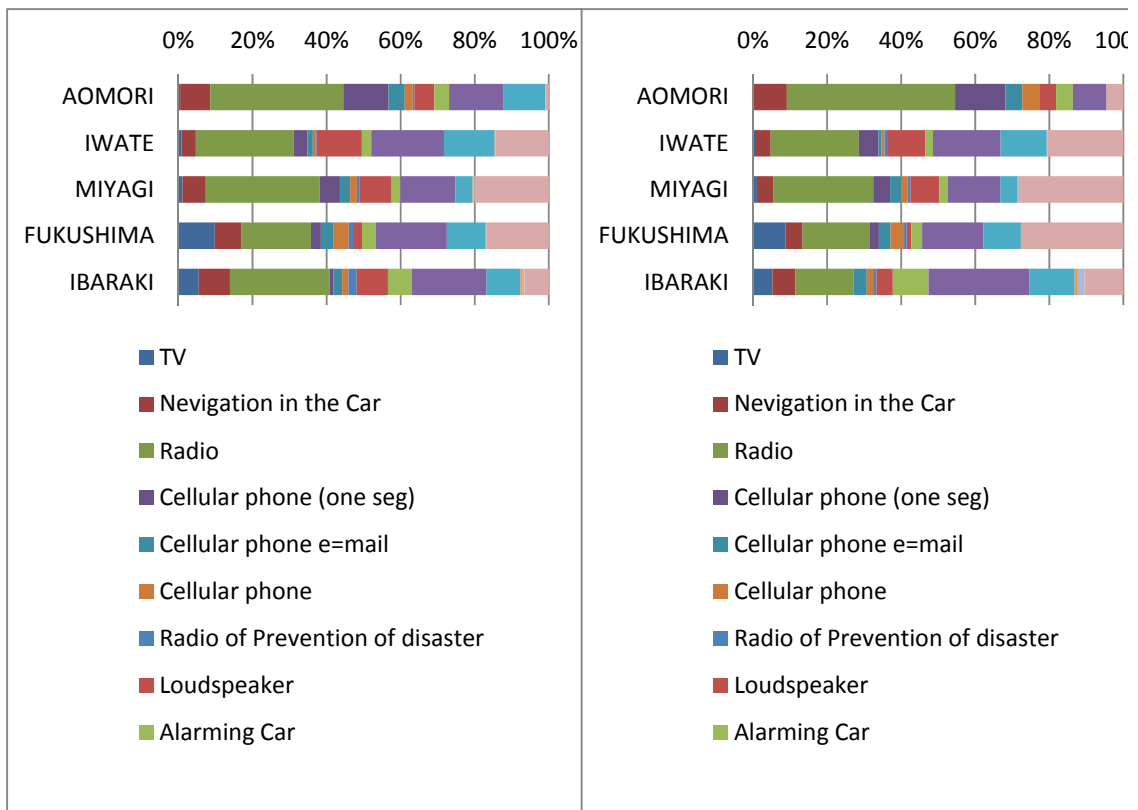
Government Officers Suggested Escaping



Total N=10,132

N=2,167

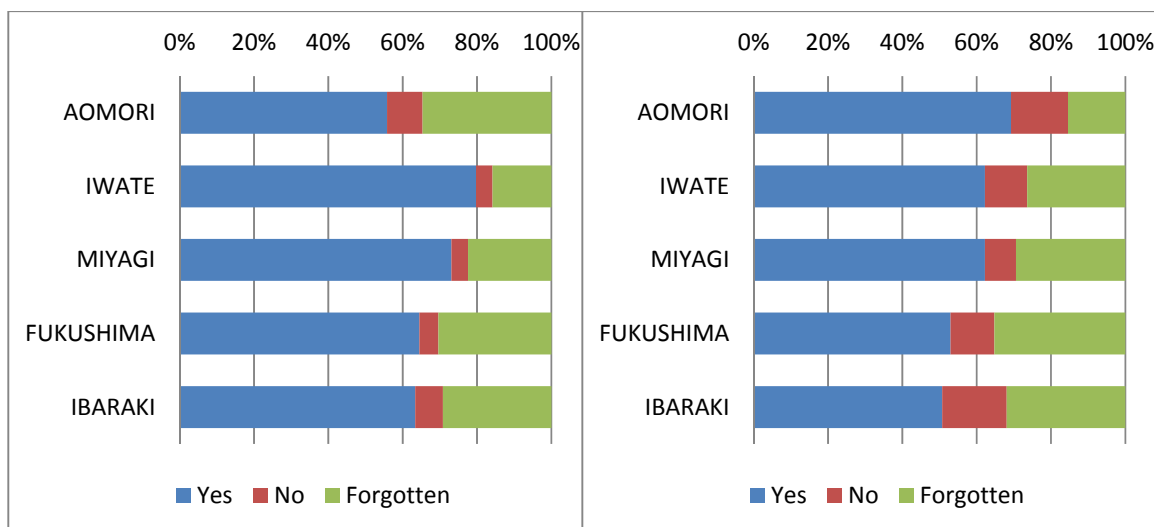
Getting Suggestion from Officers, Tried to Escape



Total N=10,132

N=2,167

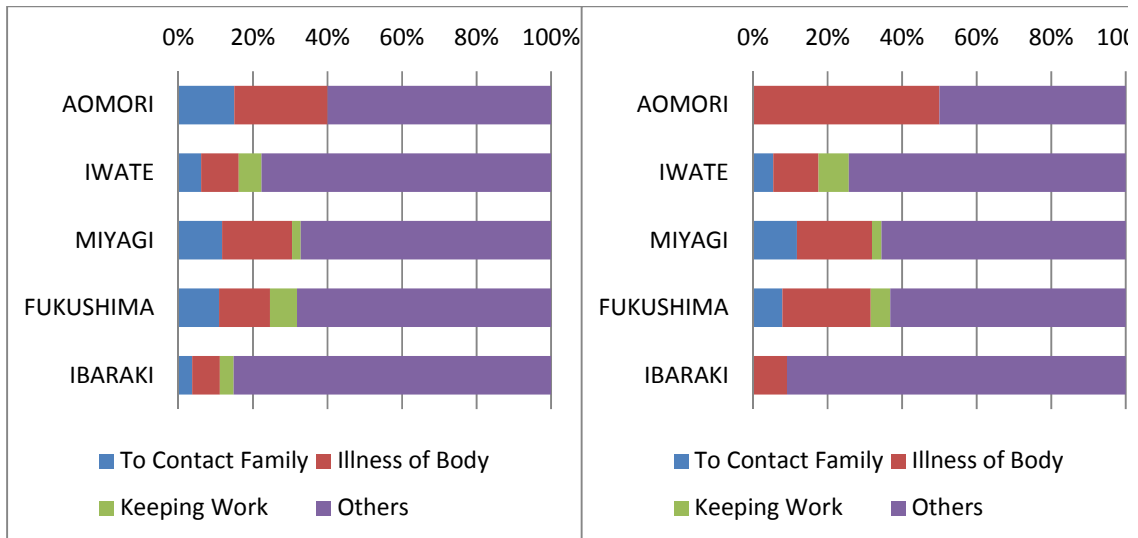
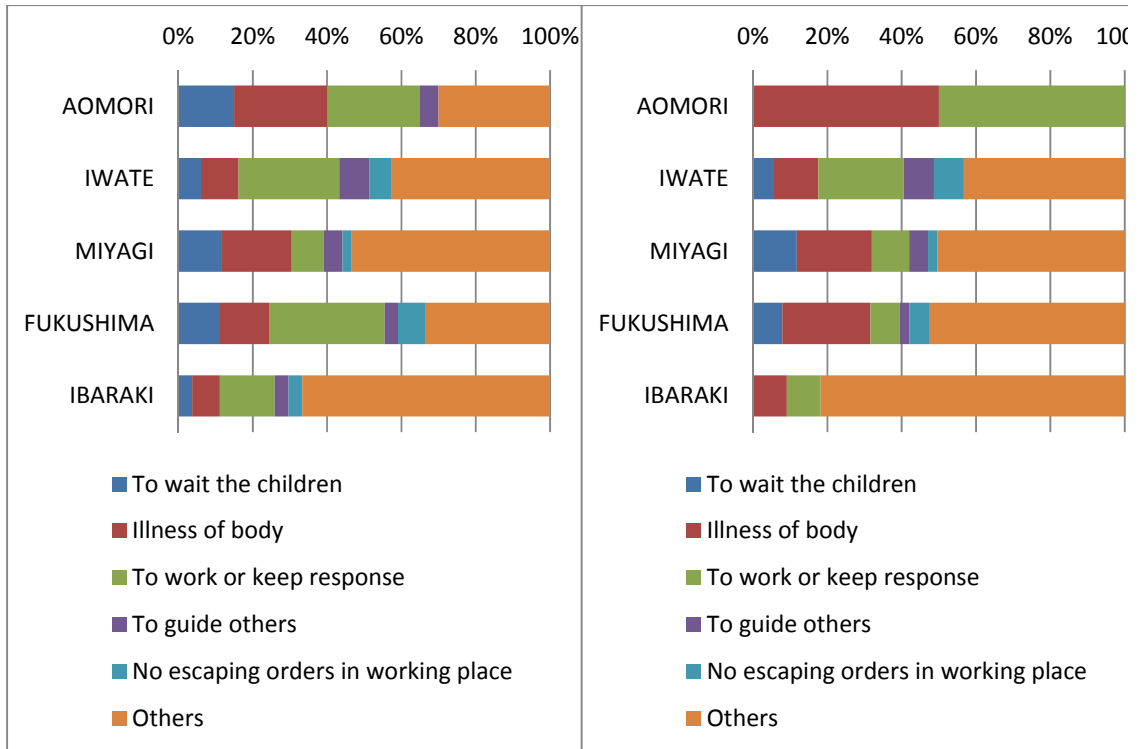
Most Useful Information



Total N=10,132

N=2,167

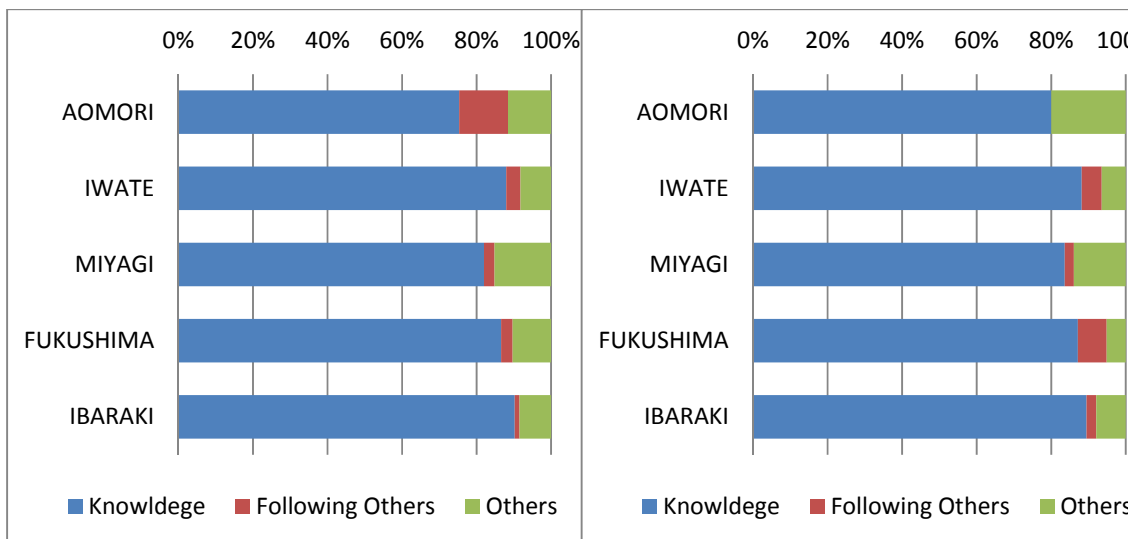
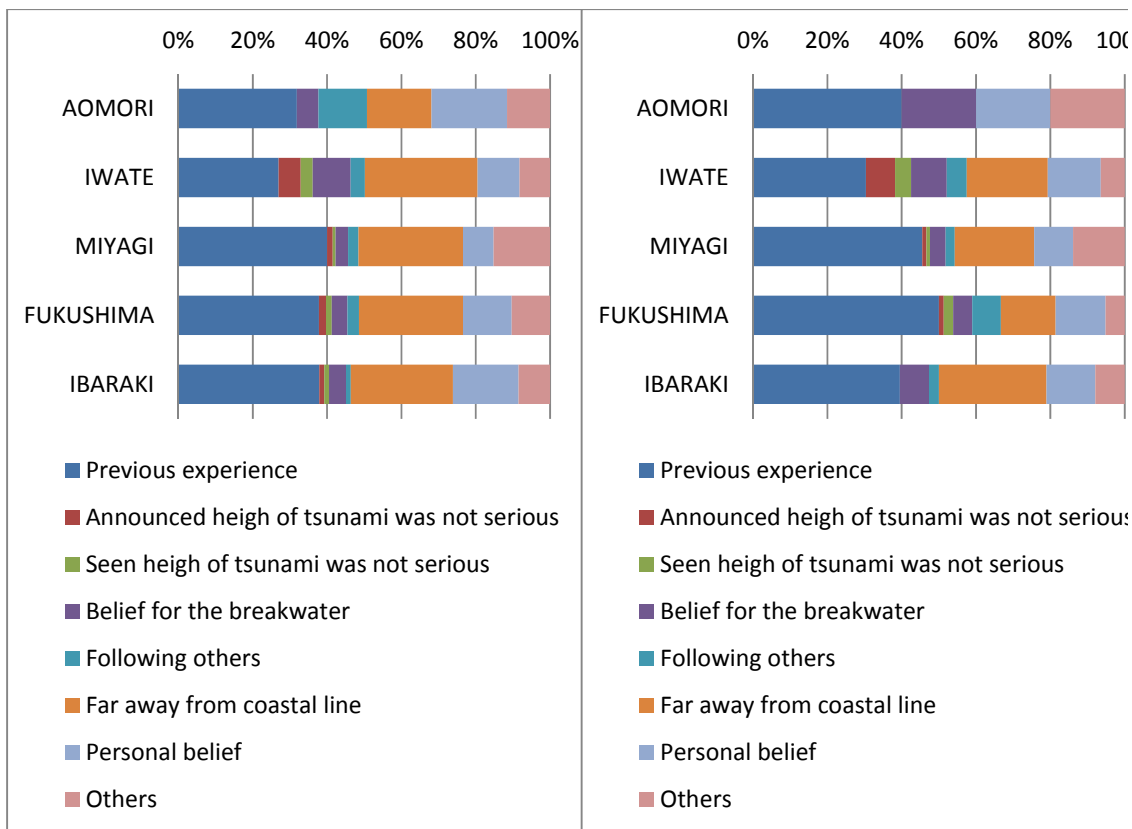
Wanted to Escape from Tsunami



Total N=10,132

N=2,167

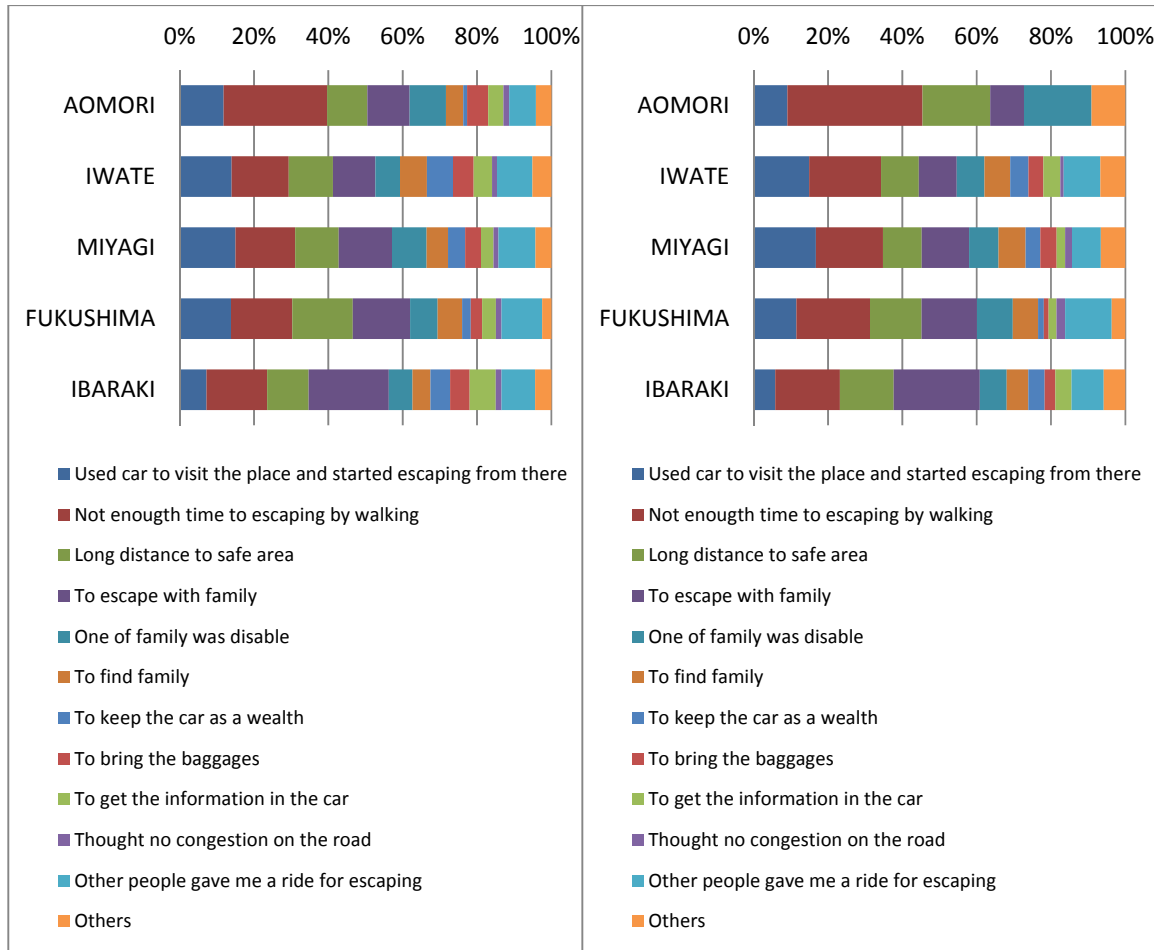
The Reason Why Evacuees could Not Escape



Total N=10,132

N=2,167

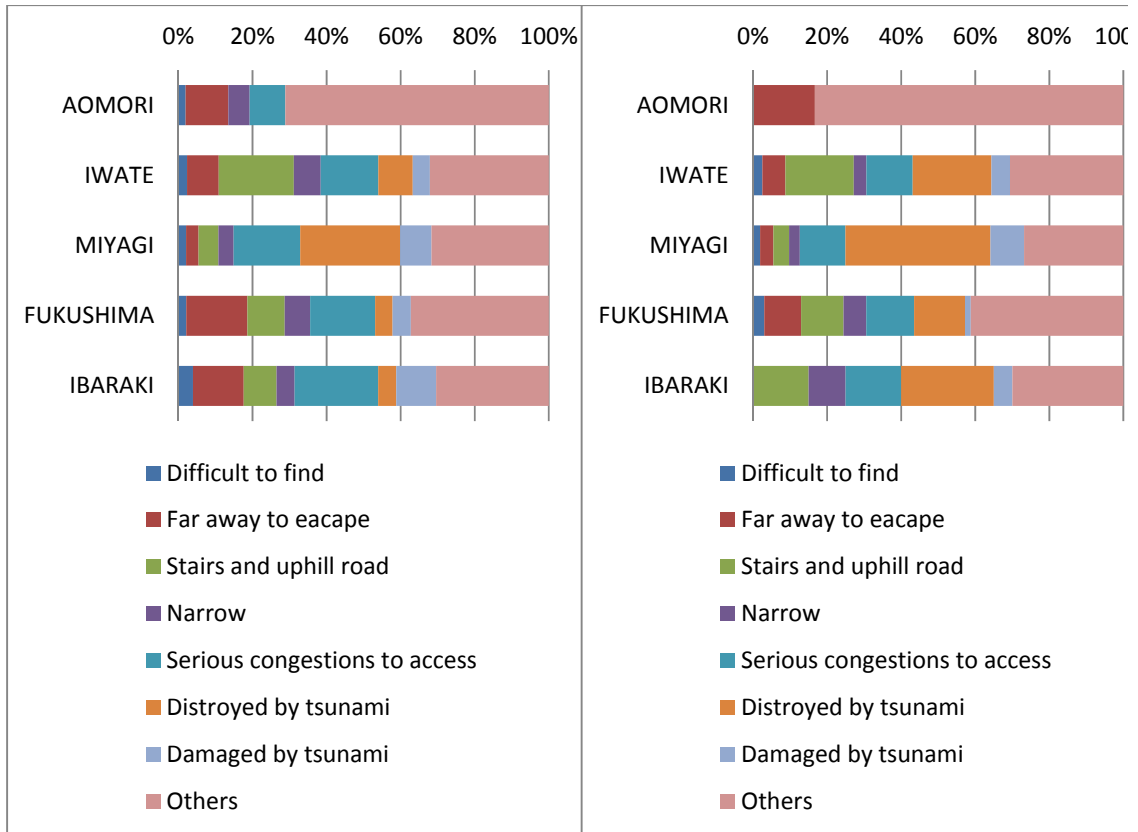
Why People did not want to escape



Total N=10,132

N=2,167

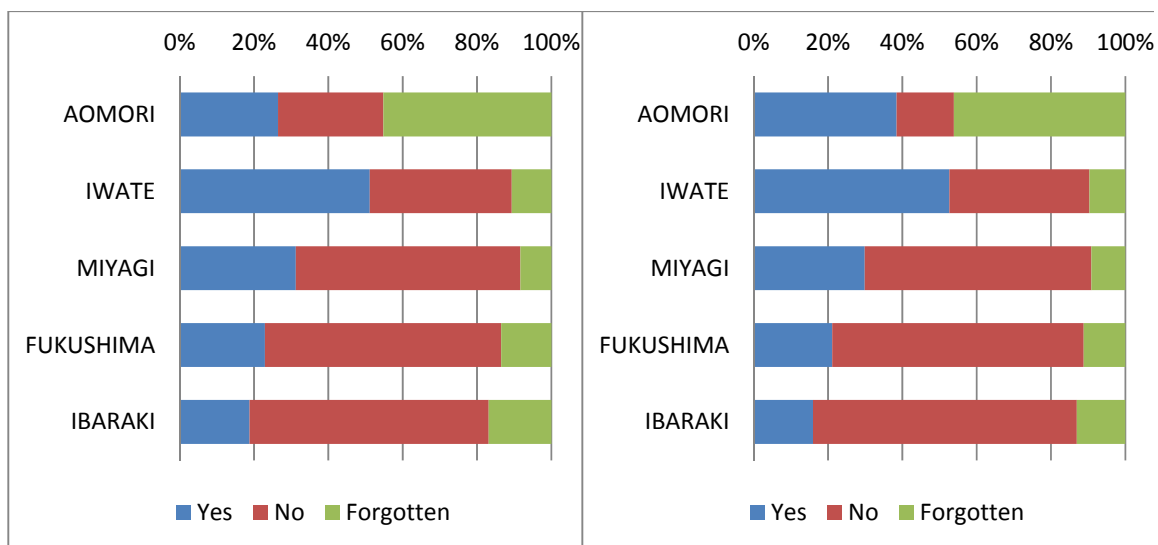
The Reasons Why Evacuees use the Car for Evacuation



