JOURNAL OF FLOOD ENGINEERING
Vol. 11 No. 1 (January-June, 2020)

Received: 15rd April 2019 Revised: 10th June 2019 Accepted: 17th October 2019

EXAMINATION OF THE REPRESENTATIVENESS OF INSTANTANEOUS FLOW RATE USING CONTINUOUS FLOW RATE DATA AT A FORESTRY NATURAL STREAM IN SENDAI CITY, MIYAGI PREFECTURE, THE NORTHERN PART OF JAPAN

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Abstract: Flow rate is important for the purpose of river and resulting receiving water environment management in addition to flood management. The former purpose requires us to know flow rate and water quality simultaneously because pollutant input to receiving water should be assessed as a load i.e. concentration times flow rate. We have done 41 water samplings at Jogi in Okura River, in Sendai which is located at the northern part of Japan since April 2011 to December 2014 on mostly monthly base. We examined to what extent the monthly base flow rate measurement represents the monthly average flow regime by comparing the instantaneous flow at the timing water samplings were done with calculated mean continuous flow rates during one-month (by centering the instantaneous flow rate collection timing for 41 data points). The simple linear regression analysis between instantaneous flow and one-month mean flow rate showed correlation coefficients of 0.834. The slopes of regression lines passing through the origin were 1.14. Frequency and the significance of the points, which exceeded the upper 95% confidence level were bigger than that exceeded the lower 95% confidence level. These results suggest that instantaneous flow at the timing of water sampling may be good estimates (known by the high correlation factor) while underestimates of the real flow (known by the bigger slope than unity). Inversely, the slope of 1.14 suggests that instantaneous flow corresponds to 88% of the magnitude of the mean monthly flow. This underestimation is, as expected, caused by the fact that water samplings were tend to be done on fine weather days. In some cases, e.g. at steep and rural forestry rivers, instantaneous flow rate measurements (often done by manually using float rather than by mechanically using velocity meter, the examination of the validity of the former method is not the target of this paper) are the only information available. Our data underlined the necessity to keep mind the possibility of the underestimation when we use the instantaneous flow at the timing of water sampling and to assess the degree of underestimation following the protocol shown in this study.

Keywords*:* Instantaneous flow rate, Mean monthly flow rate, Continuous flow rate records, Representativeness of instantaneous flow rate, Simple liner regression, 95% confidence levels.

1. INTRODUCTION

Flow rate is important, of course, for flood management. In addition to flood management, flow rate is quite important for river environmental management and resulting receiving water environmental management [9][10]. For the latter purpose, we have done water samplings at Jogi in Okura River, in Sendai which is located at the northern part of Japan since April 2011 to December 2014 on mostly monthly base. Thus 41 samplings were done (excluding at some months; see Table 1).

The reason why the flow rate is important for the receiving water environmental management is because we have to analyses the “load” of materials which can be obtained concentration times flow. While, water samplings tend to be done on fine days, so the flow is expected to be underestimated.

Figure 1 shows continuous flow rate measurements (see Materials and methods) over a 3-month period in summer 2012 together with three monthly mean flow rate points (calculated from continuous flow rate measurements collected at one-hour intervals and averaged over a month). The green and purple symbols lie on the continuous flow rate line, but the red symbol lies above the continuous flow rate line because a peak in precipitation continued for two or three days after the calculated monthly mean flow rate. This kind of discrepancy between instantaneous flow at the timing of the water sampling and mean flow is strongly expected.

Numerous approaches have been done for understanding the effects of flow rate (e.g. Quilbe *et al.* [1]; Simeonov *et al.* [2]). Our approach is to assess the degree of underestimation of real flow, concretely, when we use the instantaneous flow obtained at the timing of water samplings i.e. to examine the representativeness of instantaneous flow at the place of water sampling.

2. MATERIALS AND METHODS

We have continuous flow rate measurements lists at Jogi Station (Jogi Weir) in the Okura River in Sendai, Miyagi Prefecture at the northern part of Japan (see site map in Harada et al. [6]) from April 2011 to December 2014.

At Jogi station, the fluctuations in water stage (H) is recorded automatically and then converted to flow rate (Q) using empirical and/or experimentally obtained H-Q equation defined at Jogi Weir. The fluctuations in the water stage were obtained from the Home Page of Miyagi Prefecture (*http://www.dobokusougou.pref.miyagi.jp/miyagi/servlet/Gamen4Servlet*) by one hour intervals also some flow data were provided by paper base.

