Effect of Previous Flood on Suspended Sediment Transport during Rainstorm Runoff

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Abstract: Suspended sediment transport during several rainstorm runoffs were investigated on two watersheds of different land use in Hokkaido, northern Japan. One watershed is entirely forested, while the other is 35% agricultural land. The main agriculture in the area is of upland crops, dairy farming, and beef cattle pasturing. The behavior of suspended sediment transport was examined on both watersheds. The load of suspended sediment from agricultural watershed exceeded that of forested watershed. This reflects the difference of land use. The mechanism of suspended sediment transport was studied in terms of several hydrological factors. It became clear that the concentration of suspended sediment during rainstorm runoffs could be explained from two hydrological factors: the peak river discharge, which is an index of rainstorm runoff scale; and the D_2 factor, which can be calculated from the scale of the period since the previous flood. It was considered that the changing size of the source area of streamflow during rainstorm runoff influences the source location of suspended sediment in the watershed.
Keywords: suspended sediment , rainstorm runoff, agricultural watershed, previous flood, source area of streamflow

1 Introduction

Degradation of the water environment in agricultural watershed due to pollution outflow from cultivated land is no longer negligible. Not only does suspended sediment transported via agricultural river impair the performance of water utilization facilities such as irrigation system, but suspended sediment also has serious effects on the ecological system in the downstream basin. For conservation of the water environment, it is important to decrease the load of suspended sediment in agricultural rivers.

Many reports concern the relationship between river discharge and suspended sediment concentration (Wallig, D.E., 1977), the mechanism of suspended sediment transport (Williams, G.P., 1986, Kurashige, Y., 1993, 1994, Park, J.K., 1991) and the relationship between the behavior of suspended sediment and land use in agricultural watersheds (Nagasawa, T. *et al*., 1986, 1992). However, the mechanism of suspended sediment transport in agricultural watershed has not been clarified. This is due to the complexity of factors that relate to this phenomenon.

This study aims to clarify the mechanism of suspended sediment transport in agricultural watersheds. By comparing the characteristics of suspended sediment transport in agricultural watershed to those in forested watershed, the mechanism of such transport is examined in terms of several hydrological factors, such as peak discharge, which is an index of rainstorm runoff scale, and the period since the previous flood.

2 Methods

The investigation was carried out in the Shubuto River basin of Hokkaido, northern Japan. The basin is in a hilly area. Annual precipitation is about 1300 mm. Rainfall occurs in the basin mainly from September to October. Most of the land used in the basin is used for upland farming, dairy pasture, and a few rice paddies.

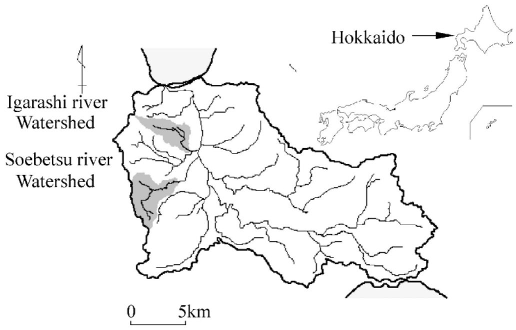

Fig.1 Investigated watersheds on Shubuto river basin

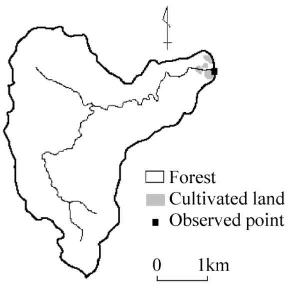

Fig.2 Landuse of forested watershed, Soebetsu river

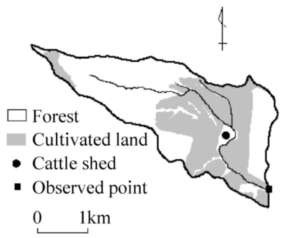

Fig.3 Landuse of agricultural watershed, Igarashi river

Suspended sediment transports during several rainstorms were investigated on two tributaries of the Shubuto River, that is the Soebetsu River and Igarashi River. The river watersheds are close to each other. Therefore we assumed that they had the same weather conditions and geological features. The characteristics of these two watersheds are shown in Table 1.

Table 1 Characteristics of investigated watersheds

Main landuse of watershed	Name	Area [km^2]	Cultivated land [km^2]	Forest etc. [km^2]	River length [km]	Cattle [head]
Forest	Soebetsu river	13.2	0.1	13.1	12.4	0
Agriculture	Igarashi river	8.6	3.0	5.6	8.2	2500

The Soebetsu River watershed is 99% forested. The remainder, cultivated land, is near the lowest reach. The soil loss from this portion of cultivated land is negligible due to its topography.

