Implementation of intelligence of flood disaster debris discharge for emergency response

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Abstract

In this study, a procedure is established for estimating and assessing the amount of flooding debris following a flood disaster. The per unit generation of flood disaster debris, which takes into account criteria such as the extent of housing damage as a function of inundation duration time, is examined. It is shown that this estimation procedure would make it possible to estimate debris discharge, which is helpful for the establishment of disaster management systems not just as emergency response measures, but also for pre-disaster planning. The proposed Relative Quantity of disaster Debris (ReQD) provides insight that makes it possible to ascertain the emergency response capability of local governments. The ReQDs of selected flood disasters in Japan are examined. For the establishment of effective emergency response systems, it is important to evaluate information on both the ReQD and the quantity of flood debris. From these facts, it is concluded that the implementation of ReQD can help in the establishment of effective support systems with a wide range of cooperative measures for districts in the process of flood recovery and reconstruction, as well as in the emergency response stage.

Keywords: flood disaster debris, estimation procedure, Relative Quantity of disaster Debris (ReQD), emergency response systems, cooperative measures.

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1 Introduction

In Japan, flood disasters frequently affect the lives of residents along with their social and economic activities. Ten typhoons struck the islands of Japan in 2004, resulting in the death of more than 200 people and damage to more than 200,000 houses. Some examples of these disasters are the Tokai flood disaster of 2000, the 2004 Heavy Rainfall in Niigata Prefecture, the 2004 Heavy Rainfall in Fukui Prefecture, the Miyazaki Flood Disaster caused by typhoon No.14 in 2005, the Flooding of Iga River caused by heavy rains in late August 2008, and the Flooding of Sayo River in August 2009.

After flood disasters, enormous quantities of debris and household goods are discharged from the affected houses and buildings. For this reason, environment and waste management authorities must establish effective and appropriate disaster management systems for the emergency removal and eventual disposal of debris from urban districts. Based on the experiences of 2004 flood disasters, the Flood Disaster Waste Management Guidelines were published by the Ministry of the Environment [1]. In order to carry out emergency debris operation as soon as possible, as well as appropriately, the quantity of disaster debris needs to be estimated.

In addition, from the viewpoint of flood recovery and response, it is important to establish emergency response systems that include cooperative measures in the emergency response phase. In effective emergency response systems, the condition of the affected districts depends not only on the number of impacted structures, but also on the values used in evaluation, since these can assess the emergency response competence of local governments that need to be understood. The purpose of this study is to develop a procedure for the estimation of flood debris discharge, including the extent of housing damage. In addition, for the establishment of an emergency response system with wide-ranging cooperative measures, we examine the effectiveness of insightful information on flood debris discharge, and suggest the use of the Relative Quantity of disaster Debris (ReQD) criterion.

2 Methodology

2.1 Estimation procedure for flood disaster debris

In 2000, a flood disaster struck the Tokai region as a result of heavy rainfall. The levees of the Shinkawa River burst and the Shonai River overflowed, inundating the Tokai region, mainly the western part of Nagoya. The flood damaged more than 70,000 houses, and resulted in 81,400 t of debris [2]. In 2004, ten typhoons struck Honshu, and many cities were severely affected. More than 70% of downtown Toyonaka was inundated for two days after typhoon No.23 hit the Hyogo Prefecture. An enormous amount of debris was generated in the stricken cities.

In Japan, the Disaster Countermeasures Basic Act assigns responsibility for reporting damage, including the extent of damage to buildings, and the progress of emergency operations to higher levels of the administration [3]. After a disaster, reports upon the damage, including the number of houses affected, are to be announced by the Fire and Disaster Management Agency (FDMA) of the Ministry of Internal Affairs and Communications of the government of Japan. The quantity of disaster debris is estimated by eqn (1) on the basis of per unit generation of debris, including rubble from damaged housing structures.

$$W_D = \sum C_i N_i \tag{1}$$

The quantity of disaster debris is designated by W_D. C_i represents the per unit generation of debris, including rubble from damaged housing structures, and the subscript i refers to the classification of building damage. The number of damaged buildings is designated by N_i.

