Simplified approach to evaluate total external loading to Kojima Lake

Shin-ichi Nishimura[*], Kenji Okubo[*], Hidenori Morita[*], Jari Koskiaho[†]
and Sirkka Tattari[†]

[*] Graduate School of Environmental and Life Science
Okayama University, 3-1-1, Tsushima-naka, Okayama, 700-8530, Japan
theg1786@cc.okayama-u.ac.jp, kenji19okubo@gmail.com, h-morita@okayama-u.ac.jp
[†]Freshwater Centre, Finnish Environment Institute, Finland
jari.koskiaho@ymparisto.fi, sirkka.tattari@ymparisto.fi

Abstract:

Loading curves for suspended sediment and Total Dissolved Solids are estimated in Kojima Lake in Japan, depending on river discharges with *TDS* flux-Discharge *L-Q* equations. Those are determined for Japanese rivers and compared with the world major river then extended to some Finnish rivers. The other empirical relationship containing particular reciprocal ionic fraction is considered to give procedures to perform temporal and spatial flux integration e.g. annual discharge, sediment yield, and nutrient loading. The flux of quantity is the quantity by the velocity and it is natural to expect a correlation between total flux and discharge in the loading curve of *L-Q* equation as discharge. The *L-Q* curve was applied to a canal in the paddy field, and it has been clarified that proposed *L-Q* curve is available to the small agricultural canals. Finally, the *L-Q* equations approach has been verified to be available for the practical use, and additionally, the unit load approach is also conducted as the most simplified method.

1. Introduction

There are still continuous needs and consisting desire to describe the total loading estimation and evaluation through the rivers to a lake or a sea during the past several years or even a few decades in future. Total Dissolvable Solids (*TDS*) or alternatively total dissolved solids corresponding to the Electric Conductivity (EC), Total Suspended Solids (*TSS* or just SS) and nutrients (TN, TP) were investigated with the daily averaged discharge (*Q*) and compared with the total 100 rivers flowing into Lake Biwa and the major 21 and minor 600 rivers flowing into the Seto Inland Sea of Japan.

In this report, the external loading to Kojima Lake is assessed by using the $L=TDS*Q$ and *Q* relationship. Since the method is simple approach and requires small amount of information, the applicability is supposed to be high for the actual problems. Although, as an approach to assess the water quality in the lake, the SWAT model is well known, and employed in all over the world, it is not used here, since the model requires large amount of information, and can not be applied easily. As a first step, the *L-Q* curve approach is very convenient to assess the water quality roughly.

As most simplified method, "the unit load method" is also employed here. Although we tried to estimate the loadings and runoff of Kojima Lake Basin applying ArcSWAT as the most accurate and sophisticated approach, it required quite long period for data collection, and then, we have tentatively started with use of simpler method, “unit load method” as preliminary approach, simultaneously with *L-Q* approach. The unit load method is applied to estimate loading of the Kojima Lake basin, also calculate results of the average runoff coefficient in the Kojima Lake basin.

Finally, the results of two approaches are compared, and the practical use of such simplified methods are discussed.

2. L-Q Equations approach

The basic correlation is assumed by putting the discharge in both the axes. Murakami (2004) collected and compiled silicate and phosphate data from more than 50 rivers flowing into Lake Biwa, Japan. In Fig.1, *TSS/TDS* is used as independent variable and *TSS* divided by SiO_2 or ionic species such as PO_4 as dependent variables, and the ratio was thought as an indicator of discharge in field as water sample is turbid when discharge is high and vice versa.

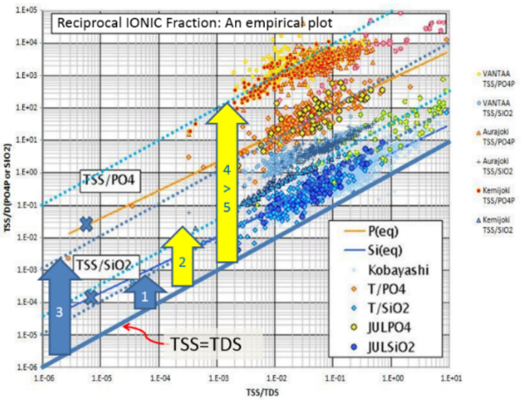


Fig. 1 Reciprocal ionic fraction for the silicate and the phosphate for three Finnish rivers and rivers flowing into Lake Biwa and the Inland Sea of Japan, the reference basis is taken as *TSS* instead of *TDS*, by putting the base line *TSS=TDS*

Murata (2008) extended Fig.1 to major river ions. It is true not only for SiO_2 and PO_4 but also major anions and cations. There is definite order in the reciprocal plot from region to region in Fig.1. The fraction of TDS is locally fixed and stable in the downstream as SiO_2 and PO_4 are both 1 to 2 orders higher in Japan than in Finland. Temperature dependence of solubility is known and recent instruments can convert EC into TDS. The group of highest fraction in western Japanese is: HCO_3^-(40), SiO_2(20), SO_4^{2-}(10), Ca^{2+}(10), Cl^-(10); a few: 1%:

Na^+(2), Mg^{2+}(2), K^+(2), NO_3^-(2); low 0.1%: NH_4^+, PO_4^{3-}, F^-, NO_2^-, Li^+.

In Figure 2, the L-Q relationships derived from the data of various rivers in all over the world. The derivation of *L-Q* curves are described as follows.