The Igarashi River watershed has a large percentage of land under agricultural use. The main agriculture in the area is of upland crops, dairy farming, and beef cattle pasturing. The ratio of cultivated land is 35%, the highest in the Shubuto River basin. The upper area of this watershed is recently developed cultivated land. The middle to lower area is used for hay production and cattle pasture. Cattle sheds exist at the middle reaches.

3 Observation

Investigation was conducted from May 1997 to October 1998 (excluding November 1997 to April 1998). Sets of automatic water sampler, rain gage, water level recorder and turbidity meter were installed at the lowest reaches of both watersheds. River water level and turbidity were monitored during the whole research period at 10-minute intervals. The sampling of river water by automatic water sampler depended on precipitation: When precipitation of more than 5 mm per hour was recorded, the automatic water sampler started sampling the river water. Collected water samples were analyzed in the laboratory to determine suspended solid concentration. The continuous change of suspended solid concentration was also estimated from the sequential turbidity data and the correlation between turbidity and suspended solid concentration. Thirty floods in the Soebetsu River watershed and 35 floods in the Igarashi River watershed were analyzed from whole investigation period.

Generally, suspended solid indicates the amount of solids in the river water, such as soil particles, organic and inorganic matter. Suspended solid is not equal to suspended sediment. However, organic and inorganic matter were negligible due to their little amounts in the river water, so we defined suspended solid concentration as being equal to suspended sediment concentration (SSC) (Nagasawa, T. *et al*., 1986).

4 Results and discussion

4.1 Behavior of suspended sediment transport during rainstorm

Fig. 4 shows an example of river specific discharge, SSC and precipitation during rainstorm. The rise and fall of SSC preceded those of discharge. It was considered that the soil components that accumulated in the watershed during dry weather or on the riverbed during the fall of river discharge at previous flood were transported as a result of increases in the transport energy during the following flood. SSC decreased more rapidly than river discharge. It seems that part of soil components settled due to a drop in flow velocity during the falling phase of the flood.

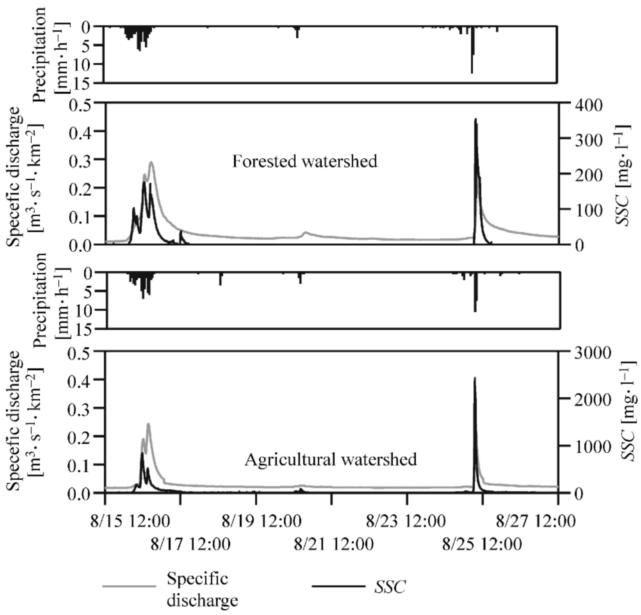

Fig.4 Precipitation, specific dischargeand *SSC* during rainstorm (1998)

The relationship between specific discharge and *SSC* was compared between forested watershed and agricultural watershed. The river discharge and *SSC* of agricultural watershed changed faster than those of forested watershed. The peak *SSC* (SSC_P) of agricultural watershed was higher than that of forested watershed. This is attributed to the difference in land use.

In Fig. 4, peak specific discharge of the two floods is similar. However, the SSC_P of the second flood is higher than that of the first flood. This suggests that the SSC_P differs in each rainstorm runoff, even if the peak specific discharge indicates a similarity in scale.

4.2 River discharge and suspended sediment transport during rainstorm

The relation between peak specific discharge (q_P) and the specific load of suspended sediment (Σ SSl) for both watersheds is shown in Fig. 5. The q_P represents an index of flood scale. The Σ*SS*l increased with higher q_P. However, the relation between q_P and Σ SSl differs between the watersheds. Σ *SS*l of agricultural watershed tends to exceed that of forested watershed at comparable scale of rainstorm runoff. As mentioned above, this tendency seems to relate to the difference in land use.