Total N=10,132

N=2,167

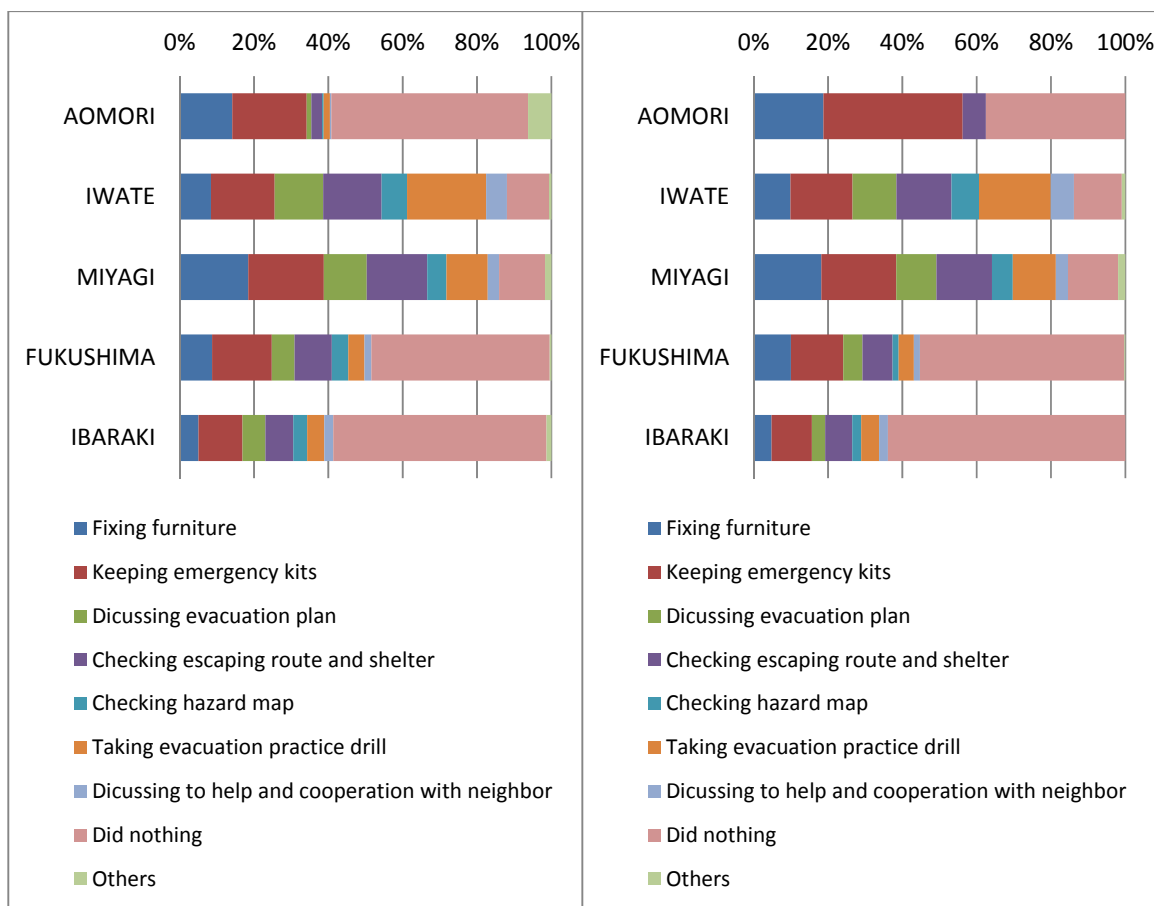
The Problems in Official Shelters



Total N=10,132

N=2,167

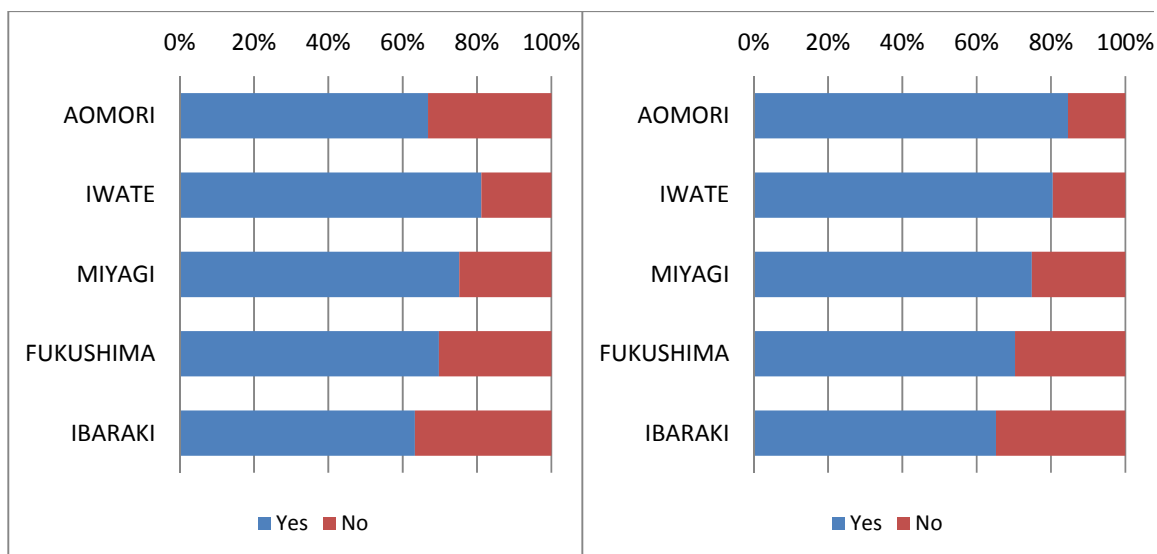
Had Seen the Hazard Map



Total N=10,132

N=2,167

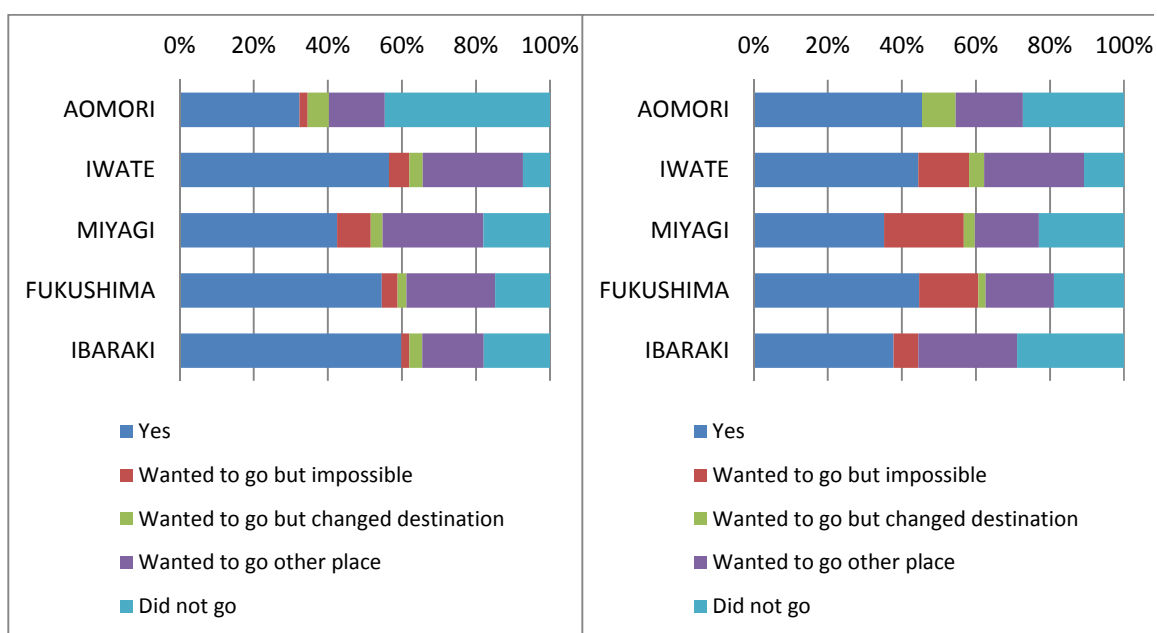
Normal Prevention Work at Home



Total N=10,132

N=2,167

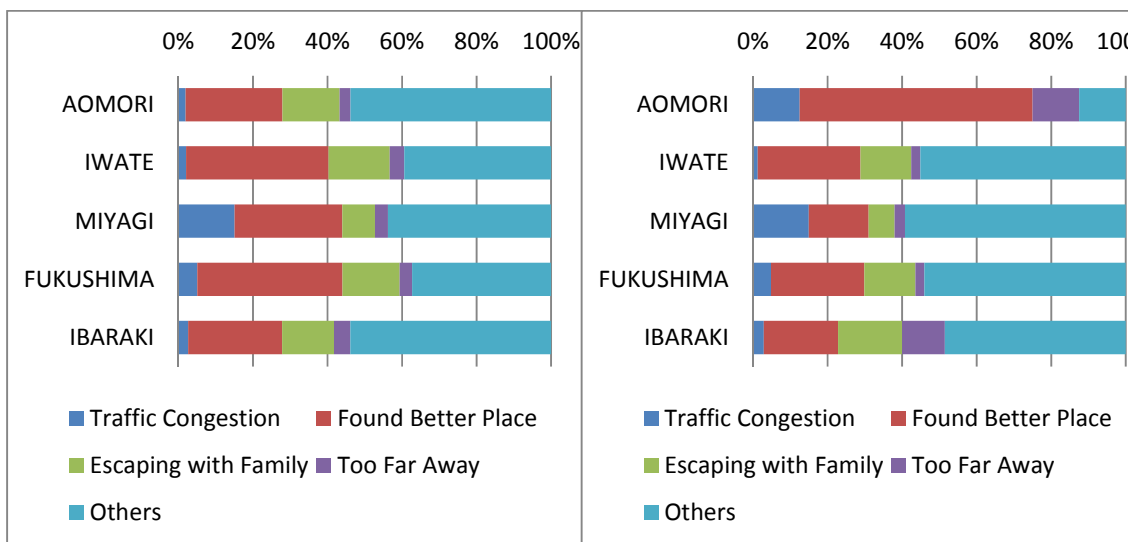
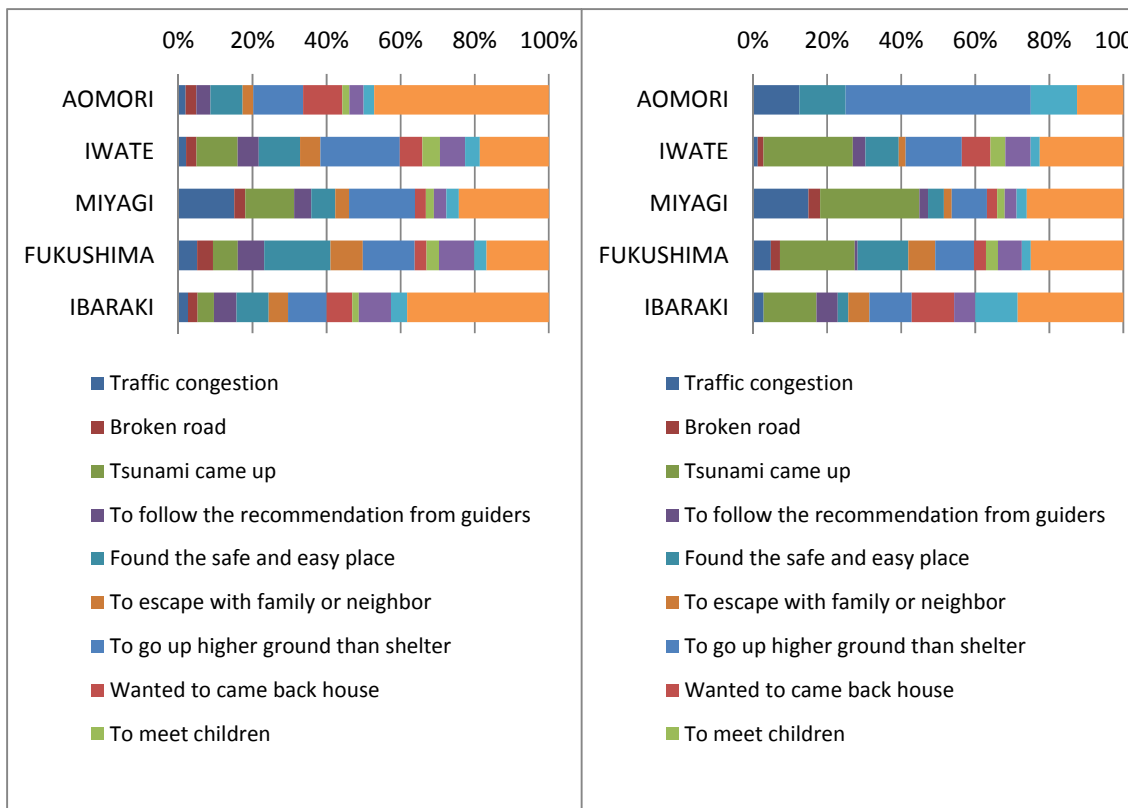
Had Known the Nearest Shelter



Total N=10,132

N=2,167

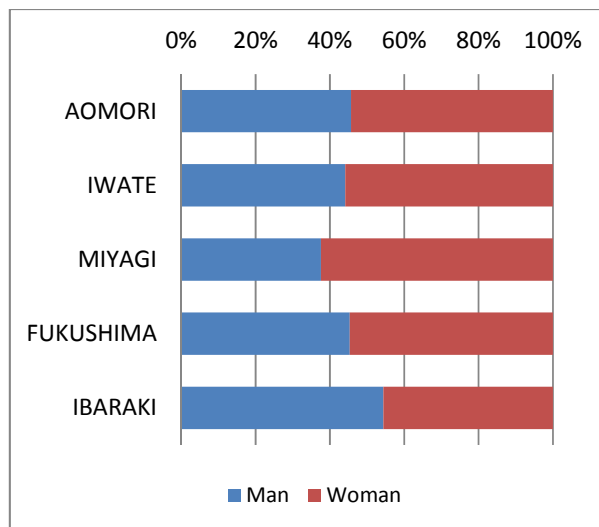
Reached the Nearest Shelter



Total N=10,132

N=2,167

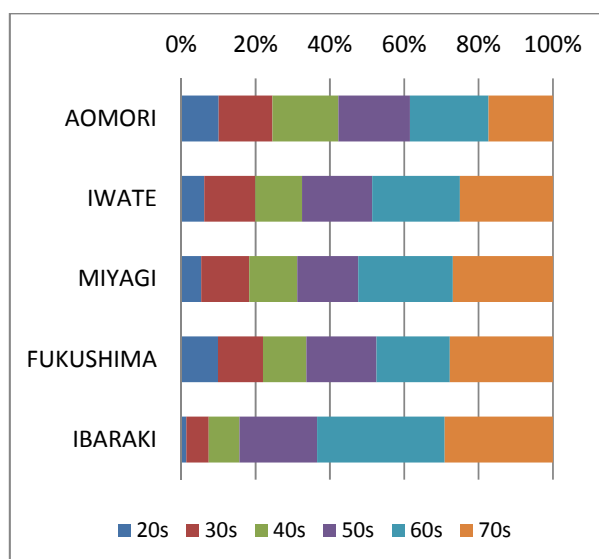
The Reasons Why Evacuees did not go to the Nearest Shelters



Total N=10,132

N=2,167

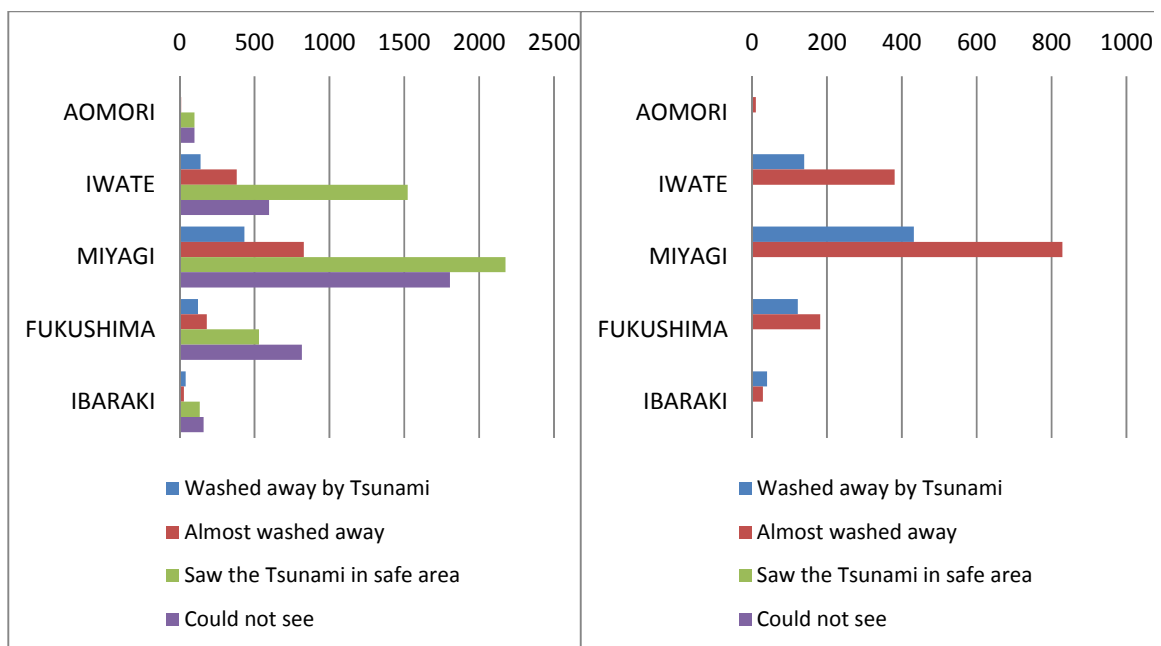
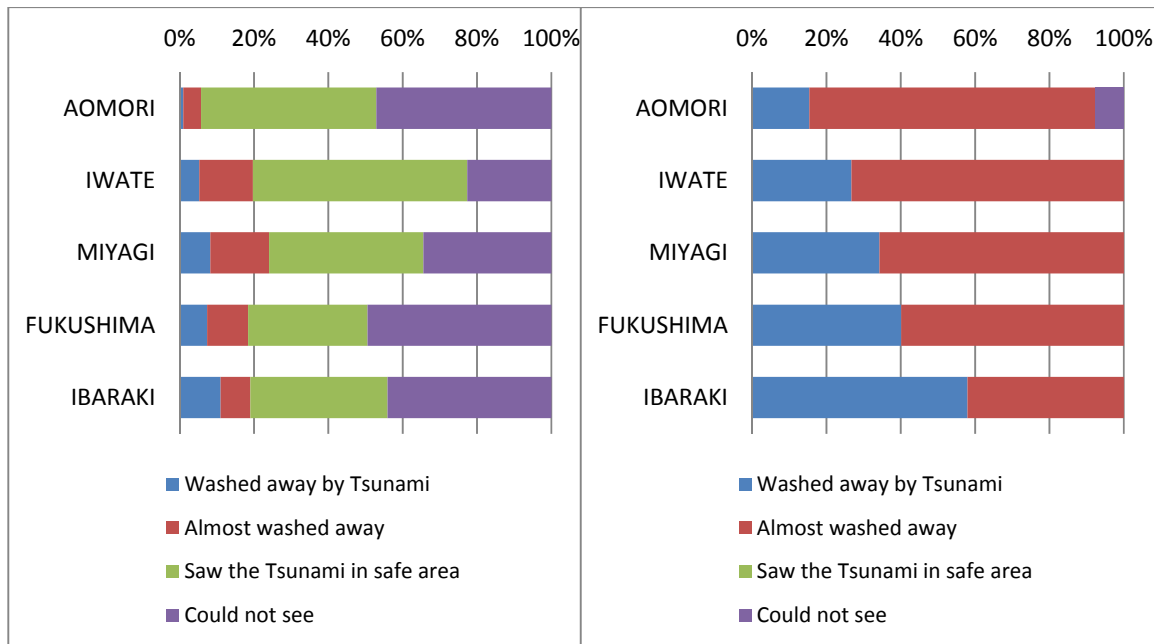
Genders

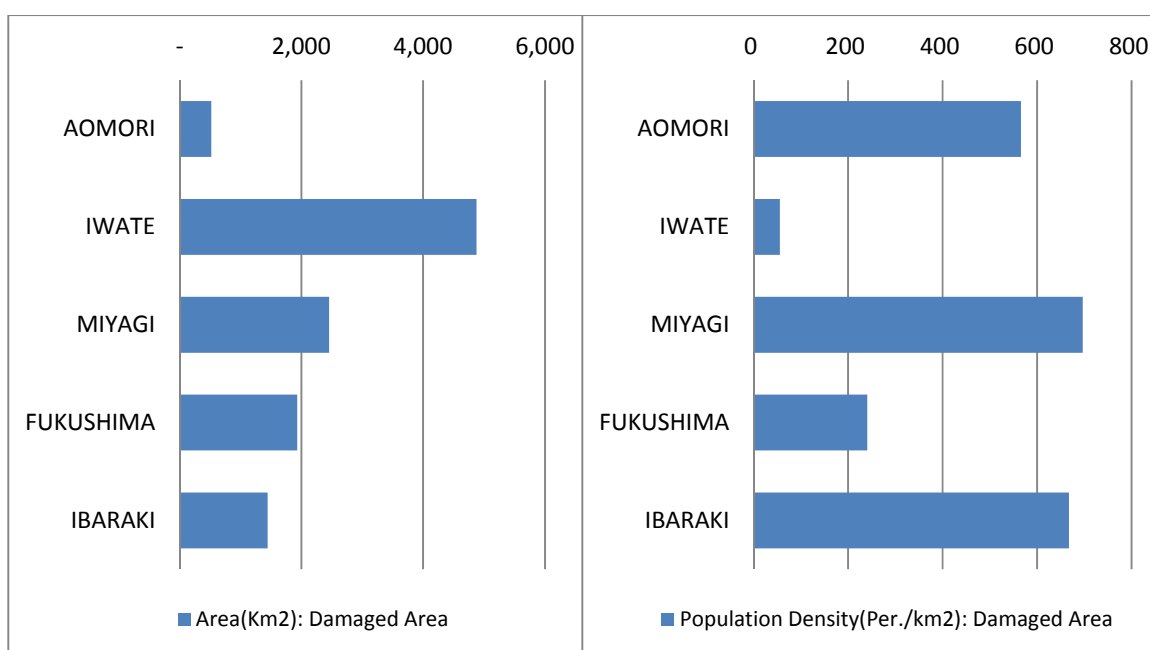
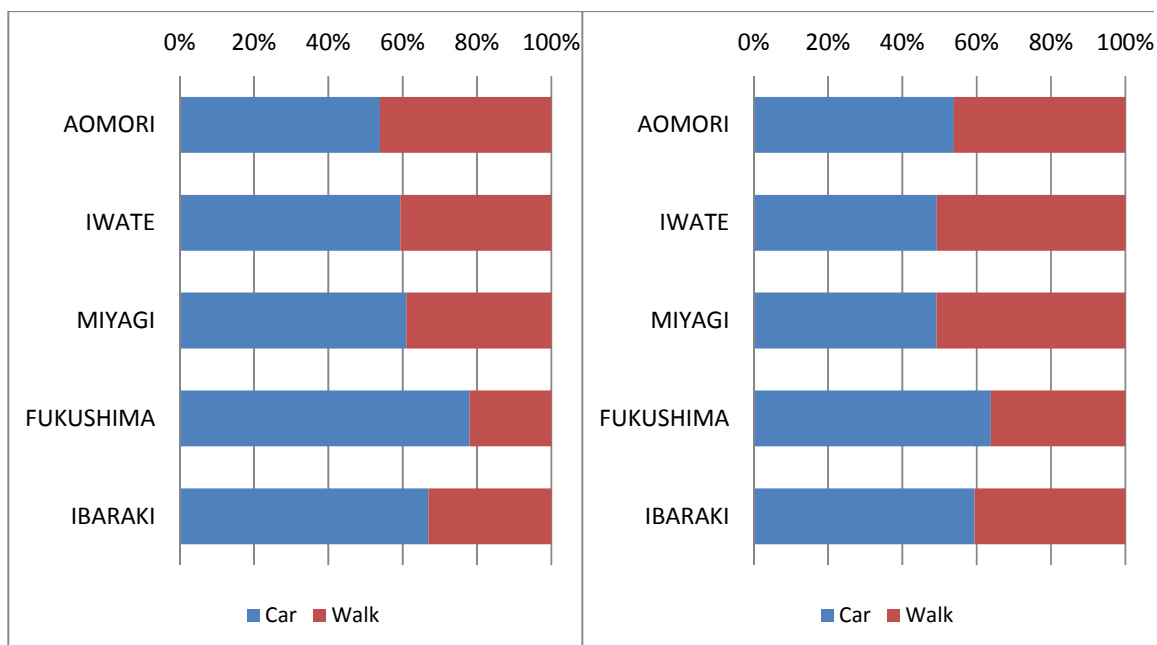


