Environmental Change of Suspended Sediment Discharge by Human Action

Jong-Kwan Park

Department of Geography, College of science, Kon-Kuk University
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Abstract

The problem of supply and transport of sediment from a mountainous catchment is very important in explaining dynamic geomorphology and the hydrological cycle. The discharge of suspended sediment is determined by a morphological system. Human interference to environment is also an important, not negligible factor in sediment production. Moreover, growing concern in recent years for the problems of nonpoint pollution and for the transport of contaminants through terrestrial and aquatic ecosystems has highlighted the role of sediment-associated transport in fluvial systems. This study was conducted in forested and quarried catchments in order to clarify the different discharge process and the mechanism of suspended sediment dynamics for each catchment.

As a forested catchment, the Yamaguchi River catchment which drains a 3.12 km^2 area was chosen. On the other hand, the Futagami River basin, which is formed by three subbasins (1.07, 1.59 and 1.78 km^2), as a quarried catchment was selected. These catchments are situated to the north and east of Mt. Tsukuba, Ibaraki, Japan. The discharge pattern of suspended sediment from the Futagami River basin is more unstable and irregular than that from forested catchment, the Yamaguchi River catchment. Under the similar rainstorm conditions, suspended sediment concentration from quarried catchment during a rainstorm event increases from 43 to 27,340 mg/l. However, in the case of the forested catchment it changes only from nearly zero to 274 mg/l. Generally, the supply source of suspended sediment is classified into two areas, the in-channel and non-channel source areas. As a result of field measurements, in the case of the forested catchment the in-channel (channel bed, channel bank and channel margin) is the main source area of suspended sediment. On the other hand, remarkable sediment source area on the quarried catchment is the non-channel that is unvegetated ground.

Key Words : Suspended Sediment Concentration, Suspended Sediment Source, Artificially Modified Catchment, Forested Catchment.

1. INTRODUCTION

In general, sediment load is classified into two groups by transport pattern, that is, bed load and suspended load. It is known that the major part of sediment load is transported by suspended sediment (Nippes, 1974 ; Wood, 1977 ; Mizuyama, 1980 ; Park, 1990). Suspended load is composed of fine particles and is predominantly a wash load ; it is almost continually in suspension and is transported rapidly through the stream system.

Suspended sediment load is transported by running water in different path ways. Usually, it can be considered that the discharge process of suspended sediment is diverse in the artificially modified catchment. Suspended sediment discharge reflects the effect of human interference in the environment (Chow, 1967). Walling and Gregory (1970) also indicated that the measurement of the effects of man upon drainage basin dynamics at present is important not only in explaining contemporary variations in water and sediment yield, but it is also an essential consideration in future predictions and in palaeohydrological reconsideration.

Now a days, man's impact to the environment becomes a social issue for lack of the planning in utilization of the nature. The destruction of the nature such as the construction of golf links, in particular, becomes into big problems on the water quality, channel bed rise and frequent occurrence of the flood. The objective of this study is to investigate the discharge difference of suspended sediment between forested and modified catchment during rainstorm events and clarify the process and mechanism of the suspended sediment dynamics for each catchment.

2. TOPOGRAPHICAL CONDITIONS OF THE FIELD AREA

The River Futagami, as an example of modified catchment, drains a 4.44 km^2 basin located in Tsukuba, Ibaraki Pref., Japan (Fig. 1). The drainage basin is situated to the north of Mt. Tsukuba and to the west of Mt. Kaba, and can be subdivided into three catchments. For convenience, each catchment was named tentatively as the KITAZAWA catchment, the NAKAZAWA catchment and the MINAMIZAWA catchment. The longitudinal profile of channel in the three catchments was mapped as shown in Fig. 2. The longitudinal profiles of channel are approximately parallel to each other. The mean channel slope of each catchment has been estimated as between 0.174 and 0.232. The geology of this area is exclusively composed of granite. In the Futagami River basin, quarries are distributed widely. Man's interference has been a feature of the area for approximately 30 years. This study area, therefore, is a typical example of the modified catchment by human activities. The most modified catchment of the three, the KITAZAWA catchment, has been 16.7 percent of the degree of human modification, with quarries occupying 12.9 percent and roads covering 7.53 km/km^2 of the catchment. The NAKAZAWA catchment, which is the largest catchment of the three, is 6.4 percent modified by human activity, 4.3 percent affected by quarrying, and the road density of 5.62 km/km^2. The MINAMIZAWA catchment is the least modified, with 3.2 percent of its catchment distributed by quarries and roads, covering 2.14 percent and 2.7 km/km^2 respectively. Vegetation consists of sparse deciduous trees approximately 15 m high and dense pinetrees with a dense ground cover of shrubs. There is no significant difference of vegetation among the three catchments. Soil type is a direct reflection of local lithology which ranges from silty-clay loams, volcanic ashes to residual deposits of granite.

