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Analysis of Flood Risk for Vulnerable People Using Assumed Flood Area Data Focused on Aged People and Infants

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Abstract: During a large-scale disaster in Japan, vulnerable people, such as aged people, injured and sick people, infants, pregnant women, and foreign visitors to Japan, are most likely to be affected. This trend has not changed even in the case of floods where the process of disaster development is relatively moderate. However, in the case of flood disasters, the impact on vulnerable people can be minimized by evaluating the actual damage condition. The purpose of this study is to estimate the flood risk in the event of flooding for the elderly, the injured and sick, and infants, among those who need special care during disasters. The infant population was calculated using data from the national census maintained by Japan, and the aged and injured population was calculated using the National Health Insurance data, which are medical big data. Using these data, the regional distribution of the population was calculated, and then a spatial analysis was conducted with the data on the expected flood area in the event of flooding to estimate the exposed population. Through the analysis in this study, it was possible to estimate the flood risk per township by attribute, focusing on the aged, injured and sick, and infants. In Komatsu City, Ishikawa Prefecture, which was the subject of analysis in this study, the exposure of the elderly population in Mukaimotoori, Imae, Shirae, and Oki was high. In addition, the exposure of the infant population was high in Imae, Oki, Shirae, and Hitotsuhari. Town characteristics with a large exposed population were obtained, which is expected to be utilized for preliminary planning in the event of a flood.

Keywords: children; women; aged person; poor person (CWAP); flood risk; natural disasters

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1. Introduction

1.1. Background

When natural disasters occur, human suffering is particularly high among vulnerable people (aged person, children, pregnant women, people with disabilities, and tourists) [1–5], who require third-party support compared to healthy people. Based on the lessons learned from the Off the Pacific Coast of Tohoku Earthquake, which caused particularly severe damage to this group of people, the Basic Act on Disaster Management was partially amended in 2013, which required each local government to create Lists of Residents in Need of Assistance in Evacuation. The creation of Lists of Residents in Need of Assistance in Evacuation designated by each local government is expected to improve the speed of evacuation support and confirmation of safety after a disaster. The list of residents in need of assistance during evacuation catalogs people who are unable to move on their own, and each municipality selects the target persons. The list mainly includes people with a high level of nursing care needs, people with disabilities, people with dementia, and others. Regarding the status of formulating Lists of Residents in Need of Assistance in Evacuation in each local government, a survey conducted by the Ministry of Internal Affairs and Communications indicated that, as of 1 June 2017, of the 1739 municipalities surveyed, 93.8% had developed such lists, and it could be said that most municipalities have these lists at present [6].

However, in the April 2016 Kumamoto earthquake that occurred after the Lists of Residents in Need of Assistance in Evacuation were made compulsory, there have been reports that the town hall itself was damaged; thus, the lists could not be utilized [7,8]. It was also indicated that there was a need to review the formulation of the lists and the manner in which the safety of these vulnerable people was confirmed during normal times [8].

Additionally, when examining the actual circumstances of the damage suffered by vulnerable people during flood disasters, such as river floods, where the progress of disasters is relatively slow, it was evident that 70% of deaths during the heavy rains of July 2018, as of 12 July, included people aged 60 years and older [9]. Furthermore, in the case of the actual utilization of the Lists of Residents in Need of Assistance in Evacuation, in Mabi Town, Kurashiki City, Okayama Prefecture, where the damage was particularly severe, as of 26 July 2018, of the 50 fatalities whose identities were confirmed by the city, 42 people (approximately 80%) were those on the lists [10].

From the above results, when considering the characteristics of flood disasters, it is possible to minimize the number of victims if appropriate evacuation support and evacuation plans are in place. Therefore, in the event of a large-scale flood, it is of great significance to understand in advance the circumstances of damage that will affect vulnerable people in need of special consideration and the population that may be affected.

1.2. Purpose of This Study

In this study, we estimate how many vulnerable people are likely to be affected by a disaster according to the people's attributes. Figure 1 shows the data used in this study, and the flow of the analysis. First, to understand vulnerable people according to the attribute, we used the following two types of data: (1) 2015 National Census and (2) National Health Insurance data ("KDB data"), which are medical big data provided by Komatsu City, Ishikawa Prefecture, which was the target area for analysis. These data are used to understand vulnerable people; however, all the data used in this study can be employed to know which people are in need of support on a "town district basis". Therefore, in the subsequent analysis, the identification and calculation of the number of people in need of support and the estimation of the affected population were conducted on a town district basis. Furthermore, evacuation advisories, evacuation, orders during flood disasters are mainly issued at the municipal level; thus, the granularity at the municipal level was considered to be appropriate for calculating the number of people in need of support and understanding the affected population in this study.

The vulnerable people who were analyzed in this study were those believed to have the greatest difficulty during evacuations following a disaster. The details of the subjects for analysis are presented later; however, in the present study, we focused on infants who have difficulty evacuating on their own and persons aged 75 years or older who particularly needed care during previous disasters. Furthermore, we targeted specific attributes, such as those certified as in need of long-term care and those aged 85 years or older.

In this study, as shown in the analysis flow in Figure 1, we first defined the vulnerable people and understood their needs on a town district basis. Subsequently, using the assumed flood area map obtained from the Digital National Land Information Download Service [11], a preliminary estimate of the number of vulnerable people who may be affected by floods was conducted by apportioning the area using the building area. In this paper, we used the assumed flood area map without considering specific levee breakage points because the purpose of this study was to understand, in advance, the disaster risk (flooding risk) that vulnerable people may suffer. The results obtained in this study aim to make citizens aware of the disaster risk to vulnerable people; thus, we used an assumed flood area map, which can be said to reflect the largest possible case of flooding.

Vulnerable people are supposed to be provided with evacuation assistance during disasters, while the rest of people are basically expected to evacuate on our own. The aged people and infants targeted in this study are rarely listed on the lists of residents in need of assistance during evacuation and basically need to evacuate on their own. Therefore, we believe that it is very important to estimate in advance the regional distribution and flood risk for aged people and infants, which was conducted in this study.

