Comparing Water Quantity between Korean and Japanese River

Noh, Jaekyoung
Department of Agricultural and Rural Engineering, College of | Science for Bioproduction Environment, Faculty of Agriculture, Kyushu University

An, Hyunuk
Department of Agricultural and Rural Engineering, College of | Science for Bioproduction Environment, Faculty of Agriculture, Kyushu University

Shinogi, Yoshiyuki
Science for Bioproduction Environment, Faculty of Agriculture, Kyushu University | Laboratory of Irrigation and Water Management, Department of Bioproduction Environmental Sciences, Faculty of Agriculture, Kyushu University

Oh, Taek-Keun
Department of Bio-Environmental Chemistry, College of Agriculture and Life science, Chungnam National University | Science for Bioproduction Environment, Faculty of Agriculture, Kyushu University

他

https://doi.org/10.5109/1854025

出版情報：九州大学大学院農学研究院紀要. 62 (2), pp.493-502, 2017-09-08. Faculty of Agriculture, Kyushu University

J. Fac. Agr., Kyushu Univ., **62** (2), 493–502 (2017)

Comparing Water Quality between Korean and Japanese River

Jaekyoung NOH[1], Hyunuk AN[1], Yoshiyuki SHINOGI[2], Taek–Keun OH[3] and Jaenam LEE[4]*

Science for Bioproduction Environment, Faculty of Agriculture, Kyushu University,
Hakozaki 6–10–1, Higashi–ku, Fukuoka city 812–8581, Japan
(*Received April 28, 2017 and accepted May 10, 2017*)

Two watersheds with similar area were selected to compare water qualities between Korea and Japan. The one from Korea is called the Yongdam dam watershed in the Geum river basin, and the other from Japan is called the Nakama watershed in the Onga river basin. The 2 water quality stations from Korea and 2 stations from Japan within each watershed were selected and water quality concentration data were collected to determine load durations, respectively. The relationships between discharge and water pollution load on BOD, COD, SS, TN, and TP were derived, and water pollution loads were estimated on a daily basis in each water quality station. And means of LDCs in each country were drawn and compared with each other. Summarizing the estimated daily water pollution loads and the results of LDCs, it was concluded that TMDL showed 1.49 times higher BOD, 1.11 times higher COD, 4.95 times higher SS, 1.43 times higher TN in Korean and the same TP, and 1st load in LDC showed 1.81 to 6.14 times higher in Korean, and remaining 95th, 185th, 275th, and 285th loads in LDC showed 1.30 to 15.43 times higher in Japanese. Specific loads were expressed with daily mean in the period of each flow duration interval, and were compared with each other between Korea and Japan, of which results were shown with 1.836~8.063 times higher to Korea in high flows, and with 1.119~8.169 times higher to Japan in other flows except SS, TN values in moist conditions. Comparing an annual sum, BOD load was 1.16 times higher in Korea, COD 1.113 in Korea, SS 4.891 in Korea, TN 1.446 in Korea, and TP was same. Evaluating with 10 year frequency, Korea showed 1.041~2.360 times higher loads than Japan except TP in high flows, Japan 1.175~14.226 times higher than Korea except TN in low flows. Annual sum showed that BOD load was 1.517 times higher in Japan, COD 1.564 in Japan, SS 1.408 in Korea, TN 1.008 in Korea, and TP 2.383 in Japan. From the above result, it was concluded that Korean river was getting more water pollution loads than Japanese river in high flow interval, but in other flow interval was higher to Japan in general.

Key words: Korean and Japanese river, Discharge–water pollution relationship, Load duration curve

INTRODUCTION

For those waters, U. S. states must establish a total maximum daily loads (TMDL) of pollutants to ensure that water quality standards can be attained. A TMDL is both a quantitative assessment of pollution sources and pollutant reductions needed to restore and protect U.S. waters and a planning process for attaining water quality standards (Copeland, 2012). As an example of Virginia state, all waters are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish. Taken together, these uses are generally stated as "fishable and swimable." Through the protection of these uses, other uses such as industrial water supply, irrigation and navigation also are protected (Benham and Zeckoski, 2009).

A review of almost 50 total maximum daily load (TMDL) and delisting documents revealed that the basis for listing or delisting a waterbody varies considerably and that, in many cases, determination of impairment was based on insufficient water quality information. Common problems include inconsistent data quality and quantity, differences in frequency of monitoring, variable interpretation of narrative water quality standards, and differences in specificity of implementation and monitoring plans, resulting in significant difference in the basis for listing and delisting waterbodies (Keller and Cavallaro, 2008).

Water quality trading programs have been an area of active development to both, reduce nutrient pollution and minimize abatement costs. A study was conducted to apply a comprehensive modeling framework, integrating a hydrologic–water quality model with an economic model, to assess and compare the cost–effectiveness of a water quality trading program over a command–and–control approach in order to reduce phosphorus loadings to Lake Okeechobee (Corrales *et al.*, 2017).

The San Joaquin River (SJR) in the Central Valley of California has been designated an impaired waterbody based on its loss of fisheries–related beneficial uses and the river is now subject to regulation under total maximum daily load (TMDL) rules. For impaired waterbod-

[1] Department of Agricultural and Rural Engineering, College of Agriculture and Life science, Chungnam National University, Daejeon 305–764, Korea
[2] Science for Bioproduction Environment, Faculty of Agriculture, Kyushu University, Hakozaki 6–10–1, Higashi–ku, Fukuoka city 812–8581, Japan
[3] Department of Bio–Environmental Chemistry, College of Agriculture and Life science, Chungnam National University, Daejeon 305–764, Korea
[4] Rural Research Institute, KRC, Ansan, Gyeonggi–do,15634, Korea
* Corresponding author (E–mail: melody_jn@naver.com) (J. LEE)

ies, numeric standards alone may not be sufficient to establish remediation priorities and priorities must be established by comparing drainages to each other. Data collected as part of regional water quality (WQ) studies in the SJR Valley were not normally distributed, so non-parametric methods based on ranking were used to compare the WQ of individual tributaries and drainages (Stringfellow, 2008).

An integrated environmental decision support system (EDSS) for water pollution control based on total maximum daily load (TMDL) was developed. Using the water pollution control of Beiyun River in China as a case study, the key development processes and technologies of the EDSS are discussed including relations and links between various environmental simulation models, and model integration, visualization and real–time simulation methods (Zhang *et al.*, 2015).