To estimate the quantity of disaster debris based on the damage report, we need to assume a value for per unit generation, including that from building damage. In Japan, local governments have developed maps of natural hazards with the assistance of the Ministry of Land, Infrastructure, Transport and Tourism. The number of damaged houses can be estimated on the basis of the fragility function of buildings drawn from census data such as population and the number of houses and households and damage data drawn from natural hazard maps, such as inundation depth and inundation areas.

2.2 Per unit generation of flood disaster debris

Researchers have established a procedure for estimating disaster debris caused by floods for use by emergency response operations, which estimates the per unit generation of disaster debris, including rubble from collapsed buildings [4]. In order to estimate the quantity of disaster debris based on the FDMA damage report, we need to also consider the per unit generation of building damage. A questionnaire-based survey on disaster debris generation was conducted among local governments in regions affected by flood disasters from 1999 to 2005 where the Disaster Relief Act was applied. Multiple regression analysis was performed to estimate the per unit generation of flood disaster debris, yielding an estimated 4.6 t/household from flood damage above the floor level and 0.62 t/household from inundation damage below the floor level.

In 2005, Hurricane Katrina created an enormous volume of debris, estimated at 51.2 million cubic meters, in the state of Louisiana [5]. This quantity of disaster debris indicates that Hurricane Katrina produced 1.34 times the volume of debris caused by the Great Hanshin-Awaji earthquake. In the aftermath of Hurricane Katrina, each home typically generated about 300 cubic yards of construction and demolition debris, presuming that a catastrophic flood would generate approximately the same quantity of debris as an earthquake.

Estimations of the per unit generation of disaster debris are shown in Table 1. These values for the per unit generation of flood disaster debris are based upon the results of statistical analysis [6]. Fragility curves have been developed for buildings in relation to the inundation depth of the overflow [7]. They indicate

Table 1: Estimations of per unit generation of flood disaster debris.

Damage extent	Inundation depth	Inundation duration time	Per unit generation (t/household)		
			Method-1	*Method-2*	*Method-3*
None	H = 0.0m	-	0.00	0.00	0.00
Inundation damage below the floor level	0.0m < H < 0.45m	-	0.62	0.62	0.62
Floor level inundation	0.45m ≤ H < 3.3m	Less than 3 days	4.60	4.60	4.60
		More than 3 days	4.60	4.60	60.0
		More than 7 days	4.60	60.0	60.0
	H ≥ 3.3m	-	60.0	60.0	60.0

that inundation depths of more than 2 m cause either a complete collapse or flow out of the house. According to these fragility curves, a house damage ratio of 50% was estimated for an inundation depth of 3 m. The Instruction Manual for River Management and Economic Investigation states that for the application of the damage ratio the floor height must be 0.45 m [8]. Furthermore, according to the Central Disaster Prevention Council, the Cabinet Office, Government of Japan, for the estimation of human casualties the height of the second floor must be 3.3 m [9]. As mentioned above, the correlation between inundation depth in flood disasters and housing damage, as shown in Table 1, could be assumed in this study.

In the per unit generation of the flood disaster debris determined by *Method-1*, the inundation duration time is not considered. *Method-2* and *Method-3* illustrate the per unit generation of flood disaster debris, including the effect of inundation duration time. According to *Method-2*, houses damaged by above-floor-level inundation lasting more than seven days and completely damaged housing generate 60.0 t/household, the same amount of debris as would be generated by an earthquake disaster. In *Method-3*, houses damaged by floor level inundation lasting more than three days would generate the same amount of debris as an earthquake disaster.