Assuming that $TSS/TDS=Q^*$ same as discharge but without dimension,

$$TSS/a = (TSS/TDS)\times(TDS/a) = TDS\cdot Q^*/a \quad (1)$$

$$TSS/b = (TSS/TDS)\times(TDS/b) = TDS\cdot Q^*/b \quad (2)$$

$$TSS = TDS\cdot Q^* \quad (3)$$

Suzuki (2010) analyzed EC and SS in the Ministry database and found the *L-Q* equations for *TSS* in the 21 Class-A rivers flowing into Seto Inland Sea. Regime theory shows that the power S_0 depends on the season in some continental rivers.

$$L_{TSS} = S_1\hat{Q}^{S_0} \qquad (4)$$

$$L_{TDS} = D_1\hat{Q}^{D_0} \qquad (5)$$

Yamada (2010) analyzed the water samples from the 21 rivers and summed up the major ions to obtain *TDS*. It was combined into a family of curves depending on the hardness of water in Figure 2. Three Kansai Rivers Yodo, Yamato and Kino Rivers are frequently surveyed on various stage of discharge to get the power D_0. It was found for these three rivers tested, 0.75 to 0.80. The latter was found to be up to 1.0. The change corresponds to that of S_0 up to 1.75 to 2.0. Zheng (2014) proved that the loading curves works satisfactorily to the sediment yields and phosphorous accumulation in Lake Poyang and watershed of the Gangjiang River, which is a major tributary of Changjiang River.

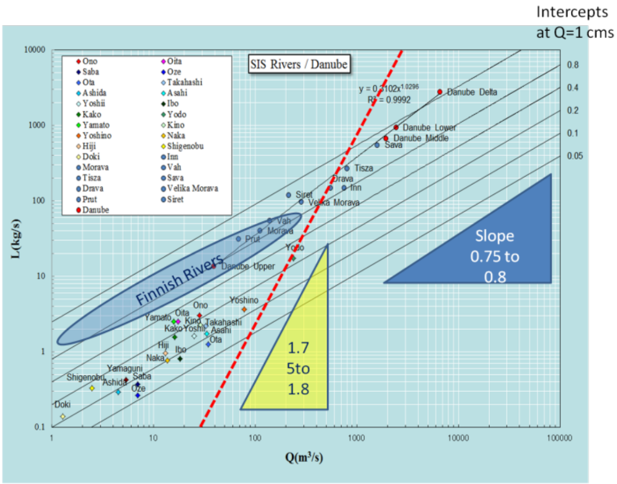


Fig. 2 Loading curves *L-Q* equation for *TDS*, Total Dissolved Solids

3. *L-Q* equation in studied field

In this report, Kojima Lake in Okayama (Photo 1), Japan is studied, and the external loading from Kojima paddy field surrounding Kojima Lake is evaluated. Three livers, namely, Sasagase River, Kurashiki River, and Kamogawa River flow into Kojima Lake as shown in Figure 3. The total external loading from three rivers and the drainage canals in the paddy field ought to be assessed to identify the external loading. The water from the drainage canals is mechanically controlled and discharged from the pumping systems. The pump stations are also exhibited with the green circles in Figure 3.

Photo 1 Planview of Kojima Lake

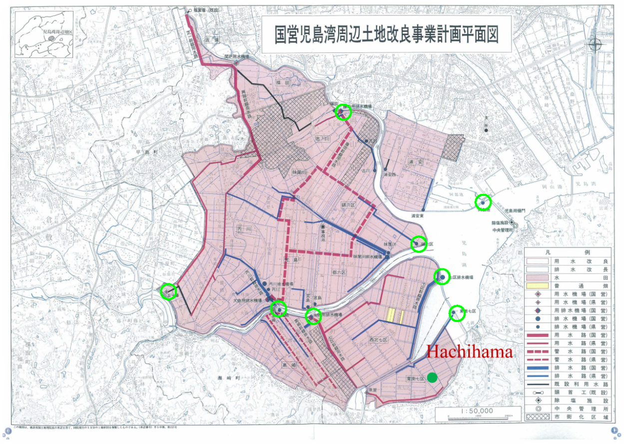


Fig. 3 Kojima Lake and surrounding paddy field

In Hachihama paddy field exhibited in Figure 3, the water has been sampled once a month from May 2013 to April 2014, and its quality has been analyzed. Figure 4 exhibits the canal and the sampling points in Hachihama, and the canal in the figure has the tasks for both of drainage and the irrigation up to the season. Photo 2 and Table1 present the situations of the canal inside the field and the sampling days. June and July are in the irrigation season, and

August is drainage one according to the table.

Figure 5 exhibits the change of the electric conductivity EC and pH values. The water quality is almost the neutral through an entire year, and the EC value is high in non-irrigation season of November and low in the irrigation seasons of June and July. Since, in non-irrigation season, the water depth is very low, the total density of resolves is supposed to be condensed. Figure 6 depicts the transient of the ions in a year. In summer season, the concentrations are relatively low. The concentrations of the sodium and chlorine are high due to the sea water, since the paddy field is originated to the sea bottom. The elements of the fertilizer, namely, ammonic nitrogen, potassium and phosphoric acid are also dominant. The values in Figures 5 and 6 are averaged ones of the sampling points of No.1 to No.4. Figure 7 presents the total phosphorus (T-P) in he points No.3 and No.0. The value of T-P is very high in spring, and relatively high also in August. Although the EC is high in November, T-P is not corresponding to the EC. T-P value is supposed to directly respond to fertilizing.

The *L*-*Q* *c*urve of the Hachihama field is presented in Figure 8. The curve is obtained from the *L*-*Q* relationship of the Japanese major rivers, and it is clarified that the *L*-*Q* relationship of Hachihama Canal is coincident to that of Japanese major rivers. This means the relationship in Figure 8 has the generality among Japanese rivers and canals.