The use of flow measurements to predict nutrient concentrations and subsequently nutrient loads is common in water quality modeling. Nevertheless, most adopted models assume that the relationship between flow and concentration is fixed across time as well as across different flow regimes. A Bayesian change point–threshold model was developed, in which it relaxes these constraints and allows for the identification and quantification of any changes in the underlying flow–concentration relationship across time (Alameddin *et al.*, 2011).

In Korea the system of TMDL for managing water quality was implemented as water quality of BOD and TP targeted since 2003 (MOE, 2015), in which the target of TMDL was defined as the mean of water quality concentrations monitored every 8 day multiplied by the reference discharge of the 275^{th} low flows averaged for the past 10 years (NIER, 2014). Heightening irrigation reservoirs, as a part of the 4–major river restoration project, have implemented to secure not only additional agricultural water but also instream flow for water quality improvement. Using SWAT model, instream flow effects on water quality of downstream were evaluated to show 2~10% water quality improvement effect on nutrients, as well as 1~8% water quantity increasing effect (Jee *et al.*, 2012).

A watershed model calibration framework was developed using an influence coefficient algorithm and genetic algorithm (WMCIG) to automatically calibrate the distributed models. The WMCIG was applied to a Gomakwoncheon watershed located in an area that presents a total maximum daily load (TMDL) in Korea. From the load duration curve analysis, the WQS exceedance frequencies of the BOD5 under dry conditions and low–flow conditions were 75.7% and 65%, respectively, and the exceedance frequencies under moist and mid–range conditions were higher than under other conditions. The exceedance frequencies of the TP for the high–flow, moist and mid–range conditions were high and the exceedance rate for the high–flow condition was particularly high. Most of the data from the high–flow conditions exceeded the WQSs (Cho and Lee, 2015).

The Load Duration Curve (LDC), which provides opportunities for enhanced pollutant source and best management practice targeting both in the total maximum daily load development and in water quality restoration efforts, has been used for the determination of appropriate total maximum daily load targets. The Web–based Load Duration Curve system (https://engineering.purdue.edu/wldc/) was developed and applied to a study watershed for an analysis of the total maximum daily load and water quality characteristics in the watershed. (Kim *et al.*, 2012)

In this study, using daily estimated water pollution loads data and the results of load duration curve, comparisons of water quality between Korean and Japanese rivers were performed to provide the reference data for an efficient water quality management by selecting one watershed with similar size in each country.

MATERIALS AND METHODS

Study areas

Watersheds with similar area were selected, in which Yongdam dam watershed with 930 km^2 has 2 water quality stations called Cheoncheon, Donghang in the Geum river basin in Korea as shown in Fig. 1 and Nakama watershed with 925 km^2 has 2 water quality stations called Hinodevasi, Nakasima in the Onga river basin in Japan as shown in Fig. 2. In the downstream 2 km from Cheoncheon station in Korea, water quality station called Geum river A is located, in which water qualities have been monitored every 8 day since 2003 for managing TMDLs.

Study flow and content include preparation of daily streamflow data, deriving discharge–load relationship, estimating water pollution loads, and comparison of water pollution loads as shown in Fig. 3.

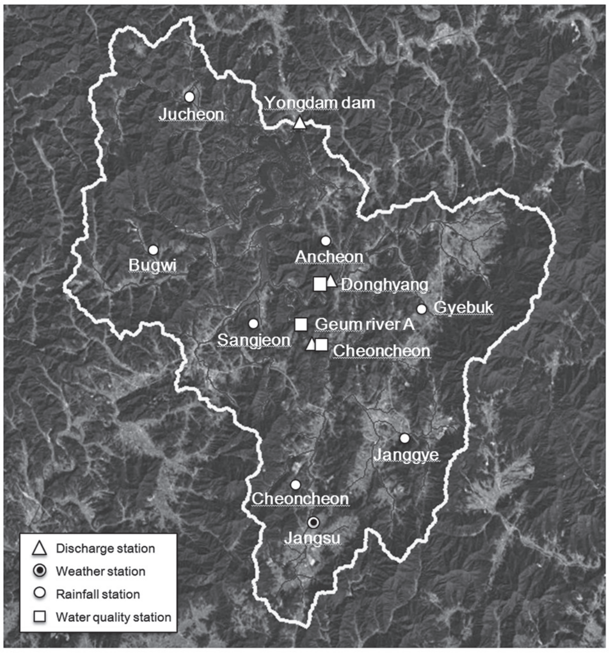

Fig. 1. Locations of discharge, rainfall, weather and water quality stations within Yongdam dam watershed.

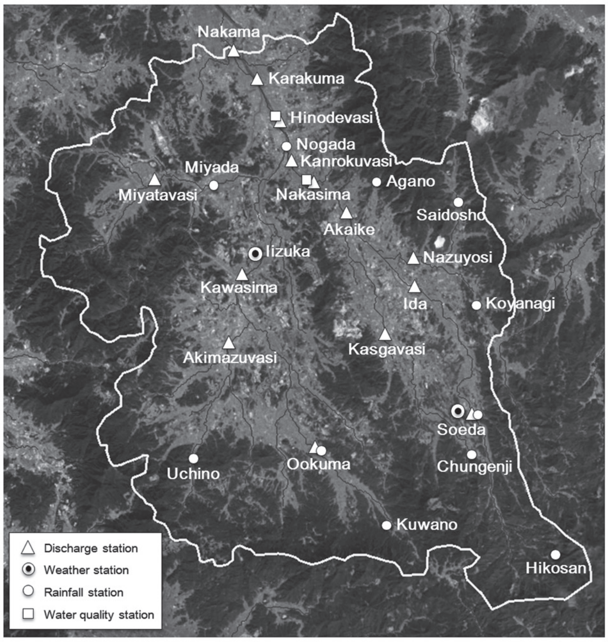

Fig. 2. Locations of discharge, rainfall, weather and water quality stations within Nakama station watershed.

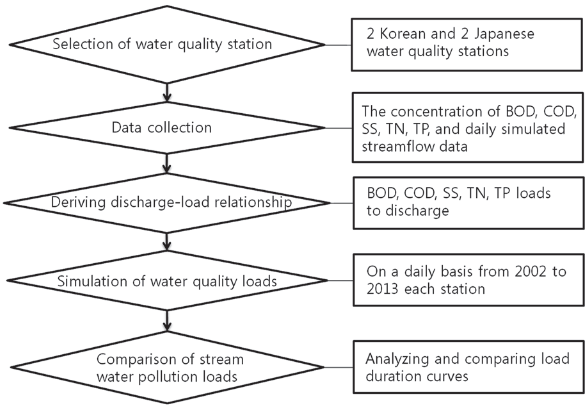

Fig. 3. Study flow and content.