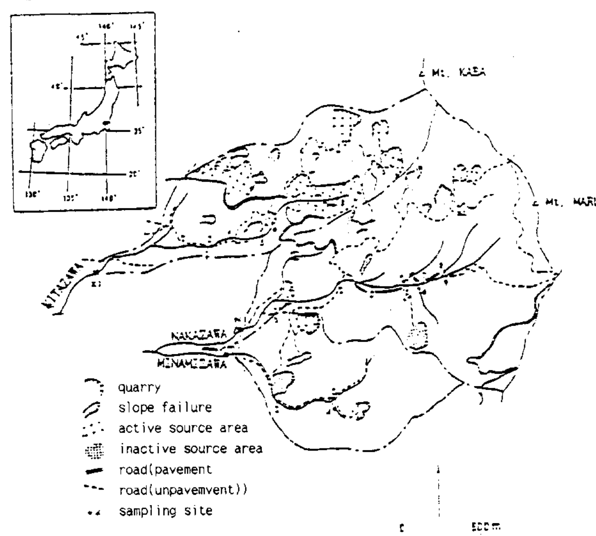

Fig. 1. The map of the Futagami River basin.

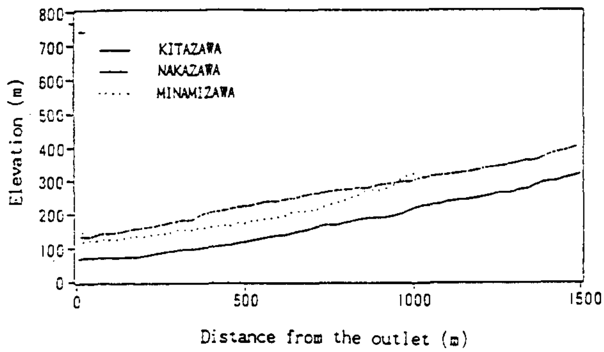

Fig. 2. Longitudinal profile of the main channel in the Futagami River basin

On the other hand, the Yamaguchi River basin as an example of forested catchment was chosen (Fig. 3). The drainage basin with an area of 3.12 km^2 is located in the north of Mt. Tsukuba. The canopy density of the catchment is generally high. This study catchment is not nearly modified by human activity, but naturally preserved, though within the catchment the road had been constructed. It is not considered that sediment discharge from the road does not occur because the road was paved. Typical morphologic factors are shown in Table 1.

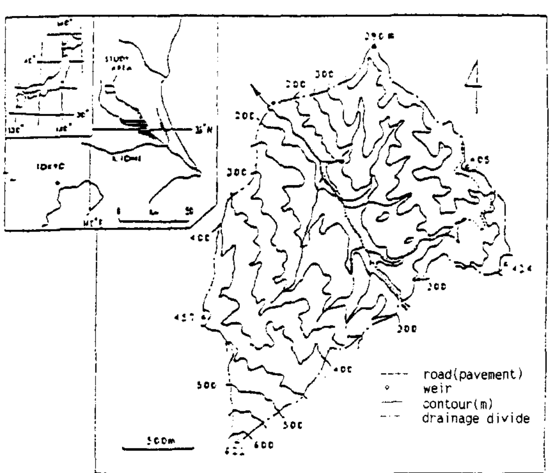

Fig 3. The map of the Yamaguchi catchment.

Table 1. Typical morphometric indices for the study catchments.

