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OBSERVATION AND ESTIMATION METHOD OF SEDIMENT PRODUCTION IN KAMANASHIGAWA BASIN, FUJIKAWA RIVER SYSTEM - TOWARD AN ACCURATE ESTIMATION OF DAM SEDIMENT VOLUME -

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1. INTRODUCTION

Conventionally, the sediment production and the flowing down situation from the upstream of the river are estimated by aerial photointerpretation or topographic survey etc. The design sediment volume in a dam is usually estimated according to sedimentation results of neighboring dams that have similar watershed condition. And the sediment transport in river channel is not properly measured during the flood event.

In recent years, the observation technology of sediment discharge in the river has greatly improved, so that the bedload can be directly observed by a hydrophone, and the suspended load by a turbidimeter. Additionally, the sediment volume variations in a mountain stream can be estimated from temporal change of riverbed height by satellite SAR (Synthetic Aperture Radar) analysis.

In this paper, using the model of Omukawa River, a branch of Kamanashigawa, Fujikawa River system, we combine the data of sediment discharge obtained by various observation techniques and try to improve the observation methods for estimating the volume of sediment from the watershed, that will be useful for the sediment management in dam.

2. OUTLINE OF STUDY SITE

2.1. OUTLINE OF STUDY SITE

The study site in Omukawa River is located at the top of the Kofu alluvial fan, left branch of the Kamanashigawa, Fujikawa River system, a rapid river with an average gradient 1/58 and an extension of 16.4 km. The study area corresponds to about 8.3 km of its downstream section (Fig. 1). The upstream area consists of low to middle mountains composed of granite and volcaniclastic materials. Within this river section, about 50 Sabo dams and groundsels exist in the channel.

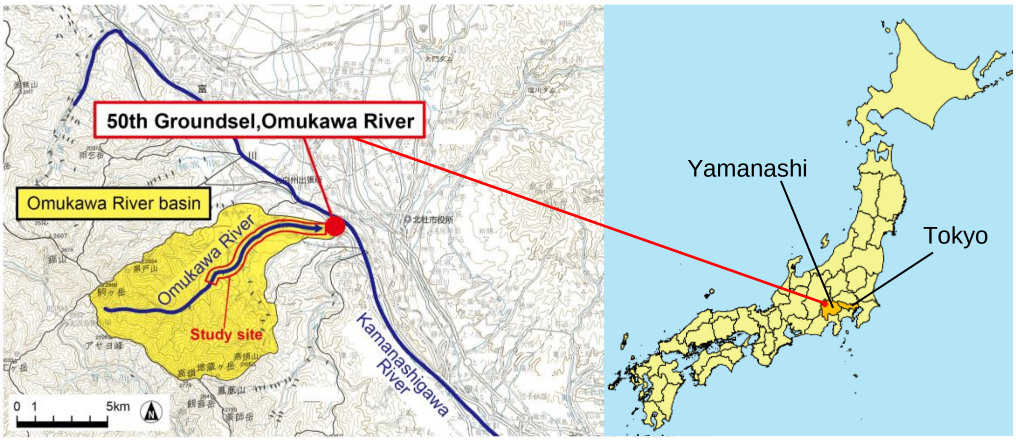

Fig. 1
Sediment discharge observation site map

2.2. IMPLEMENTATION OF SEDIMENT DISCHARGE OBSERVATION

In order to observe the volume of sediment discharge from the mountain stream, sediment discharge measurement is continuously carried out from 2011 by several equipment, such as hydrophone, turbidimeter, water level gauge, suspended load sampler, and a buried sediment trap pit, etc., on the 50th groundsel in Omukawa River. The layout of observation site and a sample of obtained data is shown in Fig. 2 and Fig. 3 respectively. The annual volume of sediment discharge calculated from the observed data is shown in Fig. 4.

The observed results of the hydrophone and sediment trap pit showed that the detectable grain diameter lower limit by hydrophone is about 2 mm, and the volume of sediment measured by the hydrophone is about 2% to 50% of the actual flowing down sediment volume that deposited in trap pit [1], and the ratio depends on the flood conditions such as the season, water depth and so on (Table 1, Fig. 5).