Total N=10,132

N=2,167

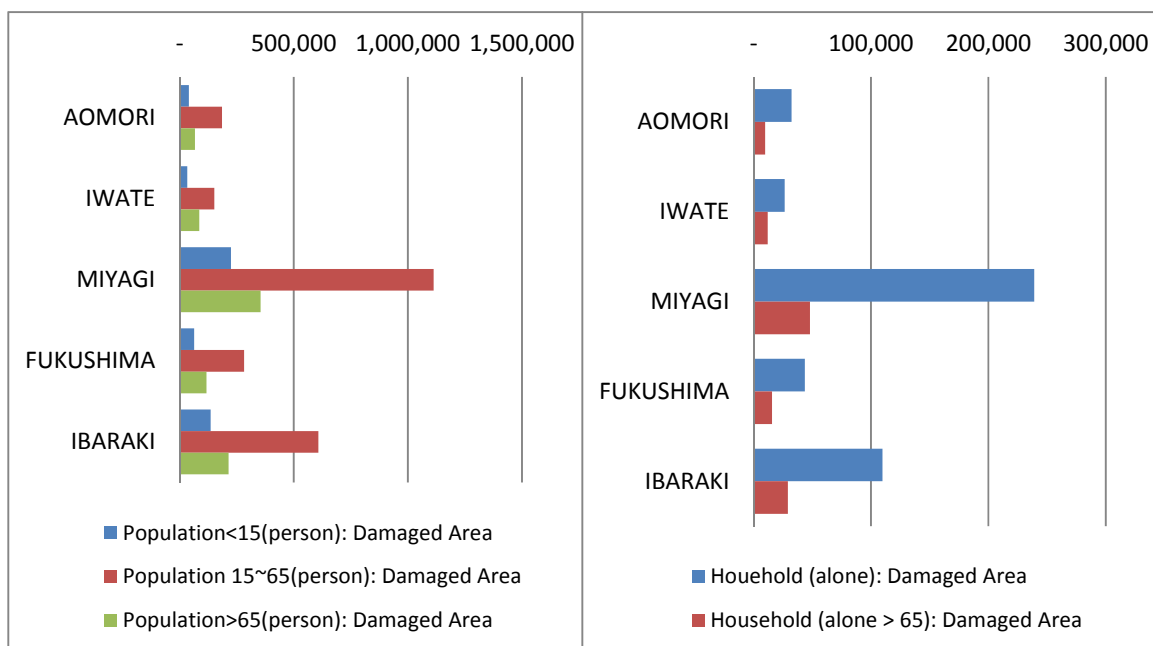
Age Structure



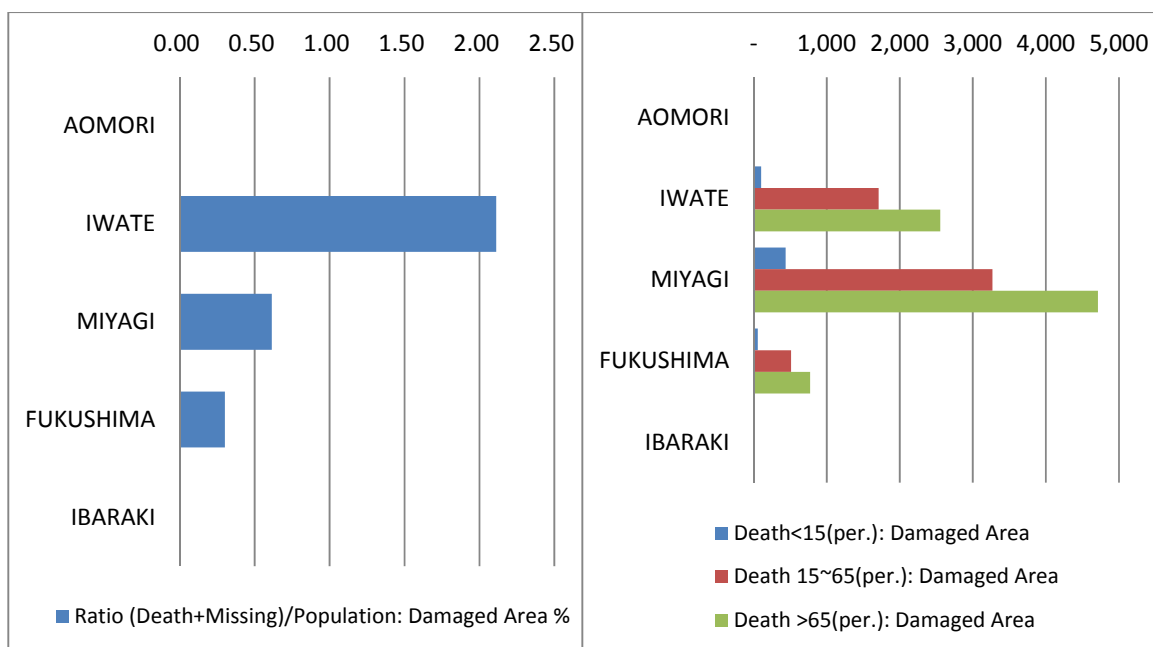


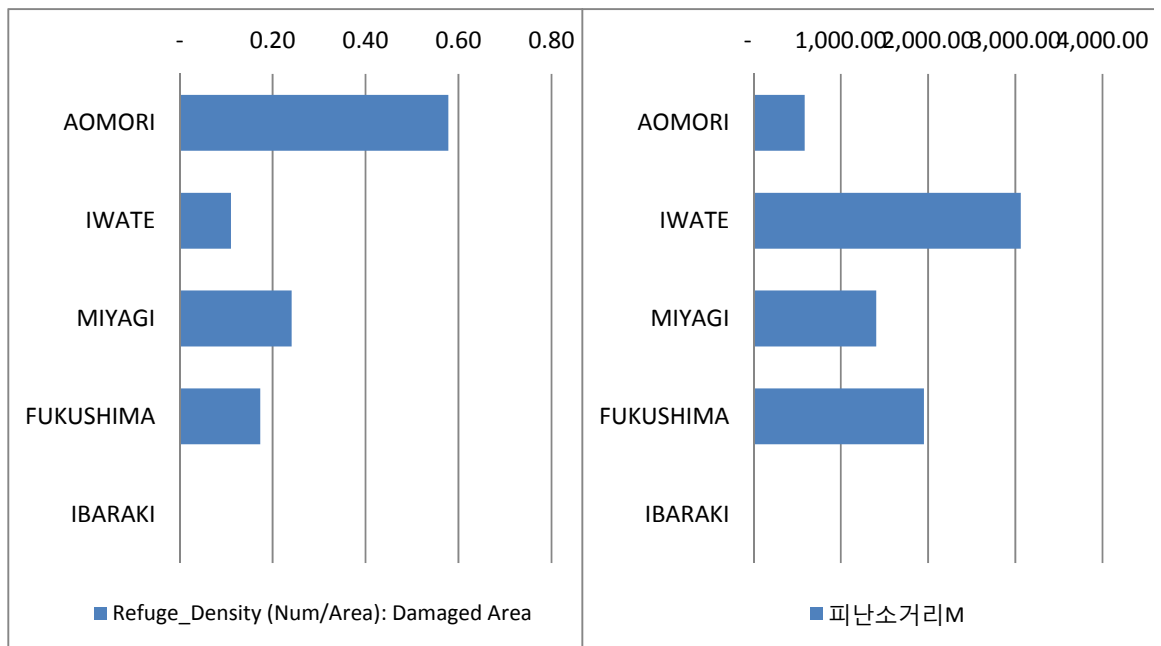
Area

Population

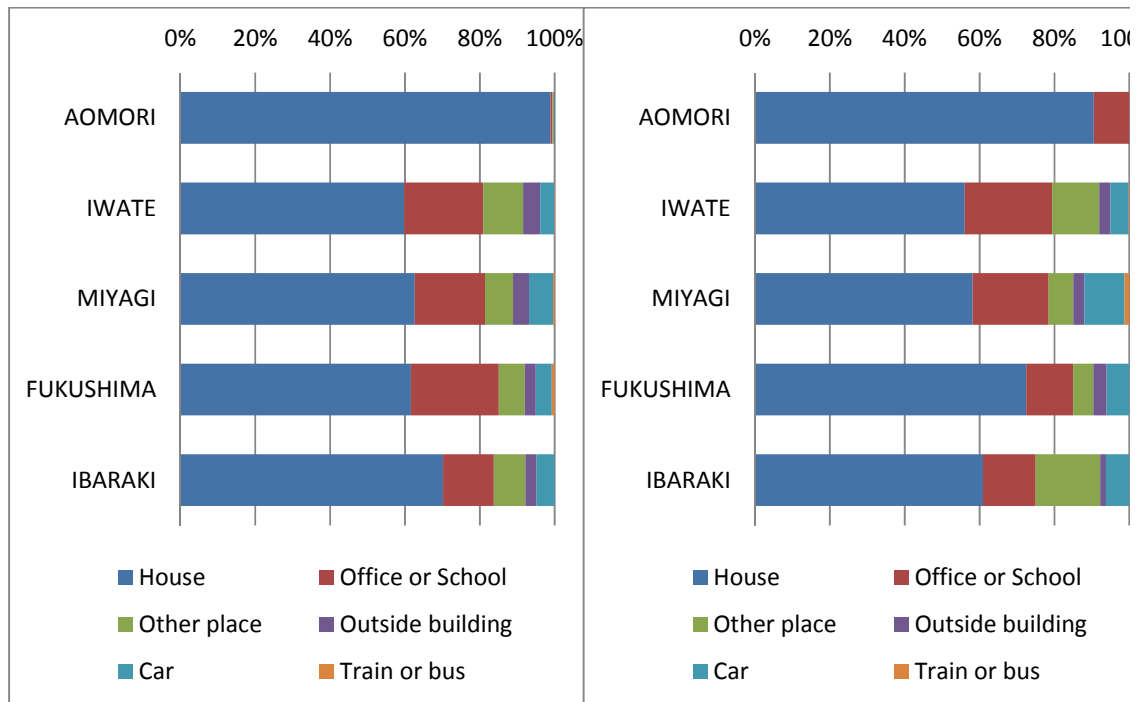


Population





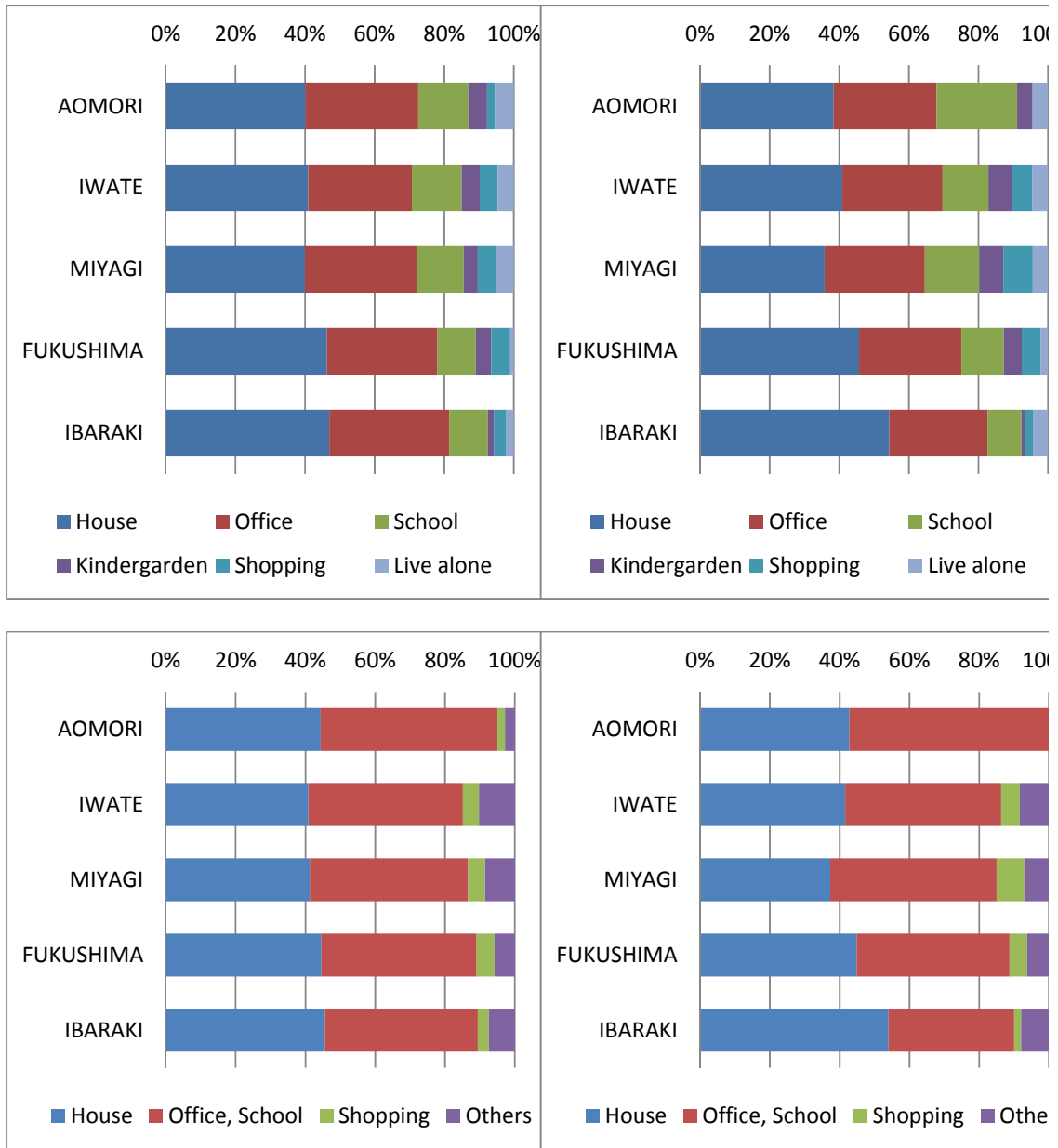
E. Summary of Questionnaire (Data Extension based on the Area and Population Density)



Total N=10,132

N=2,167

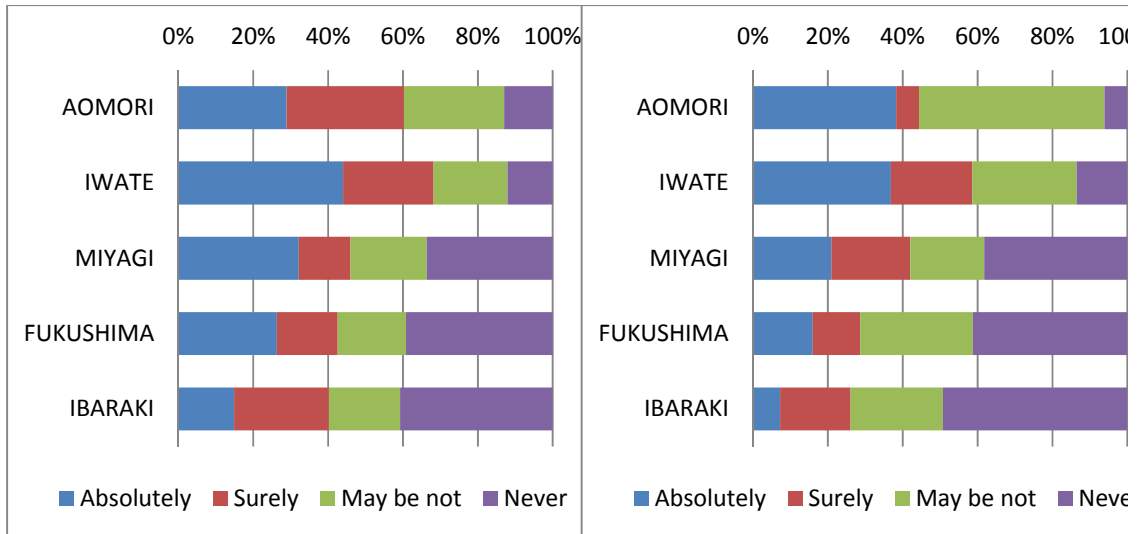
The places when the earthquake occurred



Total N=10,132

N=2,167

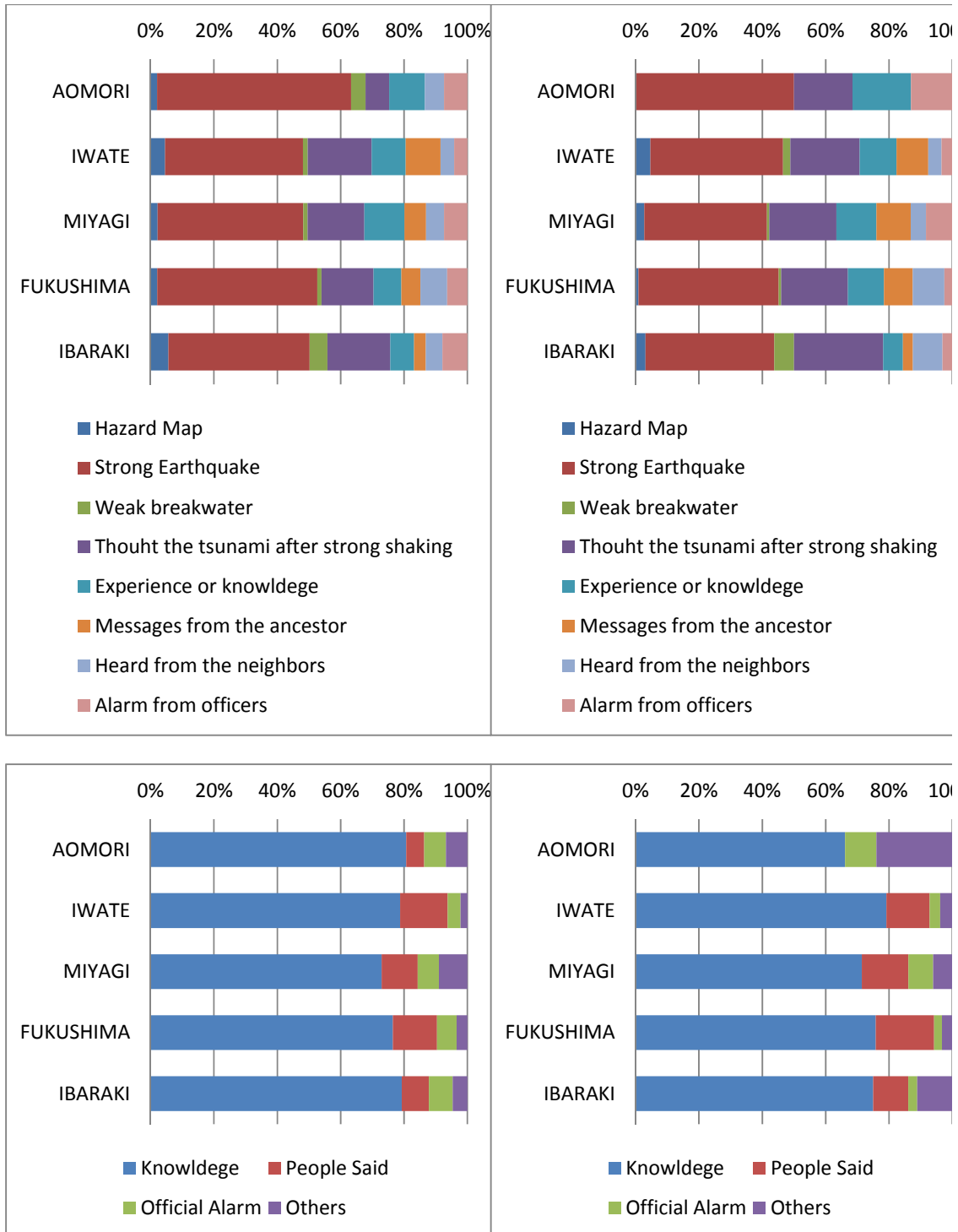
The places of Family when the earthquake occurred



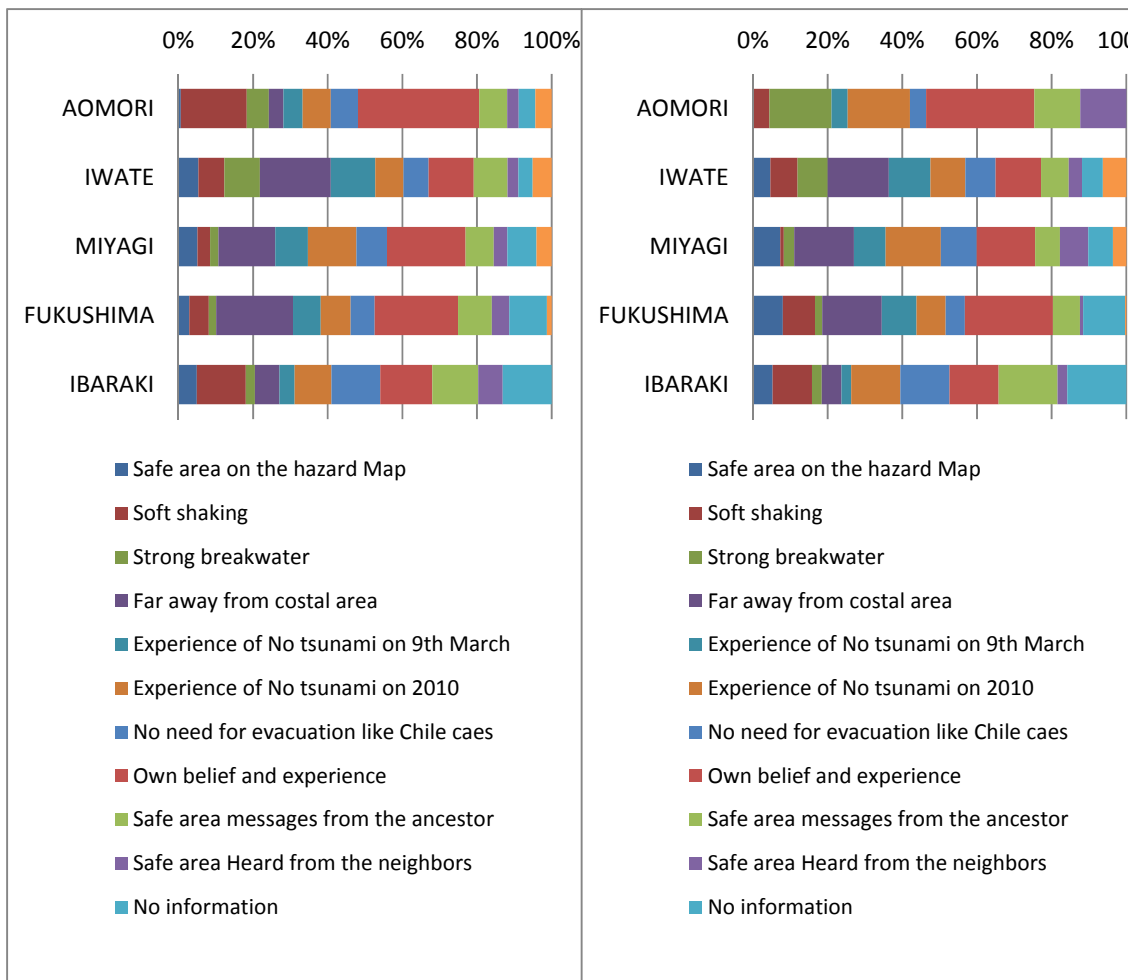
Total N=10,132

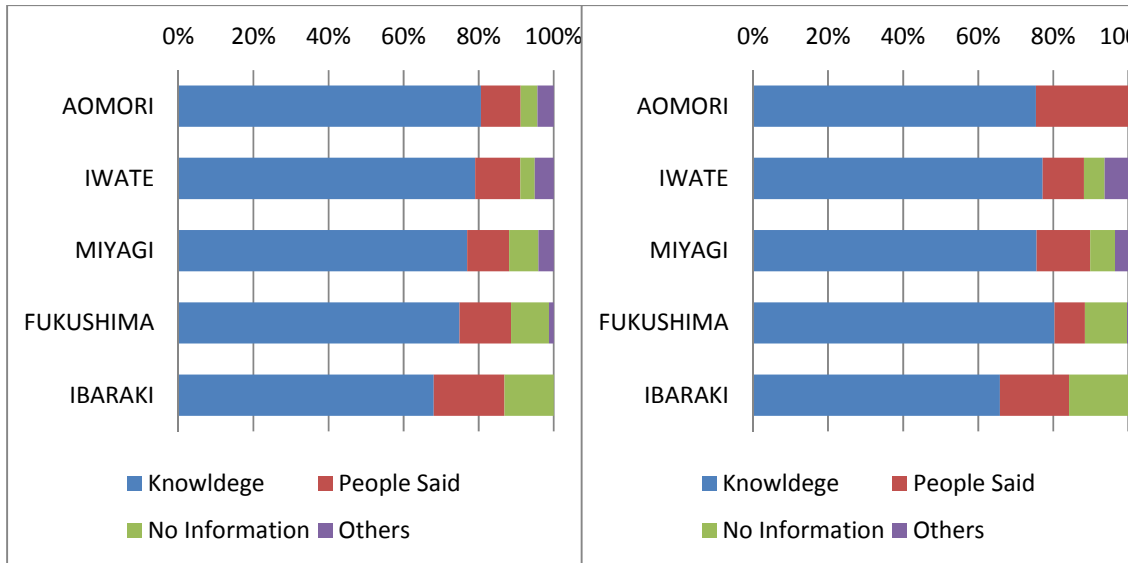
N=2,167

Belief, Tsunami comes, before the Tsunami Warning

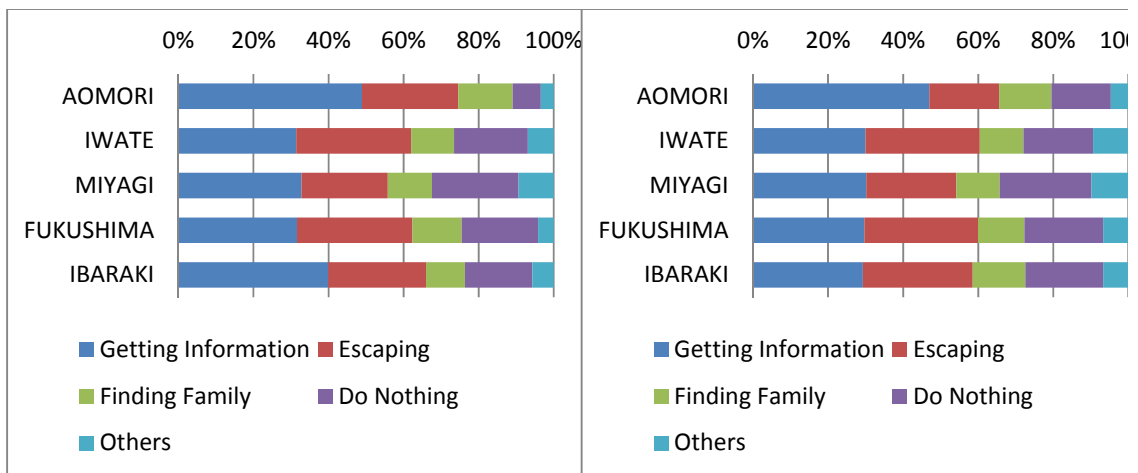
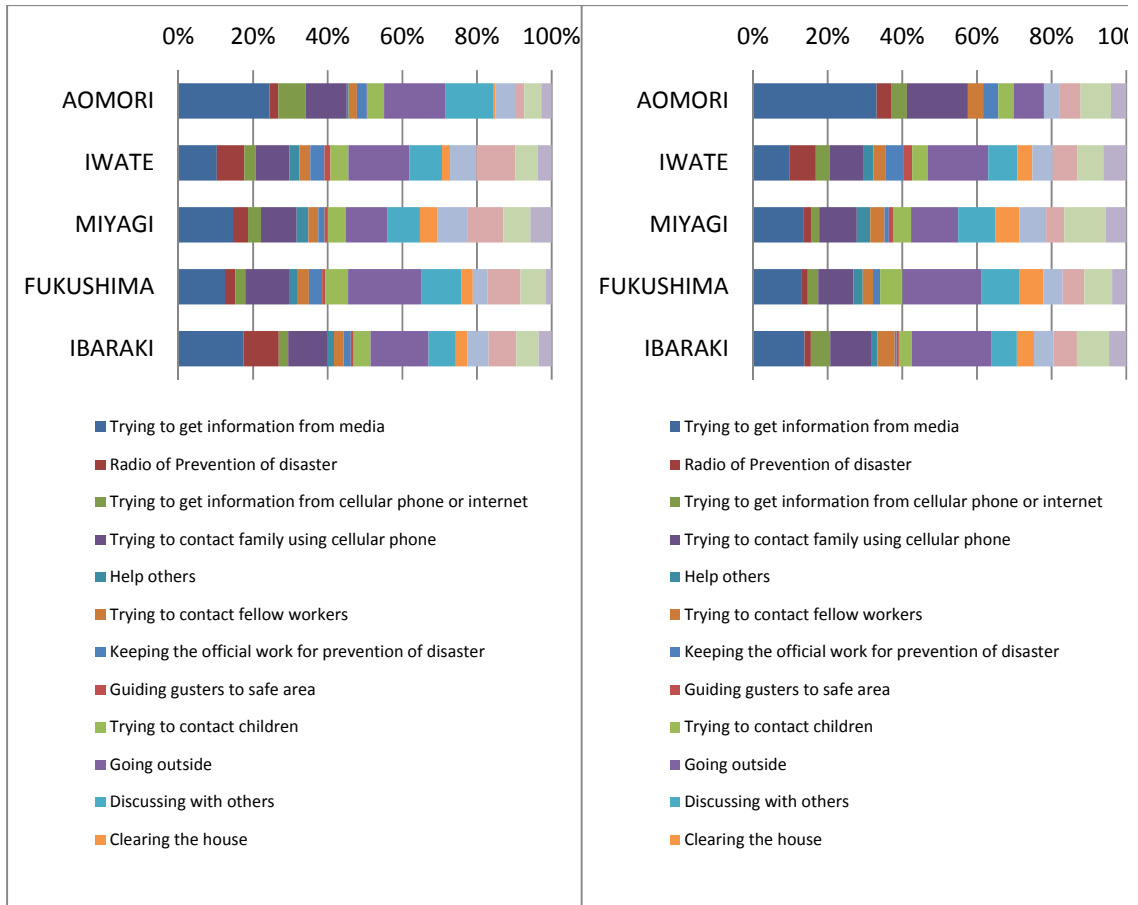


