ESTIMATING THE CHARSTERISTICS OF WOODY DEBRIS MECHANISM IN TERAUCHI DAM RESERVOIR CATCHMENT

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ABSTRACT

In 2017, numerous amounts of woody debris was exported into Terauchi dam reservoir as woody debris because of a heavy rain which seriously damaged Northern Kyushu. It took a lot of time and it was costly to remove all the woods. Although inevitable damages caused by woody debris have been increasing recently, detailed mechanism of woody debris throughout a catchment is still unknown. Thus, this study was conducted in order to understand the mechanism of woody debris and consider its characteristics in a catchment scale by taking an example of Terauchi dam reservoir catchment. The woody debris transport model was applied in this study, which expressed 2 types of woody debris export. One is the flood flow typed export, which happens along with a large amount of woody debris production. The other is the base flow typed export, which happens in a normal condition without woody debris production. The result indicated that a large amount of woody debirs production in 2012 partially affected to the vast amount of woody debris export in 2017. In addition, a previous study which analyzed dam reservoir catchments in Iwate prefecture showed that Terauchi dam reservoir catchment had a tendency to cause flood flow typed export easily. Moreover, it turned out that accumulated woody debris in Terauchi dam reservoir catchment were likely to be exported easily as the base flow.

Keywords: woody debris, woody debris export, woody debris production, Terauchi dam reservoir, landslide

1. INTRODUCTION

Woody debris in streams has both positive and negative aspects to the environment. It offers habitats for various aquatic organisms, as well as contributes in building geomorphologic conditions such as pools in streams. On the other hand, recently the negative aspects of woody debris have been getting worse. For instance, in 2017, large amounts of woody debris flowed into human living areas as woody debris caused by serious heavy rain in Northern Kyushu area in Japan. Because of this incident, many buildings were damaged and some woody debris which accumulated in front of bridges disturbed the stream flow, which worsened flooding. Especially, in Terauchi dam reservoir, which is located in Fukuoka prefecture, 8563m^3 of woody debris were exported. It took a very long time and high cost to remove all of the woods from the reservoir.

There are several studies about woody debris. Sumi et al. (2018) estimated the amount of exported woody debris and their spatial distribution in Terauchi dam reservoir by image analysis. Komori et al. (2019) established the woody debris transport model assuming two types of woody debris exports; the flood flow typed export and the base flow typed export. They adapted the model to dam reservoir catchments in Iwate prefecture. However, the detailed mechanism of woody debris export throughout a catchment is still unknown.

Based on the above background, the following two objectives were fixed in this study. 1) To understand the mechanism of woody debris caused by heavy rain in 2017 in Terauchi dam reservoir catchment by applying the woods export model. 2) To analyze the characteristics of woody debris export in Terauchi dam reservoir catchment by comparation with the previous results obtained by Komori et al.

2. METHOD

2.1 Estimation of amounts of woody debris production

Rainfall is an essential component strongly related to woody debris production (Sukegawa and Komori (2017)). Thus, the moment when an annual maximum for a 24-hour rainfall in the catchment was recorded, it was assumed to be the moment when woody debris was produced. After calculating groundwater levels in each 50m grid in the catchment by using the rainfall values, factor of security (FS) in each grid was assessed by Eq(1) (Rosso et al.,2006; Chaithong and Komori, 2017).

$$FS = \frac{c' + [(h\gamma_{sat}) + (D-h)\gamma_t - (\gamma_w h)]cos^2\beta tan\varphi'}{[(h\gamma') + (D-h)\gamma_t + (\gamma_w h)]sin\beta cos\beta} \tag{1}$$

where c' is cohesivity (kPa), h is groundwater level (m) , γ_{sat} is saturated unit weight (kN/m^3), D is soil depth (m), γ_t is total unit weight (kN/m^3), γ_w is water unit weight (kN/m^3), β is gradient (rad), φ' is internal friction angle (rad), and γ' is submerged unit weight (kN/m^3)

The grids with FS<1 were assumed as the points where landslide happened. Afterwards, the final volume of produced woody debris was calculated regarding forest density of the area which was obtained from global tree density map (Crowther et al., 2015). The analysis covered the period from 1996 to 2017.