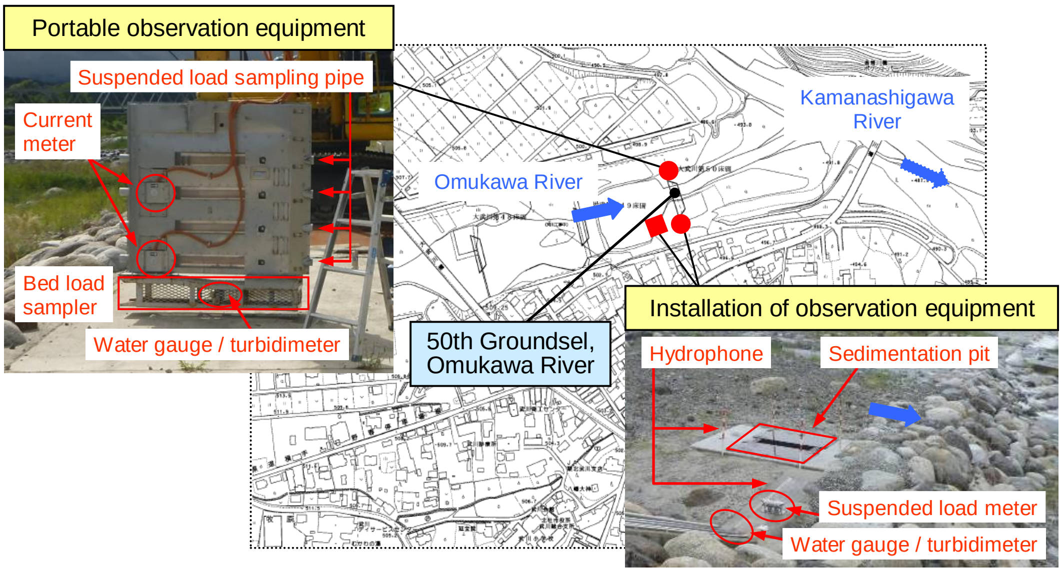

Fig. 2
Observation equipment installed in Omukawa River 50th groundsel

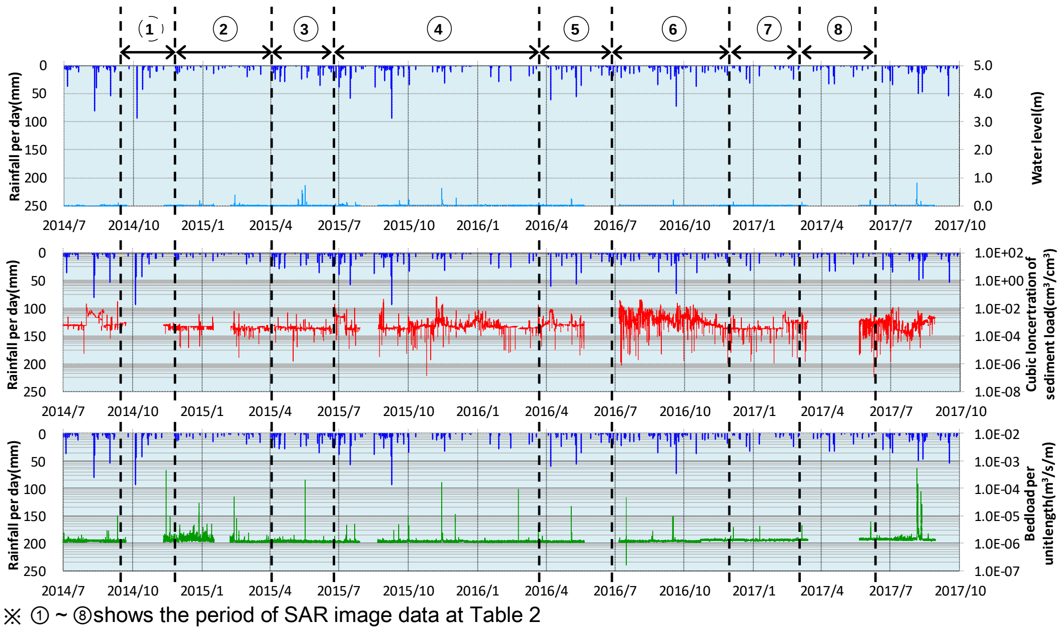

Fig. 3
Observation data from hydrophone, turbidimeter and water level gauge

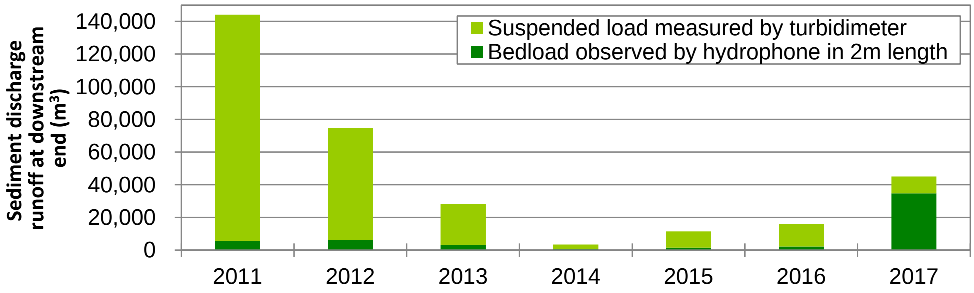

Fig. 4
Annual volume of sediment discharge by observation

Table 1
Sediment volume observed by hydrophone and trap pit

Subject flood	Hydrophone passage sediment discharge volume Whd (kg)	Pit-captured sediment Wpt (kg)	Weight ratio Whd/Wpt (%)	Pit-captured sediment weight over the lower limit grain diameter			
				Wp1 (p1≧1mm)	Wp2 (p2≧2mm)	Wp3 (p3≧3mm)	Wp4 (p4≧4mm)
① 2013 Typhoon No. 18 (Sep. 16, 2013)	1961	4335.0	45.2%	2688	2298	2124	2037
② 2013 Typhoon No. 26 (Oct. 15-16, 2013)	159	3166.4	5.0%	301.0	79.2	12.7	6.33
③ 2014 Typhoon No. 18 (Oct. 5-6, 2014)	344.5	3322.7	10.4%	697.8	99.7	66.5	49.8
④ 2014 Typhoon No. 19 (Oct. 13-14, 2014)	79.5	3348.3	2.3%	354.9	70.3	30.5	3.0

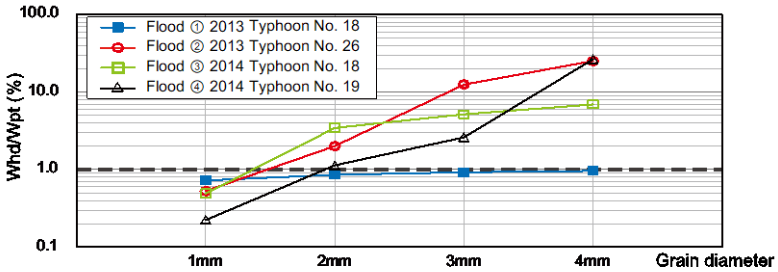

Fig. 5
Ratio of the lower limit grain diameter by hydrophone observation to the measurement in pit sedimentation

2.3. Estimation of sediment transport by SAR image analysis

2.3.1. SAR image data and analysis period