3 Intelligence of flood disaster debris discharge

3.1 What is the relative quantity of disaster debris

In the emergency response phase following a flood, it is necessary for public authorities to determine the situation of damaged districts on the basis of not only physical damages, but also the emergency response competence of local authorities. However, damage information, such as the extent of damage to housing, represents an absolute evaluation that expresses the extent of the

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damage caused by a flood, and would not be a tool in the emergency response of the local authorities. In other words, such information on physical damage alone cannot help the decision-making process of the central government and the upper-level administration as they establish support measures following a disaster that impacts a wide area. It is for this reason that we propose the Relative Quantity of Disaster Debris (ReQD), which would indicate the condition of a damaged district, including the emergency response competence of the local government. The ReQD is calculated by eqn (2) on the basis of the quantity of flood disasters debris divided by the amount of annual garbage disposal in every local government jurisdiction in Japan [10].

$$\text{ReQD (months)} = \frac{\text{The amount of disaster debris (t)}}{\text{The amount of annual garbage disposal (t)}} \times 12 \text{ (months)} \quad (2)$$

3.2 Implementation of Relative Quantity of disaster Debris (ReQD)

This section describes the implementation of ReQD for emergency response systems following a flood disaster. The ReQD has been calculated using the estimation results of flood disaster debris discharge in the damage report on the Heavy Rainfall Disaster on July 2004 in Fukui Prefecture [11]. The calculated results are shown in Figure 1.

The estimated quantity of flood disaster debris in F City shows a maximum at 20,797 t. The ReQD in F City was calculated for 2.4 months. Although the quantity of flood disaster debris in Mi Town was estimated at 1,485 t, less than a one-fourteenth of that in F City, the ReQD of Mi Town was calculated for 20.6 months, which is more than 8.5 times that calculated for F City. In addition, the

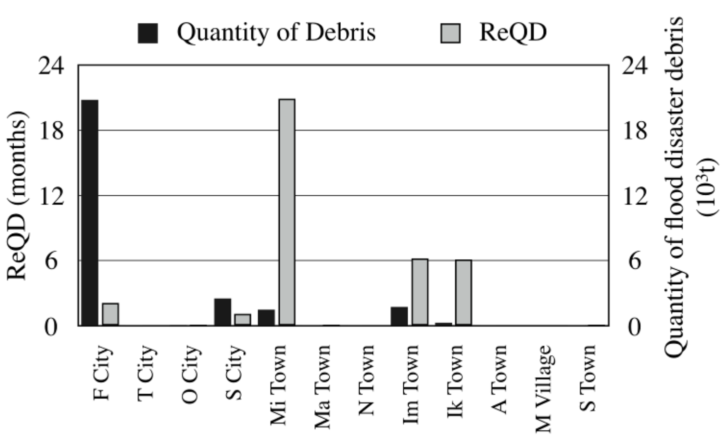

Figure 1: Estimated quantity of flooding disaster debris caused by the Heavy Rainfall disaster on July 2004 in Fukui Prefecture and the calculated results of ReQD of local governments.

quantity of flood disaster debris in both Im Town and Ik Town are less than it was in S City; however, the ReQD of both Im Town and Ik Town are calculated for more than 6 months. This figure indicates that the flooding resulted in a disaster that was beyond the emergency response competence of Mi Town, Im Town, and Ik Town. For this reason, much support would be needed in these districts not just for emergency debris management operations, but also for systems of search and rescue, flood recovery, and reconstruction.

Thus, it is important to establish support systems for Mi Town, Im Town, and Ik Town, while it is necessary to support F City in its emergency debris management systems, which would be more heavily burdened with increasing amounts of disaster debris. This finding shows that in order to optimally evaluate a situation, damage report information on both the ReQD and the number of impacted houses would give insight into the emergency response capability of local governments. It also shows that the implementation of ReQD can help in the establishment of effective support systems for damaged districts in the emergency response stage as well as in subsequent flood recovery and reconstruction.