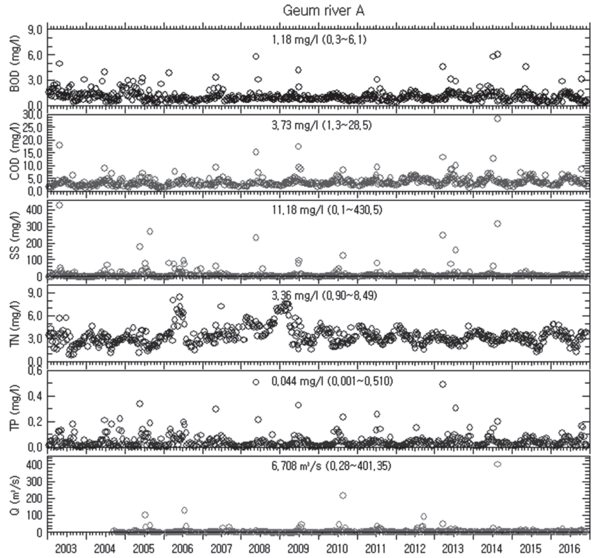

Fig. 4. Main water quality concentrations and discharges at Geum river A in Korea since 2003.

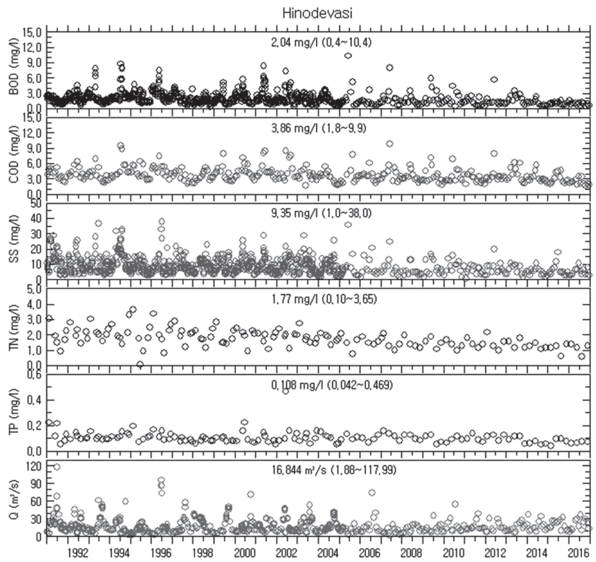

Fig. 5. Main water quality concentrations and discharges at Hinodevasi station in Japan since 1991.

Data sources

Water concentration data were collected to estimate water pollution loads. Korean data were collected from report on the result of streamflow measurement and water quality monitoring (K–water, 2002–2013), and from the Water Information System (http://water.nier.go.kr), in which can be retrieved the result monitored since 2003. Fig. 4 shows data monitored since 2003 at the Geum river A, in which BOD ranged from 0.3 to 6.1 and average 1.18 mg/l, COD 1.3, 28.5, 3.73 mg/l, SS 0.1, 430.5, 11.18 mg/l, TN 0.9, 8.49, 3.36 mg/l, TP 0.001, 0.510, 0.044 mg/l, respectively. Japanese data were collected from the Water Information System (http://www.river1.go.jp), in which data on water quantity and quality around Japan are being managed with databases. Fig. 5 shows water concentration data since 1991, in which BOD ranged from 0.4 to 10.4 and average 2.04 mg/l, COD 1.8, 9.9, 3.86 mg/l, SS 1.0, 38.0, 9.35 mg/l, TN 0.1, 3.65, 1.77 mg/l, TP 0.042, 0.469, 0.108 mg/l, respectively.

Selected stations were shown in Table 1, of which water quality stations for estimating water pollution loads are Cheoncheon, Donghang within the Yongdam dam watershed in Korea, and Hinodevasi, Nakasima within the Nakama station watershed in Japan.

Preparation of daily streamflow data

The daily streamflow data by ONE model were prepared to estimate daily water pollution loads at Cheoncheon, Donghang in Korea, and Hinodevasi, Nakasima in Japan as shown in Table 2. The result by ONE model had been applied to plan reservoir building for supplying water to upland areas in Dodota area, Ethiopia (Noh and Lee, 2012). The result by ONE model was compared and verified on the inflow data to

Yongdam dam with other study (Kim *et al*., 2014). The result by ONE model showed R^2 of 0.880, RMSE (root mean square error) of 1.750, and NSE (Nash–Schcliffe's model efficiency) of 0.871 by simulating daily inflow to Yongdam dam in the in calibration period during 2007~2009 as shown in Fig. 6. Kim *et al*. (2014) showed R^2 of 0.88, RMSE of 2.75, and NSE of 0.86 with TANK model, and R^2 of 0.68, RMSE of 2.82, and NSE of 0.67 with SWAT model on the same data. In verification period during 2010~2012, ONE model showed R^2 of 0.901, RMSE of 2.627, and NSE of 0.900 as shown in Fig. 7. On the other hand, TANK model showed R^2 of 0.90, RMSE of 2.70, and NSE of 0.90, and SWAT model showed R^2 of 0.71, RMSE of 4.82, and NSE of 0.67 (Kim *et al*., 2014). The above result could be convinced to prepare daily streamflow data on water quality station reasonably.

Table 1. Selected stations on rainfall, weather, discharge, water quality in Korean and Japanese rivers

Yongdam dam watershed			Onga river basin		
Rainfall (7)	Weather (1)	Discharge (3)	Rainfall (11)	Weather (2)	Discharge (14)
Jucheon	Jangsu	Cheoncheon (290.9)*[a]	Hikosan	Iizuka	Soeda (76)
Bugwi		Donghyang (164.4)*	Chungenji	Soeda	Ida (127)
Ancheon		Yongdam dam (930.0)	Koyanagi		Nazuyosi (47)
Sangjeon			Saidosho		Kasgavasi (72)
Cheoncheon			Kuwano		Akaike (309)
Janggye			Ookuma		Nakasima (326)*
Gyebuk			Uchino		Ookuma (42)
			Kawasima		Akimazuvasi (113)
			Agano		Kawasima (292)
			Nogada		Kanrokuvasi (366)
			Miyada		Hinodevasi (695)*
					Miyatavasi (123)
					Karakuma (887)
					Nakama (925)

[a] Water quality stations are marked with an asterisk, and numeric values in parentheses are the watershed area (km^2).