The reason why the Tsunami will come





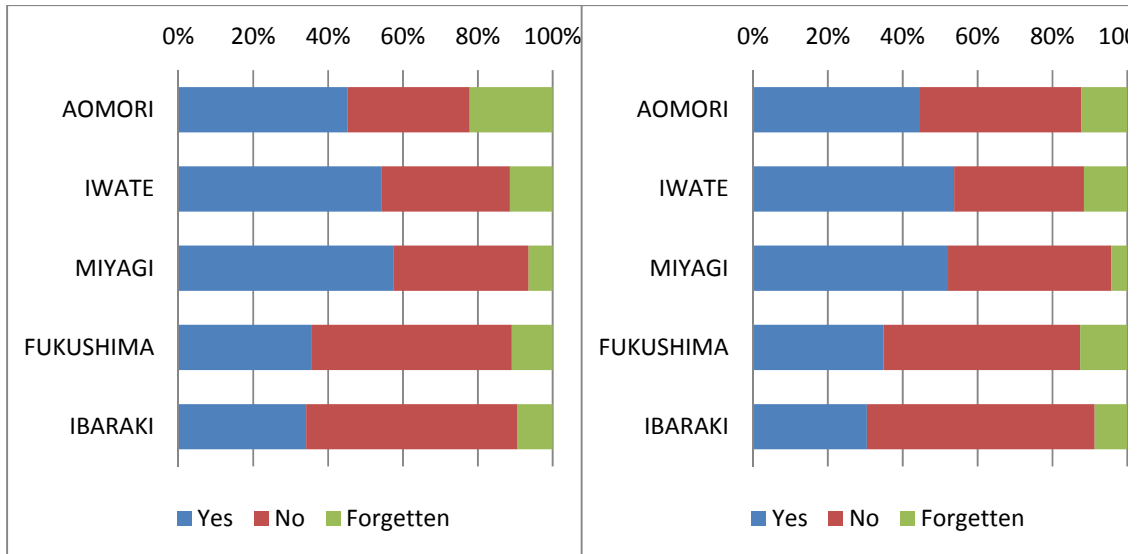
The reason why the Tsunami will NOT come



Total N=10,132

N=2,167

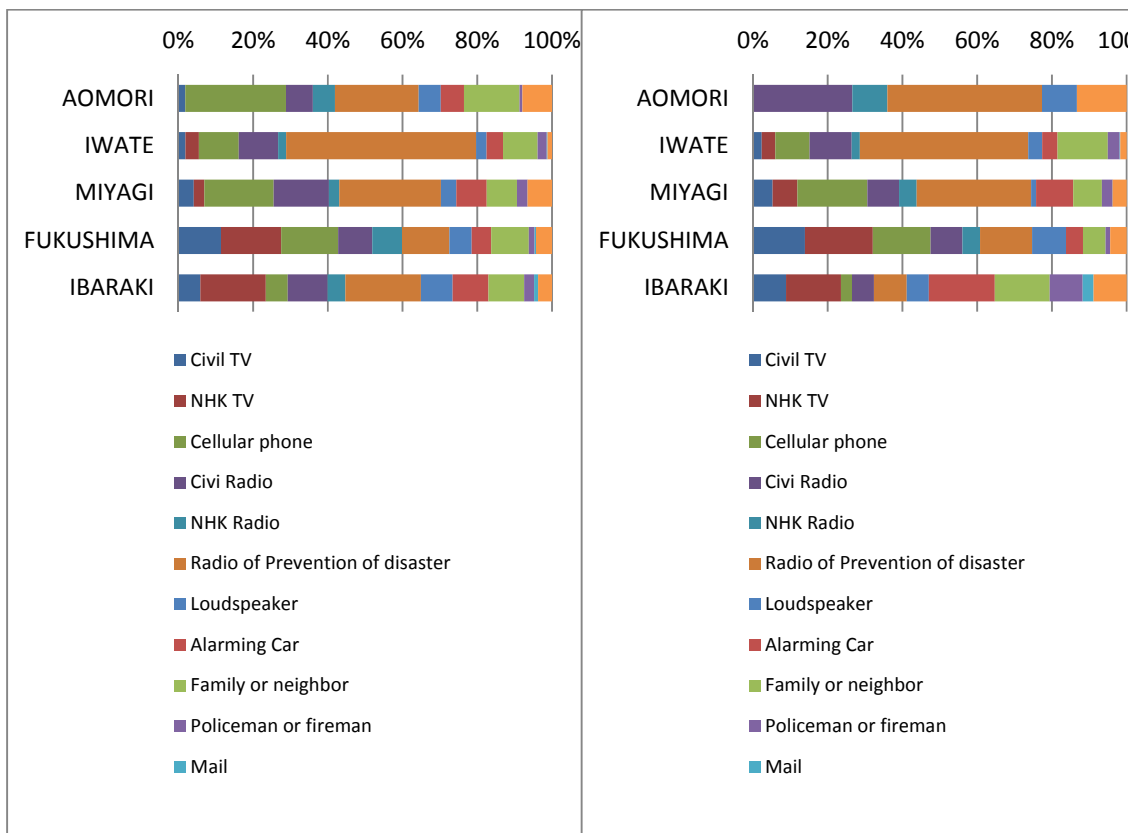
Actions just after shaking

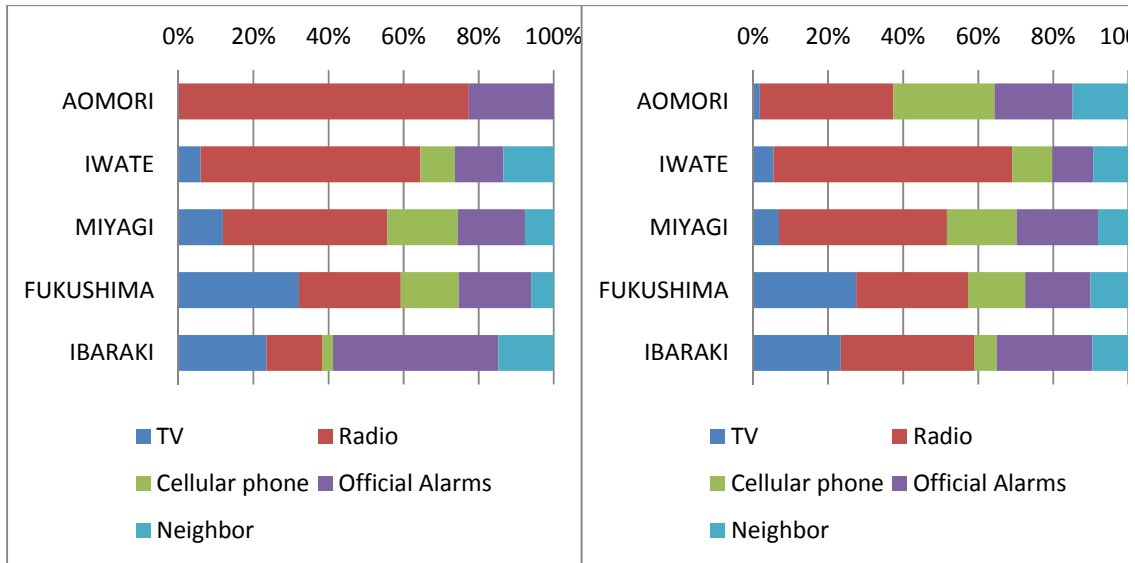


Total N=10,132

N=2,167

Catching the Tsunami Warning Sound

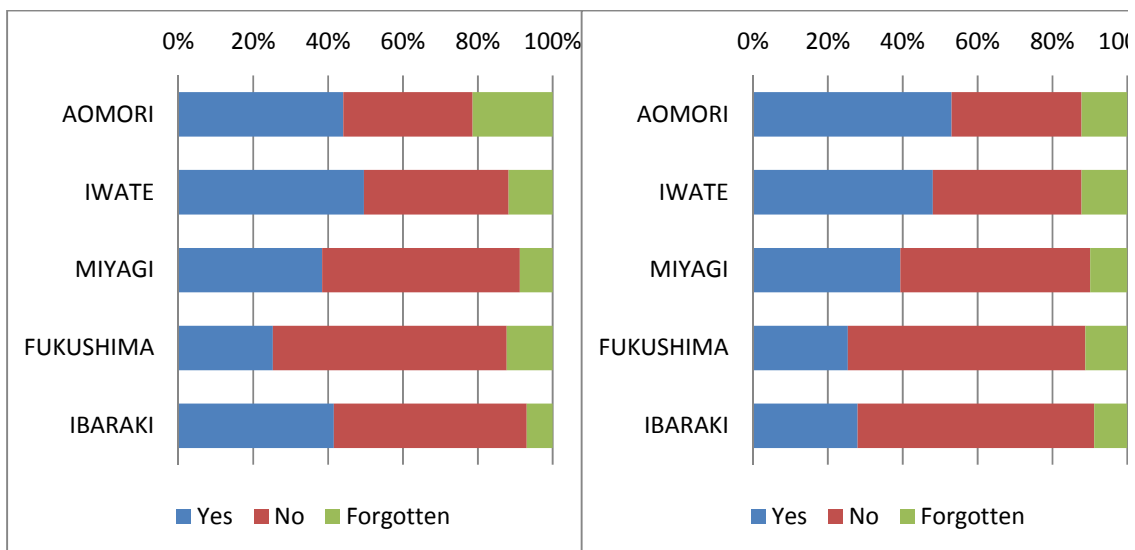




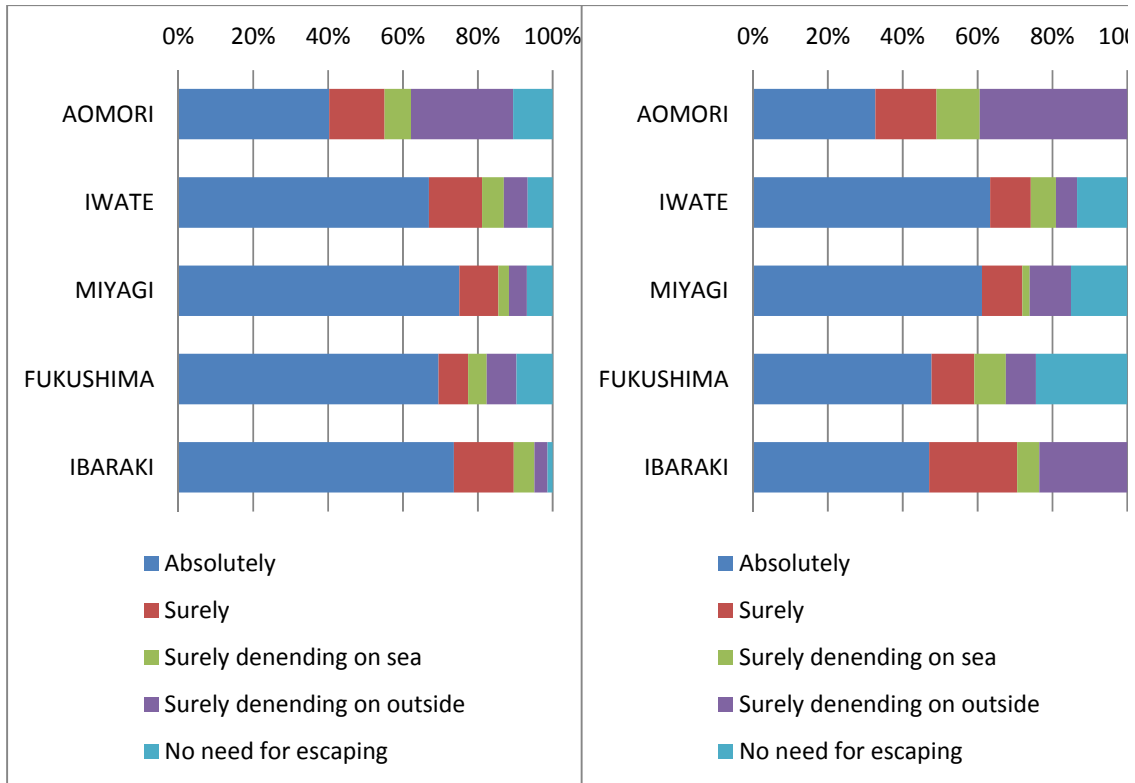
Total N=10,132

N=2,167

Getting Tsunami warning Information



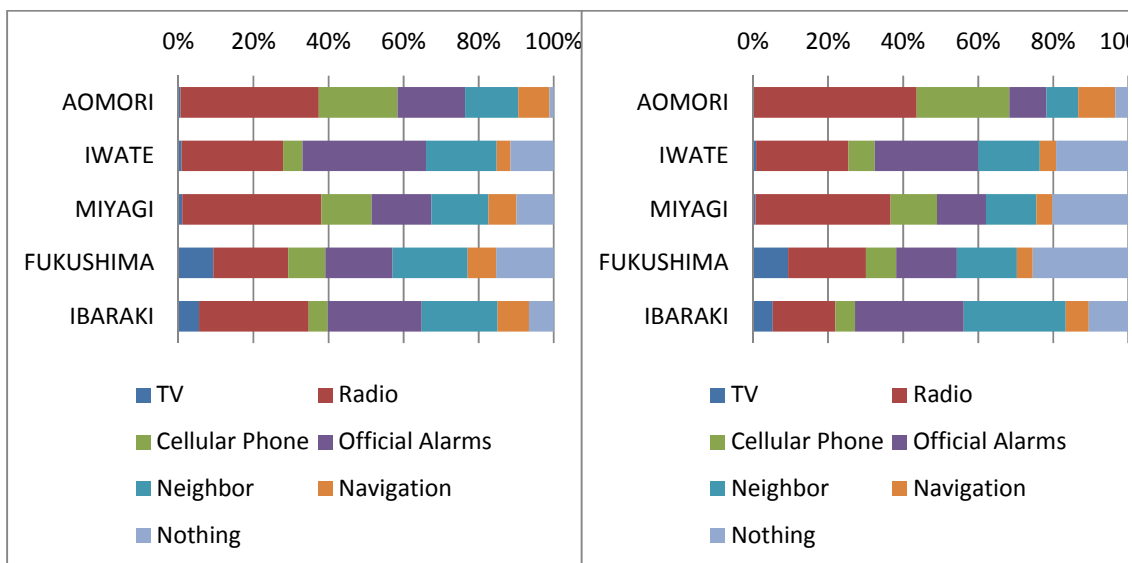
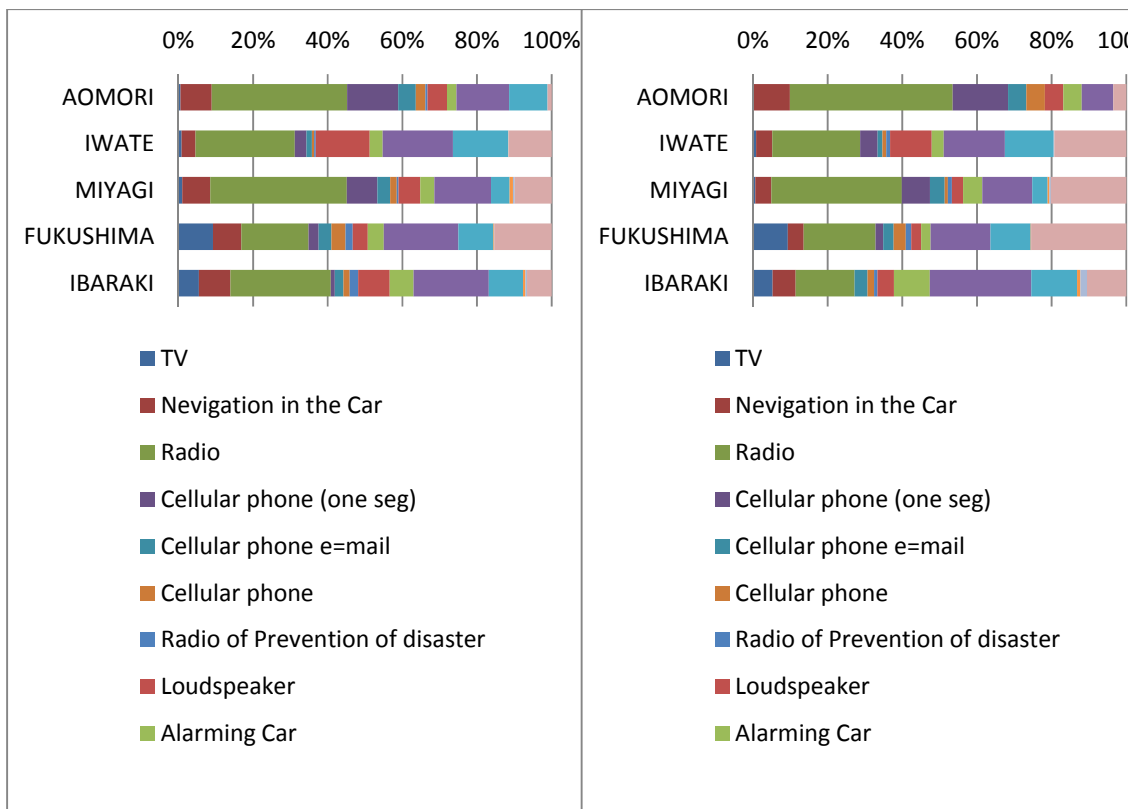
Government Officers Suggested Escaping



Total N=10,132

N=2,167

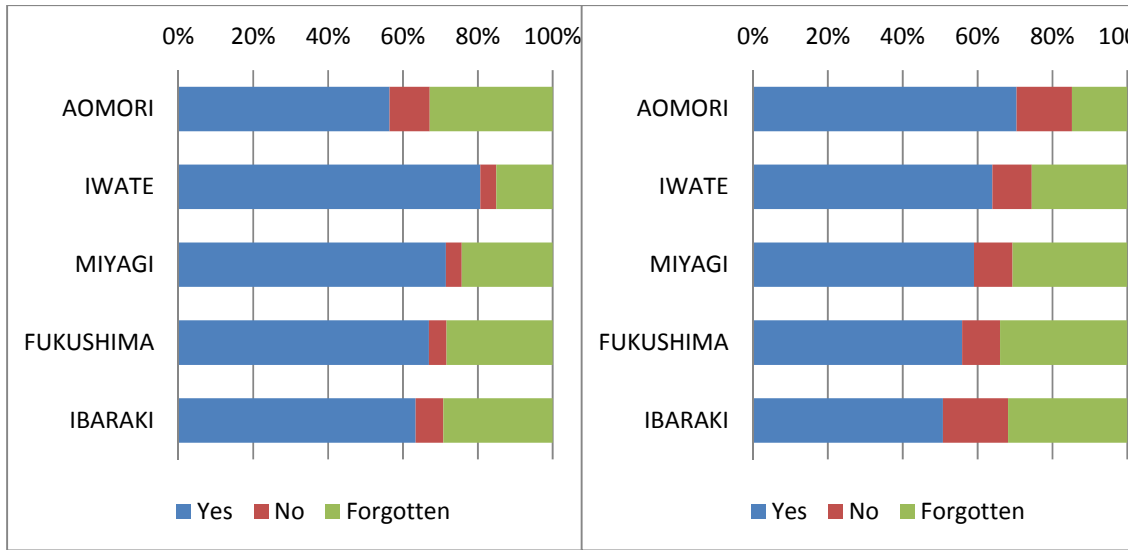
Getting Suggestion from Officers, Tried to Escape