Table 1
Timing of the water sampling at Jogi Station

2011	Apr. 6	Jun, 2	Jul. 5	Aug. 2	Sep. 1	Nov. 5
2012	Feb. 8	Mar. 1	Apr. 5	May 8	Jun. 6	Jul. 4
	Aug. 2	Sep. 4	Oct. 3	Nov. 1	Dec. 5	
2013	Jan. 9	Feb. 5	Mar. 5	Apr. 4	May 8	Jun. 5
	Jul. 2	Aug. 5	Sep. 3	Oct. 2	Nov. 6	Dec.2
2014	Jan. 8	Feb. 4	Mar.4	Apr.8	May 8	Jun. 4
	Jul. 2	Aug. 5	Sep. 2	Oct. 1	Nov. 6	Dec.1

Water samplings were done 1100 am from April 2011 to May 2015 on basically monthly base (Table 1). Thus, 41 samplings were done. The flow rates at the sampling timing shown in the Table 1 (i.e. instantaneous flow in this paper) were picked up from the continuous flow rate lists at Jogi station.

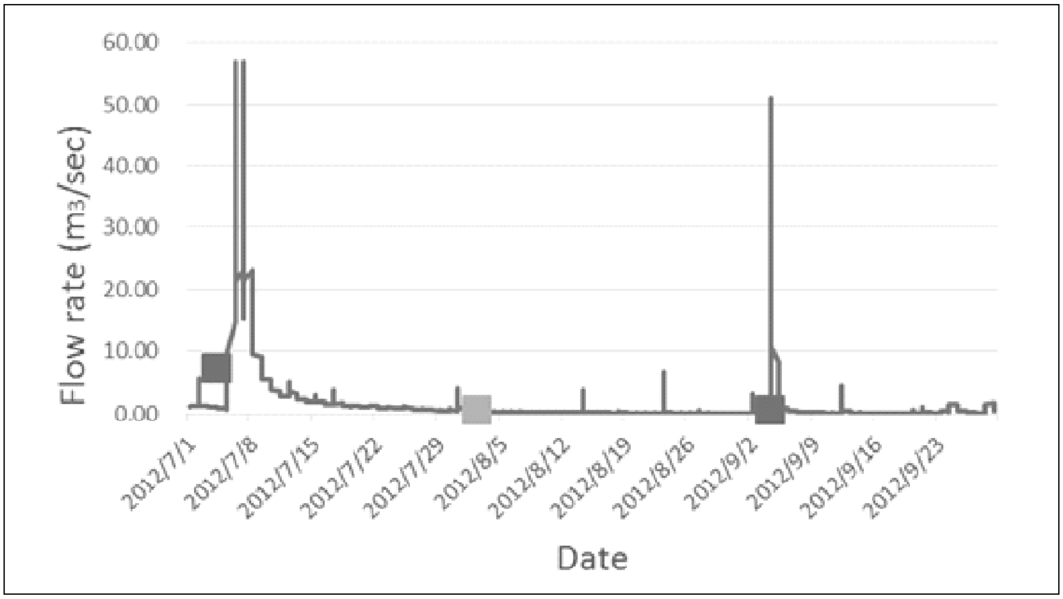

Figure 1: Temporal variation in continuous flow rate over 3 months in summer 2012 with three calculated monthly mean flow rate points

The one-month average flow rate at Jogi station from April 2011 to December 2014 (41 data) were determined from 15 days of continuous flow rate measurements collected at one-hour intervals before and after the selected instantaneous flow rate. Simple linear regression analysis was conducted together with 95% confidence analysis.

3. RESULTS AND DISCUSSION

The relationship between instantaneous and monthly mean flow rate points based on consecutive flow rate values and the 41 instantaneous flow rate measurements is shown in Figure 2. The coefficient of correlation of 0.834 is higher than the threshold value of significant correlation for a sample size of n=41. The slope of the regression line was 1.14 which exceeds 1, and many points outside of the confidence interval are higher than the line, indicating that the spot flow measurements is an underestimation of the monthly mean flow rate based on continuous measurements. Inversely using the slope, we may say the instantaneous flow estimates about 88% of the monthly mean flow rate. The instantaneous flow rate values may tend to be lower due to efforts to avoid bad weather during sampling, as expected.

These findings suggest that the instantaneous flow could represent the monthly mean flow regime satisfactory, i.e. fairly consistently, while we have to take care of the risk that the instantaneous flow rate tend to underestimate the real flow rate.

Here, we would like to underline the necessity to do water samplings at no continuous flow rate measuring is done e.g. at the rural area in Miyagi Prefecture. One point is increasing interest in the forest oriented material runoff (Harada et al. [3][4][[5][6]). And we would like to add the problem of cesium in particulate and dissolved form. In southern Miyagi, high amounts of radioactive cesium were deposited due to emissions from the Fukushima Daiichi Nuclear Power Plant incident following the Great East Japan Earthquake (Harada and Goko [7]).