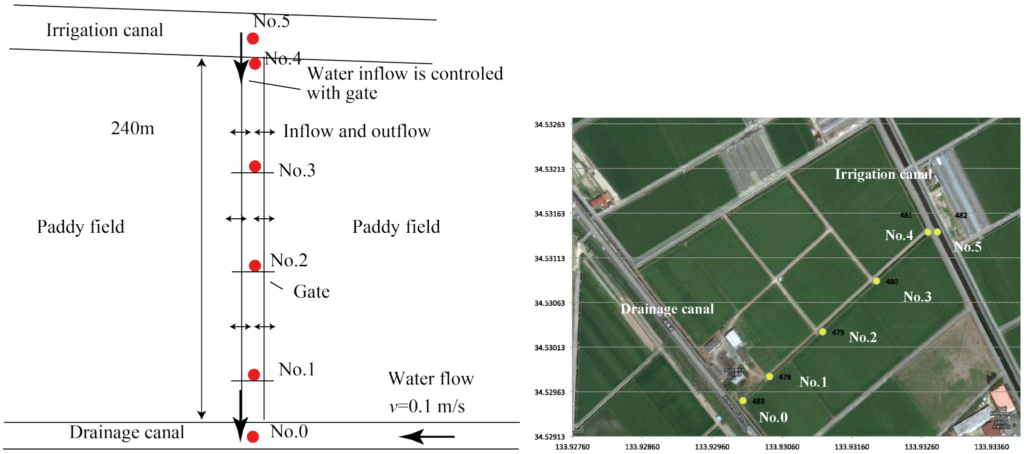


Fig. 4 Water sampling points in Hachihama

Table 1 Water sampling schedules

Date	Weather	Canal state	Water depth(cm)	Water Temp (°C)
23-May-13	Fine	Rest	15	--
27-Jun-13	Rainy	Irrigation	60	--
17-Jul-13	Fine	Irrigation	100	--
31-Jul-13	Fine	Irrigation	100	--
26-Aug-13	Cloudy	Drainage	50	25
1-Oct-14	Fine	Rest	30	24
14-Nov-14	Fine	Rest	7	10
25-Dec-14	Fine	Rest	10	6
30-Jan-14	Rainy	Rest	20	6.2
5-Mar-14	Rainy	Rest	30	8.8
1-May-14	Cloudy	Rest	18	20

May 23 Fine Rest 15cm; Jul 17 Fine Irrigation 100 cm Aug 26 Cloudy Drainage 50 cm