2.2 Estimation of amounts of woody debris export

The woody debris transport model expresses two types of woody debris export by two tanks. One is the flood flow typed export, which happens along with a large amount of woody debris production. The other is the base flow typed export, which happens in a normal condition without woody debris production. The first tank expresses the flood flow typed export by following equations.

When $S_1 \geq$ Z,

$$q_1 = S_1 - Z \tag{2}$$

$$P_{inf} = b \cdot S_1 \tag{3}$$

Additionally, when $S_1 <$ Z,

$$q_1 = 0 \tag{4}$$

$$P_{inf} = b \cdot S_1 \tag{5}$$

Also,

$$\frac{dS_1}{dt} = P - P_{inf} \tag{6}$$

where q_1 is woody debris export from the first tank (m^3), S_1 is woody debris storage in the first tank (m^3), Z is the capacity of the first tank (m^3), P_{inf} is infiltration from the first tank to the second tank (m^3), b is parameter, P is woody debris production (m^3).

The second tank expresses base flow type by the following equations.

$$\frac{dS_2}{dt} = P_{inf} - q_2 \tag{7}$$

$$S_2 = k \cdot {q_2}^p \tag{8}$$

where q_2 is woody debris export from the second tank (m^3), S_2 is woody debris storage in the second tank (m^3), k, p are parameter.

Unknown parameters (*Z, b, k, p*) were fixed so that the gap between observed values and calculated values from the above equations could be minimized.

3. RESULT AND DISCUSSION

3.1 Application of the woody debris transport model

Figure1 shows the calculated amounts of woody debris export and production. The flood flow typed export for 2012 and 2017 is shown here along with the large amount of woody debris production. The flood flow typed export in 2017 was considered to be caused by the heavy rain in Northern Kyushu as mentioned above. Regarding the another flood flow typed export in 2012, this could also be related to heavy rain which seriously damaged Northern Kyushu in July 2012. However, compared to 2017, the amount of woody debris export in 2012 was relatively small. In order to look into the causes, void ratio in each year in the first tank was calculated (see figure2). Figure2 indicated that there was enough space to store woody debris in the first tank until 2012. However, along with the woody debris production in 2012, void ratio turned out to be almost 0 immediately.

After that, before the tank got recovered, numerous woody debris were produced in 2017. After all, the first tank couldn't hold that much amount of woody debris , which caused a vast amount of woody debris export.