Table 2. Annual result on daily simulated streamflows at water quality station in Korean and Japanese rivers

River	Watershed	Area	Duration	Annual rainfall		Annual streamflow		Runoff ratio
		km^2		mm	Mm^3	mm	Mm^3	%
Yongdam dam	Cheoncheon	290.9	2000–2013	1,473.4	428.62	906.0	263.55	61.0
	Donghang	164.4	2000–2013	1,356.4	222.99	794.1	130.55	58.5
Onga	Nakasima	326.0	1980–2013	1,975.8	644.11	1,454.6	474.21	73.6
	Hinodevasi	695.0	1980–2013	1,936.8	1,346.05	1,407.3	978.06	72.7

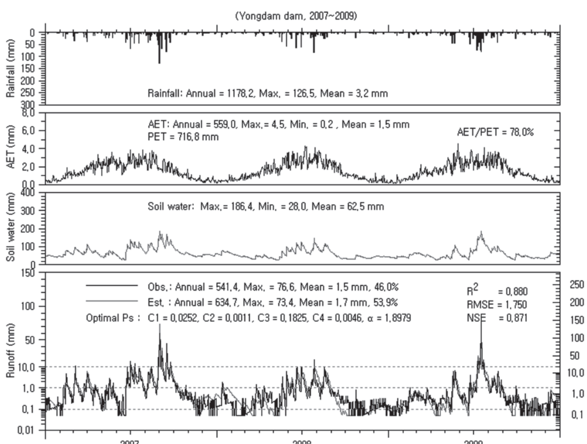

Fig. 6. Comparison of daily inflow to Yongdam dam by ONE model in calibration period during 2007~2009.

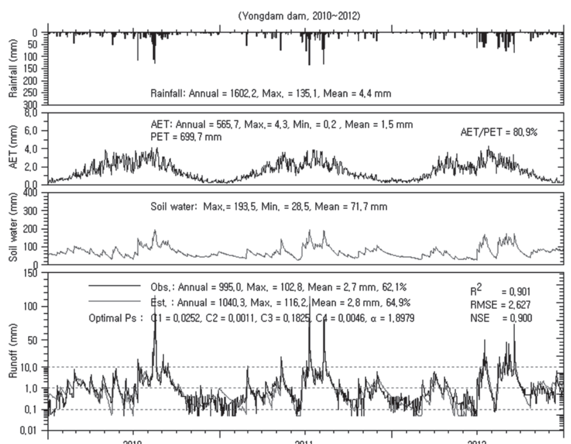

Fig. 7. Comparison of daily inflow to Yongdam dam by ONE model in verification period during 2010~2012.

Load duration analysis

In this study the water qualities of BOD, COD, SS, TN, and TP were selected to compare the levels of water qualities between Korean and Japanese river. The relationships between discharge and water pollution load were derived, and the daily loads were estimated by multiplying daily discharges simulated with the ONE model to the water quality loads obtained from the above derived relationships. And load duration analysis was performed in the same way with the flow duration curve (FDC) of streamflows.

RESULTS

Deriving discharge–load relationship

The relationships between discharge and water pollution load were derived as shown in Fig. 8 as an example of BOD load equation on Cheoncheon, and Fig. 9 as an example of TP load equation on Hinodevasi, in which daily water pollution loads (kg/day) are calculated by 86.4 times water quality concentration (mg/l) multiplied by daily discharge (m^3/day). BOD, COD, SS, TN, and TP water pollution load equations on Cheoncheon, Donghang, Hinodevasi, and Nakasima station were arranged in Table 3, in which the coefficients of determination, R^2, of each load equation ranged from 0.423 to 0.973.

Estimating water pollution loads

BOD, COD, SS, TN, and TP pollution loads on each station were estimated on a daily basis by applying load equations in Table 3 to daily streamflow data prepared by ONE model, of which an example of BOD loads in Cheoncheon station was shown in Fig. 10, and an example of TP loads in Hinodevasi station was shown in Fig. 11. Water pollution loads were summed by each station annually and were compared with each other with a specific value divided by watershed area, of which a comparison of BOD specific loads was shown in Fig. 12, and a comparison of TP specific loads was shown in Fig. 13 with an annual mean value. Specific annual loads on each station was summarized annually in Table 4, in which BOD ranked 1, 1, 4, 3 in an annual averaged value in higher order of Cheoncheon, Donghang, Hinodevasi, Nakasima, and COD 2, 1, 4, 3, and SS 2, 1, 3, 4, and TN 1, 2, 4, 3, and TP 4, 1, 2, 2, respectively. From the above results, water pollution loads showed higher in Korean than those in Japanese river as an annual sum.

Load duration analysis

The procedure for load duration is consisted of deriving the relationship between discharge and water pollution load, estimating daily loads, and drawing load duration curves by sorting daily loads on BOD, COD, SS, TN, and TP with higher order. The averaged results of

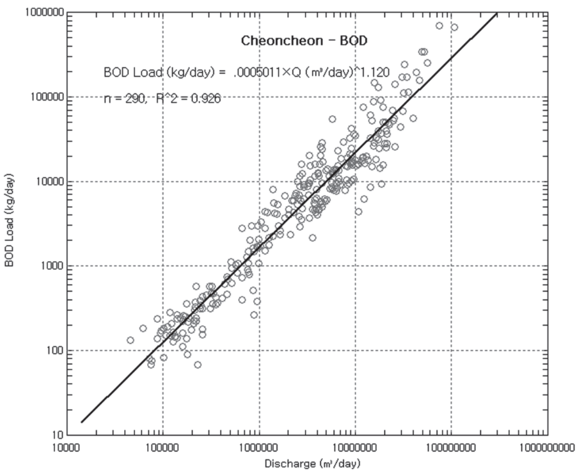

Fig. 8. An example of the relationship between discharge and BOD load in Cheoncheon station.