	Kita.	Naka.	Mina.	Yama.
Catchment area(km^2)	1.075	1.783	1.585	3.12
Basin shape factor	1.203	0.445	0.439	0.41
Mean channel gradient	0.174	0.207	0.232	0.18
Mean slope degree	20.5	22.3	24.7	22.9
Minimun altitute(m)	65	115	120	135
Maximum altitute(m)	709	675	627	621

Kita. : kitazawa, Naka. : Nakazawa
Mina. : Minamizawa, Yama. : Yamaguchi

3. METHODOLOGY

The hydrologic response to the rainfall was monitored at the outlet in each catchment as shown in Figs. 1 and 3. Water discharge from the Futagami River basin was measured by using a weir and established constructures such as pipe. A stage/discharge relation for the weir has been derived from formulae supplemented by a current meter. It was not very effective, however, in shallow water. On the other hand, running water from the Yamaguchi River catchment was measured by a contracted rectangular weir. Three water stage recorders were established at the weir, which two of them are the digital type gauges and the other one is a daily chart type gauge. Therefore, discharge during rainstorm events could be measured very accurately.

Suspended load samples were collected by a hand sampling method using 1 liter polyester bottle at the each sampling site. An automatic pumping sampler could not be used because the water depth was too shallow. Sampling sites are shown in Figs. 1 and 3. Dry weights of suspended load samples were measured later in the laboratory, and grain sizes were analyzed by a setting tube system, the efficiency of which was discussed in detail by Gibbs (1974) and Gibbs *et al.* (1971). Precipitation was measured by using a natural siphon rainfall recorder placed in each catchment.

4. MAGNITUTE AND PATTERN OF SUSPENDED SEDIMENT DISCHARGE

4.1. Concentrations and loads of suspended sediment

In the case of the Futagami River basin, many storms were recorded in the course of the study between June and October in 1987. The storm of June 20 which is the typical rainstorm in the measured events was selected. The total rainfall was 32.0 mm and the peak rainfall intensity of the storm was 10.0 mm/hr. On the other hand, five rainstorm events were measured at the outlet of the Yamaguchi River basin for the analysis of the suspended sediment discharge. Table 2 shows the hydrologic characteristics and suspended sediment concentrations during the measured events. Total rainfall amount ranges from 30.5 mm to 32.0 mm. Although it ranges almost same values, various sediment concentrations were observed because the rainfall intensity is different each other. Fig. 4 represents the relationships between the peak water discharge (Qp) and the suspended sediment concentration at Qp (Cp). Usually, it is known that the value of Qp and max. value of suspended sediment concentration (C_{max}) does not coincide. This phenomenon is, in general, called the hysteresis effect and it is found from the Table 2. Park(1991) also described that the loops of suspended sediment concentration in the Yamaguchi catchment showed the clockwise hysteresis. In the Futagami River basin, the hysteresis loops of suspended sediment concentration are shown in Fig. 5. It shows clockwise hysteresis loops. From the Fig. 5, it is clear that the suspended sediment concentration during the rainstorm is in the decreasing order, the KITAZAWA, the MINAMIZAWA, the NAKAZAWA catchment. Fine-grained materials under 4 ϕ, in particular, were transported during rainstorms about 80 % in suspended sediment concentration. The transport rate of silt and clay is the highest value in the MINAMIZAWA catchment (Fig. 6).

On the other hand, the max. values of suspended sediment concentration from the Yamaguchi River basin range from 103 to 274 mg/l, even if the values of the rainfall intensity have

Table 2. Hydrologic characteristics and suspended sediment concentrationsduring the measured events.