Total N=10,132

N=2,167

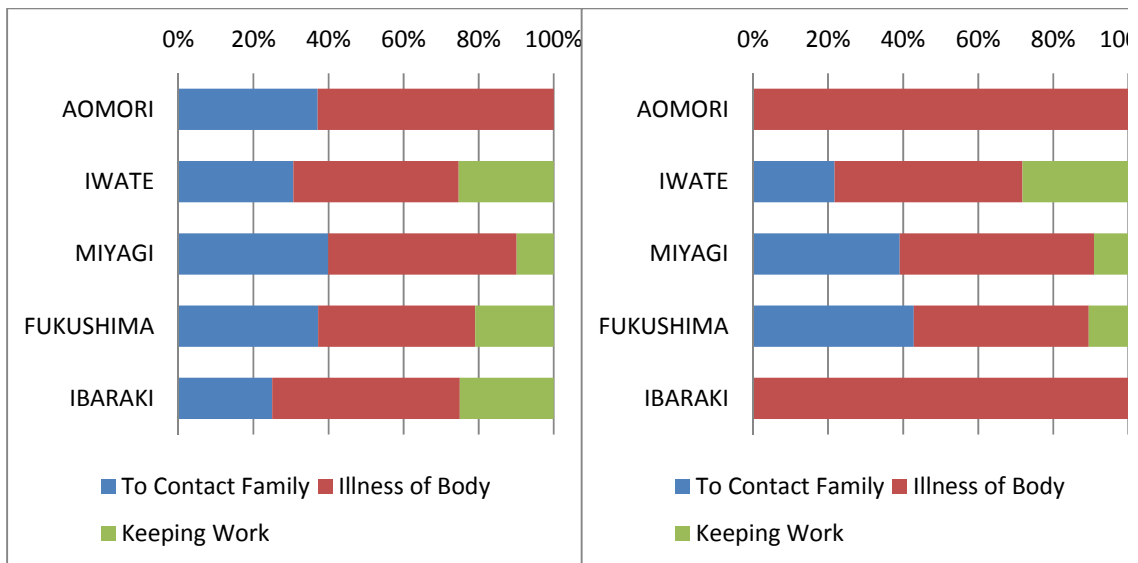
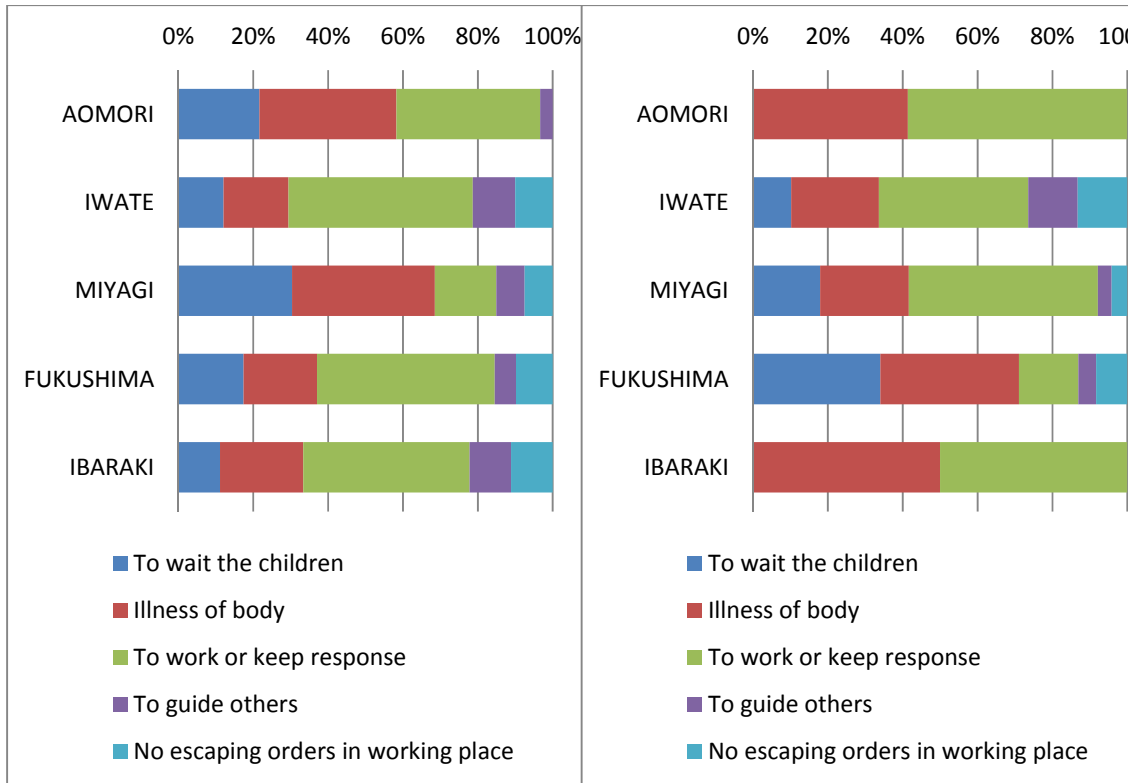
Most Useful Information



Total N=10,132

N=2,167

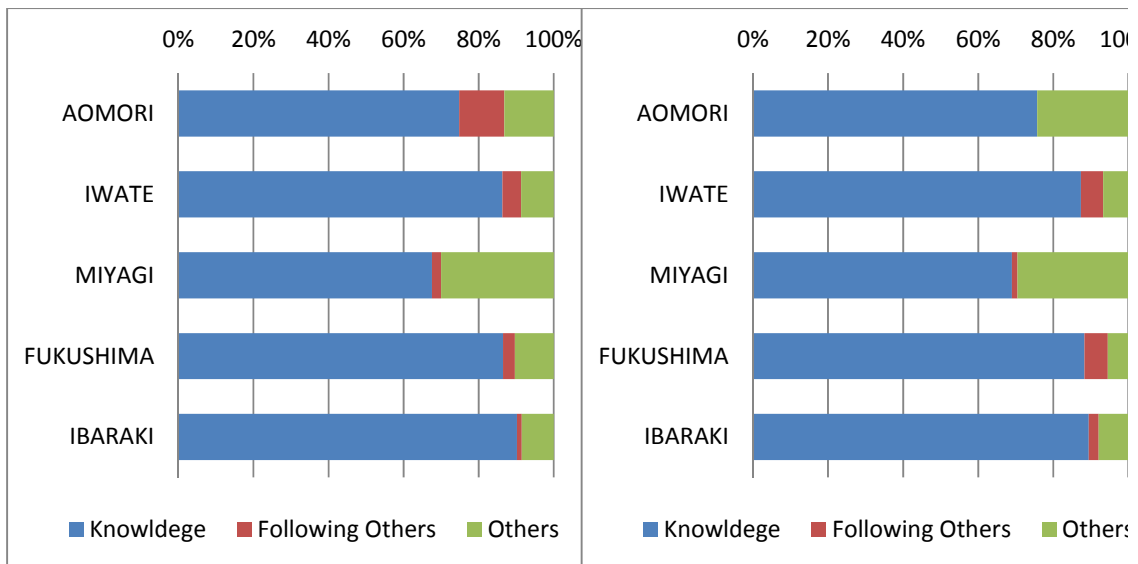
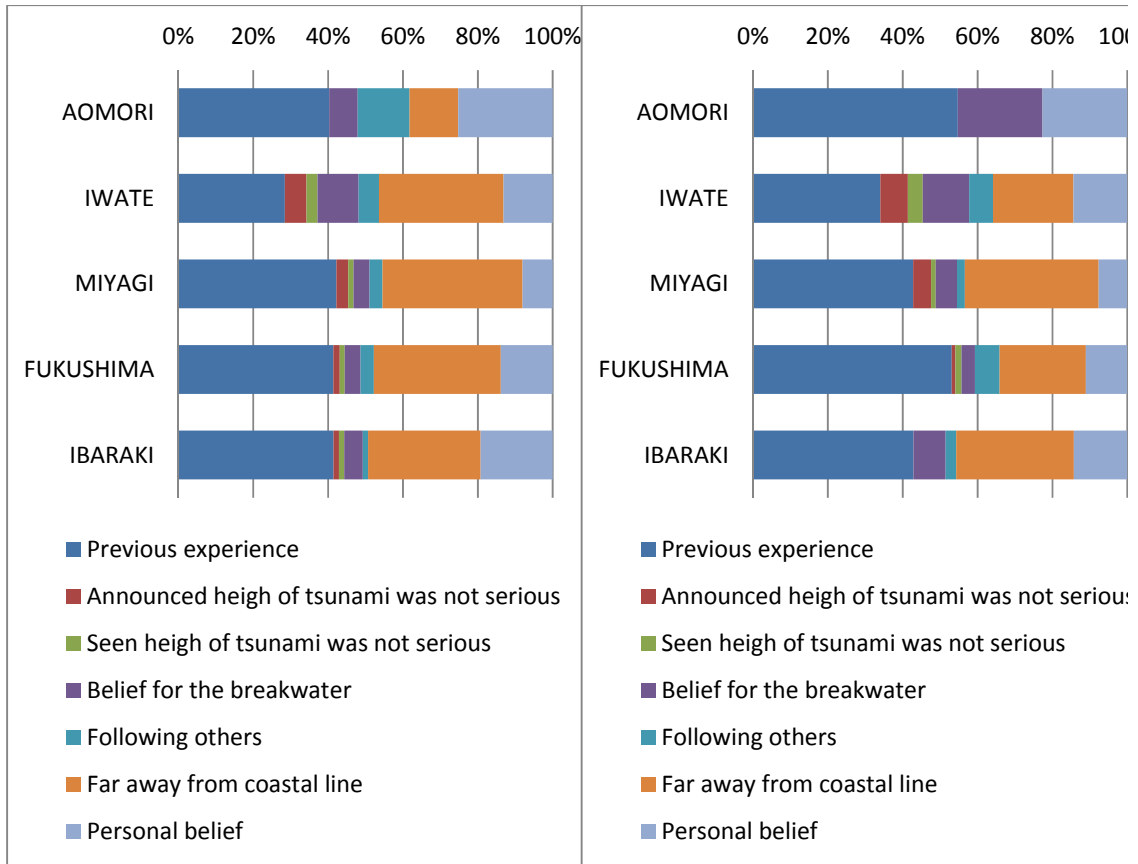
Wanted to Escape from Tsunami



Total N=10,132

N=2,167

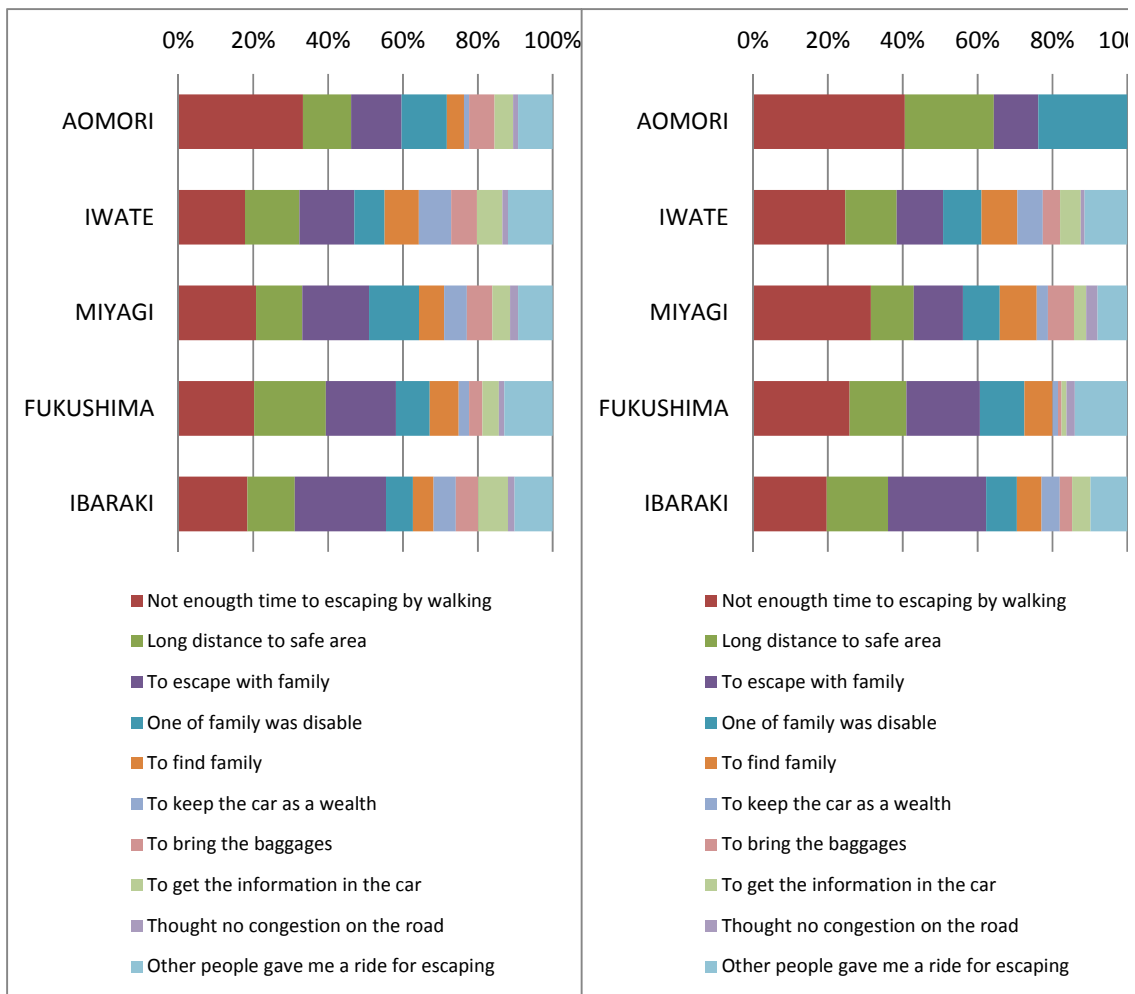
The Reason Why Evacuees could Not Escape



Total N=10,132

N=2,167

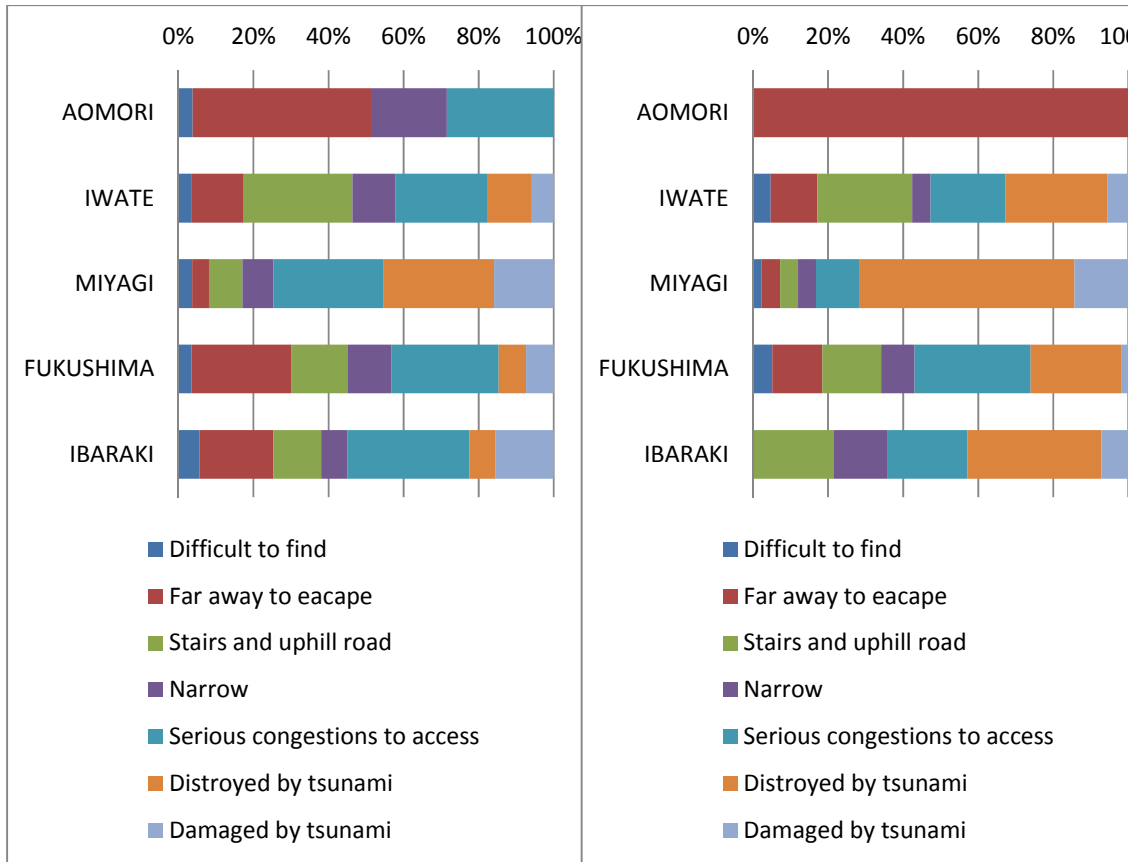
Why People did not want to escape



Total N=10,132

N=2,167

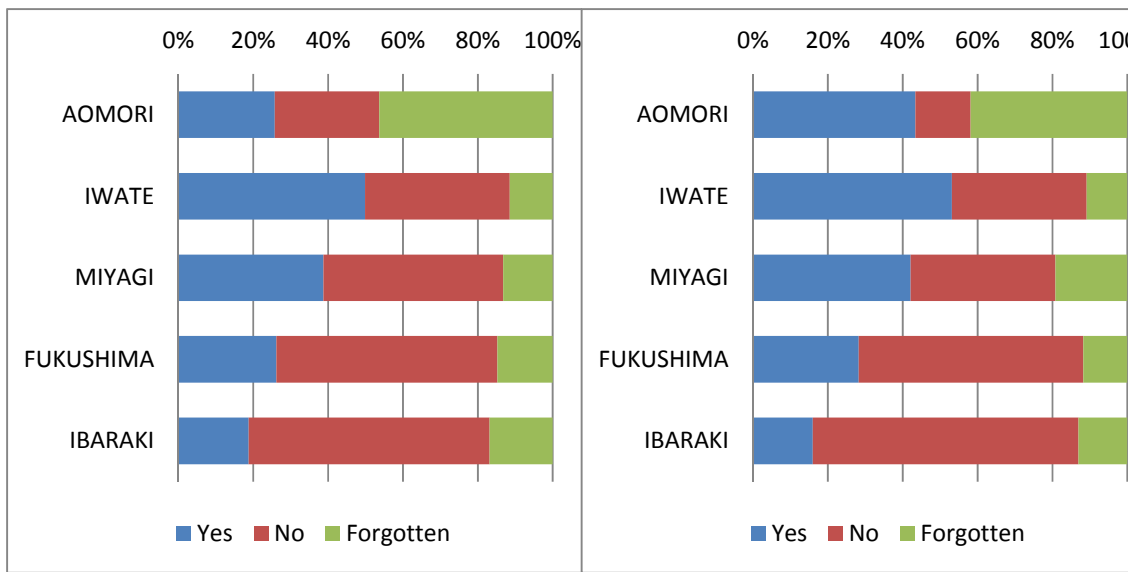
The Reasons Why Evacuees use the Car for Evacuation



Total N=10,132

N=2,167

The Problems in Official Shelters



Total N=10,132

N=2,167

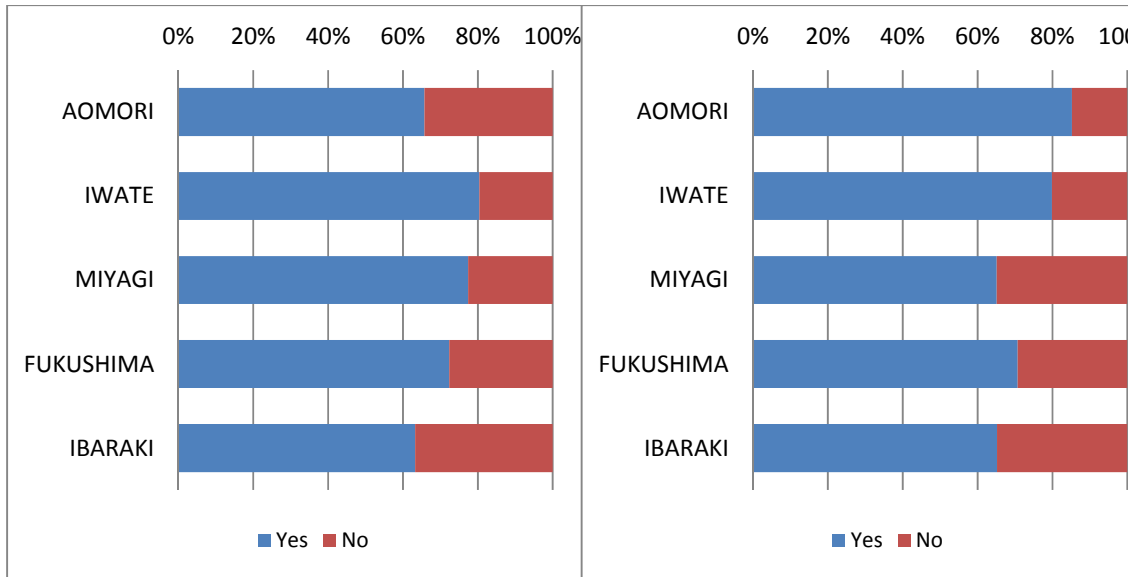
Had Seen the Hazard Map



Total N=10,132

N=2,167

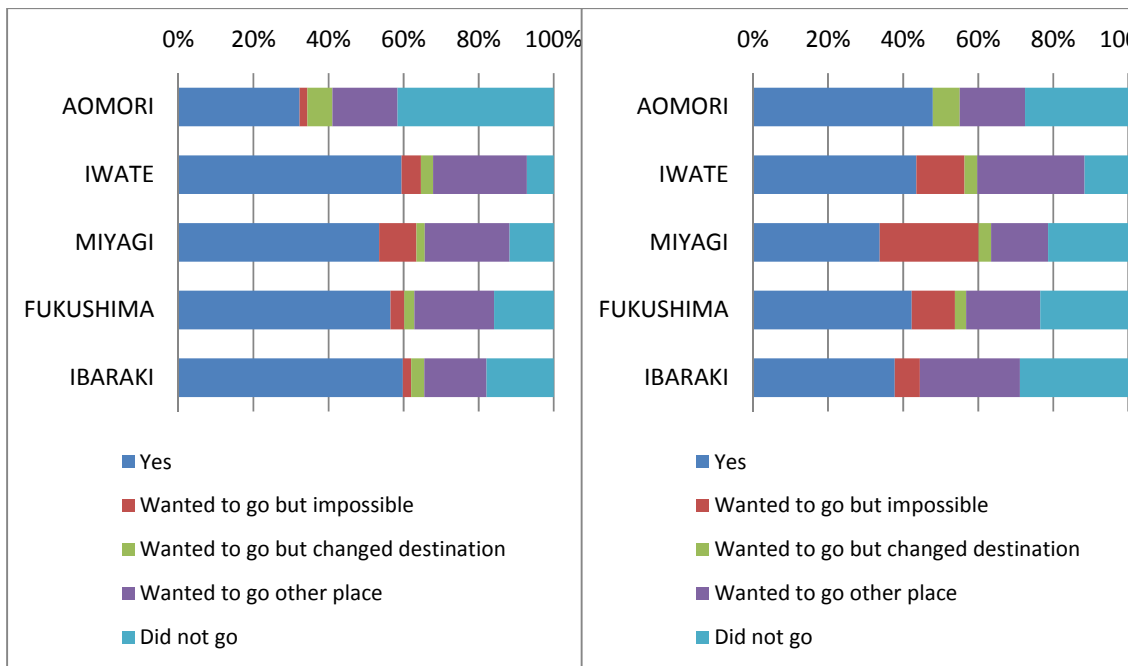
Normal Prevention Work at Home



Total N=10,132

N=2,167

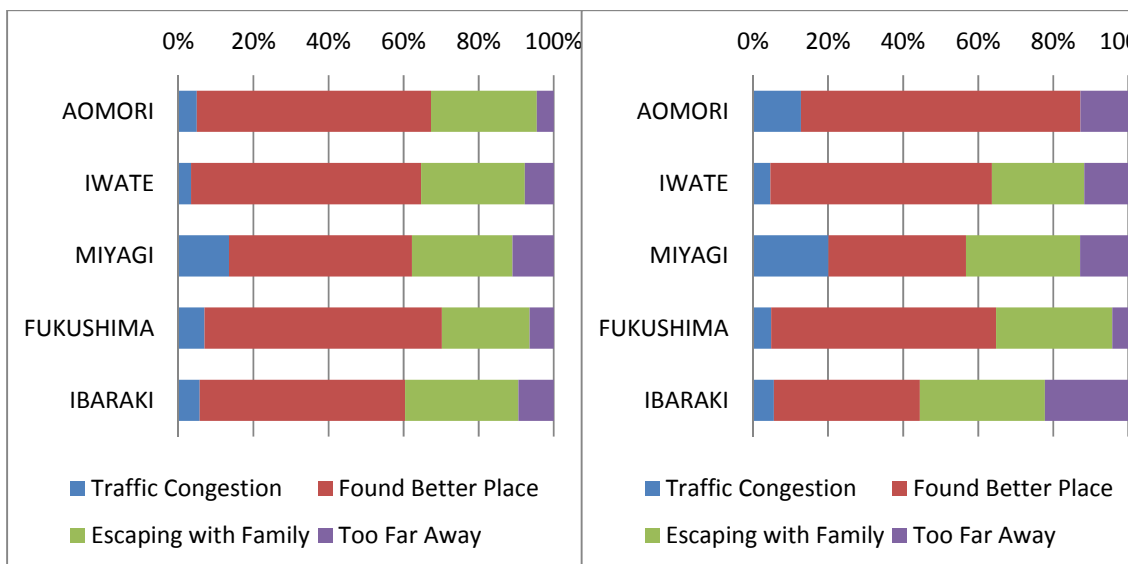
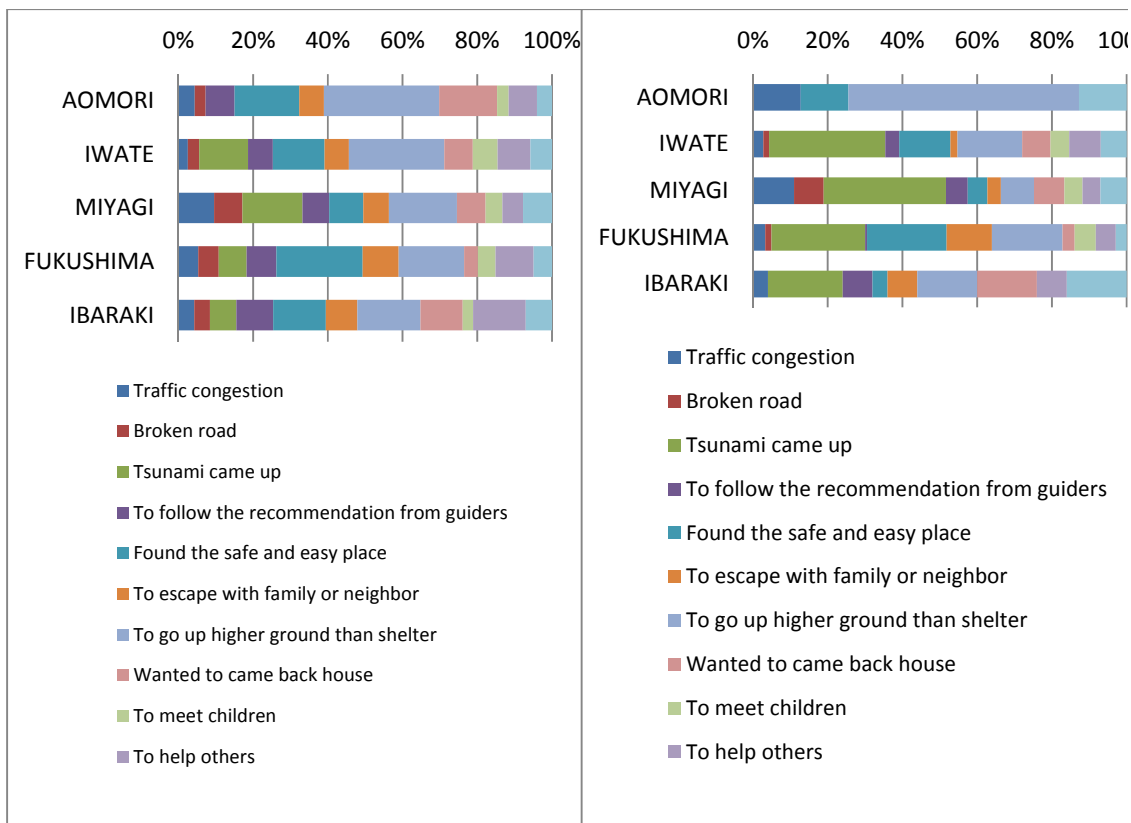
Had Known the Nearest Shelter