In the SAR image analysis, a SAR sensor mounted on an artificial satellite sends microwave obliquely to the ground surface and receives backscatter. The image data are obtained by receiving backward scattering from the ground surface. By interference analysis of two observed SAR images next to each other, the ground displacement that occurred during the observation period can be calculated. Using SAR image interference analysis, it is possible to observe ground surface displacemet without being influenced by weather and day or night [2].

Here, we use the following 9 SAR images acquired from the ALOS-2 satellite passing over Japan. Interference SAR image (inSAR) analysis of 8 periods (① ~ ⑧) with pairs next to each other were carried out to obtain river bed fluctuations of about 8 km river section on the upstream of 50th groundsel in Omukawa River (Table 2).

Table 2
Satellite specification and SAR image analysis periods

Items of satilite		No	Analysis period	
			from	to
Satellite	ALOS PASAR-2, SM-1 mode	①	2014/09/19	2014/11/28
		②	2014/11/28	2015/04/03
Running direction	North toward	③	2015/04/03	2015/06/26
		④	2015/06/26	2016/03/18
Survey direction	Right side	⑤	2016/03/18	2016/06/24
		⑥	2016/06/24	2016/11/25
Polaried wave	35.4°HH	⑦	2016/11/25	2017/03/03
		⑧	2017/03/03	2017/06/09

2.3.2. Analysis method

In SAR image analysis, the width of river channel more than 5 times the minimum image resolution (3m) is needed, so that we choose the middle to downstream river section of Omukawa River as a study site, where sediment discharge observation has been carried out at the downstream end since 2011.