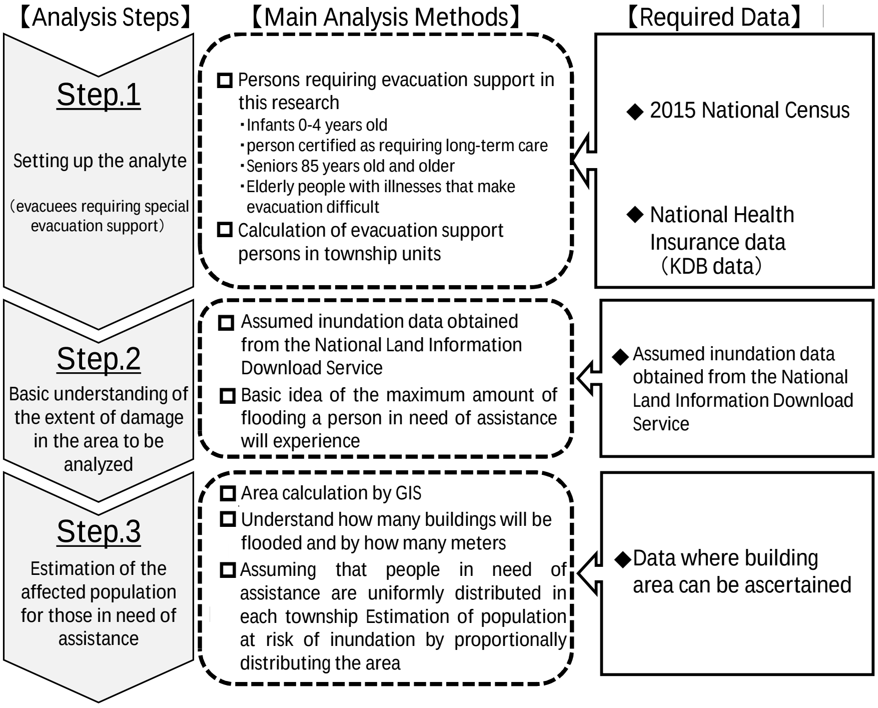

Figure 1. Flow of analysis in this study.

2. Related Work

In this section, we present previous research based on the following three perspectives: research focusing on the evacuation behavior of vulnerable people and the actual state of damage during flood disasters caused by river floods; research focusing on estimating the number of victims during flood disasters; and research that utilizes KDB data in the field of disaster prevention, which is a feature of the present study.

2.1. Previous Research Focusing on the Evacuation Behavior of Vulnerable People and the Actual State of Damage during Flood Disasters Caused by River Floods

To date, several studies have focused on the evacuation behavior of vulnerable people, such as aged people, people with disabilities, and infants, and the actual state of the disaster during flood disasters.

As an example of research on the evacuation status of aged people during river floods, Katada et al. [12] used the flood disaster in Koriyama City, Fukushima Prefecture, in August 1998 as an example to conduct a questionnaire survey to understand the actual circumstances regarding the evacuation behavior and evacuation assistance of aged people who were members of senior citizens' clubs. Nagaie et al. [13] proposed a method for determining the risk of elderly facilities from a flood damage perspective, while considering the local characteristics of those facilities.

2.2. Research Focusing on Estimating the Number of Victims during River Floods

Examples of research that estimated how many people are affected by a disaster in the event of river floods include a study by Ikeuchi et al. [14]. They used the LIFESim model to estimate human damage during the flooding of the Tone River. They also assessed the effects of reducing human damage caused by the operation of drainage facilities, such as drainage pump stations and water gates. Ikeuchi et al. [15] classified the types of floods that occur when rivers, such as the Arakawa River, flood, and they estimated the number of deaths in the event of a large-scale flood. An example of research on evacuations in the event of a large-scale river flood that considers the social situation of Japan's super aging society in recent years includes the study by Machida et al. [16]. They quantitatively predicted the increase in human damage when considering the future increase in the aging rate in the case of a large-scale river flood.

2.3. Research Utilizing KDB Data in the Disaster Prevention Field

Several studies have applied KDB data, which is a feature of the present study, to the disaster field, such as Fujiu et al. [17]. These studies all employed KDB data to identify people who needed special consideration during disasters and vulnerable people. However, their research content is based on the scenario of an earthquake disaster. The present study focused on flood disasters, which is different from previous studies that utilized KDB data. As mentioned above, "evacuation behavior" is even more important in flood disasters than in earthquake disasters. Thus, in this study, focusing on flood disasters and using KDB data to accurately understand the number of vulnerable people were considered extremely important.

2.4. Relevance of the Present Study Based on Previous Research

The subjects in the present study were vulnerable people according to specific attributes, such as infants, people aged 75 years or older who are certified as in need of long-term care, people aged 85 years or older, and people with illnesses that render evacuation actions difficult. The previous research mentioned in Sections 2.1 and 2.2 did not consider the detailed attributes of the subjects when estimating evacuation behavior, actual damage status, and damage. It is believed that there is a major element of novelty in the present study owing to the conduction of a detailed analysis of the attributes of aged people in particular. Although it is certain that infants have difficulty evacuating on their own, there is a wide disparity with the physical condition of people aged 65 years and over, and it is thought that all aged people should not be judged as finding it difficult to evacuate on their own. A 65-year-old person who has been certified as in need of long-term care level 5 should not be considered as being in the same position as a 65-year-old person who is physically and mentally healthy during an evacuation. In the present study, subjects were narrowed down to "aged persons" and "infants" as a broad framework; however, among these subjects, those who definitely find it difficult to evacuate were targeted based on their specific attribute. Thus, the narrowing down of vulnerable people was conducted in a precise manner.

We also estimated the number of subjects that are affected by the maximum amount of flooding by town district by apportioning the area using the building area; this is considered a novel method that is useful in estimating the affected population on a town district basis. This method facilitated an understanding of which town districts were at high risk of having people in need of support. The analysis results of the present study are considerably useful as advance information before the occurrence of a disaster.

3. Analysis of the Target Area: Komatsu City, Ishikawa Prefecture

3.1. Overview of Komatsu City, Ishikawa Prefecture

The target area of the present study was Komatsu City, Ishikawa Prefecture, located in the southern part of Ishikawa Prefecture. As of 1 July 2018, the population was 108,570, as registered in the Komatsu City Basic Resident Register, and there were 43,184 households [18]. The area is 371.05 km^2. Figure 2 shows the location of Komatsu City, Ishikawa Prefecture. In Komatsu City, Ishikawa Prefecture, four levels of weather advice and warnings are announced before a flood occurs, based on the standards of the Japan Meteorological Agency. The lowest level is "weather advice", which is announced to increase preparedness for disasters and to confirm evacuation information. The highest level is a "weather warning", which is announced to encourage immediate evacuation.