3.3 Case study of catastrophic flood disasters in the Tokyo Metropolitan Area

In this section, we describe the insight provided by ReQD, as calculated from the estimated results of disaster debris caused by catastrophic flood disasters in the Tokyo Metropolitan Area in the pre-disaster stage. In its investigation of countermeasures against catastrophic flood disasters in the Tokyo Metropolitan

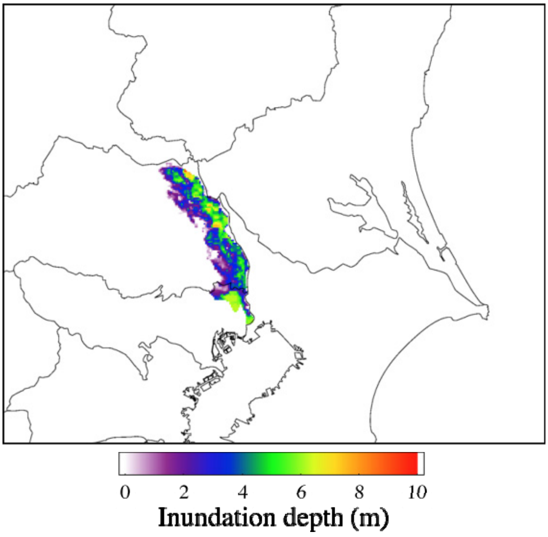

Figure 2: Map of the projected flood zone of the Tone River in the case of catastrophic flooding in the Tokyo Metropolitan Area.

Area [9], the Central Disaster Prevention Council estimated the damage from flood disasters in the area. Figure 2 illustrates a map of the projected flood zone of the Tone River in the case of a catastrophic flood in the Tokyo Metropolitan Area.

The number of damaged houses was estimated on the basis of the fragility function of buildings taken from the number of households except for those on the third floor or higher, as shown in Figure 3, and the inundation depth shown on hazard zone maps. Thus, the number of damaged houses shown in Figure 4 was calculated on the basis of the correlation between inundation depth and housing damage, as mentioned above. According to estimates of damage from

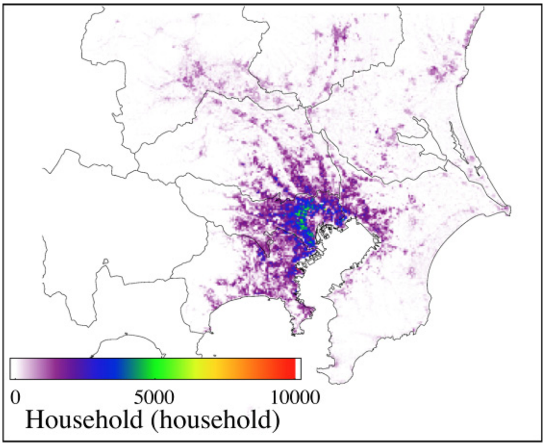

Figure 3: Distribution of households, except for those on the third floor or higher.

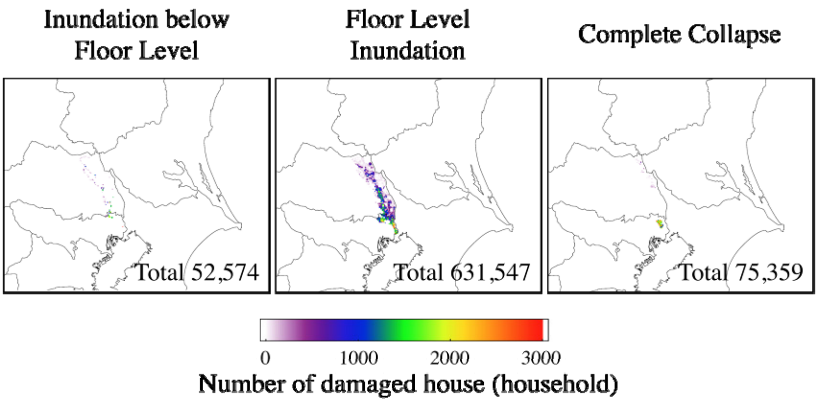

Figure 4: Calculated results of the number of damaged houses caused by flooding in the Tokyo Metropolitan Area.

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flood disasters, 631,547 households would suffer damage beyond floor level inundation. It can be shown that as many as 247,491 households in Adachi, Edogawa, and Katsushika wards on the coast of Tokyo Bay would be damaged. In these wards, an inundation duration time, in these wards, of more than three weeks was estimated. It can be assumed that the damage to housing on the Tokyo Bay coast would be even greater.