	Event date	Total rainfall (mm)	Rainfall intensity (mm/30min)	Water discharge		Suspended sediment	
				Qb(1/sec)	Qb(1/sec)	Cp(mg/ℓ)	Cp(mg/ℓ)
KITAZAWA	June 20, 1987	32.0	10.0*	14.8	42.7	22,374	27,338
NAKAZAWA	June 20, 1987	32.0	10.0*	22.1	82.7	12,868	19,501
MINAMIZAWA	June 20, 1987	32.0	10.0*	12.5	54.0	2,431	6,438
YAMAGUCHI	Jan. 23, 1989	31.5	3.5	72.4	153.1	126	233
YAMAGUCHI	Feb. 17, 1989	32.0	3.0	61.5	179.3	97	103
YAMAGUCHI	Apr. 15, 1989	31.0	4.0	84.0	240.2	107	274
YAMAGUCHI	June 28, 1989	31.5	3.5	117.1	243.4	273	273
YAMAGUCHI	July 13, 1989	30.5	3.5	97.9	179.3	139	155

Qb; baseflow before the rainstorms.
Qp; peak value of water discharge during a event.
Cp; suspended sediment concentation at Qp.
Cmax; Max value of suspended sediment concentration.
* indicates the rainfall intensity per one hour (mm/hr).

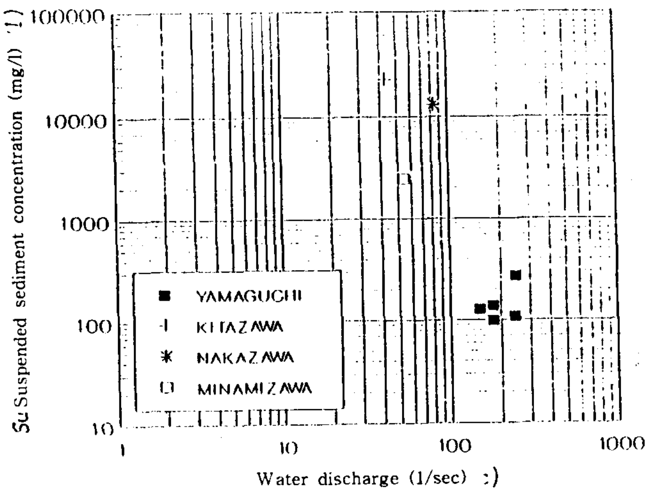

Fig 4. The relationship between the peak water discharge (Qp) and the suspended sediment concentration at Qp (Cp) in each catchment.

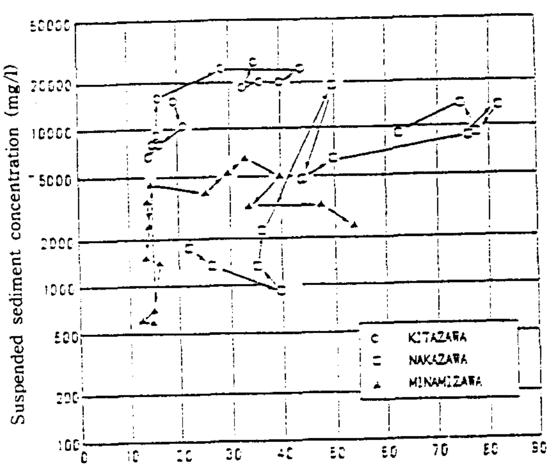

Fig 5. The hysteresis loops of suspended sediment concentration in each catchment during rainstorms.

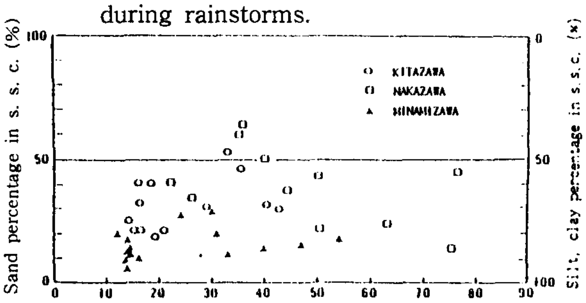

Fig 6. Sand (<4 Φ) percentage and silt-clay(>4 Φ) percentage in suspended sediment concentration

similar to that of the Futagami River basin (Table 2). The suspended sediment concentrations in the forested catchment are low values about two orders of magnitute over that those in the artificially modified catchment.