Generally, *SS*l can be represented as a function of river discharge (e.g., *SS*l = $a \Sigma q^n$). Actually, the correlation between discharge and *SS*l differs for each flood. Even when the scale of discharge is comparable, the *SSC* outflow may differ from flood to flood. The hydrological factors such as the differences in surface land condition, dry weather period, and dry and wet conditions of watershed seem to affect the suspended sediment transport on the next rainstorm

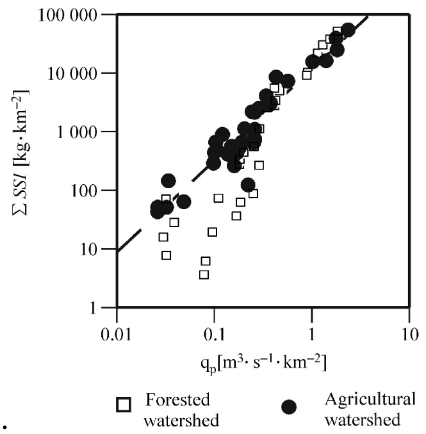

Fig.5 Relationship between q_p and SS1

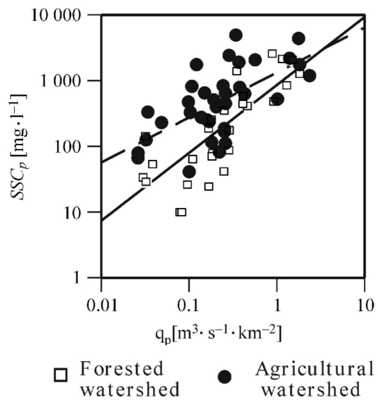

Fig.6 Relationship between q_p and SSC_p

4.3 Suspended sediment concentration and hydrological factor during rainstorm

The relationship between q_P and SSC_P for both watersheds is shown in Fig. 6. The tendency of SSC_P to be larger with increase of q_P was apparent. This is due to greater soil loss from cultivated land and greater re-transport of sediment from the riverbed with increase in flood scale. However, the correlation between SSC_P and q_P is not significant.

The duration of dry weather affects the behavior of suspended sediment transport during rainstorm runoffs (Nagasawa, T. *et al.*, 1992). Therefore, we assumed that the behavior of suspended sediment transport during rainstorm runoff might be affected by the scale of previous floods and the period since the previous flood. We defined the following hydrological factors.

Factor D_1 is the period from the previous flood to the subsequent flood.

Factor D_2 is the period from a flood exceeding q_p to the subsequent flood.

Factor D_3 is the period from a flood exceeding the total discharge of the subsequent flood to the subsequent flood.

The purpose of defining D_2 and D_3 are containing idea of varying source area of streamflow (Hewlett, J. D. and Nutter, W. L., 1970) during each event. These are river route, pit and valley, which are the source area of suspended sediments (Nagasawa, T. *et al*. 2000). The relationships between SSC_P and D_1, D_2 and D_3 are shown in Fig.8, 9 and 10. With increase of D_2, the SSC_P also increases, but their correlation is not significant. No relationships were found between SSC_P and D_1 or D_3. Regarding individual correlations between SSC_P and q_P or D_2, weak correlations were recognized. Multi-regression between q_P, D_2 and SSC_P was examined. Equations 1 to 6 were used for multi-regression analysis.