Total N=10,132

N=2,167

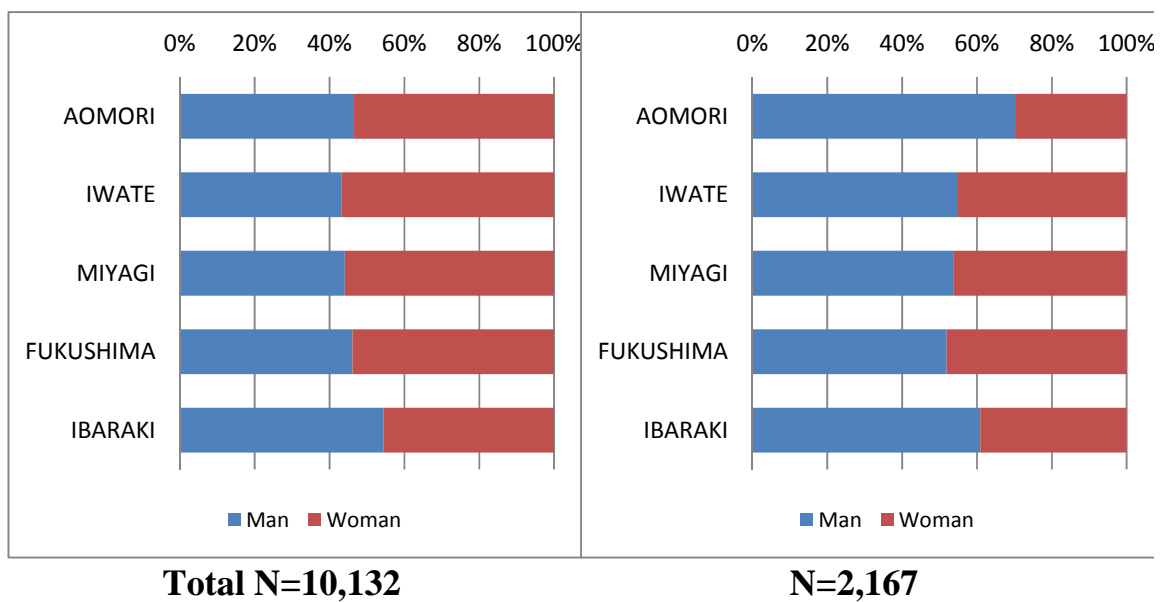
Reached the Nearest Shelter



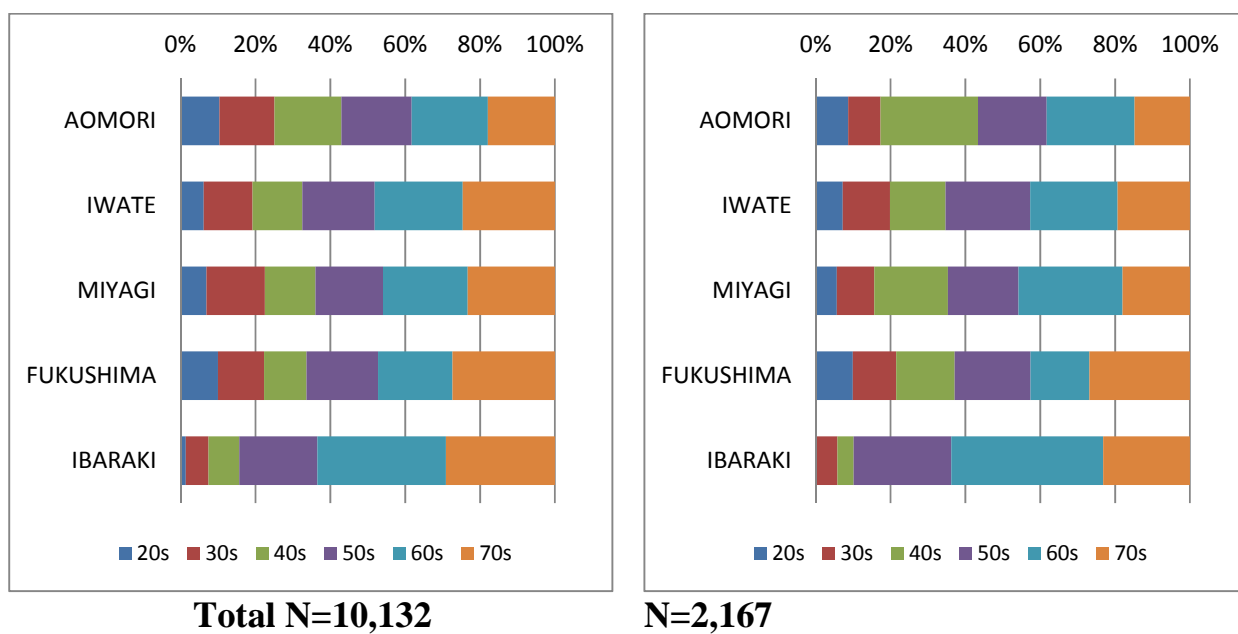
Total N=10,132

N=2,167

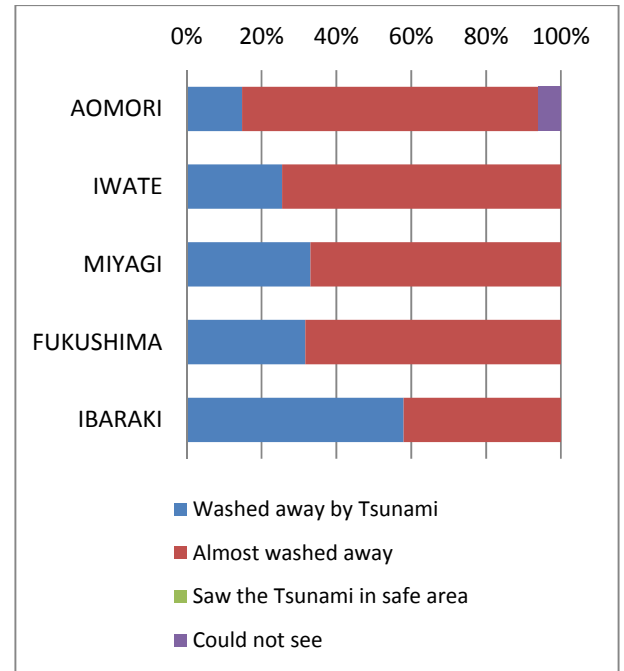
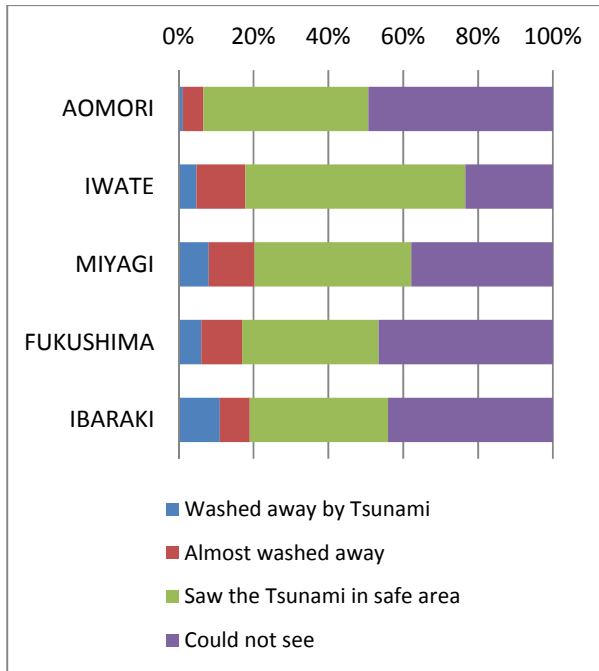
The Reasons Why Evacuees did not go to the Nearest Shelters