4.2. Discharge process of suspended sediment

Universally, the supply source of suspended sediment loads during unrainy days is almost in-channel because suspended sediment transport from unvegetated ground does not occur. This regulation, of course, is not only applied in the forested catchment but in the quarried catchment. The in-channel process including in-channel sediment transport, and in-channel storage, is a very important factor in understanding suspended sediment dynamics. There is a great amount of fine-grained particles well sorted in the channel. Particularly, the parts of the channel margin which deposited much fine-grained particles influence the fluctuation of suspended sediment concentration during ordinary stages in the case of the modified catchment. Fig. 7 represents the suspended sediment concentration which was measured along the upstreams in the Futagami River basin. It is found that the values of suspended sediment on the falling stage, July 19, 1987 (total rainfall ; 17.0 mm) is less than those of ordinary stages, July 7 and 8, 1987. In the case of the KITAZAWA catchment, sampling site K2, K3, K7 and of the NAKAZAWA, N2, N8, N9, of the MINAMIZAWA, M1, M2 and M4, it can be seen that the values of suspended sediment concentration during unrainy days are large. It suggests that the suspended sediment concentration taken during ordinary stages is not always stable, and also indicates that the importance of the role of channel on the problem of suspended sediment transport has to be reappreciated a new.

On the other hand, the sediment source becomes to be changed during rainstorm events. Rainfall amount, rainfall intensity and raindrop impact are important as input factors of the suspended sediment delivery system. Especially, in the artificially modified catchment which unvegetated grounds range in basin, the pattern of suspended sediment discharge has some distinctive features. In the case of the Futagami River basin, sediment supply from scattered waste heaps of earth in quarries has a direct effect on the fluctuations of suspended sediment concentration (Fig. 8). It was confirmed, even if not recored, that surface flow from a quarry in the MINAMIZAWA catchment flowed into the forest along a sloping road (Fig. 9). Moreover, unpaved road plays an important role of the increment of the suspended sediment concentr-ation. Under the conditions of the concentrated heavy rains, running water produces rill or gully erosion and a great deal of fine materials is transported into the stream. Duck (1985) also described that the effect of road construction on sediment deposition has to be considered in the estimation of the process of sediment discharge. These road effect as one of the morphological factors in modified catchment can not be considered in natural condition.

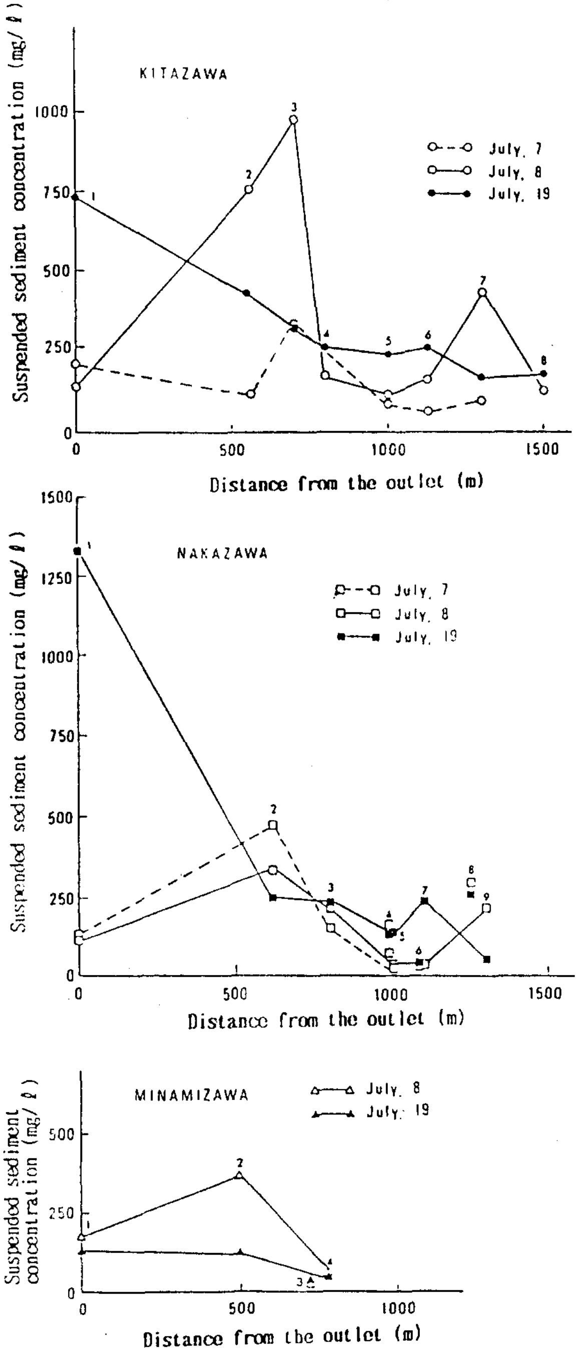

Fig 7. Logitudinal change of suspended sediment concentrations in each catchment (Number represents the sampling site of Fig. 1.).