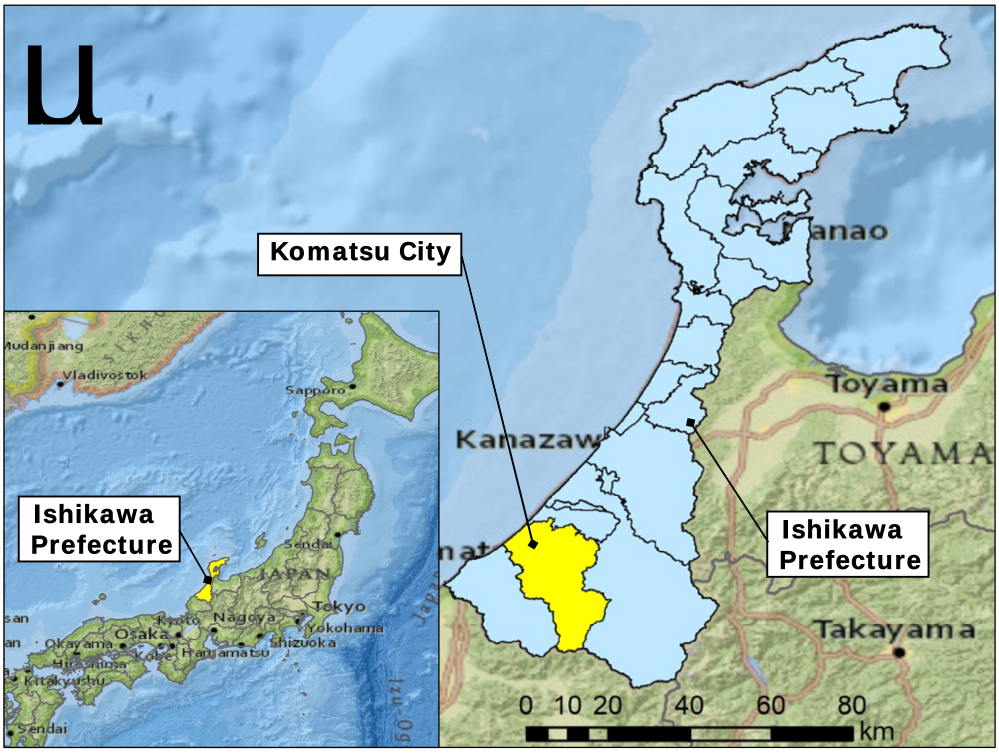

Figure 2. Location of Komatsu City, Ishikawa Prefecture.

3.2. Setting Target Rivers and Flood Assumptions during a Flood

In the present study, we focused on the rivers that exist in Komatsu City, Ishikawa Prefecture, which was the target area. For the assumptions, we used the "assumed flood area maps" obtained from the National Land Numerical Information Download Service. Among the rivers in Komatsu City, the Kakehashi River is expected to be flooded the most, and in the present study, the Kakehashi River system of the Ishikawa Prefecture assumed flood area map was the target river. Furthermore, according to the National Land Numerical Information Download Service, the assumed flood area map is the assumed flood area designated by the provisions of the Flood Control Act and the assumed flooding when the applicable area is flooded in the event of flooding in the flood warning section from the mouth of the Kakehashi River to a point 12.2 km upstream. Additionally, this data were obtained through a simulation of the assumed flood situation if the Kakehashi River overflows owing to heavy rain, which occurs approximately once every 100 years and is the basis of flood prevention plans. The "assumed flood area maps" used in this analysis were based on the following procedure for a flooding simulation. This procedure was published by the Ministry of Land, Infrastructure, Transport and Tourism, which provided guidelines for this simulation [19].

1. Creation of longitudinal and cross-channel geometry models for flow prediction in the river channel.
2. Topographic elevation modeling for river flood analysis.
3. Calculation of the maximum expected rainfall.
4. Prediction of the river flow at the maximum expected rainfall.
5. Prediction of the outflow from rivers due to levee breaches and overflows.
6. Flood inundation forecasting.

Figure 3 shows the assumed flood area in the event of the Kakehashi River flooding. The area around the Kakehashi River in the northern part of Komatsu City is flooded over a wide area. As evident, many locations are expected to be flooded with a height of less than 1.0–2.0 m, and certain locations are expected to be flooded with a height of 2.0–5.0 m. Furthermore, in the present study, the targets were all 126 town districts that have even a small amount of assumed flood area within the range of each town district.

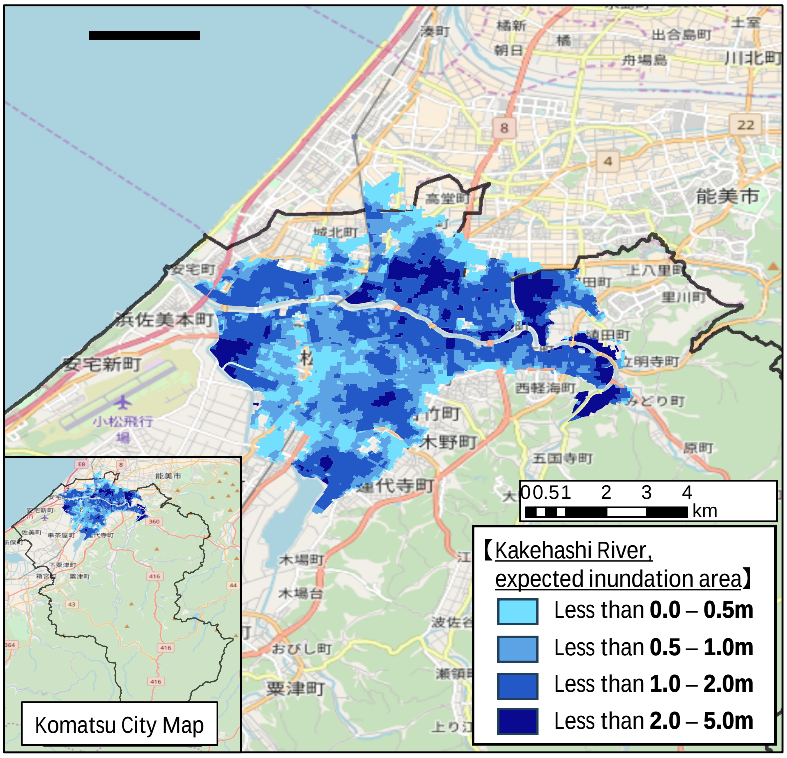

Figure 3. Assumed flood are map in the event of Kakehashi River flooding.

Additionally, the flood depth and approximate extent of flooding (building height) according to the Ministry of Land, Infrastructure, Transport and Tourism's river disaster prevention information [20] are shown in Table 1. Based on this information, the flood depth and extent of flooding are presented in the hazard map [21] published by Komatsu City, as shown in Figure 4. Furthermore, according to Suetsugi [22], Figure 5 shows the flood height and proportion of people who have difficulty evacuating. As evident, most people found it difficult to evacuate when the floo depth reached knee depth (approximately 0.5 cm) or more.

Table 1. Flood depth and approximate extent of flooding.

Flood Depth	Approximate Extent of Flooding
0~0.5 m	Inundation below floor level
0.5~1.0 m	Inundation above floor level
1.0~2.0 m	Flooding to the eaves of the first floor
2.0~5.0 m	Flooding to the eaves of the second floor
5.0 m~	Flooding above the roof of the second floor

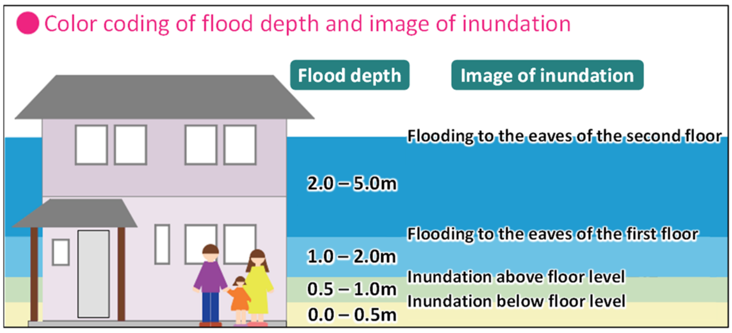

Figure 4. Estimated flood depth and approximate extent of flooding (obtained from Komatsu City flood hazard map) [21].