Oct 1 Fine Drainage 50 cm Nov 14 Fine Rest 7 cm March 5 Rainy Rest 30cm

Photo 2 States of canal in Hachihama paddy field

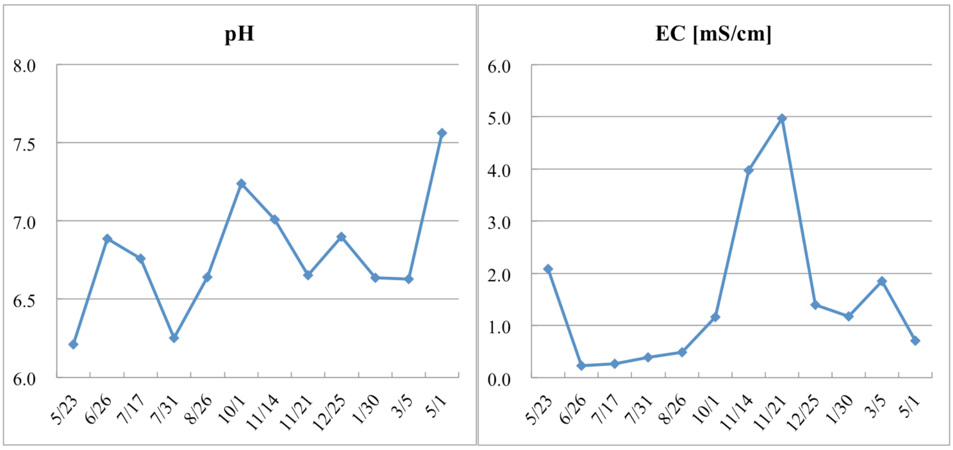


Fig. 5 Transient of pH and EC values of Hachihama Canal in a year

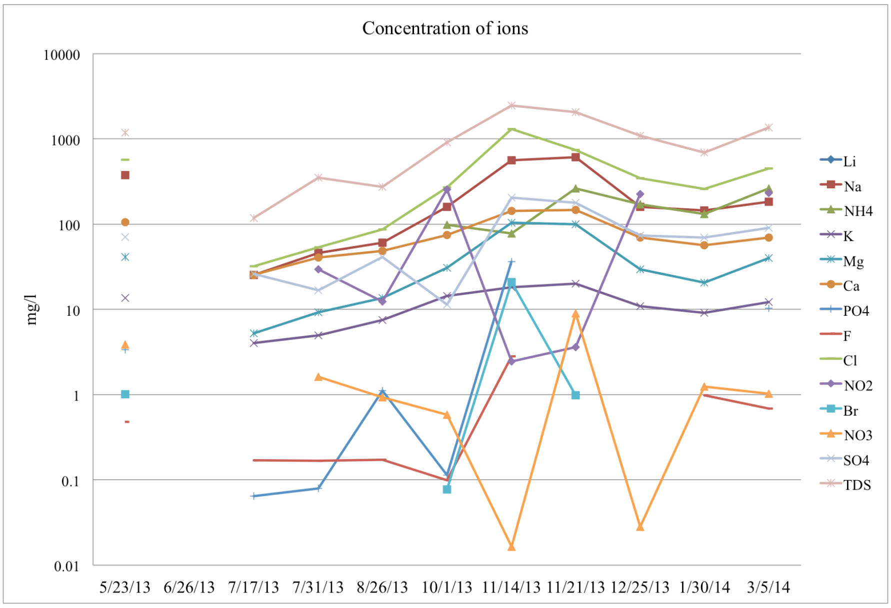


Fig. 6 Transient of ions of Hachihama Canal in 2013

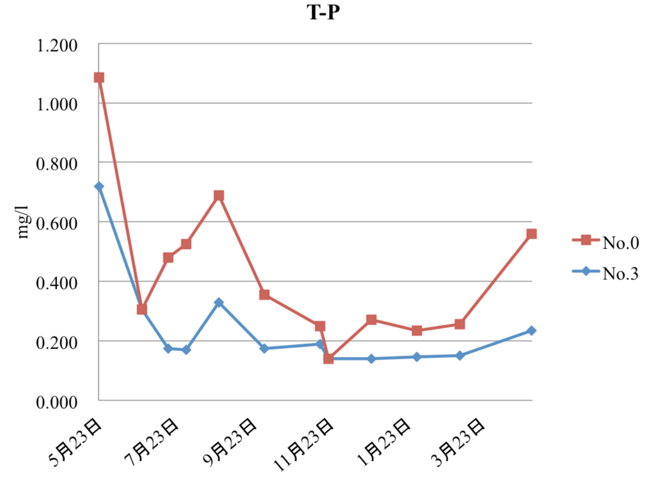


Fig. 7 Transient of TP of Hachihama Canal in 2013

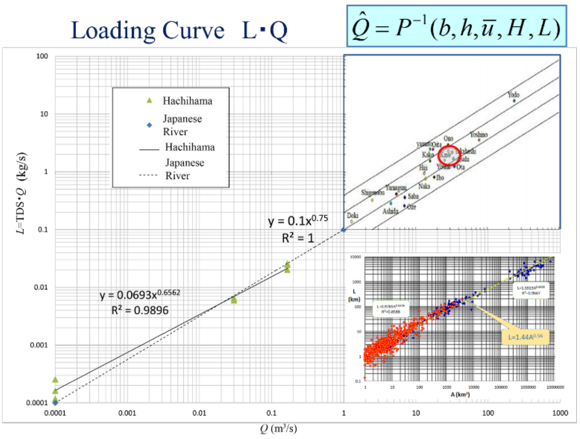


Fig. 8 *L*-*Q* equation of Japanese rivers and Hachihama canal

Table 2 Parameters of the tank model

Kojima Rivers		Sasagase R	Kurashiki R	Kamo R
o		3	3	3
A	k m2	297.5	154.0	92.2
L	k m	23.8	13.8	6.9
Runoff				
α11	1/day	0.19	0.19	0.19
α12		0.15	0.15	0.15
α2		0.03	0.03	0.03
α3		0.02	0.02	0.02
α4		0	0	0
Infiltration				
β1	1/day	0.01	0.01	0.01
β2		0.01	0.01	0.01
β3		0.002	0.002	0.002
Outlet				
Z11	mm	3	3	3
Z12		1	1	1
z2		1	1	1
z3		0	0	0
z4		0	0	0
evapotranspiration				
constant	mm/d	2	2	2
fraction		0.4	0.4	0.4

4. Discharge hydrograph into Lake

The equations are for the surface tank, *i*=1,

$$\begin{aligned} & dh_1/dt = R - E - q_{11} - q_{12} - I_1 \\ & q_{1j} = \alpha_{1j}(h_1 - \xi_{1j}), \quad I_1 = \beta_1 h_1 \end{aligned} \qquad (6)$$

then, subsurface tanks, i>1

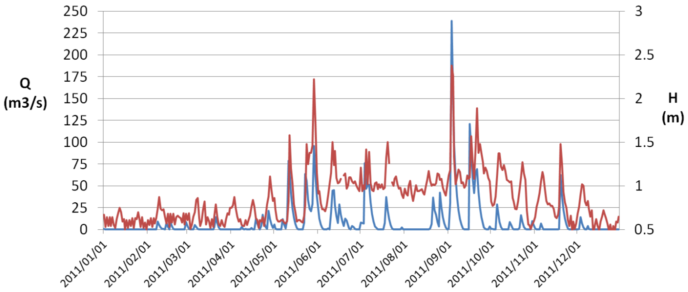
$$\begin{aligned} & dh_i/dt = I_{i-1} - q_i - I_i \\ & q_i = \alpha_i(h_i - \xi_i), \quad I_i = \beta_i h_i \end{aligned} \qquad (7)$$

where h is the R: precipitation; E: evapotranspiration; q: the surface or subsurface runoff in lateral direction; I: infiltration to the lower reservoir; and α and β are the coefficients . Evapotranspiration is calculated in the following paths: daily constant E_o; proportional to rain The cascading runoff model in the above is an array of four-storied reservoirs in the soil column so called tank model in Japan.

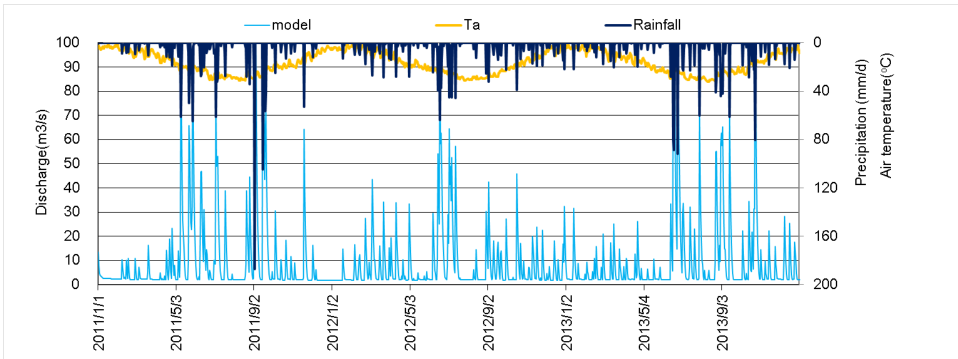
Discharge hydrographs are compared in Figure 9 and measured discharges are used for calibration of the runoff model, which is selected here a four storied serial tank model for watersheds as in Table 2.

Figure 10 shows *L*-*Q* curves of the suspended solid, SS and the phosphorous acid, PO_4 are identified of Sasagase, Kurashiki, and Kamogawa rivers. The inclination of the line of SS is greater than that of PO_4. The order of the inclination values are corresponding to the discharge volumes, namely, the order of Sasagase, Kurashiki and Kamogawa Rivers.