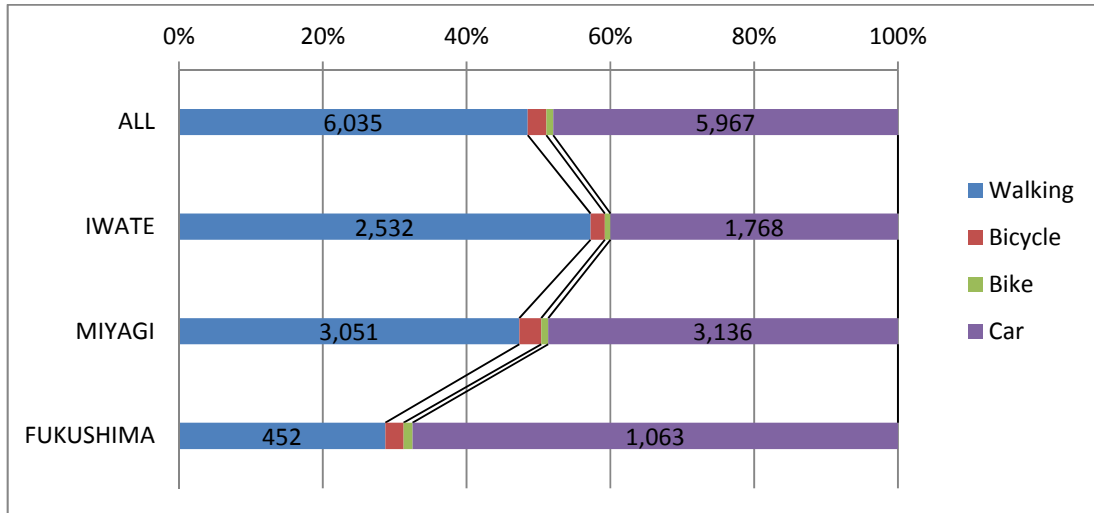
Genders



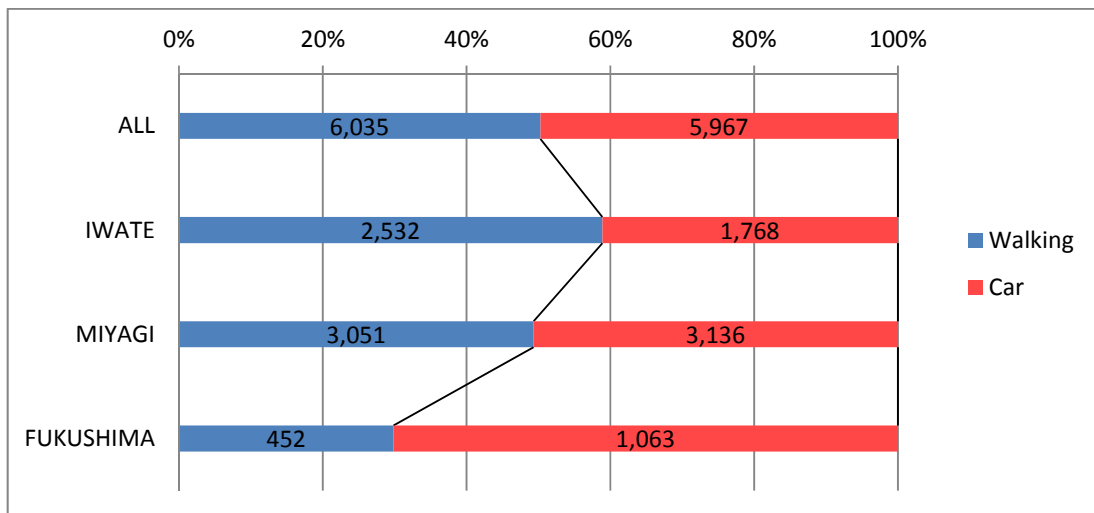
Age Structure



F. Summary of Questionnaire (Prefecture Level)



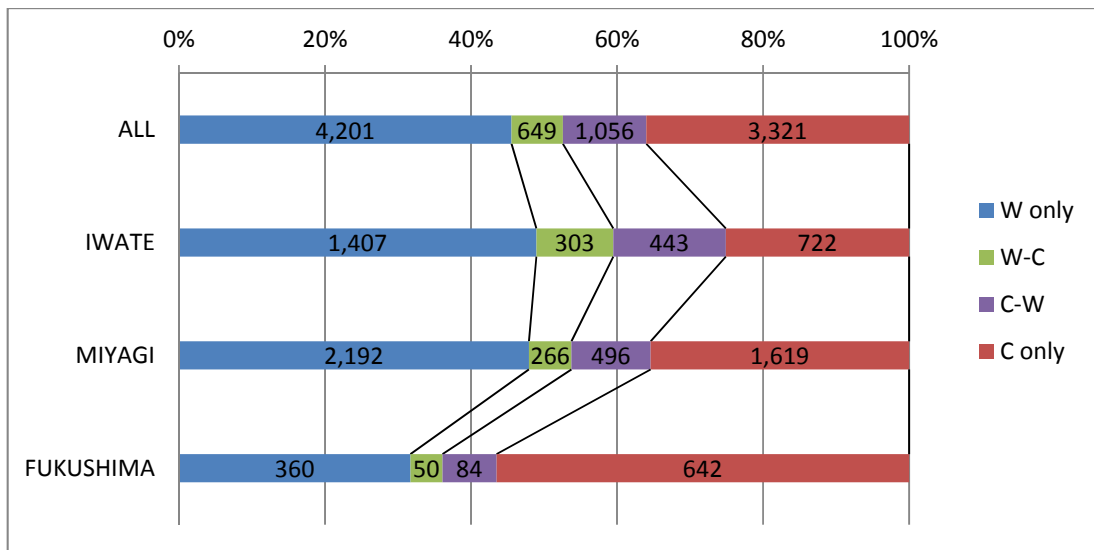
(A) Each trip



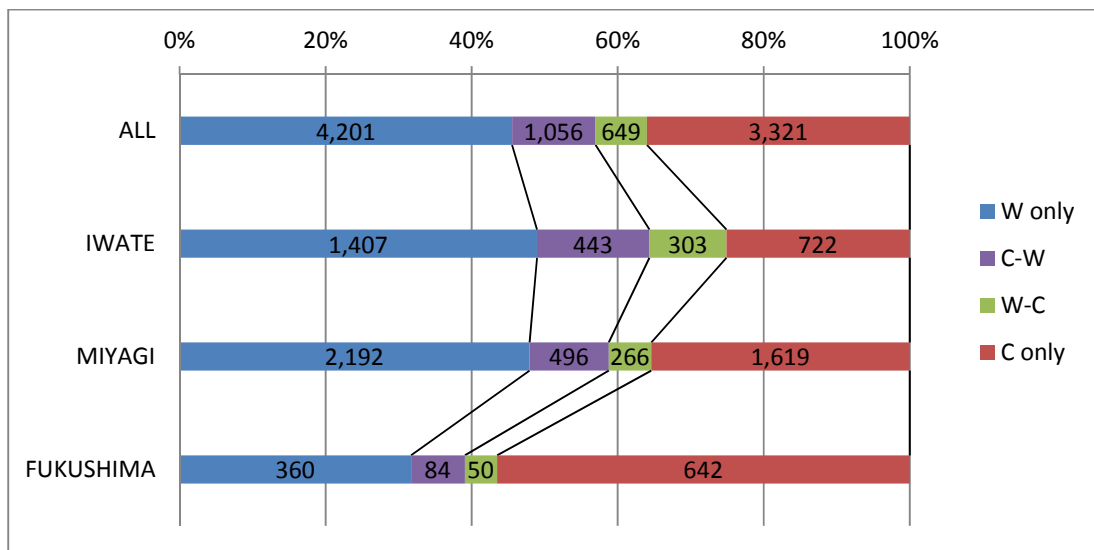
(b) each trip for walking and car modes

Figure. Mode Share Ratio for Each Trip

Total 13,288 Trips, Iwate 4,424 Trips, Miyagi 6,448 Trips, Fukushima 1,577 Trips



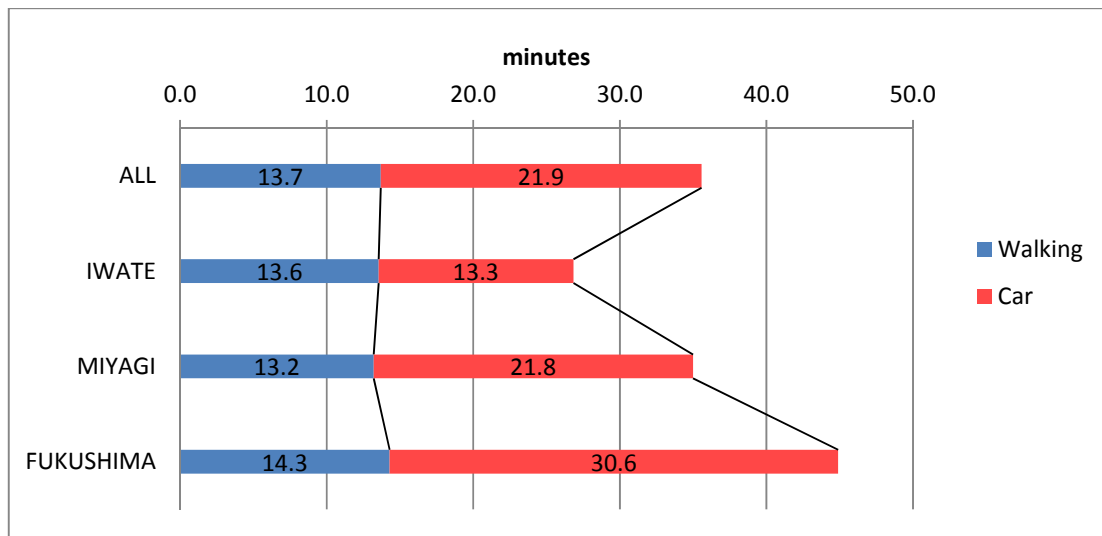
(a) Origin Based Trip Chain



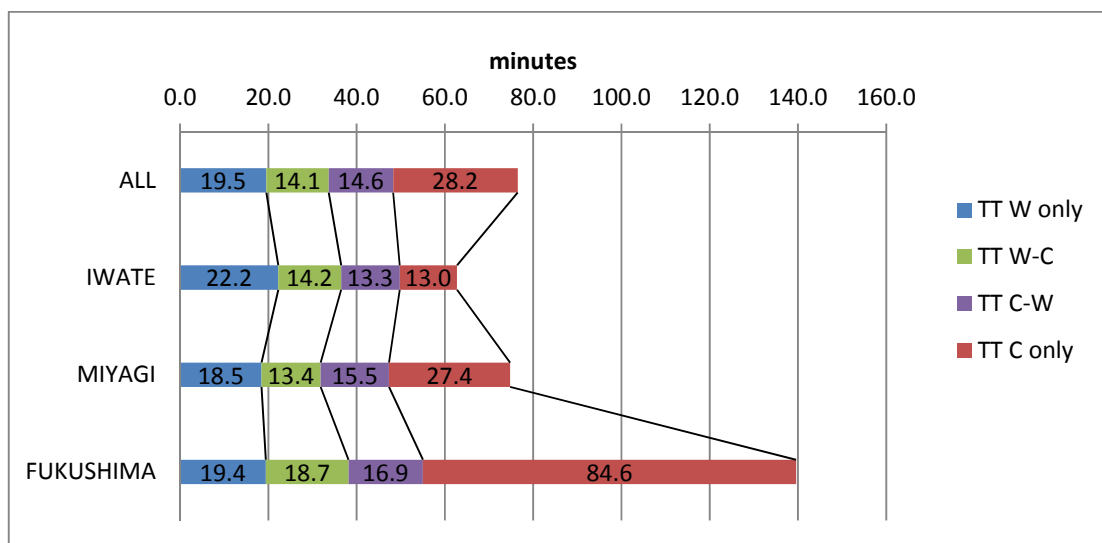
(b) Destination Based Trip Chain

Mode Share Ratio for Evacuation

Trip Chain Total 9,227 Chain, Iwate 2,875 Chain, 4,573 Chain, 1,136 Chain

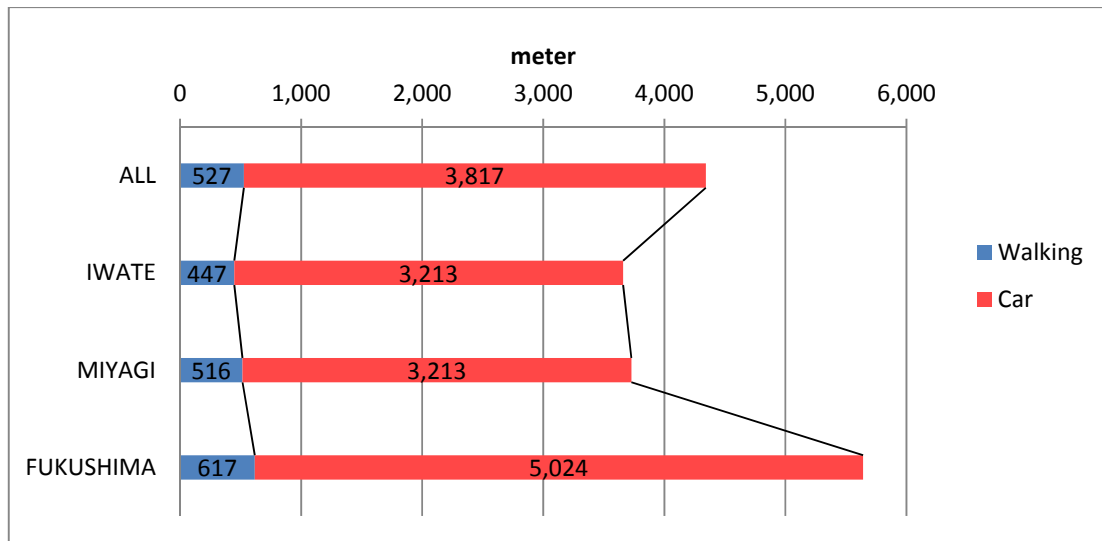


(a) Each Trip

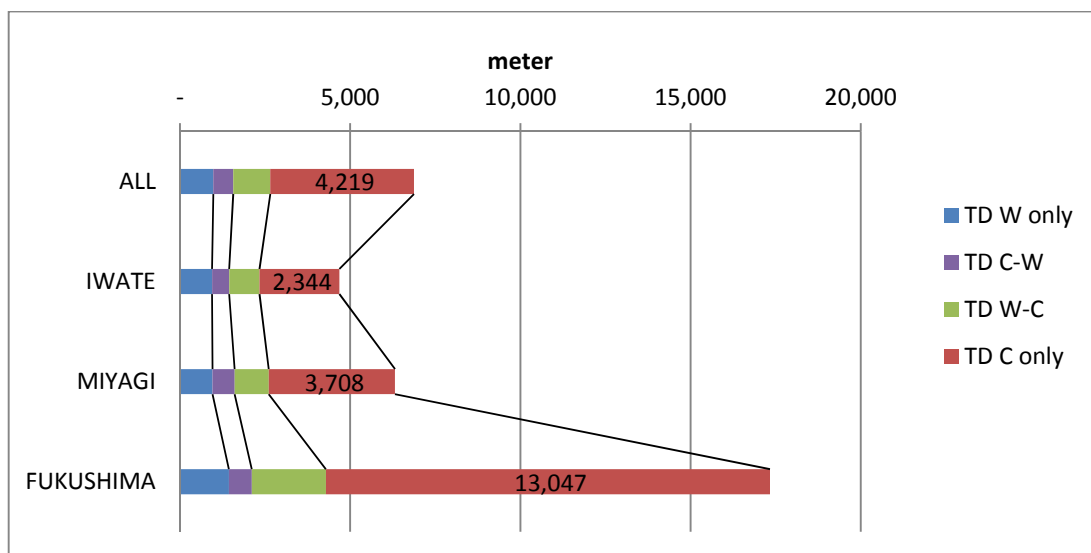


(b) Trip Chains

Figure. Evacuation Time

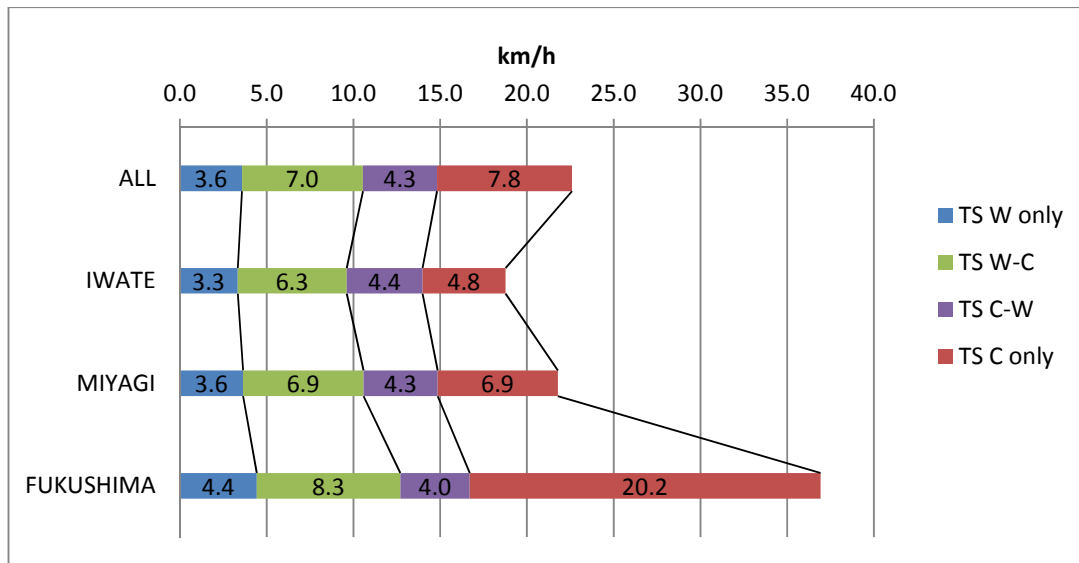


(a) Each Trip

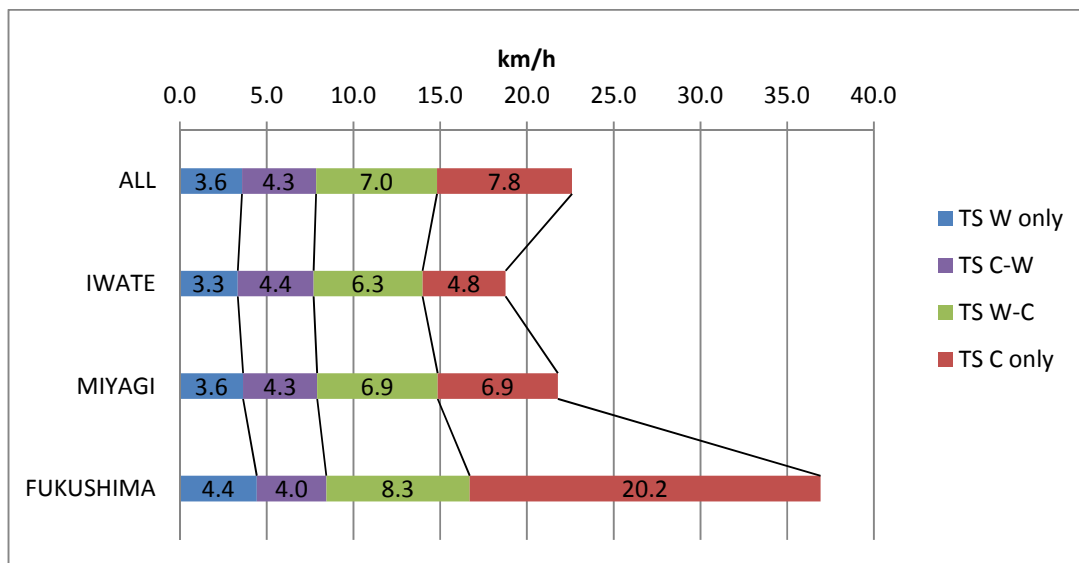


(b) Trip Chain

Figure. Evacuation Distance

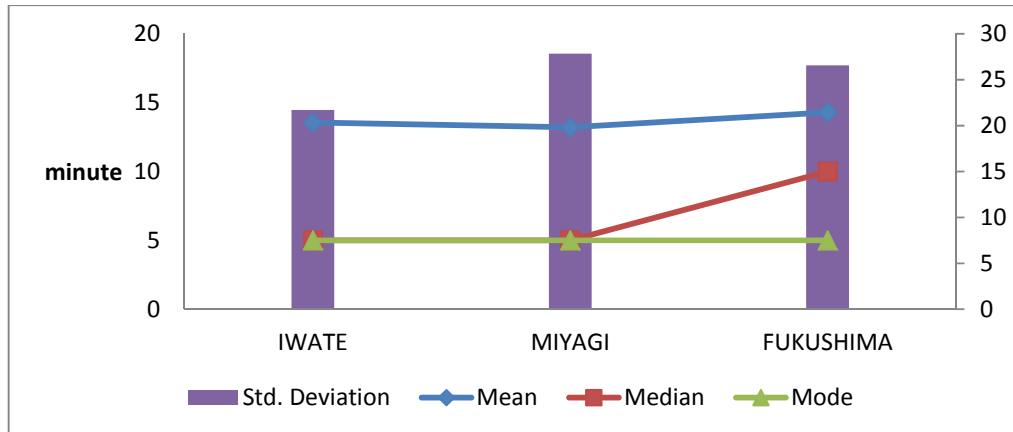


(a) Each Trip

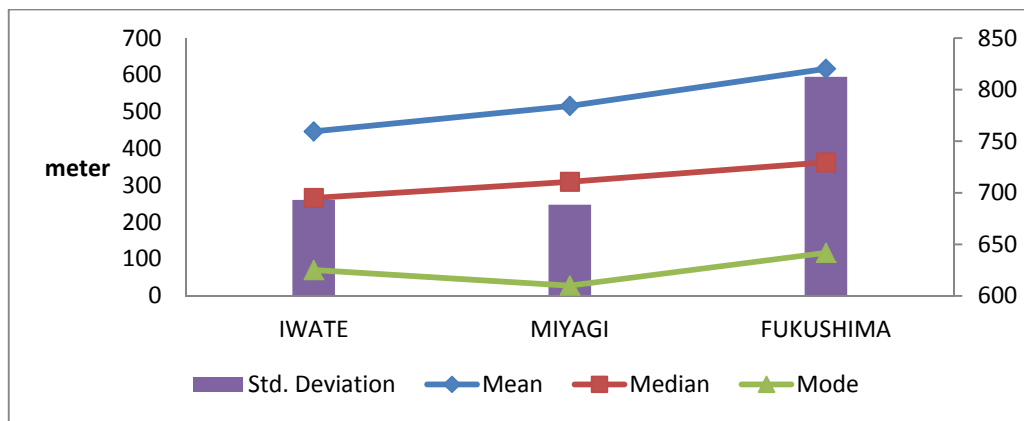


(b) Trip Chain

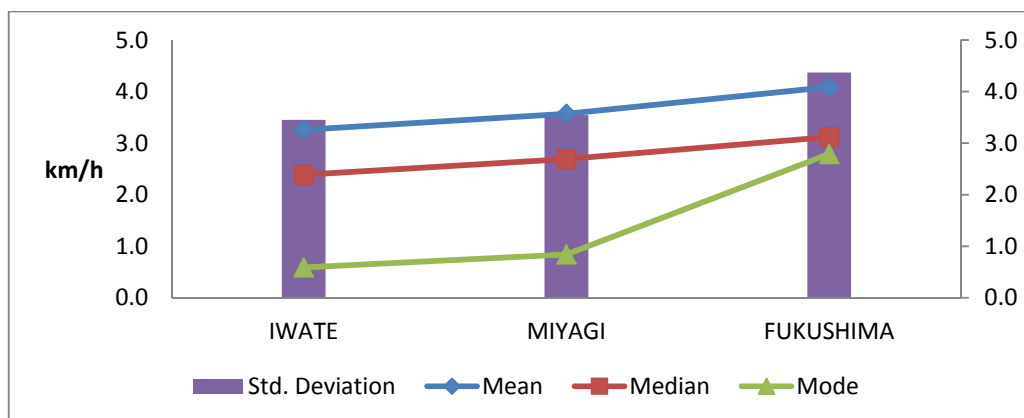
Figure. Evacuation Speed



(a) Evacuation Time



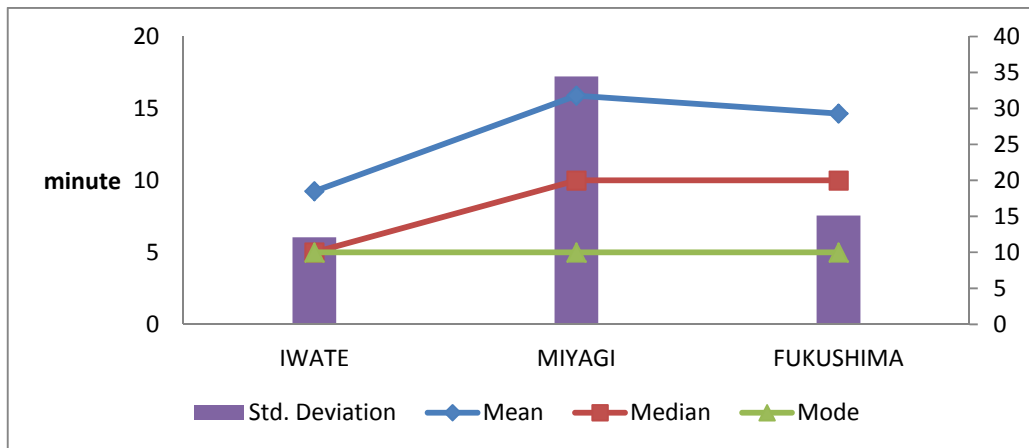
(b) Evacuation Distance



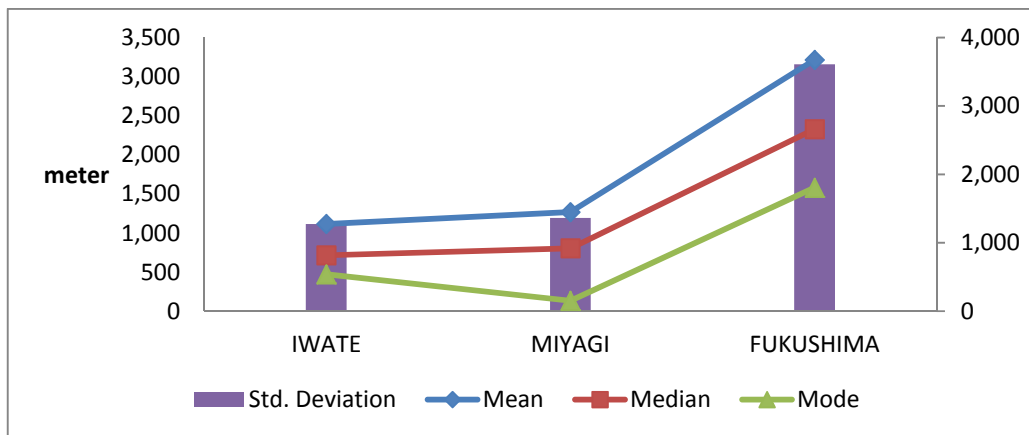
(c) Evacuation speed

Figure. Evacuation Parameters for Walking Mode

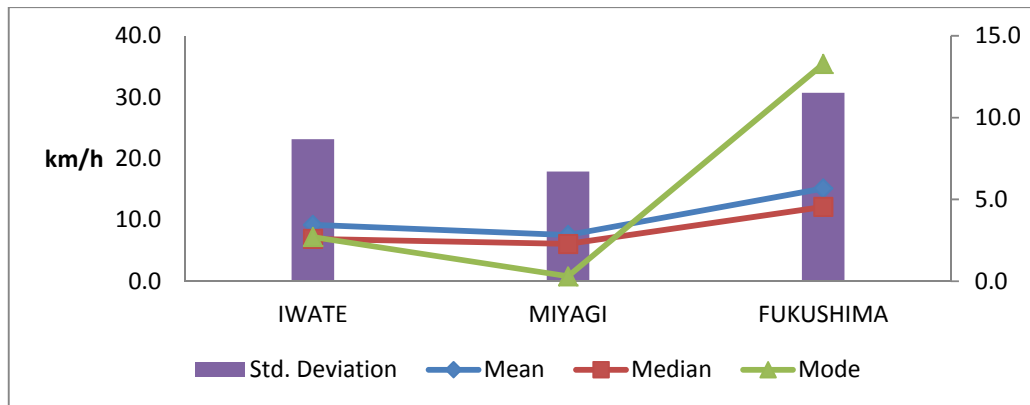
Sample: Iwate(2,532 Trips), Miyagi (3,051 Trips), Fukushima (452 Trips)



(a) Evacuation Time



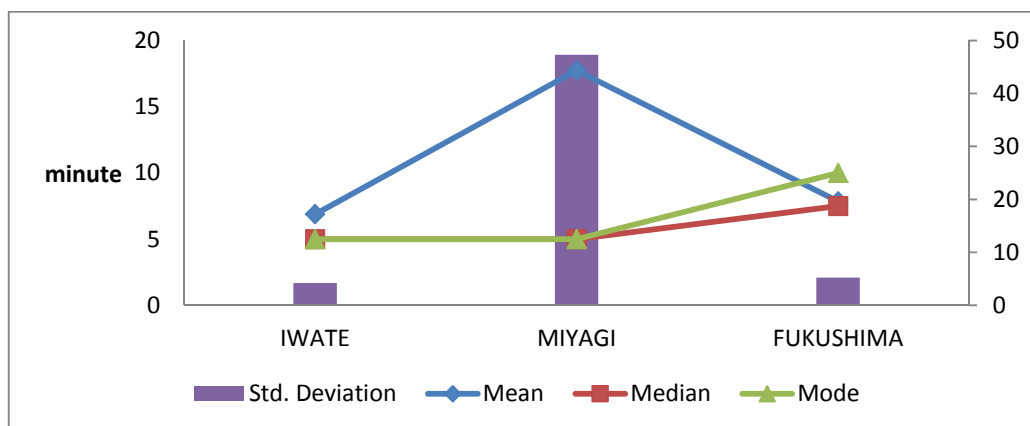
(b) Evacuation Distance



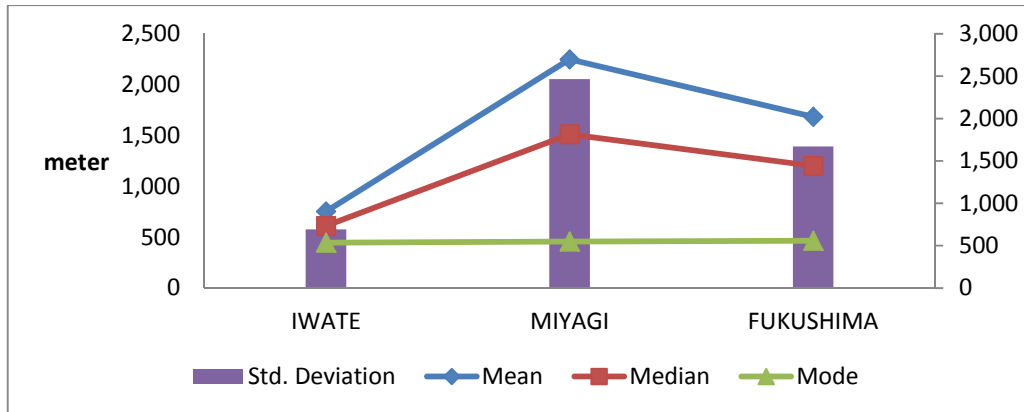
(c) Evacuation speed

Figure. Evacuation Parameters for Bicycle Mode

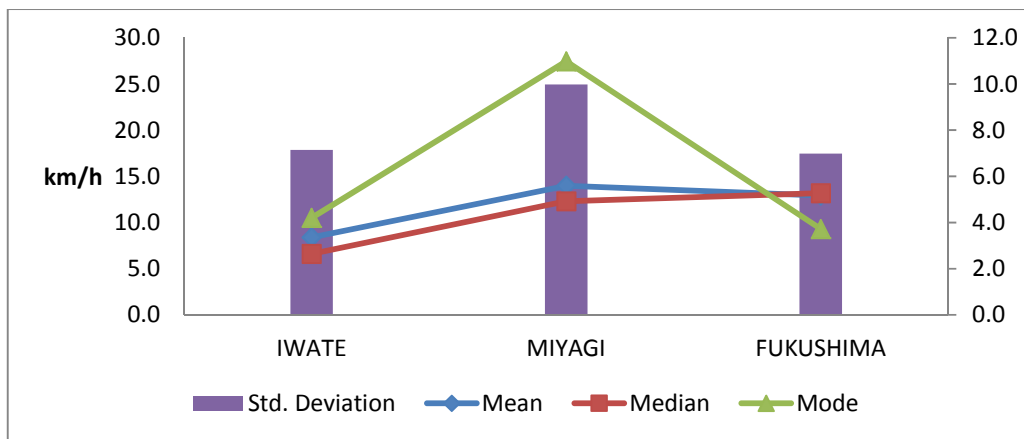
Sample: Iwate(88 Trips), Miyagi (197 Trips), Fukushima (40 Trips)



(a) Evacuation Time



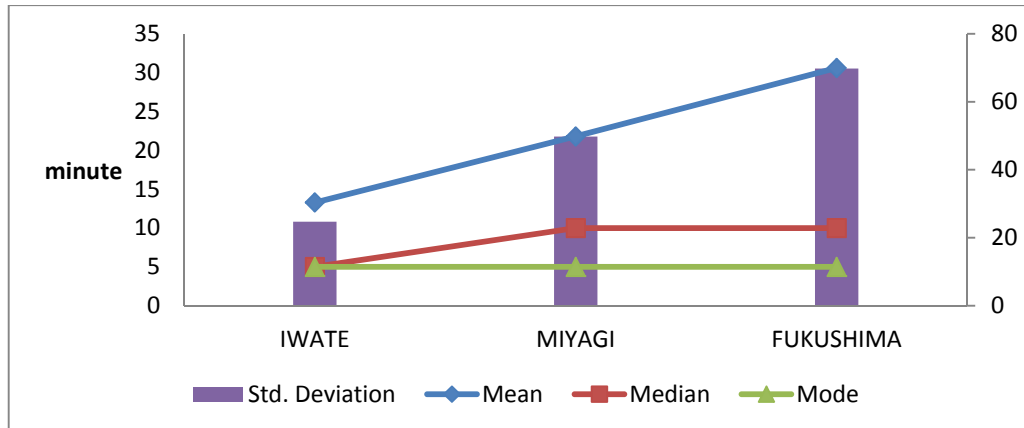
(b) Evacuation Distance



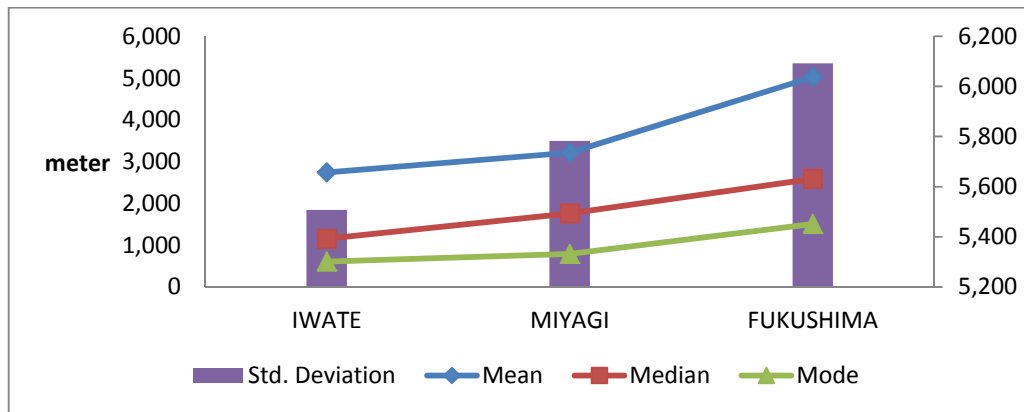
(c) Evacuation speed

Figure. Evacuation Parameters for Bike Mode

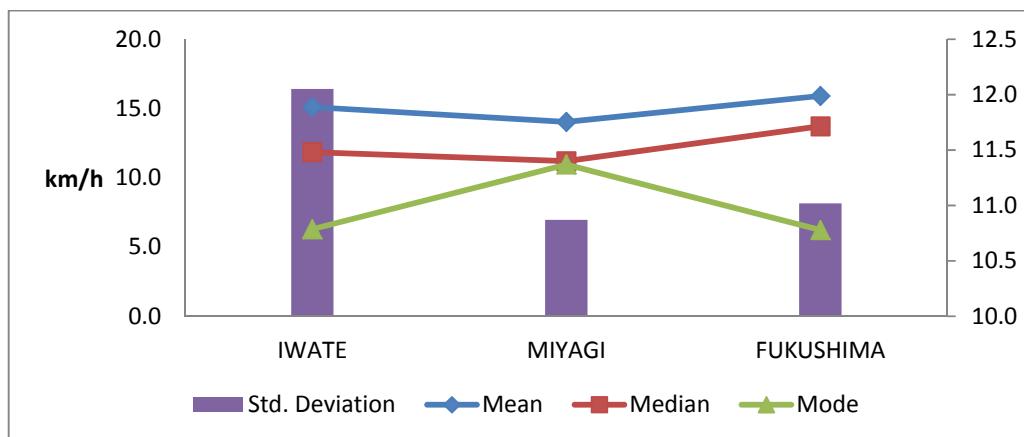
Sample: Iwate(34 Trips), Miyagi (63 Trips), Fukushima (20 Trips)



(a) Evacuation Time



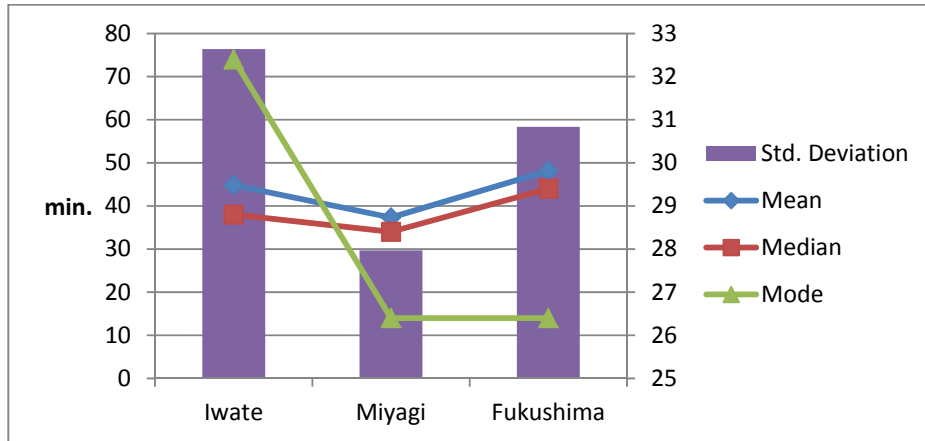
(b) Evacuation Distance



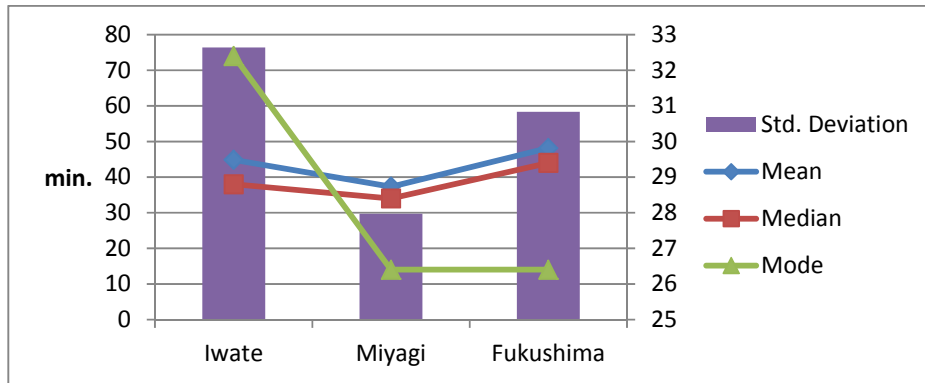
(c) Evacuation speed

Figure. Evacuation Parameters for Car Mode

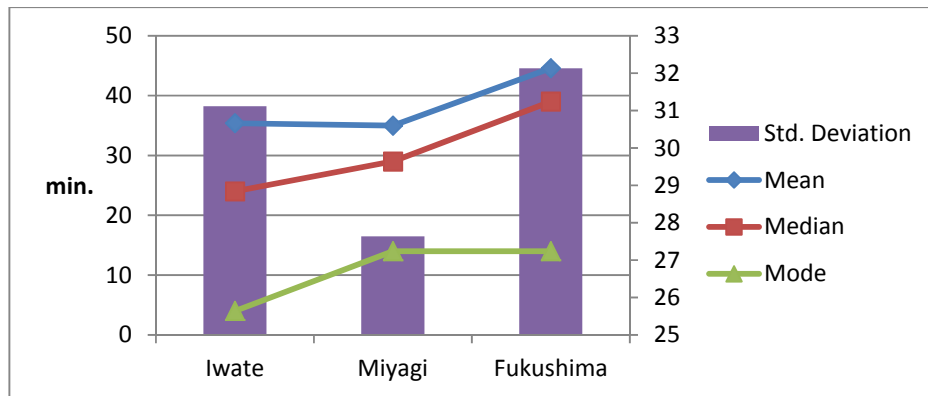
Sample: Iwate(1,768 Trips), Miyagi (3,136 Trips), Fukushima (1,063 Trips)