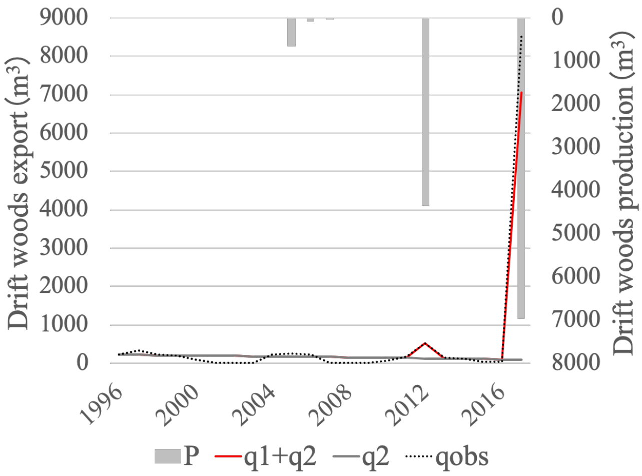

Figure1. Calculated amounts of woody debris production and export

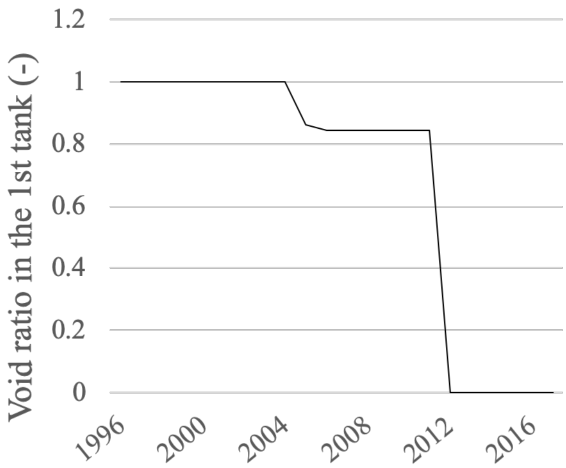

Figure2. Void ratio in the first tank

3.2 Comparation with the previous results in Iwate prefecture

First, in order to compare characteristics of flood flow typed export between Terauchi dam reservoir catchment and dam reservoir catchments in Iwate prefecture (Gosyo, Yuda, Ishibuchi, Tase), each parameter Z, Z per catchment area (Z/A), *b* were listed in Table1. Looking into the values of Z/A, there were not significant differences between Terauchi dam reservoir and others. Z/A is considered to indicate a capacity of woody debris storage in the first tank per catchment area. Terauchi dam reservoir catchment was likely to have as much capacity as the other catchments when taking catchment area into consideration. On the other hand, looking into the values of parameter *b*, the value in Terauchi dam reservoir catchment was quite lower than the others. Since parameter *b* is considered to indicate effectiveness of infiltration of woody debris from the first tank to the second tank, this result meant that Terauchi dam reservoir catchment had a tendency to fill the first tank in a short term. Therefore, in case the woody debris are produced frequently in a limited time, the flood flow typed export can easily happen in Terauchi dam reservoir catchment. In contrast, in the dam reservoir catchments in Iwate prefecture, the values of parameter *b* were higher, which meant they could resist more than Terauchi dam reservoir catchment before the flood flow typed export happens.

Table1. Comparation of the parameters

	A(km^2)	**Z(m^3)**	**Z/A(m^3/ km^2)**	**b(-)**
Terauchi	51	4700	92.2	0.00010
Gosyo	635	91200	143.6	0.10
Yuda	583	22800	39.1	1.0
Ishibuchi	154	32900	213.6	0.090
Tase	740	79100	106.9	0.010

Next, in order to compare the characteristics of the base flow typed export between Terauchi dam reservoir catchment and the others, export ratio in the second tank (r) was calculated according to Eq(9).

$$r = \frac{q_2}{S_2} \tag{9}$$

Table 2 shows average values of r in the period in each catchment. Terauchi dam reservoir catchment had a higher value compared to the others. This meant that woody debris which accumulated in Terauchi dam reservoir catchment tended to be exported easily in a normal condition as the base flow, whilst that of other catchments in Iwate prefecture tended to remain in the catchment. Seo et al. (2015) have studied about accumulation of woody debris in Japan, and clarified that there were less amounts of woody debris in southern Japan than Northern Japan. Regarding the reason for that, they made an assumption that higher frequency of heavy rain and flooding in southern Japan made the difference of accumulation. Our results about the difference of the base flow typed export between Terauchi dam reservoir catchment and the dam reservoir catchments in Iwate prefecture could be a quantitative evidence which explains Seo's assumption.

Table2. Export ratio in the second tank

Terauchi	**Gosyo**	**Yuda**	**Isibuchi**	**Tase**
10.06	0.60	0.13	3.02	4.60

4. Conclusion

In this study, the mechanism of woody debris in Terauchi dam reservoir catchment was analyzed by applying the woody debris transport model. In addition, the results were compared to the previous study which was focused on the dam reservoir catchments in Iwate prefecture for further understanding of characteristics of woody debris in Terauchi dam reservoir catchment. Consequently, the following results were obtained.

1. The vast amount of woody debris export to Terauchi dam reservoir catchment in 2017 was caused by considerable woody debris production related to heavy rain in 2012 as well as in 2017.
2. Terauchi dam reservoir catchment has a high risk of the flood flow typed export occurring in a condition of frequent woody debris production in the short term.
3. Accumulated woody debris in Terauchi dam reservoir catchment tends to be exported easily as the base flow compared to the dam reservoir catchments in Iwate prefecture, which quantitatively explains the previous assumption about the difference of the characteristic of woody debris accumulation between Northern Japan and Southern Japan.

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