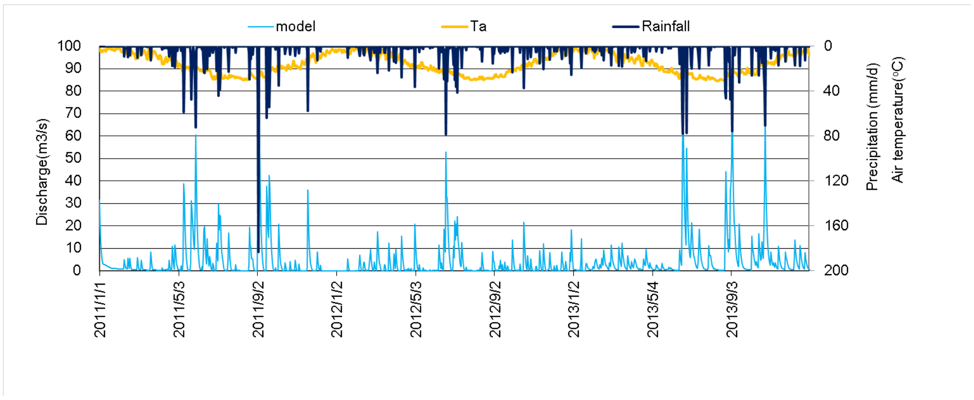
The accumulated sediment and phosphorus are shown in Figure 11.The runoff through the rivers in 2011, 2012 and 2013 was 1604 million m^3. Sediment yields in the rivers of the three years are 19,500 t. The average concentration Qs/Q is 0.012 gL^{-1} in total, or 0.01 gL^{-1} in the Sasagase River, 0.017 gL^{-1} in the Kurashiki River and 0.01 gL^{-1}, in Kamogawa River. The riverine phosphate concentrations Qp/Qs are 0.07 g/kg (S), 0.03 g/kg (K), and 0.06 g/kg (Ka), and the lake average is 0.05 g/kg.



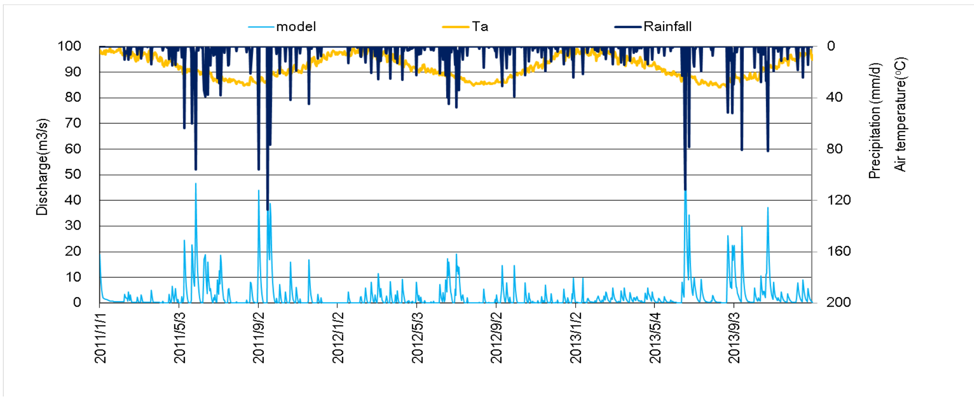
(a) Water level (red line) and discharge water (blue line) in Kojima Lake



(b) Hydrograph in Sasagase River and precipitation in Okayama



(c) Hydrograph in Kurashiki River and precipitation In Kurashiki



(d) Hydrograph in Kamogawa River and precipitation in Tamano

Fig. 9 Water level in Kojima Lake and discharge hydrographs in three rivers

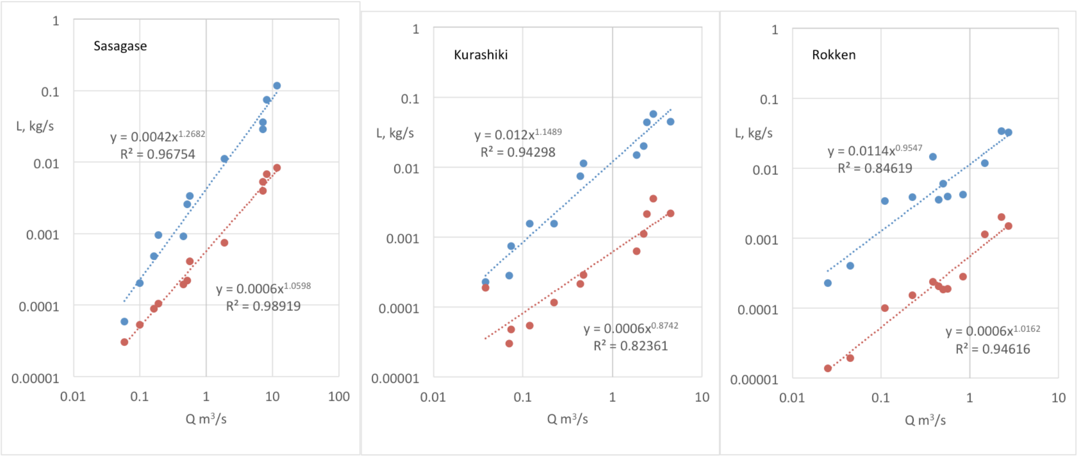
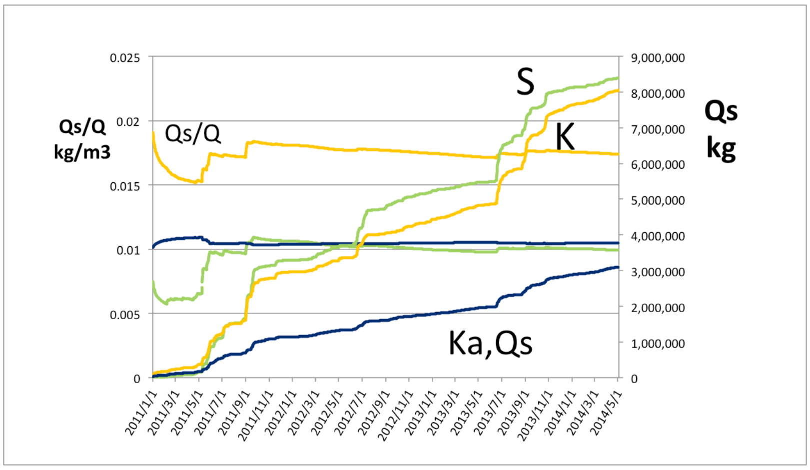
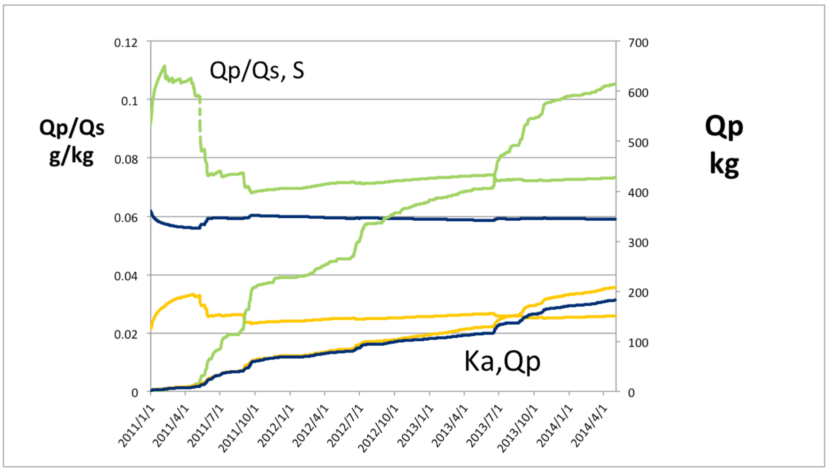