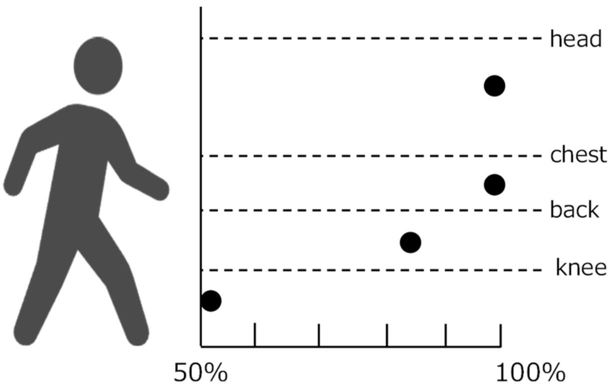

Figure 5. Flood height and percentage of people who have difficulty in conducting evacuation actions [22].

4. Overview of Data Used and Calculation of Vulnerable People

In this section, we provide an overview of the data used to calculate the vulnerable people on a town district basis, the attributes of the people to be analyzed, and the results of calculating vulnerable people using these data.

4.1. Overview of the Data Used and Setting of Analysis Targets

In this study, vulnerable people were those who find it extremely difficult to evacuate on their own following a disaster. Among the people who are vulnerable during disasters, “infants” and “people aged 75 years and older” were targeted in this study. The reason for targeting these people is because, first, among CWAP, “infants” are unable to evacuate on their own. Regarding “aged people”, given Japan’s considerably aging society at present, the number of “aged people” will increase rapidly in the future—an attribute that cannot be ignored when considering future evacuation support before and after a disaster.

The 2015 National Census was used to determine “infants” on a town district basis. We used the 2015 National Census’s “Basic population count” and “Population by age (five-year age groups), population by gender, total age, and average age (foreigners–special mention), town district basis”. According to the Child Welfare Act [23], infants are defined as people under the age of one year, and toddlers are defined as up to the commencement of elementary school. “Infants” in this study referred those from the age of birth up to the commencement of elementary school. Therefore, infants refer to those aged 0–6 years; however, the Census used in the present study only measured the population in five-year age groups, rendering the ascertaining of infants according to the above definition impossible. Therefore, infants in the present study referred to those aged 0–4 years.

Next, we explain the calculation of “aged people” on a town district basis. KDB data were used for calculations. KDB data contain information on health checkups, medical care, and long-term care, and in this study, we used the "Status of matching people in need of long-term care (support)" (Table 2), which facilitates the understanding of the status of support and long-term care needs on an individual basis. Furthermore, the Ministry of Health, Labor, and Welfare form (Form 1-1) (Table 3) data were used, which allowed for a detailed understanding of injuries and illnesses, in our analysis.

Table 2. Example of data on the status of matching persons in need of long-term care (support).

Gender	Age	Date of Month	Address	Medical Points	Nursing Level	Start Date	Residence	Nursing Facility	Medical Total Point	Personal Number
				3345	2	2015.4	1	0	13,581	1
				7275	1	2016.4	0	1	1444	2
				28,446	2	2014.10	1	0	3326	3
				62,071	3	2014.11	1	0	3603	4
				3396	4	2015.4	1	0	7275	5
				9464	5	2016.4	1	0	29,444	6
				3972	7	2016.4	1	0	66,922	7
				4147	7	2014.12	0	1	4888	8

Table 3. Example of data from the Ministry of Health, Labor and Welfare form (Form 1-1).

Gender	Age	Date of Month	Address	Hypertension	Diabetes	Dyslipidemia	Hyperuricemia	Amount of Expense	Personal Number
				•				328,140	1
					•			324,960	2
				•		•		318,150	3
					•			314,320	4
				•			•	301,170	5
				•			•	299,340	6
				•	•	•		293,221	7
						•		222,211	8

The "Status of matching people in need of long-term care (support)" includes personal attributes, such as gender, age, data of birth, and address up to the town district, as well as health checkup items, initial and current levels of long-term care, and residence/housing service usage status, all on an individual basis. In addition, the Ministry of Health, Labor, and Welfare form (Form 1-1) includes detailed data on personal attributes such as gender, age, date of birth, and address up to the town district, as well as inpatient/outpatient classification, amount of expenses, and type of disease, on an individual basis. In this study, vulnerable people were determined using the individual disease information obtained from the KDB data. Furthermore, in both data, the age, date of birth, and address, which are considered personal information, were left blank. Furthermore, owing to space limitations, the "Second highest disease name" onwards in the Ministry of Health, Labor and Welfare form (Form 1-1) was left blank. Of the data provided by Komatsu City, we used the data as of September 2015. KDB data were maintained monthly; however, for consistency with the 2015 National Census, the analysis conducted in this study focused on October 2015.

Next, we extracted those among "aged people" who had a particular difficulty in conducting evacuation actions. From the KDB data used in the present study, those who have difficulty in conducting evacuation actions were obtained. The selection of subjects was determined based on advice from faculty members of the School of Health Sciences, College of Medical, Pharmaceutical and Health Sciences, Kanazawa University. Figure 6 shows a diagram of the aged vulnerable people who can be obtained from the KDB data, categorized by risk level during evacuation behavior for each attribute. As is evident, aged people, who were the subject of the analysis of the study, can be broadly divided according to three attributes. The main premise was to target people in Komatsu City who were 75 years or older and who were not hospitalized or receiving admission services (achieved through data squashing using KDB data). The first attribute was those considered in need of special care during evacuation and received long-term care certification 1–5. Long-term care certification is determined based on the degree of physical independence and cognitive independence, but those who are certified as in need of long-term care level 1 or higher were considered as the subjects of analysis because they are believed to face difficult circumstances during evacuation. Next, the second attribute was aged people aged 85 years or older who have not been certified as in need of long-term care. Aged people aged 85 years or older often experience physical vulnerability as they age. This condition is referred to as "frailty", and they may not be able to climb even the slightest step. Therefore, aged people aged 85 years or older who were not certified as in need of long-term care were also included in the analysis. Additionally, the third attribute was people who have not been certified as in need of long-term care, under the age of 85 years, and suffer from a disease that render evacuation actions difficult. In the KDB data, up to six types of injuries and diseases suffered by individuals are listed in order of the amount of expenses required. The types of the injuries and diseases are those listed in the Disease Classification for Social Insurance Receipts [24]. Among these people, those who suffer from injuries or diseases that render evacuation actions difficult were extracted from the KDB data. Table 4 presents the types of the applicable injuries and diseases. Diseases of the musculoskeletal system and connective tissue, such as lower back pain and joint pain, as well as bone fractures, were selected because they were thought to render walking during evacuation or going up and down steps difficult. In addition, diseases of the nervous system and circulatory system were chosen because they are highly likely to cause physical disadvantages as sequelae. When extracting the data, when even one of the types of the applicable injuries or diseases in Table 4 was applicable to the "Main disease type", "Second (highest disease type)", "Third (highest disease type)", etc. shown in Table 3, the individuals were treated as the vulnerable people under analysis in the present study because there were cases wherein patients suffer from more than one of the applicable injuries and diseases.