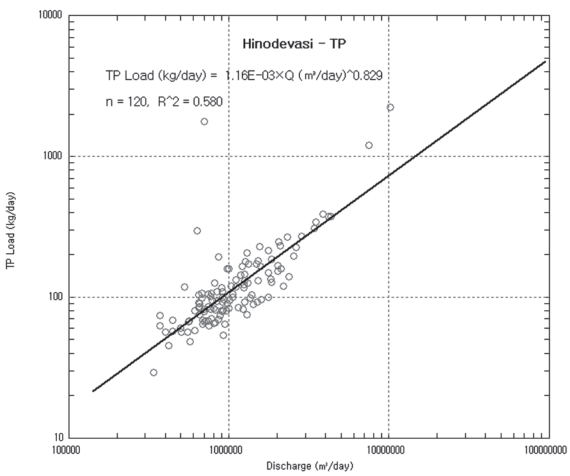

Fig. 9. An example of the relationship between discharge and BOD load at Hinodevasi station.

Table 3. The relationships between discharge and water pollution load at each station

Load	Cheoncheon			Donghang			Hinodevasi			Nakasima		
	a	b	R^2	a	b	R^2	a	b	R^2	a	b	R^2
BOD	0.0005011	1.120	0.926	0.000525	1.082	0.914	0.3839	0.618	0.423	0.0487	0.745	0.631
COD	0.000334	1.175	0.957	0.000235	1.201	0.968	0.0489	0.816	0.719	0.0258	0.855	0.849
SS	0.00000036	1.770	0.858	8E–08	1.890	0.837	0.00166	1.112	0.577	0.0075	1.006	0.596
TN	0.00241	1.009	0.973	0.0011	1.051	0.964	0.0279	0.800	0.605	0.0034	0.936	0.821
TP	0.00000014	1.434	0.857	4E–08	1.537	0.898	0.00116	0.829	0.580	0.000464	0.887	0.754

Cf.) Water pollution load (kg/day) = a Q (m^3/day) ^{b}

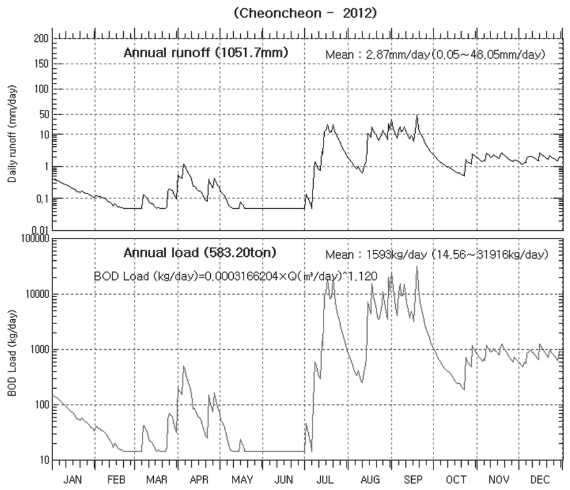

Fig. 10. An example of estimating the BOD daily loads in Cheoncheon station (2012).

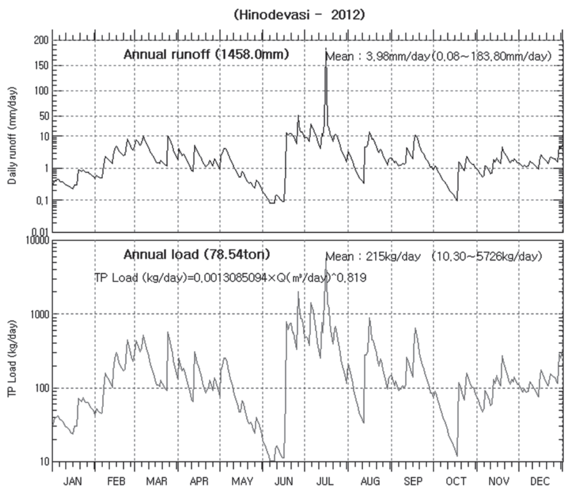

Fig. 11. An example of estimating the TP daily loads in Hinodevasi station (2012).

load duration analysis on BOD, COD, SS, TN, and TP at the Korean and Japanese rivers were summarized in Table 5, of which an example of BOD load duration curve (LDC) at Cheoncheon station was shown in Fig. 14 and an example of averaged BOD LDC with loads of Cheoncheon and Donghang in the Yongdam dam watershed was shown in Fig. 15, and examples of TP at Hinodevasi and in the Nakama watershed with mean of Hinodevasi and Nakasima's loads were in Fig. 16 and Fig. 17, respectively. Comparing with 10 year frequency value as shown in Table 5, 1st loads in Korean showed 1.81 to 6.14 times higher than those in Japanese, the remaining 95th, 185th, 275th, and 355th loads in Japanese showed 1.30 to 15.43 times higher than those in Korean without 355th TN load with 1.42 times higher in Korean. Summarizing the above results, it was concluded that TMDL showed 1.49 times higher BOD, 1.11 times higher COD, 4.95 times higher SS, 1.43 times higher TN in Korean and the same TP, and 1st load in LDC showed 1.81 to 6.14 times higher in Korean, and remaining 95th, 185th, 275th, and 285th loads in LDC showed 1.30 to 15.43 times higher in Japanese.

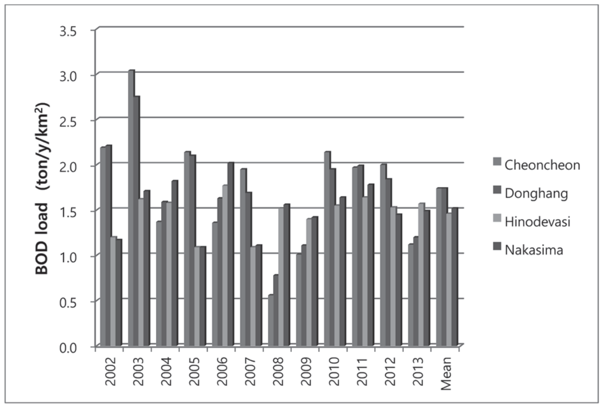

Fig. 12. Comparison of annual BOD loads (ton/y/km²).

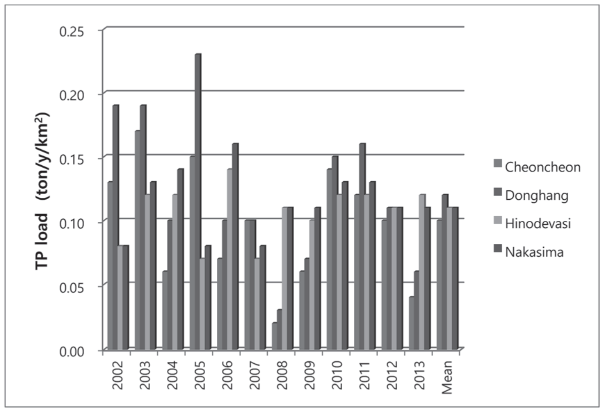

Fig. 13. Comparison of annual TP loads (ton/y/km²).