$$SSC_P = aq_P+b \quad (1)$$

$$SSC_P = aq_P^{\,b} \quad (2)$$

$$SSC_P = aD_2+b \quad (3)$$

$$SSC_P = aD_2^{\,b} \quad (4)$$

$$SSC_P = aq_P + bD_2 + c \tag{5}$$

$$SSC_P = aq_P^{\,b} \square D_2^{\,c} \tag{6}$$

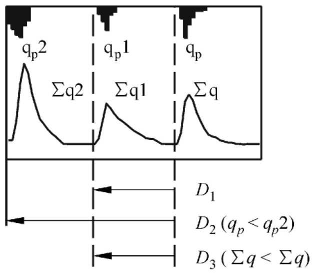

Fig.7 Conceot of factors D_1, D_2 and D_3

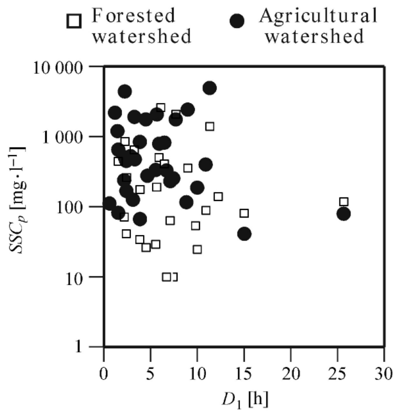

Fig.8 Relationship between D_1 and SSC_p

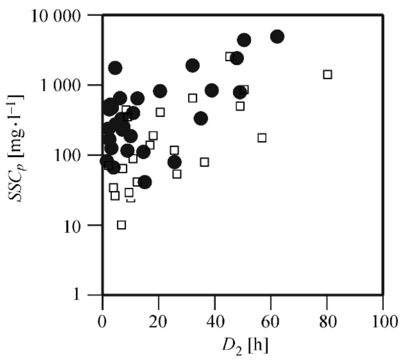

Fig.9 Relationship between D_2 and SSC_p

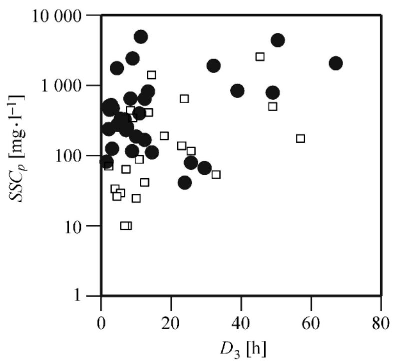

Fig.10 Relationship between D_3 and SSC_p

The results of multi-regression analysis of both watersheds are shown in Table 2 and 3. P value was used for judging the significance of regression coefficients (a, b and c). The regression coefficients of Eq.2， Eq.4， Eq.6 in forested watershed, and that of all equations except for Eq.3 and Eq.5 in agricultural watershed were found to be significant.

The adjusted R square (R^2) of these significant equations were also examined. Eq.6 had the highest R^2 in agricultural watershed. It became clear that the suspended sediment transport during rainstorm is affected by the q_p as an index of rainstorm runoff scale, and by D_2 as an index of previous flood. It was considered that the changing source area of streamflow influences the suspended sediment source. The source area of streamflow may change its area in each rainstorm, as a result of the hydrological conditions. Namely, part of soil components will be settled in the source area during the falling phase of flood. Then, the soil components that had settled in the previous flood will be re-transported by a lager flood than the previous one.

In forested watershed, the R^2 of Eq.2 exceeded that of Eq.6. The soil components at the source area of forested watershed, in contrast, are in such little amount that the total amount of soil components is scant. Therefore, the relationship between SSC_P, q_P and D_2 was not as clear as the individual relationship between SSC_P and q_P.

Table 2 Result of multi-regression analysis (Forested watershed:Soebetsu river)

	Adjusted R square	Regression coefficient		
		a	b	c
Eq.(1)	0.751	1114.83	39.03	
		(0.000)	(0.730)	
Eq.(2)	0.771	2.93	10.80	
		(0.000)	(0.000)	
Eq.(3)	0.587	16.88	-29.84	
		(0.001)	(0.829)	
Eq.(4)	0.558	1.10	7.34	
		(0.002)	(0.002)	
Eq.(5)	0.726	1027.27	9.28	-128.20
		(0.005)	(0.055)	(0.298)
Eq.(6)	0.741	126.11	0.78	0.54
		(0.002)	(0.025)	(0.000)

Table 3 Result of multi-regression analysis (Agricultural watershed:Igarashi river)

	Adjusted R square	Regression coefficient		
		a	b	C
Eq.(1)	0.449	975.77	513.03	
		(0.004)	(0.024)	
Eq.(2)	0.623	3.12	4.83	
		(0.000)	(0.000)	
Eq.(3)	0.732	50.32	–23.72	
		(0.000)	(0.909)	
Eq.(4)	0.455	2.08	3.33	
		(0.000)	(0.007)	
Eq.(5)	0.798	1262.68	41.29	–203.26
		(0.006)	(0.000)	(0.296)
Eq.(6)	0.655	456.96	0.62	0.42
		(0.000)	(0.002)	(0.010)

(*P* value＜0.005：significant）

5 Conclusion

Suspended sediment transport during several rainstorms was investigated in agricultural and forested watersheds. The load of suspended sediment transport from agricultural watershed exceeded that of forested watershed. The mechanism of suspended sediment transport was also examined in terms of several hydrological factors such as q_P as an index of rainstorm runoff scale, and the period from previous flood in forested and agricultural watersheds. It was clarified that the difference of SSC_P in each flood can be explained based on the factor of flood scale (q_P) and the factor of previous flood (D_2).

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