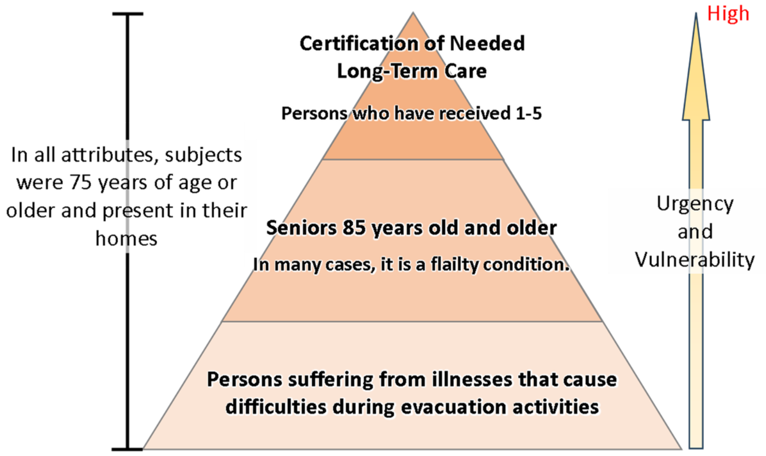

Figure 6. Relationship between urgency and vulnerability during evacuation actions for "aged" vulnerable people.

Table 4. Types of injuries and diseases analyzed in this study.

Type of Injuries	Diseases Analyzed in This Study
Nervous system disease	Parkinson's disease
	Alzheimer's disease
Cardiovascular Diseases	Subarachnoid hemorrhage
	Brain hemorrhage
	Cerebral infarction
	Other diseases
Musculoskeletal and Connective Tissue Diseases	Inflammatory polyarthritis
	Osteoarthritis
	Spinal cord injury
	Intervertebral disc disorder
	Lower back pain and sciatica
	Other spinal disorders
	Disorders of bone density and structure
	Other diseases
Injury, Poisoning, and Others	Fracture

4.2. Calculation Results of Vulnerable People

The calculations of vulnerable people, with a focus on the "infants" and "aged people" described in the previous section, were conducted using the KDB data and National Census. The target population was calculated on a town district basis; however, there were 126 target town districts, and it was difficult to list all of them. Thus, in this section, the calculation results for the 126 target town districts are shown in summarized form in Figure 7. The number of people in need of long-term care 1–5 was 1528 (long-term care level 1: 577 people; long-term care level 2: 436 people; long-term care level 3: 301 people; long-term care level 4: 123 people; and long-term care level 5: 91 people), the number of aged persons aged 85 years or older was 1369, the number of people with the diseases shown in Table 4 was 1578, and the number of infants aged 0–4 years was 3143 in the 126 target town districts. These people were located in towns within the assumed flood area of the Kakehashi River system, and as the number of people who were not hospitalized or were not admitted to nursing care facilities was calculated, it was considered that there is an extremely high possibility that these people resided at home.

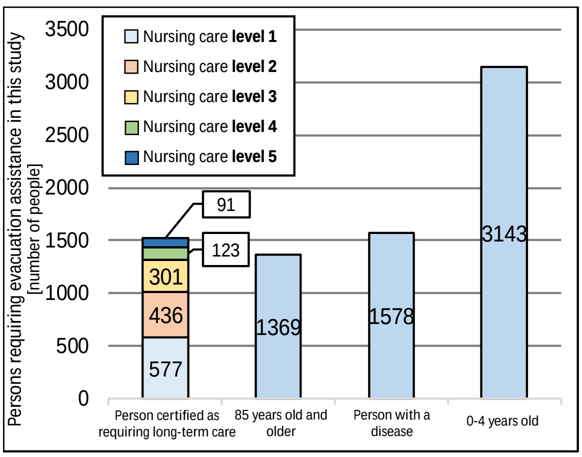

Figure 7. Calculation results of vulnerable people.

5. Analysis of the Flood Risk for People in Need of Support

In this section, we estimated the maximum flood depth (flood risk) that vulnerable people experience, which was calculated in the previous section. Specifically, we analyzed how many people in need of support may reside in an area at a given flood depth.

5.1. Overview of the Calculation Method

First, we discuss the calculation method used to estimate the flood risk, which represents the greatest risk for people in need of special consideration. In the previous section, it was considered that the vulnerable people analyzed in the present study are not hospitalized or admitted to facilities and are considered to have more difficulty moving around independently than in normal times, making it highly likely that they would be present at home in the event of a disaster. Therefore, when estimating the affected population, we decided to use area apportionment using the building area to estimate how many people would be affected by floods and to what extent. In this analysis, building polygon data were obtained using data sold by Esri Japan [25]. These data contain building types, and commercial facilities, hotels, public facilities, and houses can be identified. From these categories, we extracted the building polygon data using only the "Houses" category. Figure 8 shows a diagram of area apportionment when estimating the affected population. When calculating the affected population for each flood depth, the extent of flooding that buildings in each town district experience ("building flood rate") was calculated on a town district basis for each assumed flood depth. The building flood rate for each flood depth that was calculated for each town district was then multiplied by the number of vulnerable people calculated on a town district basis to obtain the affected population for each flood depth.

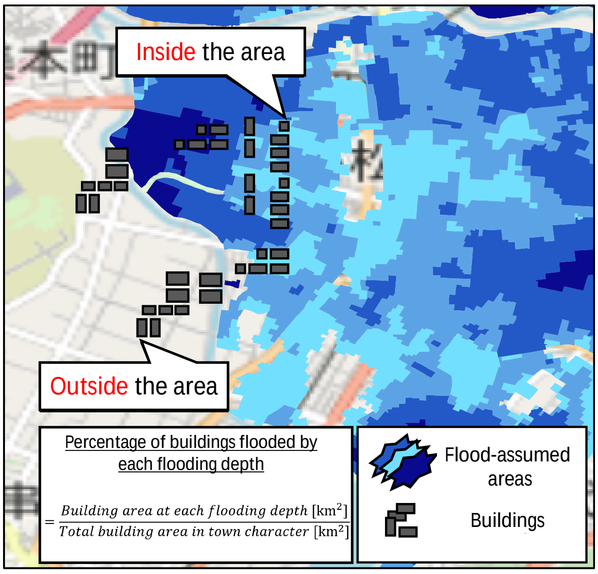

Figure 8. Diagram used to calculate the affected population for each assumed flood depth.