Comparison of water pollution loads

Water pollution loads were estimated on a daily basis and LDCs was drawn by each station. Mean LDCs were drawn by averaging the values on LDCs of 2 water quality stations by country, and were compared with each country, of which an example of BOD LDC with annual mean during 2002~2013 was shown in Fig. 18, and the other LDC was shown in Table 6. Flow duration interval (%) in LDC was separated to high–flow of 10%, moist–conditions of 30%, mid–range flow of 20%, dry–conditions of 30%, and low flow of 10% (Kim *et al.*, 2012). In Table, specific loads were expressed with daily mean in the period of each flow duration interval, and were compared with each other between Korea and Japan, of which results were shown with 1.836~8.063 times higher to Korea in high flows, and with 1.119~8.169 times higher to Japan in other flows except SS, TN values in moist conditons. Comparing an annual sum, BOD load was 1.16 times higher in Korea, COD 1.113 in Korea, SS 4.891 in Korea, TN 1.446 in Korea, and TP was same. Here are characteristics of high SS to Korea during high flow interval.

Comparison examples of LDCs with 10 year frequency were shown in Fig. 18 of BOD case, and in Fig.

Table 4. Yearly water pollution loads per km2 at each water quality station

(ton/yr/km^2)

Item	Station	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean
BOD	Cheoncheon	2.19	3.04	1.37	2.14	1.36	1.95	0.56	1.01	2.14	1.97	2.00	1.12	1.74
	Donghang	2.21	2.75	1.59	2.10	1.63	1.69	0.78	1.11	1.95	1.99	1.84	1.20	1.74
	Hinodevasi	1.20	1.62	1.58	1.09	1.77	1.09	1.52	1.40	1.55	1.64	1.53	1.57	1.46
	Nakasima	1.17	1.71	1.82	1.09	2.02	1.11	1.56	1.42	1.64	1.78	1.45	1.49	1.52
COD	Cheoncheon	5.37	7.47	3.26	5.42	3.28	4.68	1.25	2.48	5.34	4.86	4.85	2.57	4.24
	Donghang	5.86	7.07	3.90	5.87	4.03	4.10	1.70	2.71	4.98	5.19	4.56	2.76	4.39
	Hinodevasi	2.79	4.20	4.13	2.61	4.92	2.56	3.84	3.69	4.13	4.33	4.03	4.17	3.78
	Nakasima	2.86	4.43	4.81	2.77	5.51	2.80	4.01	3.73	4.34	4.64	3.82	3.93	3.97
SS	Cheoncheon	72.74	88.7	26.21	107.75	34.62	46.37	5.81	32.97	97.29	69.17	47.84	16.08	53.80
	Donghang	106.54	89.94	40.00	170.36	45.26	41.26	8.47	29.65	77.91	92.74	47.86	21.52	64.29
	Hinodevasi	7.99	13.91	14.39	8.33	18.73	7.90	12.43	14.09	15.77	14.87	14.6	15.32	13.19
	Nakasima	6.92	11.61	13.14	7.30	15.72	7.26	10.46	10.34	12.05	12.26	10.58	10.72	10.70
TN	Cheoncheon	3.10	4.26	2.05	2.85	1.99	2.88	0.93	1.42	2.97	2.76	2.90	1.80	2.49
	Donghang	2.94	3.67	2.15	2.76	2.21	2.29	1.09	1.51	2.61	2.66	2.49	1.66	2.34
	Hinodevasi	1.23	1.84	1.80	1.15	2.13	1.13	1.68	1.61	1.80	1.89	1.76	1.82	1.65
	Nakasima	1.17	1.89	2.10	1.18	2.46	1.19	1.71	1.64	1.91	1.99	1.67	1.71	1.72
TP	Cheoncheon	0.13	0.17	0.06	0.15	0.07	0.10	0.02	0.06	0.14	0.12	0.10	0.04	0.10
	Donghang	0.19	0.19	0.10	0.23	0.10	0.10	0.03	0.07	0.15	0.16	0.11	0.06	0.12
	Hinodevasi	0.08	0.12	0.12	0.07	0.14	0.07	0.11	0.10	0.12	0.12	0.11	0.12	0.11
	Nakasima	0.08	0.13	0.14	0.08	0.16	0.08	0.11	0.11	0.13	0.13	0.11	0.11	0.11

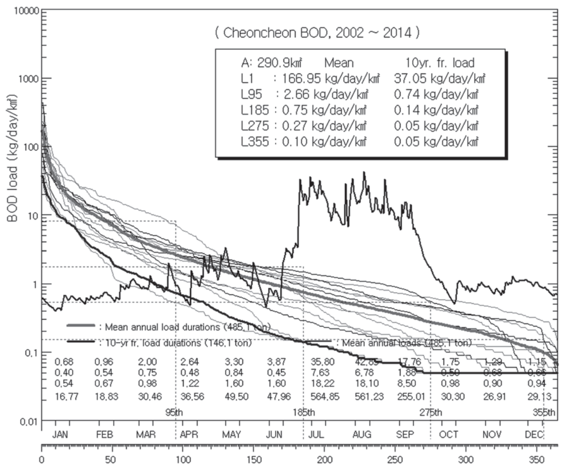

Fig. 14. An example of BOD load duration curves at Cheoncheon station in Geum river.

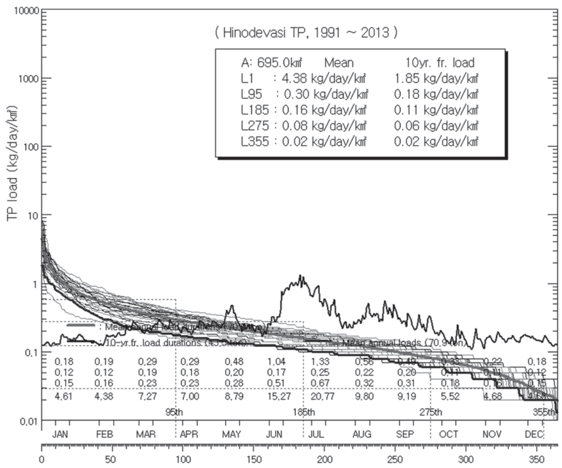

Fig. 16. An example of TP load duration curves at Hinodevasi station in Onga river.