In calculating the volume of sediment transport in the river way, the channel was divided into 58 blocks, in order to remove the range of river crossing constructions (e.g., bridges, groundsels etc.) where there is no displacement during floods. Furthmore, each block was subdivided into meshes of 5m squares. The procedure of interference analysis of SAR image was shown in Fig. 6 and Fig. 7.

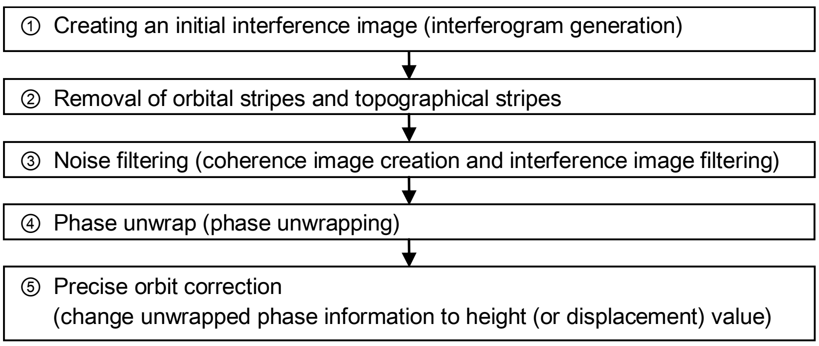

Fig. 6
Procedure of SAR image interference analysis

Fig. 7
Image of channel block division and SAR interference analysis

2.3.3. Results of SAR image analysis

Interference analysis on adjacent SAR images by the method shown in Fig. 6 and Fig. 7, the changes in ground height of each mesh occured between two SAR images is directly obtained. And by each mesh area (si) x average height (Δhi), the volume change (Δvi = si × Δhi) of each mesh is calculated. Then, cumulating the results from each mesh the total volume of sediment transport for each block or the whole section can be calculated.

The vertical sectional view of the riverbed height variation (block average) calculated by the above method is shown in Fig. 8. While, the volume of sediment transport for every analysis period (① to ⑧) is shown in Table 3 and Fig. 9, and the temporal change of sediment volume within the study river section is shown in Fig. 10.

Table 3
Sediment transport volume by inSAR image analysis

No.	Analysis period		Period (Day)	Sediment change volume by inSAR analysis Vs (m^3)
	from	to		
①	2014/09/19	2014/11/28	70	9743.98
②	2014/11/28	2015/04/03	126	-5361.75
③	2015/04/03	2015/06/26	84	1840.07
④	2015/06/26	2016/03/18	266	-21229.55
⑤	2016/03/18	2016/06/24	98	9752.34
⑥	2016/06/24	2016/11/25	154	1599.06
⑦	2016/11/25	2017/03/03	98	-648.32
⑧	2017/03/03	2017/06/09	98	9596.02

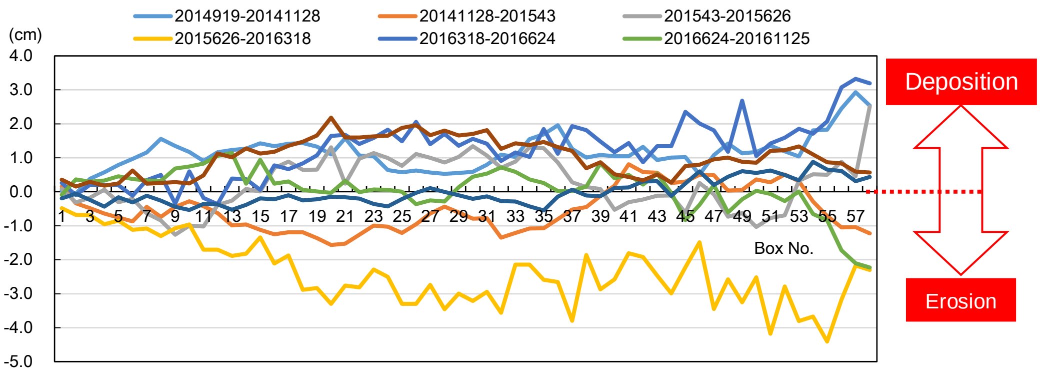

Fig. 8
River bed height variation on longitudinal section during each analysis period