5.2. Basic Analysis of the Flood Risk for Vulnerable People

The calculation method described in the previous section was used to obtain the building flood rate for each assumed flood depth on a town district basis as well as the affected population by attribute. Additionally, as mentioned earlier, the building flood rate for each flood depth was omitted in this paper as it is difficult to list them all considering that there were 126 target town districts.

Figure 9 shows the population by attribute for each flood depth in the entire analyzed town district area as a basic understanding of the affected population. It is possible to understand from Figure 9 how many vulnerable people by attribute would be affected by flooding and to what extent. Across all four attributes, approximately 65% of those in need of support are affected by flooding, and approximately 35% are not. Additionally, in the analysis conducted in the present study, the deepest assumed flood classification was "less than 2–5 m". The number of people who were estimated to live in those areas according to attribute was as follows: those certified as in need of long-term care were approximately 26.3 people (approximately 1.7% of the proportion of all people certified as in need of long-term care); people aged 85 years and older were approximately 21.1 people (approximately 1.5% of the proportion of all persons aged 85 years and older); those with diseases that were considered to make evacuation actions difficult were approximately 26.3 people (approximately 1.8%); and those aged 0–4 years were approximately 49.7 people (approximately 1.6%). Furthermore, as shown in Figure 5, when the flood depth exceeded 0.5 m, most people found it difficult to evacuate. The number of people when evacuation was thought to become sufficiently difficult as the flood depth exceeded 0.5 m was as follows: those certified as in need of long-term care were approximately 691.7 people (45.3%); people aged 85 years and older were approximately 601.6 people (approximately 43.9%); those with diseases that were considered to make evacuation actions difficult were approximately 684.2 people (approximately 43.4%); and those aged 0–4 years were approximately 1546 people (approximately 49.2%). Moreover, it is highly likely that those affected by a flood depth ranging from 0 to less than 0.5 m may have difficulty in evacuating.

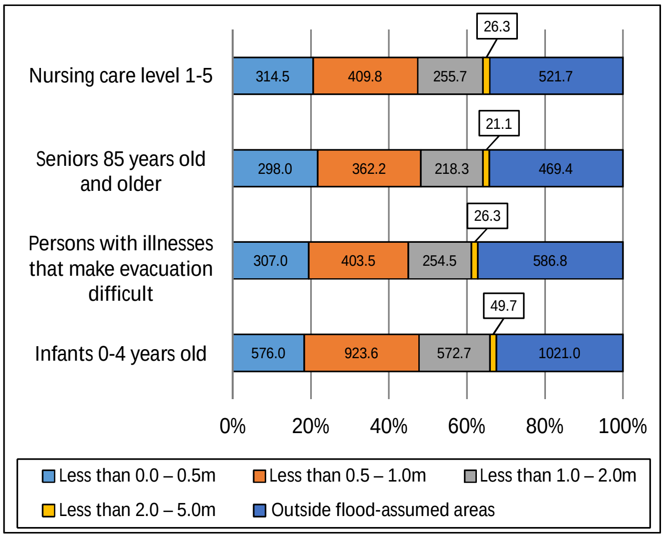

Figure 9. Affected population by attribute for each flood depth.

5.3. Analysis Results Regarding Flood Risk on Town District Basis

The results of estimating the maximum extent of flooding experienced by the "aged people" in the previous section on a town district basis are presented in this section. Even among aged people, showing the estimation results on a town district basis by each of the three attributes was difficult due to space limitations. Thus, in this paper, the estimation results of "aged people" as a summary of the three attributes are in this section. Figures 10 and 11 show the affected population of aged people by town district and flooding depth, respectively, summarized across the three attributes. Based on these figures, the number of aged people who have difficulty in evacuating and the maximum extent of flooding that is experienced in each town district could be determined. For example, in Figure 10, in Oki Town, the flood risk was evident for approximately 13.6 people at a flood depth of 0–0.5 m, approximately 74.6 people at a flood depth of 0.5–1.0 m, approximately 13.8 people at a flood depth of 1.0–2.0 m, 0 people at a flood depth of 2.0–5.0 m, and 0 people outside of the assumed flood area. Figures 12 and 13 also summarize the results of similar estimations made for infants, which depicts the number of infants facing a flood risk in each town district.

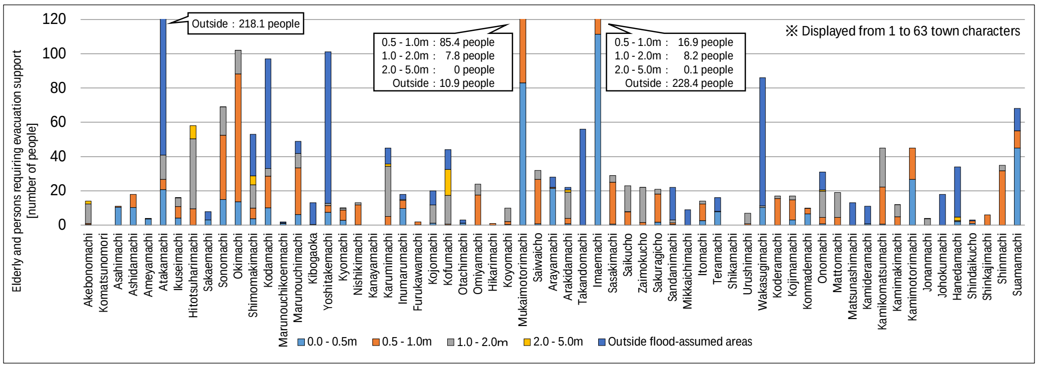

Figure 10. Flood risk for aged people by town district and assumed flood depth (town districts 1–63 out of the target of 126 town districts displayed).

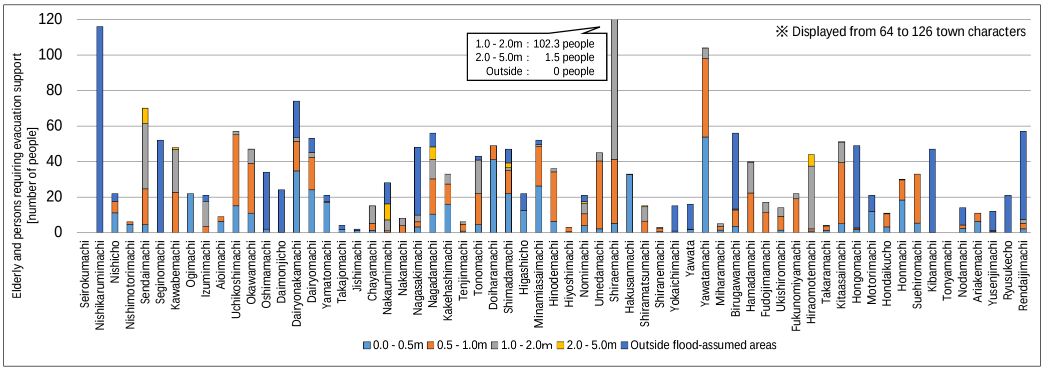

Figure 11. Flooded population of aged people by town district and assumed flood depth (town districts 64–126 out of the target of 126 town districts displayed).