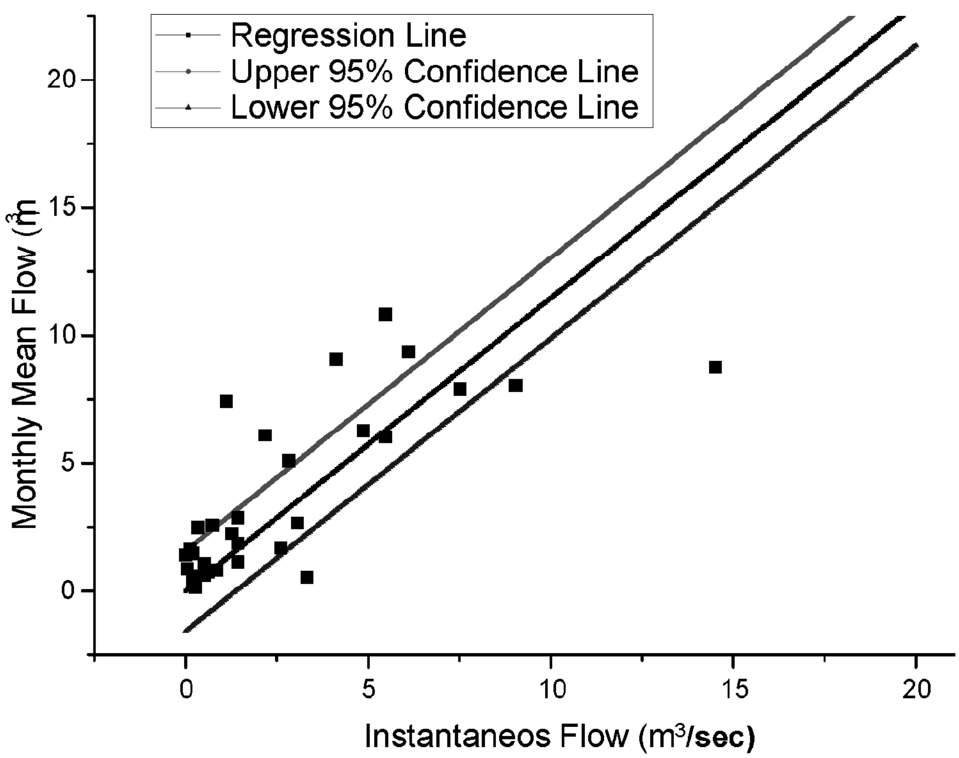

Figure 2: Regression analysis of monthly mean flow rate points calculated from continuous flow rate versus instantaneous flow rate with upper and lower 95% confidence lines

Runoff analyses especially at forest edge (Harada and Goko [7]) absolutely will gain higher attention than before along with the success in decontaminating urban areas [8]. Because continuous measurements are not performed for most mountain streams flowing out from such forests, instantaneous flow measurements provide important information. The validity of instantaneous flow measurements such as those made by measuring float velocity together with the cross-sectional area should be examined considering the differences raised by the accuracy and precision between float velocity method and mechanical velocity measuring methods, however this is not the target of this paper. The target of this paper is to know the degree of underestimation when using the instantaneous flow.

4. CONCLUSIONS AND FUTURE WORKS

In this study, we examined the validity of the instantaneous flow rate measurements using statistical analyses methods of regression and correlation analyses together with confidence interval analyses.

As a results, instantaneous flow rate measurements conducted once per month were representative of monthly mean flow rate based on continuous flow rate values to some extent.

However, the risk of underestimation, in the case of using flow rate, should be kept in mind. Underestimation may be more likely to occur due to the difficulty of performing instantaneous flow rate measurement in inclement weather.

The main question is whether instantaneous flows are meaningful or not. We think they are. There are many places and situations in which continuous measurements are difficult. For example, in forested areas of Miyagi Prefecture, Japan, it is important to understand high flow rate runoff (flooding) in hilly areas (where continuous measurements are not taken) due to the problems caused by outflow from forested areas that are high in cesium at 4.5 years after the Fukushima Daiichi Nuclear Power Plant incident following the Great East Japan Earthquake. In this sense, the meaningfulness of flow rate data is high in both the areas of flood control and environmental control involving nutrient runoff in hilly areas. This point has been true since the age of Egyptian civilization. In this case we have to measure nutrients and flow rate during high flow rate periods. The analysis methods presented in this study could be key to understanding high flow rate in both flooding water quality controls.

As further works, we have to know the degree of underestimation when we use the instantaneous flow, at other sites during other periods with different sampling frequency using the protocol shown in this study.

Acknowledgement

At the time of this study, Taisuke Hashimoto was graduate student, and Taisuke Sato, Takuma Shiraishi and Ami Tanno were undergraduate students, at Miyagi University.0This study was supported by Miyagi University Research Funds.

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