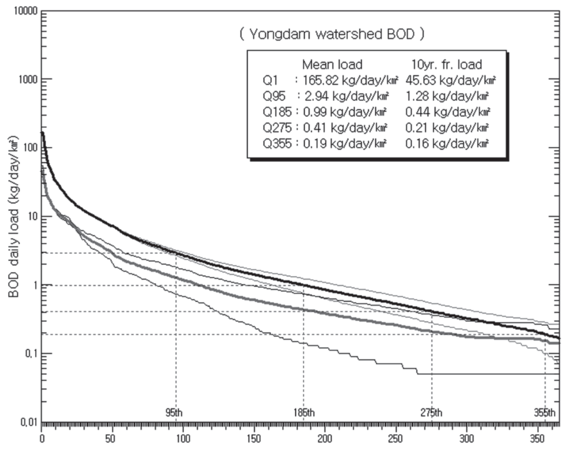

Fig. 15. An example of BOD load duration curves at Yongdam dam watershed in Geum river.

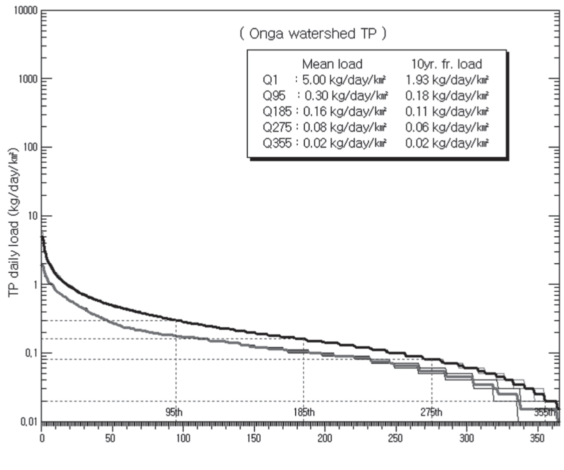

Fig. 17. An example of TP load duration curves at Nakasima watershed in Onga river.

Table 5. Comprehensive results on load duration analyses in Yongdam dam and Nakama watersheds

(kg/day/km^2)

Watershed	Item	Divide	1st load	95th load	185th load	275th load	355th load
Yongdam dam	BOD	Mean	165.82	2.94	0.99	0.41	0.19
		10yr	45.63	1.28	0.44	0.21	0.16
	COD	Mean	491.85	6.24	1.92	0.74	0.32
		10yr	121.87	2.50	0.77	0.34	0.25
	SS	Mean	16932.21	17.98	2.84	0.67	0.17
		10yr	1684.02	4.20	0.71	0.21	0.12
	TN	Mean	199.27	4.58	1.64	0.71	0.34
		10yr	60.48	2.04	0.70	0.34	0.27
	TP	Mean	20.98	0.09	0.02	0.01	0.01
		10yr	3.49	0.03	0.01	0.01	0.01
Nakama	BOD	Mean	42.51	4.50	2.70	1.59	0.56
		10yr	19.84	2.96	1.97	1.20	0.37
	COD	Mean	167.59	10.73	5.71	2.97	0.82
		10yr	66.25	6.36	3.83	2.06	0.46
	SS	Mean	903.05	26.63	11.94	5.22	1.05
		10yr	274.23	13.56	7.14	3.24	0.47
	TN	Mean	80.03	4.55	2.37	1.21	0.33
		10yr	29.98	2.65	1.57	0.84	0.19
	TP	Mean	5.00	0.30	0.16	0.08	0.02
		10yr	1.93	0.18	0.11	0.06	0.02
Comparing with 10 year frequency value	BOD		2.30 K[a]	2.31 J[b]	4.48 J	5.71 J	2.31 J
	COD		1.84 K	2.54 J	4.97 J	6.06 J	1.84 J
	SS		6.14 K	3.23 J	10.06 J	15.43 J	3.92 J
	TN		2.01 K	1.30 J	2.24 J	2.47 J	1.42 K
	TP		1.81 K	6.00 J	11.00 J	6.00 J	2.00 J

[a] K means that water pollution loads in Korean river were higher than those in Japanese river.
[b] J means that water pollution loads in Japanese river were higher than those in Korean river.

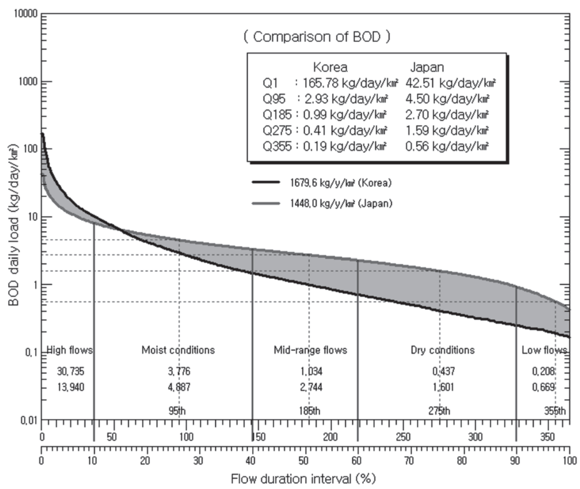

Fig. 18. Comparison example of mean BOD load duration curves with annual average between Yongdam watershed in Korea and Nakama watershed in Japan.

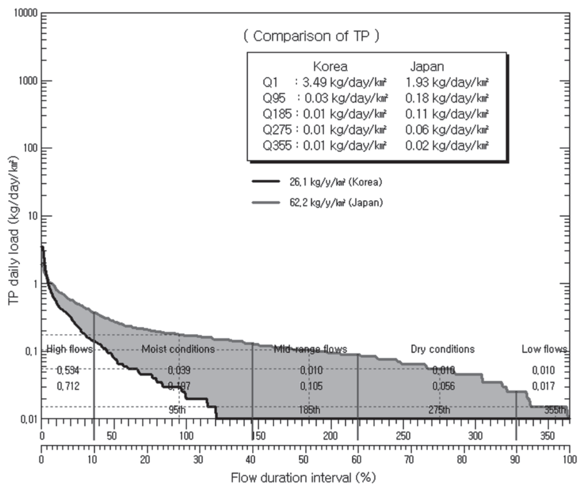

Fig. 19. Comparison example of mean BOD load duration curves with 10 year frequency between Yongdam watershed in Korea and Nakama watershed in Japan.