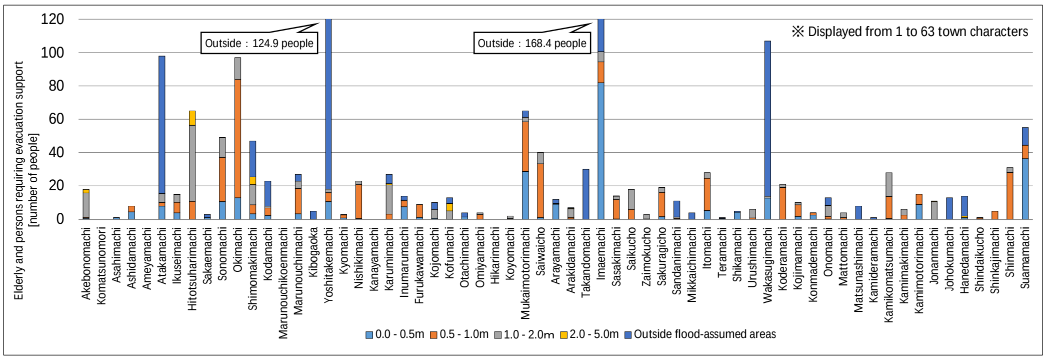

Figure 12. Flood risk for infants by town district and assumed flood depth (town districts 1–63 out of the target of 126 town districts displayed).

For example, as with the analysis results for aged people, using Oki Town as an example, the flood risk was evident for approximately 12.9 people at a flood depth of 0–0.5 m, approximately 70.9 people at a flood depth of 0.5–1.0 m, approximately 18.2 people at a flood depth of 1.0–2.0 m, 0 people at a flood depth of 2.0–5.0 m, and 0 people outside of the assumed flood area. Figures 10–13 show the variations in the population within each town district, and the assumed range of flooding within the town district also differed. Thus, there were naturally large variations in the number of people in need of support as obtained by the estimations. In Figures 10–13, the vertical axis (number of people in need of support) was limited to 120 (people) to render it easier to observe the number of people facing a flood risk for each town district. Town districts exceeding 120 people are indicated in the figure. These results show that the estimations conducted in the study facilitated the estimation of the populations facing a flood risk in detail on a town district basis, with a focus on aged people by attribute and infants among vulnerable people.

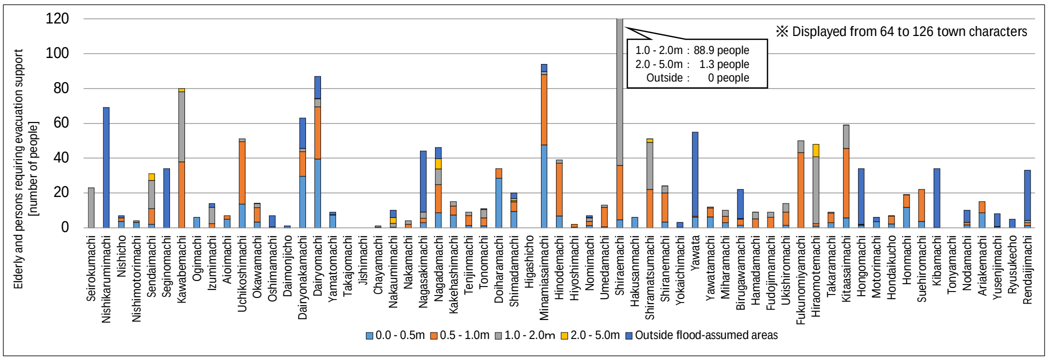

Figure 13. Flood risk for infants by town district and assumed flood depth (town districts 64–126 out of the target of 126 town districts displayed).

Of the results obtained above, the results of visualizing the number of people in need of support who face a flood risk on a town district basis for each flood depth are shown in Figures 14 and 15. Figure 14 shows the cases of aged vulnerable people obtained from the KDB data, and Figure 15 shows the cases of infants aged 0–4 years. As is evident, the number of people in need of support who face a flood risk differed according to each flood depth and according to each town district. Moreover, densely populated town district areas, with a large number of people in need of support who face a flood risk, tended to differ depending on the flood depth. In the 0–0.5 m flood depth case, there were several people in need of support in Mukaimotoori and Imae. In the 0.5–1.0 m flood depth case, several people encountered difficulties in Oki, Uchikoshi, Shirae, and Kitaasai. In particular, in the 1.0–2.0 m flood depth case, there were several people in need of support in Shirae, Hiraomote, and Hitotsuhari. The aged vulnerable people who were the subjects of the present study and who live around these town districts face a considerable flood risk.

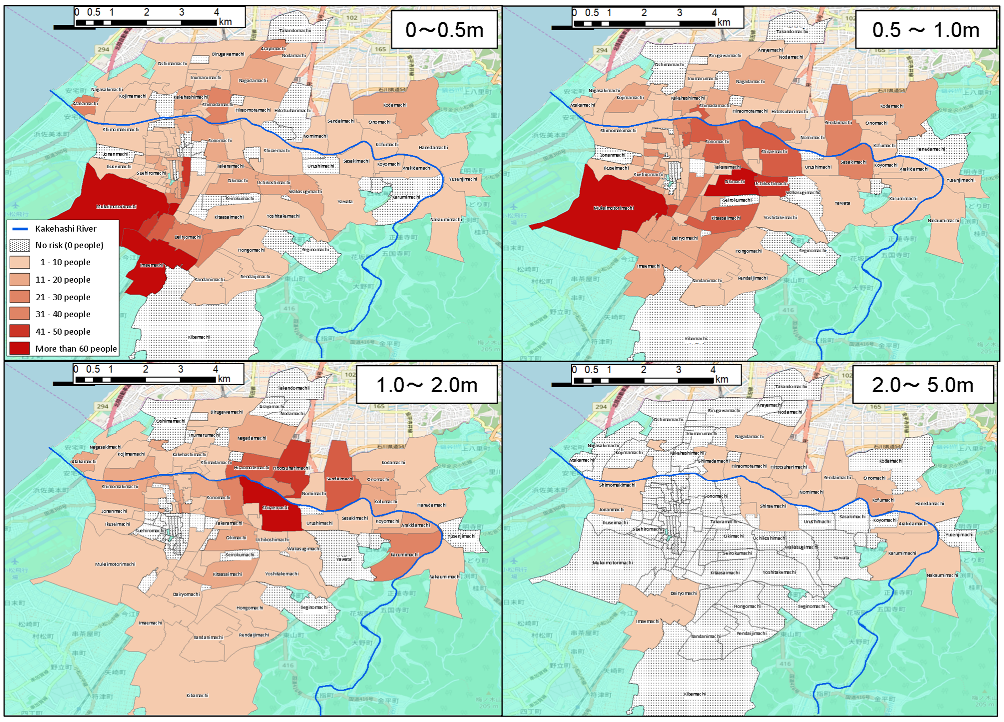

Figure 14. Visualization of the flood risk for aged vulnerable people obtained from the KDB data.