(a) Walking

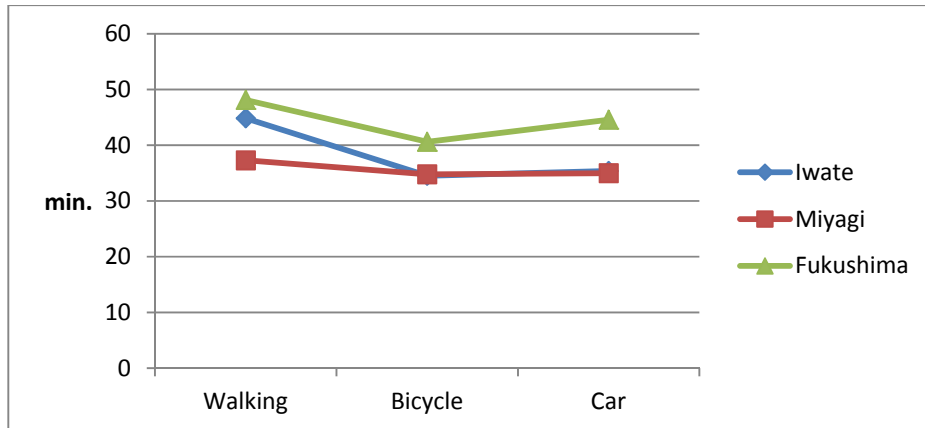


(b) Bicycle

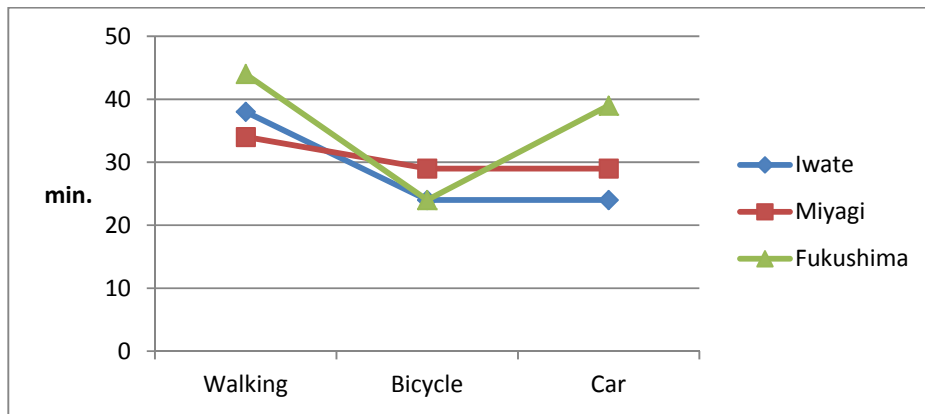


(c) Car

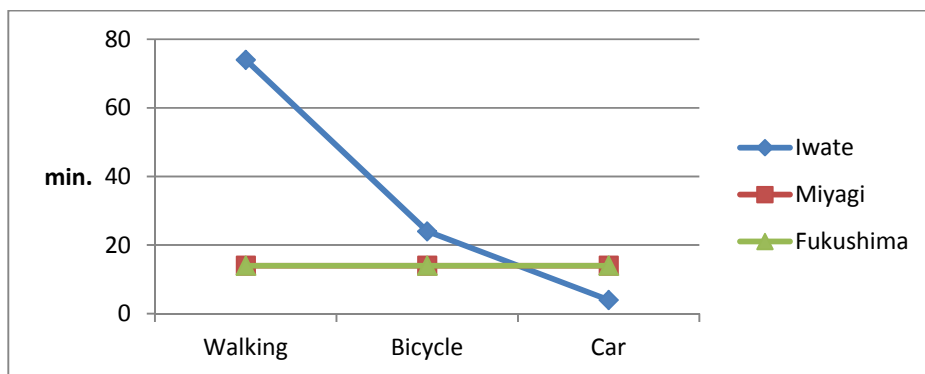
Figure. Evacuation Starting Time of Each Mode from 14:46



(a) Mean

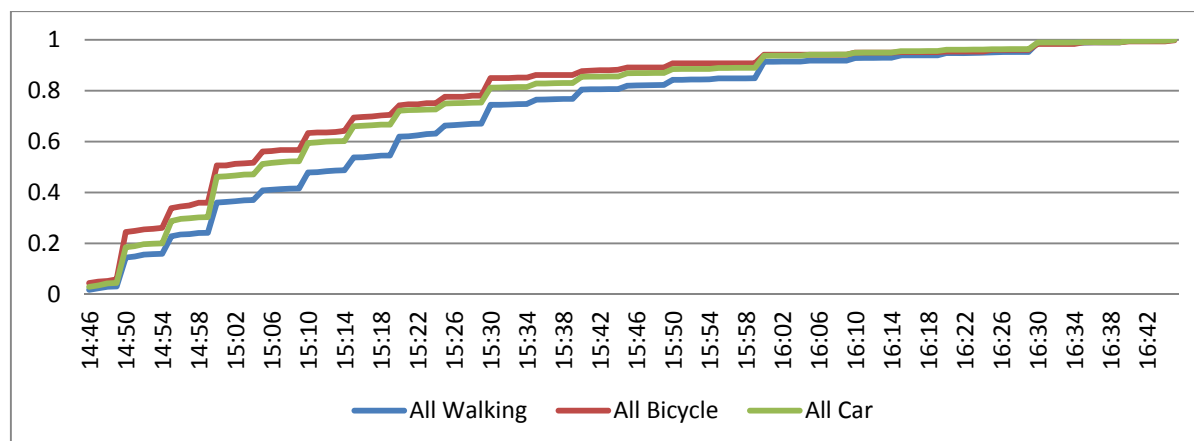


(b) Median

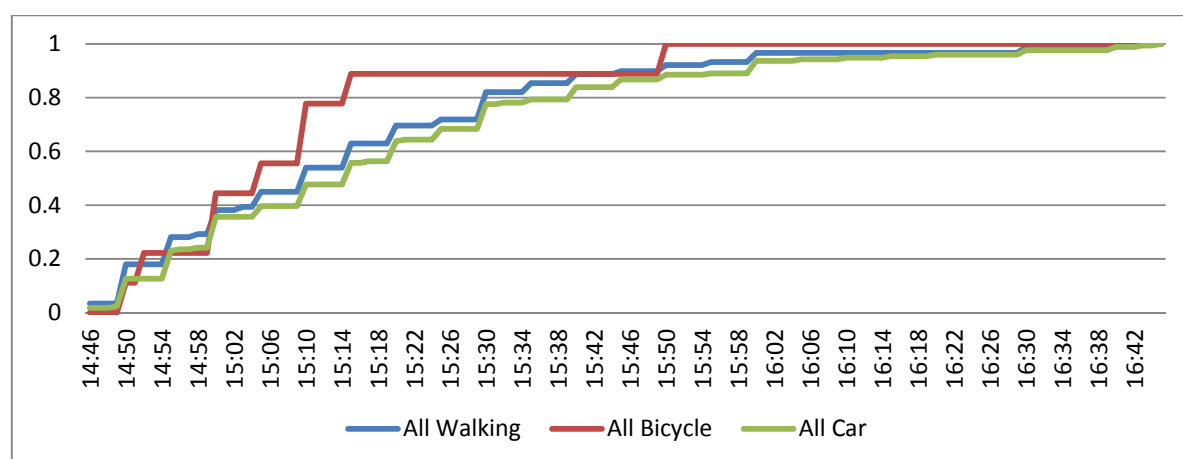


(c) Mode

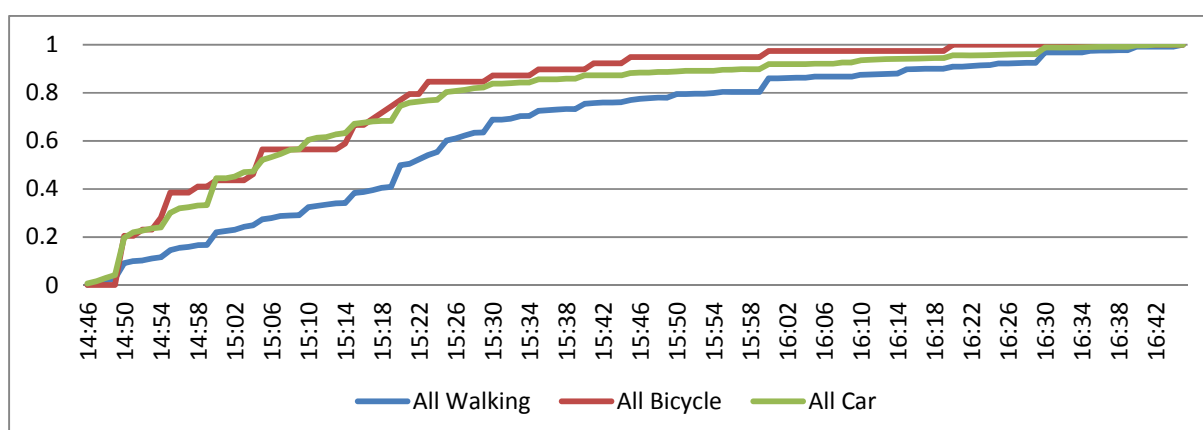
Figure. Evacuation Starting time of Each Mode from 14:46



(a) Tohoku Area



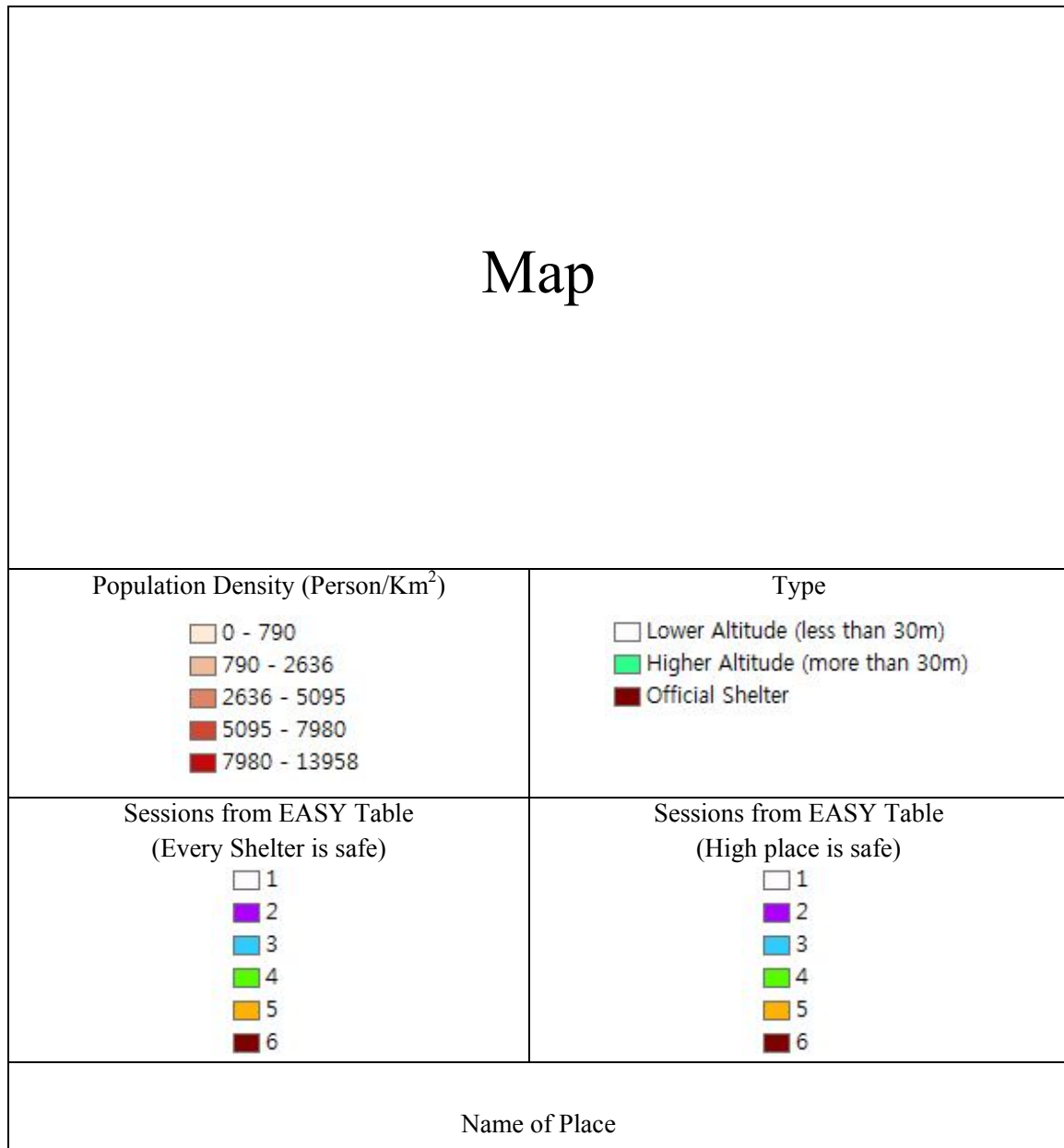
(b) Sendai City

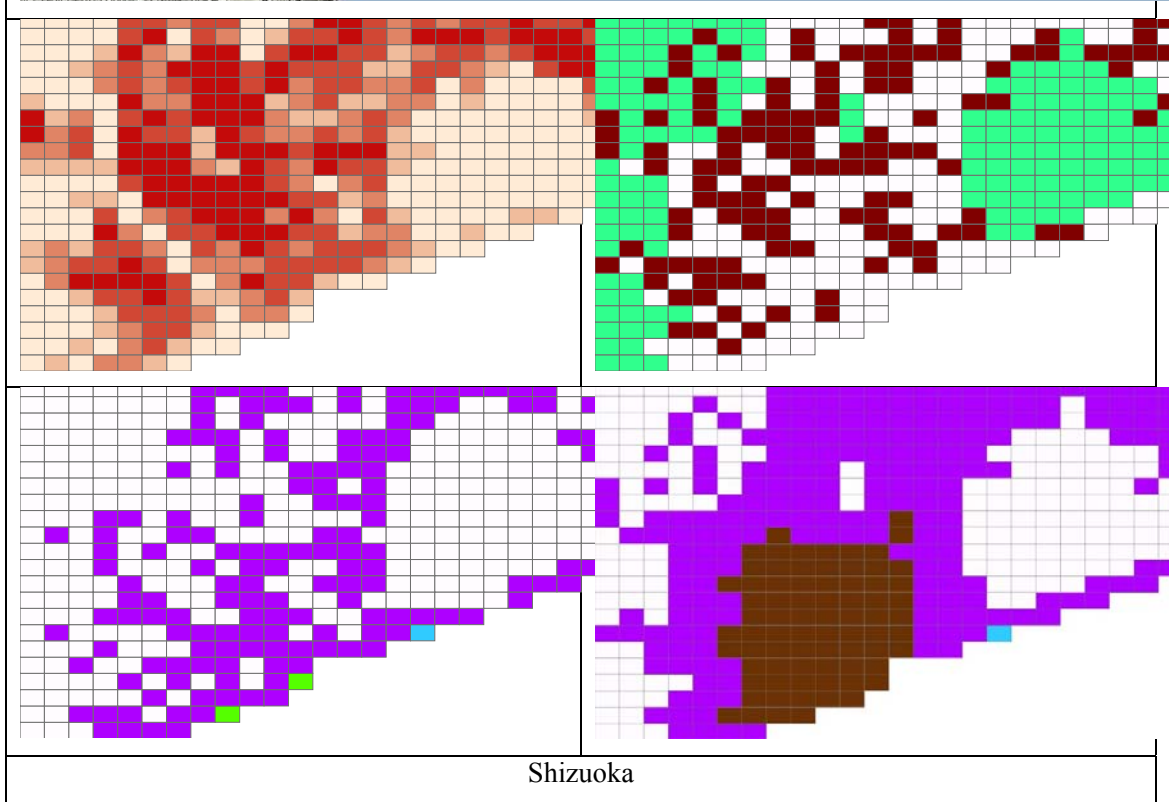
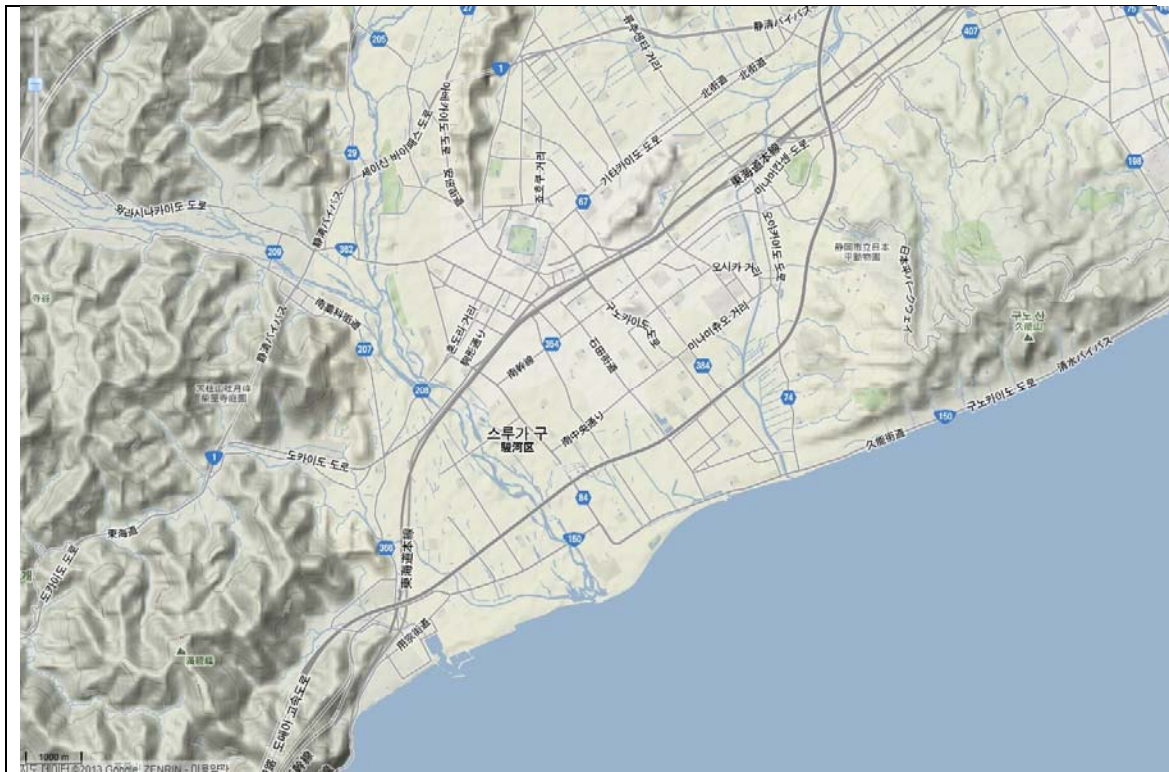


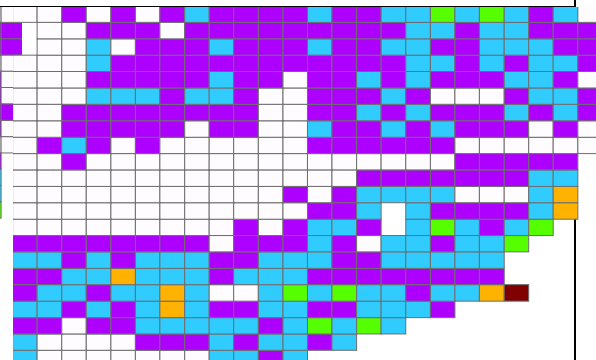
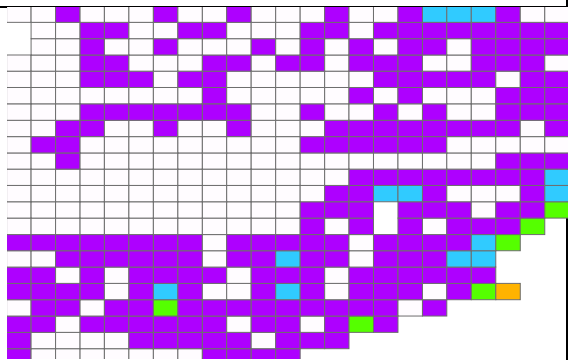
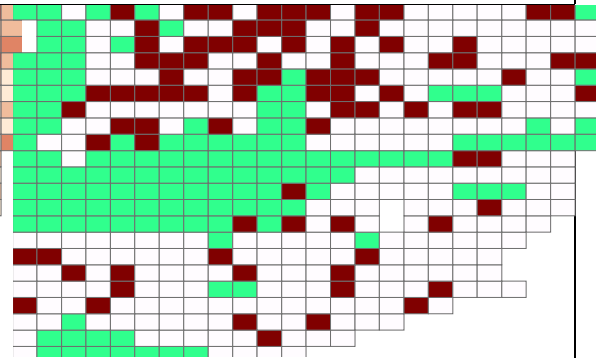
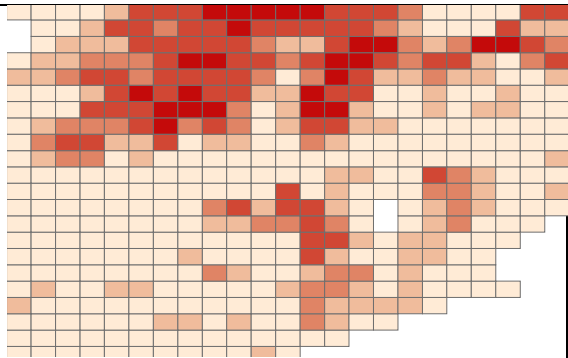
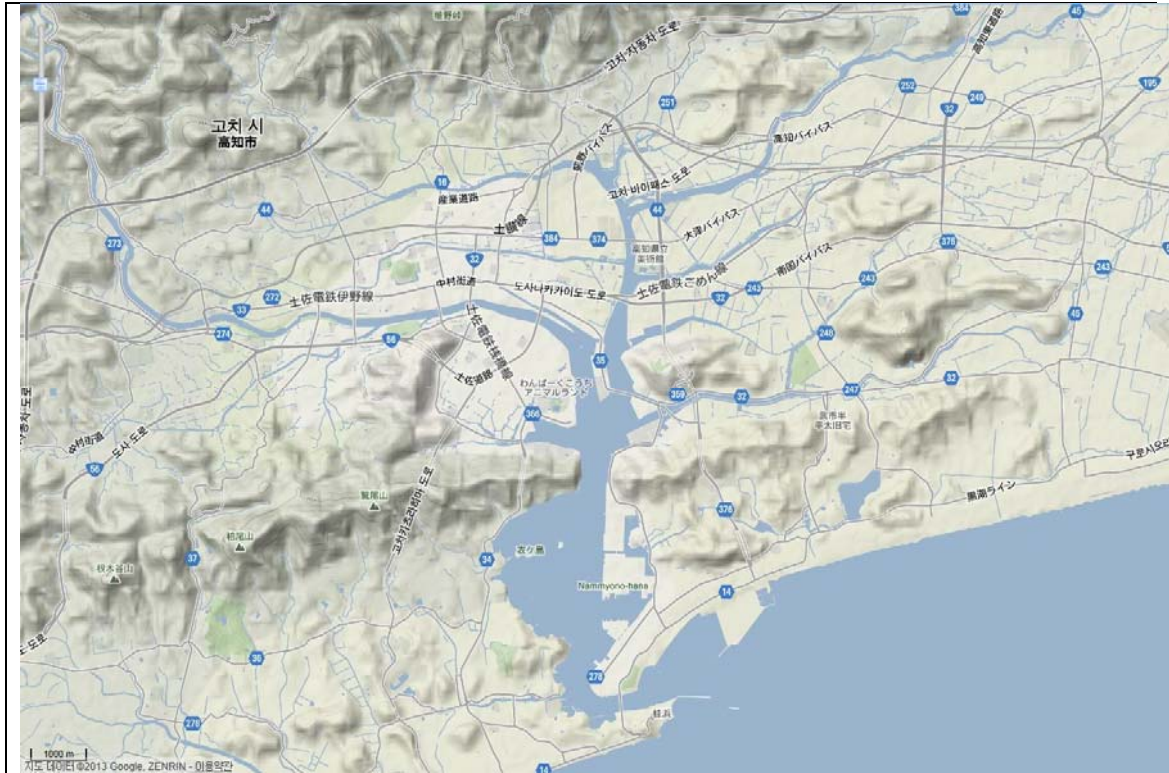
(c) Rikuzentakata City

Figure. Evacuation Starting Time (Cumulative Relative Frequency)

G. Outputs of EASY-LEE Method in City Level







Kochi