Fig. 10 L-Q curves of three rivers, Sasagawa, Kurashiki and Kamogawa Rivers (SS: blue line, PO_4: red line).



(a) Discharge of SS, Qs



(b) Discharge of PO_4, Qp

Fig.11 Cumulative sediment and phosphorus and their average concentrations (S: Sasagase, K: Kurashiki, Ka: Kamogawa)

5. Unit load method

1) Introduction of approach

Figure 12 is the satellite image of Kojima Lake Basin which has the area of 548km^2. Figure 13 shows the population distribution, the total population in the basin is approximately 600,000. Figure 14 shows the river and canal network in the basin, there is many irrigation and drainage canal in the reclaimed area.

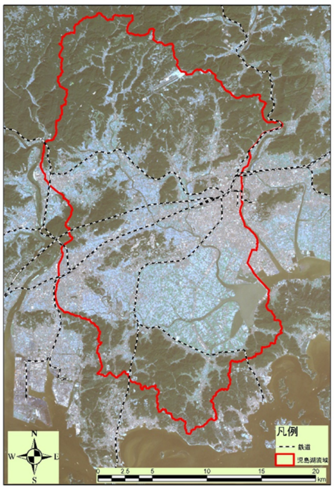


Fig.12 Satellite image

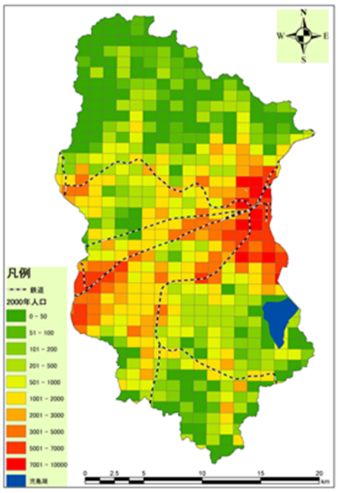


Fig.13 Population distribution

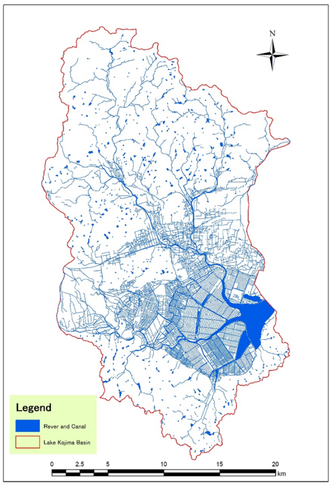
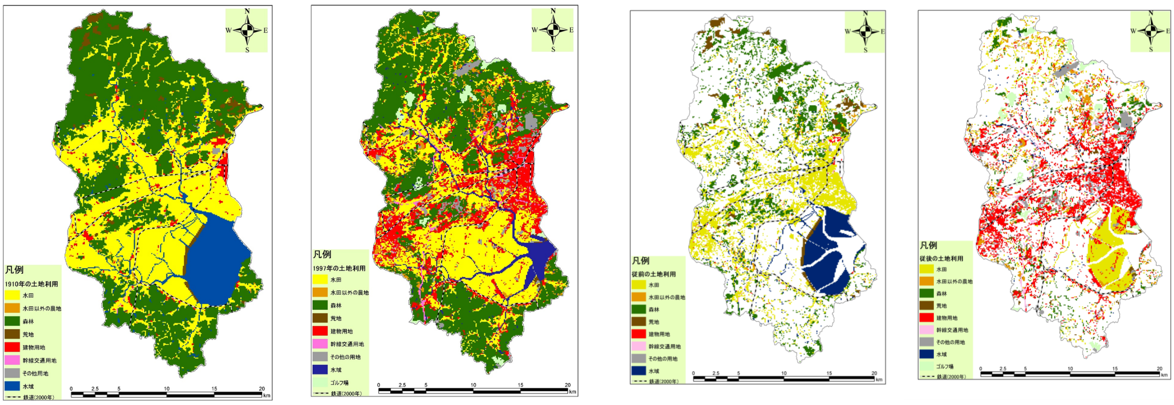


Fig.14 River and canal network

Figure 15 shows the land use of the basin in 1910 and 1997, and its change. In the last century, the land use in Kojima Lake Basin has been significantly changed, especially urbanization and land reclamation.