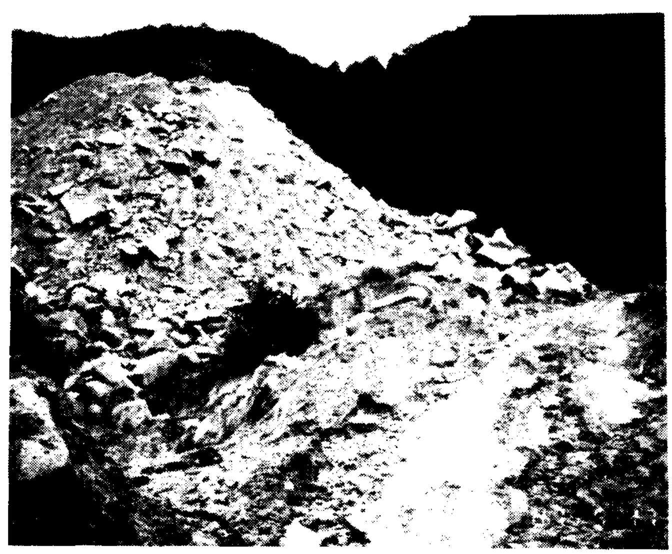

Fig 8. The waste heaps of earth in the quarry.

Fig 9. Surface flow flowed from a quarry into forest along the sloping road.

The unvegetated ground is classified into two types, that is, active unvegetated ground and inactive unvegetated ground. Active ground is mainly formed by the heaps of earth with steep slope. On the other hand, inactive type is determined by not steep and hard top soil ground with few fine materials. These types must be classified in the estimation of the source of sediment supply.

5. CONCLUSIONS

This study on the suspended sediment dynamics was conducted in a forested catchment and quarried catchment. Suspended sediment discharge depends upon the morphological characteristics of catchment. Under the similar rainstorm conditions, suspended sediment concentration in the modified catchment during a event is higher than that in the forested catchment. And the discharge pattern of suspended sediment from the artificially modified catchment is more unstable and irregular than that from the forested catchment. Moreover, in the case of the modified catchment the non-channel area is more important as the main source area of suspended sediment. The variation of suspended sediment concentrations reflects the difference of artificial rate to the catchment. And the degree of catchment modification is also important to the sediment discharge.

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人間活動으로 인한 浮流土砂流出의 環境變化

박 종 관

건국대학교 이과대학 지리학과

(1992년 12월 11일 접수)

山地流域에서의 土砂供給과 移動에 관한 문제는 動的地形學뿐만 아니라 水文學的 순환의 입장에서 매우 중요하다. 土砂流出은 자연의 改變정도등 지형학적 요인에 크게 지배된다. 본 연구에서는 강우시 자연의 개변정도가 서로 다른 유역에서 유출되는 浮流土砂量을 비교하여 浮流土砂 流出過程과 메카니즘을 알아 보았다. 降雨强度가 유사한 30mm의 비가 내렸을때 채석장이 분포하고 있는 人工改變流域의 부유토사농도는 최고 27,000 mg/l인 반면, 自然流域의 부유토사농도는 270 mg/l에 불과해 100배정도의 농도차이가 나타났다. 또 人工流域중에서도 人工改變度에 따라 最大浮流土砂濃度도 6,400 mg/l에서 27,000 mg/l까지 다양하게 관측되었다. 일반적으로 浮流土砂 供給源은 自然流域의 경우 河床, 河岸, 그리고 河道周邊등 河道內이며, 人工改變流域은 斜面등의 河道外 地域이다

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