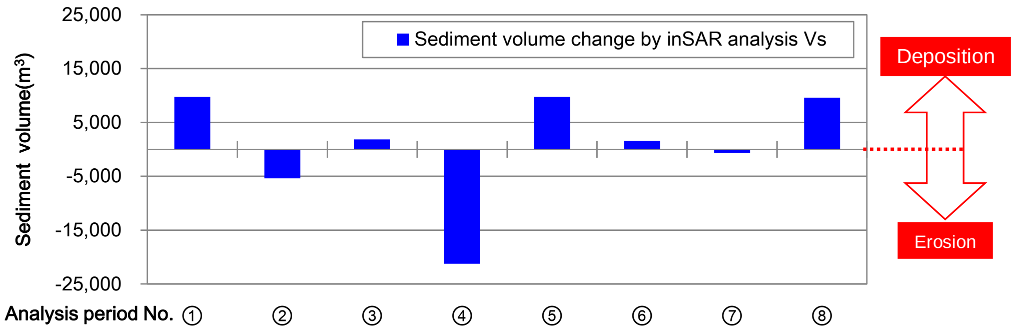

Fig. 9
Sediment transport volume during each analysis period

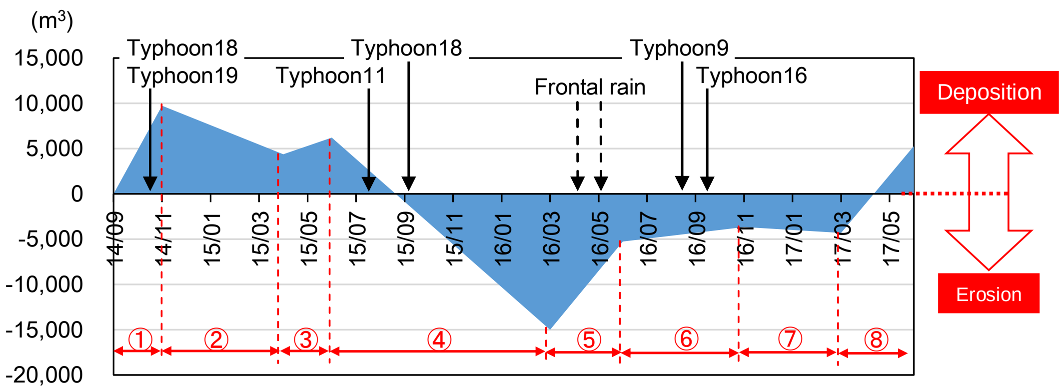

Fig. 10
Sediment temporal change in river channel

From above results, the riverbed rise (deposition) or decrease (erosion) was observed according to the observation target periods. Basically, during the period when large floods (typhoon) occurred, a riverbed rise (deposition) appeared and if there is no flood in a long term, a tendency of river bed decrease (erosion) is recognized due to the sediment gradually flowing out.

3. RESULTS

3.1. RESULT COMPARISON AND ITS CONSIDERATION

A comparison of transport sediment volume (bedload and suspended load) observed by equipment (hydrophone, turbidimeter, water level gauge etc.) installed at the downstream end in Omukawa River and that calculated from SAR image interference analysis in the same period is shown in Table 4 and Fig. 11.

Table 4
Comparison between results by SAR image analysis and observation

No	Analysis period		Period (Day)	Sediment change in volume by inSAR analysis V_{ss} (m^3)	Sediment discharge observed by hydrophone V_{sH}(m^3)	Event occurred in the period
	from	to				
①	2014/09/19	2014/11/28	70	5846.39	-1469.05	Typhoon18 Typhoon19
②	2014/11/28	2015/04/03	126	-3217.05	-2234.88	
③	2015/04/03	2015/06/26	84	1104.04	-514.11	
④	2015/06/26	2016/03/18	266	-12737.73	-10970.63	Typhoon11 Typhoon18
⑤	2016/03/18	2016/06/24	98	5851.40	-1312.48	
⑥	2016/06/24	2016/11/25	154	959.43	-12317.24	Typhoon9 Typhoon16
⑦	2016/11/25	2017/03/03	98	-388.99	-1458.5	
⑧	2017/03/03	2017/06/09	98	5757.61	-1483.2	

※ Sediment change in volume revised by void ratio of river bed material (0.40)