First, the amount of debris from a Tone River flood disaster in the Tokyo Metropolitan Area was calculated based on housing damage and per unit generation in Method-1. The total amount of flood disaster debris was estimated at 2.81 million t.

According to the inundation duration time, it is presumed that most of the inundation area in a Tone River flood disaster would suffer housing damage from a long-term inundation of more than two weeks. From the amount of disaster debris caused by Hurricane Katrina, it seems reasonable to suppose that long-term inundation would generate debris from damaged houses. If it is assumed that the housing damage from above-floor-level inundation generates the same quantity of flood disaster debris as earthquake disasters, the per unit generation of flood disaster debris from long-term inundation could be as much as 60 t/household, as determined by *Method-3* (see Table 1). The total quantity of flood disaster debris was estimated at 19.2 million t. The results of flood debris estimation for catastrophic flood disasters in the Tokyo Metropolitan Area are shown in Figure 5.

The quantity of disaster debris from the viewpoint of the emergency response competence of the public authorities was examined. The ReQD were calculated

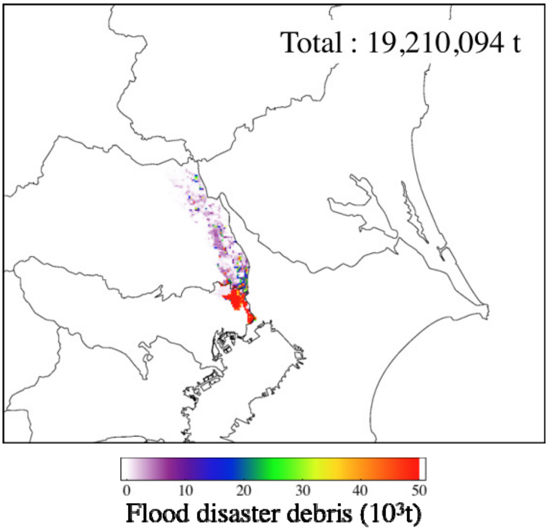

Figure 5: Estimation results of flood debris from catastrophic flood disasters in the Tokyo Metropolitan Area caused by Tone River overflow.

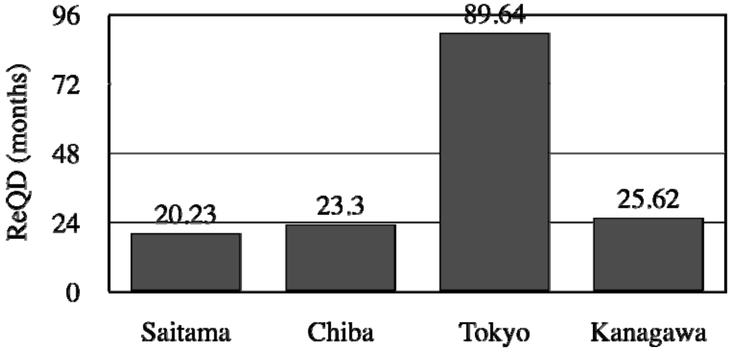

Figure 6: The ReQD from a case of catastrophic flooding in the Tokyo Metropolitan Area caused by overflow of the Tone River.

on the basis of the estimated quantity of flood debris divided by the amount of annual garbage disposal in every local government jurisdiction in Japan [10]. The ReQD from a case of catastrophic flooding in the Toyo Metropolitan Area caused by the overflow of the Tone River is shown in Figure 6 for all prefectures. The results indicate that local governments would be affected by the flood disasters to an extent that was beyond the capacity of their emergency response systems.

3.4 Results and discussion

In this paper, a procedure for the estimation of flood debris discharge, including the extent of housing damage was developed. The per unit debris generation of catastrophic flood disasters was examined. The value for per unit generation for flood damage above floor level was estimated at 4.6 t/household. Considering the amount of flood disaster debris caused by Hurricane Katrina, it seems reasonable to suppose that long-term inundation would damage houses and generate disaster debris. It was pointed out that the per unit generation of debris from long-term inundation can be as much as 60 t/household, a value similar to that in the case of earthquake disasters. According to this estimation procedure, the quantity of flood disaster debris from simulated catastrophic flooding in the Tokyo Metropolitan Area was calculated on the basis of maps of hazard zones. It was shown that this estimation procedure would make it possible to estimate debris discharge for the establishment of disaster management systems not just as emergency response measures but also for pre-disaster planning.