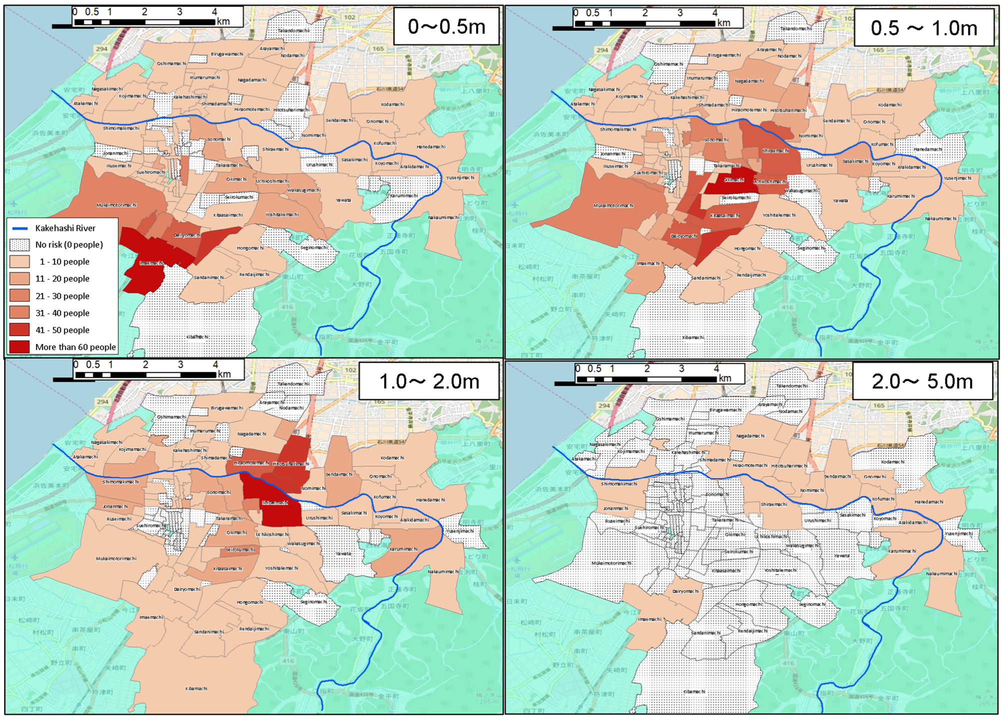

Figure 15. Visualization of the flood risk among infants aged 0–4 years obtained from the National Census.

Next, we examined the cases of infants aged 0–4 years (Figure 15). It can be confirmed here as well that the number of people in need of support who face a flood risk differed for each flooding depth and for each town district. The trends in the number of infants at each flood depth were not significantly different from those for aged persons. However, regarding infants, in the 1.0–2.0 m flood depth case, there were several people in need of support in Shirae, Hiraomote, and Hitotsuhari, and infants residing in these town districts face a considerable flood risk.

Through the analysis in this study, it was possible to estimate, in advance, the flood risk for the elderly and infants. Figures 13 and 14 show that the flood risk of the elderly and infants differs from town to town. The exposure of the elderly populations in Mukaimotoori, Imae, Shirae, and Oki is high. In addition, the exposure of infants is large in Imae, Oki, Shirae, and Hitotsuhari. We believe that the results of this study are very im- portant for a preliminary understanding to estimate the exposure vulnerable people by attribute.

6. Conclusions and Future Tasks

This study analyzed Komatsu City, Ishikawa Prefecture, and used an assumed flood area map of the Kakehashi River system in Komatsu City to understand the flood risk faced by vulnerable people. Vulnerable people were estimated by targeting "aged people by attribute" and "infants", with aged people in particular being categorized according to the attributes that were considered to render evacuation actions difficult. We used two types of data to understand vulnerable people: the 2015 National Census and KDB data, which are medical big data. Our detailed understanding of vulnerable people on a town district basis enabled the estimation of how many infants and aged people are affected by flooding in each town district.

The estimates made in this study enable the understanding of the type of people living in risk regions and the circumstances they face. Thus, we believe that our results can be used as advance information on the risks before the occurrence of a disaster and after a disaster as a way for properly deploying personnel for rescue operations.

In addition, the utilization of KDB data in this study enabled the extraction of data that depict the detailed attributes of aged people who have difficulties in conducting evacuation actions, which is extremely important in the event of a flood. It is believed that a detailed advance understanding of people in need of support that considers their physical attributes will form the basis for considering evacuation during flood disasters.

A limitation of the present study is that the analysis and estimates were limited to "aged people" and "infants". Various attributes exist among vulnerable people, and there are also those who require urgent evacuation more so than the subjects considered in the present study, such as those with disability certificates. Therefore, expanding the number of subjects for analysis is essential for future research. To that end, there is a need for obtaining more detailed data, such as Lists of Residents in Need of Assistance in Evacuation, and for understanding who needs support through large-scale questionnaire surveys. Furthermore, hospitals and nursing care facilities should be considered as future research topics. Hospitals and nursing care facilities have a particularly large number of people who are vulnerable to disasters, and they are places with an extremely high density of human vulnerability. In the present study, we targeted vulnerable people living at home; however, we will also conduct analyses that consider hospitals and nursing care facilities.

Furthermore, in this study, the height of buildings was not considered when calculating the number of vulnerable people. This should be considered because the number of people living in an apartment complex varies depending on the height of the building. Therefore, we will use the Digital Surface Model (DSM) to estimate building heights and improve the refinement of population distribution estimation. In addition, this study only estimated the exposed population focusing on floods, which is an analysis from a macro-perspective. Regarding evacuation during floods, a micro-simulation analysis should be conducted to reduce the evacuation time. Based on the results of a micro-simulation, we will also make suggestions on the actions to be undertaken before a flood, such as the proposed start time of evacuation.

Finally, this study aimed to develop a sustainable disaster management plan focusing on vulnerable people who need third-party assistance during disasters. Japan has a declining birthrate and an aging population, with a particularly high proportion of aged people. In this context, there is an urgent need to develop a disaster prevention plan to protect the elderly in order to achieve a sustainable society. It is also necessary to create a safe and secure community for infants and young children, who will be the future leaders of the society. Based on both of these perspectives, this research aimed at creating a sustainable, safe, and secure social infrastructure.

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