(a) (b) (c) (d)

(a)Land use in 1990, (b) Land use in 1997, (c) Previous land use of the changed site (1910-1997), (d) Present land use of the changed site (1910-1997)

Fig. 15 Land use change in the Kojima Lake basin

2) Methods

We tried to estimate the loadings in the Kojima Lake Basin by simple unit load method, and also tried to calculate the average runoff coefficient in the basin. The equations are as follows.

a) Estimation method of Loading in the Kojima Lake Basin (Unit load method)

$$L_j = \sum_i UL_{ij} LU_i \qquad (8)$$

L_j : Total loading of material *j* in Kojima Lake Basin

UL_{ij} : load unit of material *j* from land use category *i* (g/ha/day)

LU_i : area of land use category *i*

i: suffix for land use category (paddy, upland, forest, urban)
j: suffix for loaded material (COD, TN, TP)

b) Calculation method of average runoff coefficient in the Kojima Lake Basin

$$ARC = \sum_i RC_i LU_i / TA \qquad (9)$$

ARC: average ranoff coefficient

RC_i : runoff coefficient of land use category *i*

LU_i : area of land use category *i*

TA: total area of the Kojima Lake Basin
i: suffix for land use category (paddy, upland, forest, urban)

Table 3 shows the unit load (g/ha/day) and the runoff coefficient by land use type.

Table 3 Unit load and runoff coefficient by land use type

Unit load(g/ha/day)

	COD	TN	TP
paddy	139	31.2	13.4
upland	22.6	6.5	1.79
forest	38.7	3.8	0.22
urban	98.4	20.6	1.92

Runoff coefficient

paddy	0.2
upland	0.2
forest	0.3
urban	0.9

3) Results

Figure 16 shows the land use changes of Kojima Lake Basin in these 100 years. Urban area has been increased while paddy and water field has been decreased. Figure 17 shows the changes of the estimated loadings of COD in this basin applying equation (8). The total loading of COD has not so changed, but the share of loadings by land use have been shifted from paddy field to urban area.

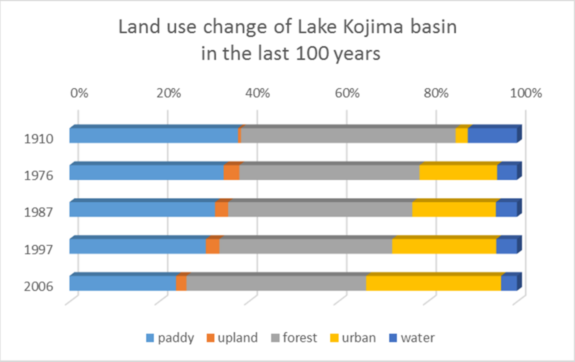


Fig.16 Land use change in these 100 years

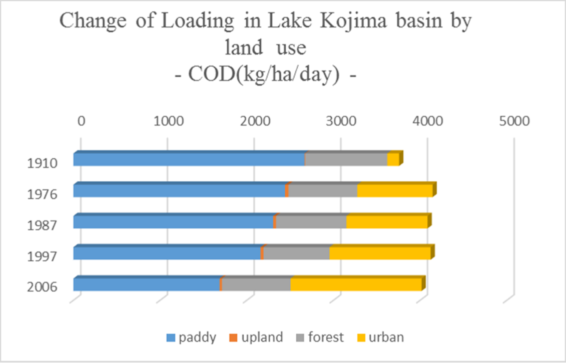


Fig.17 Estimated loadings of COD

Figure 18 also shows the changes of the estimated loadings of TN in this basin applying equation (8). The result was similar with the result of COD because these results are affected by land use. Figure 19 shows the changes of the estimated loadings of TP in this basin applying equation (8). The total loading of TP has been decreasing and paddy field has been occupying the large share.

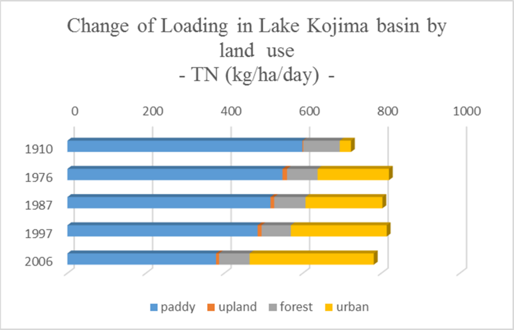


Fig. 18 Estimated loadings of TN

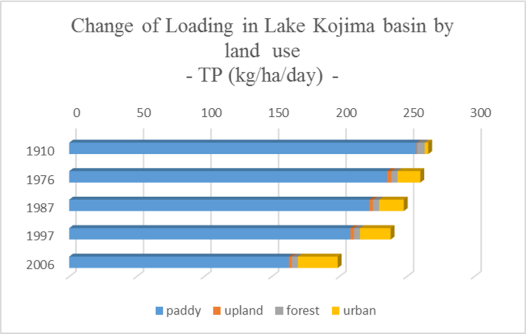
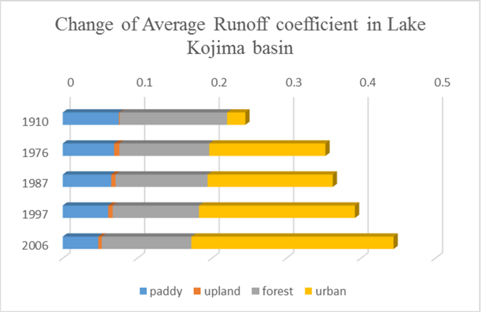


Fig. 19 Estimated loadings of TP

Figure 20 shows the change of the estimated average runoff coefficient in this basin applying equation (9). Thanks to the large runoff coefficient of urban land use and rapid urbanization, the average runoff coefficient has been increasing in these 100 years. Figure 21 shows the sub-catchments in Kojima Lake Basin. There are 5 sub-catchments as shown in Figure 21. We tried to estimate the loadings and the average runoff coefficient by sub-catchments applying equations (8) and (9).