Let us now consider the effectiveness of such intelligent information on flooding debris discharge. In this paper, we propose the Relative Quantity of disaster Debris (ReQD) as information that offers gain true insight into the emergency response capabilities of local governments. The ReQDs of the Heavy Rainfall Disaster on July 2004 in Fukui Prefecture and catastrophic flood disasters in the Tokyo Metropolitan Area were examined. As a result of this investigation, we may conclude that catastrophic flood disasters in the Tokyo Metropolitan Area are not just regional crises that local governments can deal with, but rather, that they are enormous calamities that require the intervention of the national government. Furthermore, these catastrophic disasters would need a higher level of response capacity than local authorities can offer. From the viewpoint of the human security in a stricken district, it is also important for wide-ranging cooperative measures to be established not only emergency debris removal and related operations, but also for flood recovery and reconstruction.

Figure 7 illustrates the calculated results of the ReQD for each grid cell. The number of residents in these districts, where the ReQD would be estimated for ten years (120 months) or more, is calculated as 927,000. The population in the grid cell in which the ReQD would be estimated for more than six months is 1.86 million. These results show that the evaluation of information on both the ReQD and the quantity of flooding debris would produce sufficient insight to enable authorities to grasp the true circumstances of these districts. The ReQD would thus provide intelligence that is crucial to the establishment of effective support systems with wide ranging cooperative measures, in terms of flood recovery and reconstruction as well as the emergency response stage. We may therefore conclude that emergency response systems that include a wide range of cooperative measures are essential to recovery from catastrophic flooding and to reconstruction.

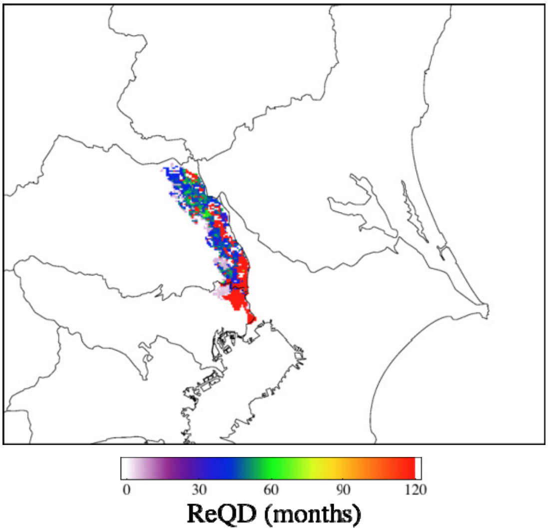

Figure 7: Calculated results of the ReQD for each grid cell.

4 Conclusions

A procedure for the estimation of flood debris discharge was established based on per unit generation, and the effectiveness of this insightful information was examined. From this study, we reached the following important conclusions:
1) A procedure for the estimation of flood debris discharge, including the extent of housing damage, was developed. This procedure would make it possible to estimate debris discharge for the establishment of disaster management systems not just as emergency response measures, but also for pre-disaster planning.
2) The per unit generation of flood disaster debris from long-term inundation can be as much as 60 t/household, a figure similar to that in the case of earthquake disasters.
3) The Relative Quantity of disaster Debris (ReQD), a value which offers insight into the emergency response capability of local governments, was proposed. For the establishment of effective emergency response systems, it is important to evaluate information on the ReQD along with absolute values such as the quantity of flood disaster debris and the number of houses that are impacted.
4) The implementation of ReQD would help in the establishment of effective support systems that include cooperative measures for districts in the flood recovery and reconstruction phase, as well as the emergency response stage.
5) Catastrophic flood disasters in the Tokyo Metropolitan Area are not just regional crises that local governments can deal with, but rather, are enormous calamities that require the intervention of the national government.

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