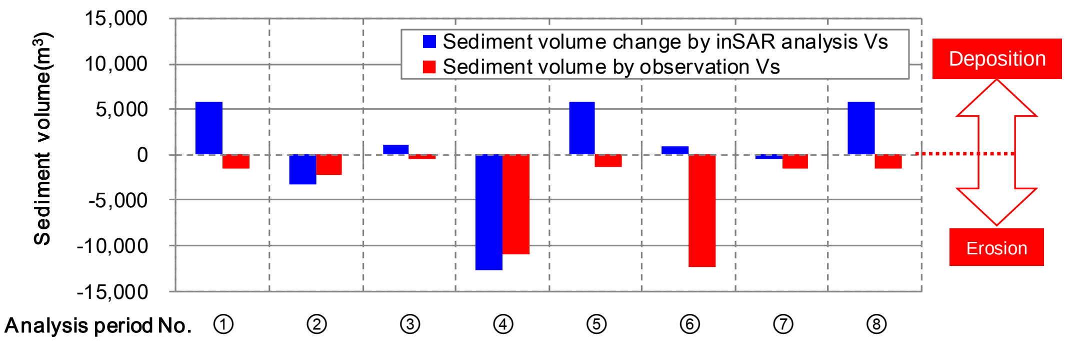

Fig. 11
Comparison between results by inSAR image analysis and observation

During flood period, i.e. ①, ③, ⑤, ⑧, sediment balance within the river section showed positive (deposition). It is presumed that there was abundantly sediment supply from the upstream.

In other hand, during the non-flood period, i.e. ② and ⑦, the balance of sediment within the river section shows negative because the volume of outflow is larger than the inflow. Meanwhile, the period ④ that spans both the flood and non-flood periods, is influenced both by the in-flow during the flood and the outflow in the non-flood season. As the result, the sediment balance showed negative in this case.

Relationship between the sediment volume change in the river section by inSAR analysis and the sediment discharge observed at downstream end by the equipment is shown in Fig. 12. Although the data showed some dispersion, an approximate linear correlation was recognized.

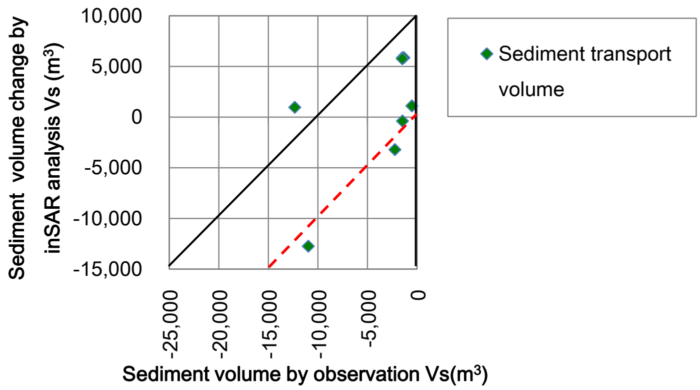

Fig. 12
Relationship between results by SAR image analysis and sediment observation

4. CONCLUSION

In this study, even though it was difficult to precisely analyze and verify the results, because there was limited SAR image data taken in accordance with the flood event (immediately before/after), but the followings can be concluded from the above examination:

1) Combinating observation with trap pit can verify the accuracy of sediment observation with hydrophone as well as measure spatio-temporal sediment transport during flood event. By interference analysis of adjacent SAR images, it is possible to capture the change of micro topography in the riverbed.

2) This method can be fully utilized to measure and analyze geomorphologic changes in mountain streams where periodical survey is difficult.

3) In this study, clear correlation between sediment volume obtained by SAR analysis and observed one by hydrophone, turbidimeter, etc. was not be

confirmed due to the limitation of the verifiable data. Moreover, since a hydrophone (length = 2.0 m) is installed at one side near the sidebank of about 72m wide river, it maybe have some difficulties to represent the sediment transport volume calculated by the hydrophone for the entire width of the river.

4) Measurement of topography deformation by interference SAR image analysis is a new technology that rapidly progressed in recent years. In order to obtain accurate data and make precisely analysis, further study and improvement on observation equipment and analysis technique are needed in the future.

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SUMMARY

Taking the middle to downstream section of Omukawa River (extension L = 8.3 km, gradient 1/58) as a study site, A comparison between sediment transport obtained by SAR image interference analysis and sediment discharge observed by hydrophone etc. during 2014-2016 period.

The result shows that, although there was data variation, an approximate linear correlation was recognized.

The reason of the difference between two data is assumed that sediment discharge is measured only at the downstream end with a length L= 2.0 m, with respect to the river width of 72 m, which is not adequate for representing the entire river cross section.