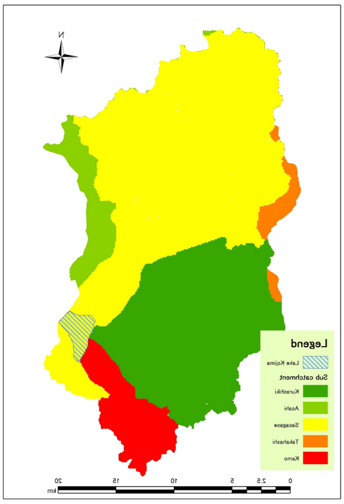
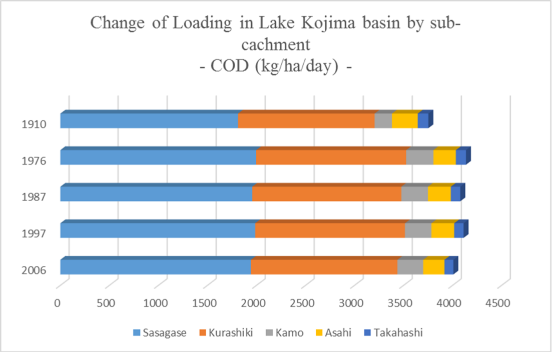


Fig. 20 Average runoff coefficients

Fig. 21 Sub-catchment

Figure 22 shows the changes of the estimated loadings of COD by sub-catchments applying equation (8). The share of each sub-catchments has not so changed. Figure 23 shows the changes of the estimated loadings of TN by sub-catchments applying equation (8). The result was similar with the result of COD.



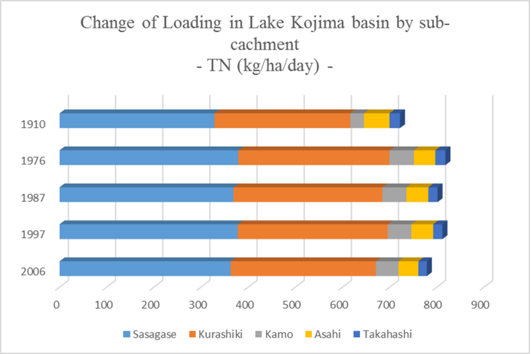


Fig. 22 Loadings of COD by sub-catchment

Fig. 23 Loadings of TN by sub-catchment

Figure 24 also shows the change of the estimated loadings of TP by sub-catchments applying equation (8). The total loading of TP has been decreasing but the share of each sub-catchments have not so changed. Figure 25 shows the estimated average runoff coefficients by sub-catchment. The average runoff coefficient have been increasing in all sub-basins, especially, Asahi and Takahashi sub-basin, thanks to the rapid increase of urban land use.

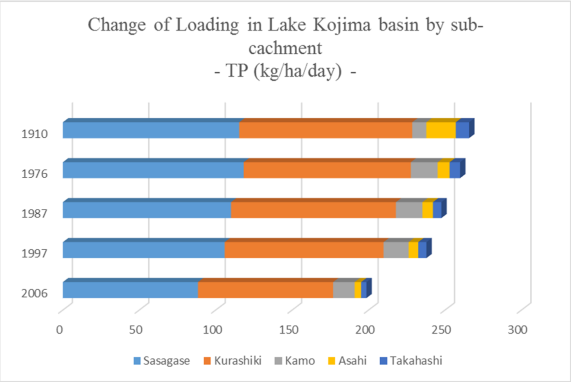


Fig. 24 Loadings of TP by sub-catchment

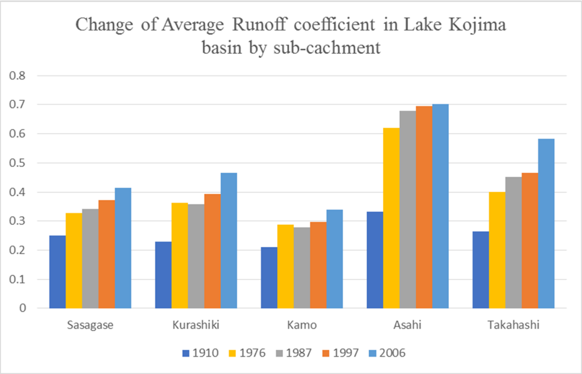


Fig. 25 Average runoff coefficient by sub-catchment

4) Summary

a) Estimation of Lording

Land use in Kojima Lake Basin has drastically changed in the last 100 years, but estimated loading amounts of COD, TN, TP have not so much changed. Main non-point source of loadings (COD, TN, TP) have been shifting from paddy field to urban area. Share of loadings within sub-basins have not so changed in these 100 years.

b) Calculation of average runoff coefficient

The average runoff coefficient in Kojima Lake Basin has been increasing. It indicates that the volume of surface runoff water tends to increase in this basin. Increase of average runoff coefficient has mainly owed to the increase of urban land use. Also, the average runoff coefficient has been increased in all sub-basins, especially, Asahi and Takahashi sub-catchments marked rather high value, because of much increase of urban land use.

6. Conclusions

1) A series of water quality survey has been conducted in Hachihama Paddy Field throughout year. Total phosphorus concentration is high in spring due to fertilizing. The *L-Q* curve for the Hachihama canal was derived from the *TDS* measurement. It was found that the *L-Q* relationship of Hachihama is the same as that of major Japanese rivers.

2) The loading curves of *TDS*, *TSS* and the nutrient are used in the tank model and it resulted in as follows for 3.33 years: S: Sasagase; K: Kurashiki and Ka: Kamo Rivers and the total or average.
Sediment yields: (S: 2,520, K: 2,400, Ka: 900 and totally 5,820) t/a in the three rivers and sediment concentrations: (S: 10.0, K: 17.5, Ka: 10.1 and simple average 12.5) mgL^{-1}.

The phosphates loading: (S: 198, K: 63, Ka: 54, and totally 315) kg/a; and concentrations: (S: 72, K: 27, Ka: 60, Average 53) ppm in the sediment are estimated.

3) Results of unit load method are strictly confined to the values of unit load and runoff coefficient, so we must pay much attention to the validity of the values. The sum or average of the runoff tank model would offer a chance of calibration of the higher end ArcSWAT.

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