19 of TP case. The results of comparing LDCs for each flow duration interval were summarized in Table 7, in which Korea showed 1.041~2.360 times higher loads than Japan except TP in high flows, Japan 1.175~14.226 times higher than Korea except TN in low flows. Comparing an annual sum, BOD load was 1.517 times higher in Japan, COD 1.564 in Japan, SS 1.408 in Korea, TN 1.008 in Korea, and TP 2.383 in Japan.

From the above result, it was concluded generally

Table 6. Comparison of mean load duration curves with annual mean between Yongdam watershed in Korea and Nakama watershed in Japan

Item	Country	High flows (kg/day/km^2)	Moist conditions (kg/day/km^2)	Mid–range flows (kg/day/km^2)	Dry conditions flows (kg/day/km^2)	Low flows (kg/day/km^2)	Sum (kg/year/km^2)
BOD	Korea	30.735	3.776	1.034	0.437	0.208	1679.6
	Japan	13.940	4.887	2.744	1.601	0.669	1448.0
COD	Korea	81.226	8.301	2.012	0.792	0.349	4156.3
	Japan	44.230	11.982	5.831	3.014	1.02	3734.5
SS	Korea	1396.682	32.087	3.113	0.774	0.208	55494.1
	Japan	173.214	31.193	12.288	5.394	1.389	11345.3
TN	Korea	40.433	5.766	1.702	0.747	0.365	2343.7
	Japan	19.952	5.108	2.424	1.230	0.409	1621.1
TP	Korea	2.409	0.126	0.020	0.010	0.010	105.8
	Japan	1.281	0.336	0.161	0.082	0.028	105.8
BOD		2.205 K	1.294 J	2.654 J	3.666 J	3.217 J	1.160 K
COD		1.836 K	1.443 J	2.898 J	3.806 J	2.924 J	1.113 K
SS		8.063 K	1.029 K	3.947 J	6.967 J	6.676 J	4.891 K
TN		2.027 K	1.129 K	1.424 J	1.647 J	1.119 J	1.446 K
TP		1.880 K	2.669 J	8.003 J	8.169 J	2.797 J	1.000 J

Table 7. Comparison of mean load duration curves with 10 year frequency between Yongdam watershed in Korea and Nakama watershed in Japan

Item	Country	High flows (kg/day/km^2)	Moist conditions (kg/day/km^2)	Mid–range flows (kg/day/km^2)	Dry conditions flows (kg/day/km^2)	Low flows (kg/day/km^2)	Sum (kg/year/km^2)
BOD	Korea	10.854	1.594	0.452	0.223	0.158	638.4
	Japan	8.857	3.203	1.982	1.194	0.449	968.3
COD	Korea	26.005	3.235	0.802	0.368	0.249	1422.8
	Japan	24.983	7.060	3.876	2.079	0.600	2225.6
SS	Korea	190.132	7.110	0.766	0.235	0.121	7895.9
	Japan	80.549	15.681	7.259	3.343	0.677	5608.9
TN	Korea	15.513	2.512	0.732	0.366	0.264	950.9
	Japan	10.924	2.951	1.592	0.845	0.244	943.2
TP	Korea	0.534	0.039	0.010	0.010	0.010	26.1
	Japan	0.712	0.197	0.105	0.056	0.017	62.2
BOD		1.225 K	2.009 J	4.385 J	5.354 J	2.842 J	1.517 J
COD		1.041 K	2.182 J	4.833 J	5.649 J	2.410 J	1.564 J
SS		2.360 K	2.205 J	9.477 J	14.226 J	5.595 J	1.408 K
TN		1.420 K	1.175 J	2.175 J	2.309 J	1.082 K	1.008 K
TP		1.333 J	5.051 J	10.500 J	5.600 J	1.700 J	2.383 J

that Korean river was getting more water pollution loads than Japanese river in high flow interval, but in other flow interval was the above situation reversed.

DISCUSSION

To compare water quality on Korean and Japanese rivers, watersheds with similar area were selected. The one from Korea is called the Yongdam dam watershed in the Geum river basin with watershed area of 930 km^2, the other from Japan is called the Nakama watershed in the Onga river basin with watershed area of 925 km^2. The 2 water quality stations from Korea and 2 water quality stations from Japan within watersheds were selected and water quality concentration data were collected to determine load durations, respectively.

The relationships between discharge and water pollution load on BOD, COD, SS, TN, and TP were derived, and water pollution loads were estimated on a daily basis in each water quality station. And means of LDCs in each country were drawn and compared with each other.

Summarizing the estimated daily water pollution loads and the results of LDCs, it was concluded that TMDL showed 1.49 times higher BOD, 1.11 times higher COD, 4.95 times higher SS, 1.43 times higher TN in

Korean and the same TP, and 1st load in LDC showed 1.81 to 6.14 times higher in Korean, and remaining 95th, 185th, 275th, and 285th loads in LDC showed 1.30 to 15.43 times higher in Japanese.

Specific loads were expressed with daily mean in the period of each flow duration interval, and were compared with each other between Korea and Japan, of which results were shown with 1.836~8.063 times higher to Korea in high flows, and with 1.119~8.169 times higher to Japan in other flows except SS, TN values in moist conditions. Comparing an annual sum, BOD load was 1.16 times higher in Korea, COD 1.113 in Korea, SS 4.891 in Korea, TN 1.446 in Korea, and TP was same. Evaluating with 10 year frequency, Korea showed 1.041~2.360 times higher loads than Japan except TP in high flows, Japan 1.175~14.226 times higher than Korea except TN in low flows. Annual sum showed that BOD load was 1.517 times higher in Japan, COD 1.564 in Japan, SS 1.408 in Korea, TN 1.008 in Korea, and TP 2.383 in Japan.

From the above result, it was concluded that Korean river was getting more water pollution loads than Japanese river in high flow interval, but in other flow interval was higher to Japan in general.

AUTHOR CONTRIBUTIONS

Jaekyoung NOH carried out substantial contribution to the concept and design on this paper. Hyunuk AN and Taek–Keun OH carried out analysis and interpretation of data. Yoshiyuki SHINOGI verified the Japan's data. Jaenam LEE supervised the project, analyzed the data and wrote the paper. All authors commented on the manuscript.

ACKNOWLEDGMENTS

This work was supported by research fund of Chungnam National University, Republic of Korea.

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