The estimation of pollutant loads in the Kinokawa River, Japan

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ABSTRACT

Pollutant loads for organic matter, nitrogen and phosphorus were estimated in the Kinokawa River basin in central Japan. Water quality of the Kinokawa River has not been satisfied with the Japanese environmental quality standard and BOD, T-N and T-P concentrations increased in the middle stream. Main industrials in the Kinokawa River basin are artificial fiber in the middle stream. Moreover, there are many orange and other fruits orchards in the middle stream. The pollutant loads for BOD, T-N and T-P were estimated to specify the origins of pollution of the Kinokawa River. Moreover, pollution load at flood is estimated using automatic observation data including flood data.

Many floods are often observed and it is necessary to estimate an effect of flood on pollutant loads. The frequency is limited and particularly at the flood condition, sampling is difficult for safety. Then previous periodical 1 month measurement does not include flood condition. Recent 1 hour measurement is automatically sampled and measured in situ at the station and then includes flood condition. Pollutant loads at flood condition was clarified comparing the 1 month measurement and the 1 hour measurement. Using the relationships between COD and flow rate, COD loads were calculated. As a result, the COD load calculated by the 1 hour measurement was about 2 times as large as the COD load calculated by the 1 month measurement. Therefore the flood loads is very large in the Kinokawa River.

Then, origins of pollution in the Kinokawa River were analyzed by L-Q equation and pollutant load per unit production using a field survey result and the previous data. As a result, BOD and T-N values calculated from L-Q method were in good agreement with those calculated from pollutant load unit production method. The T-P loads calculated from the pollutant load per unit production was 2 times as large as the actual T-P loads measured by L-Q equation. Pollutant load source was estimated by pollutant loads per basic unit method. Main sources of BOD, T-N, and T-P in the Kinokawa River basin were estimated to be domestic sewage, orchard and industrial wastewater respectively. Comparing the lower and the upper stream of the Kinokawa River basin, main sources of BOD and T-P in the upper stream were forest. Main sources of BOD and T-P in the lower stream were domestic sewage and industrial wastewater. Main source of T-N in the middle stream was orchard.

KEYWORDS; land use, L-Q equation, pollutant load per unit production, BOD, T-N, T-P

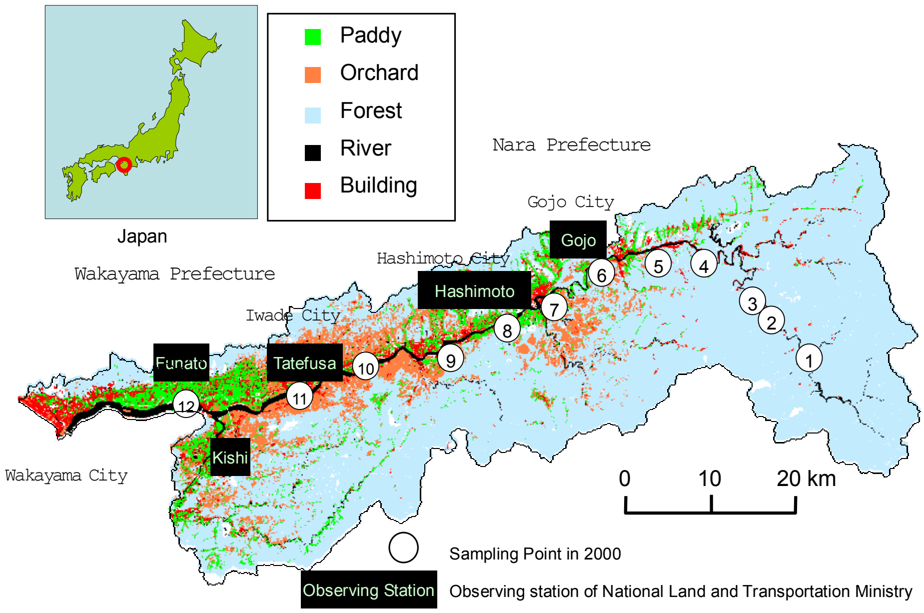

Figure 1. Location of the Kinokawa River basin, investigation spot and fixed observing station

1. INTRODUCTION

Kinokawa River is a very important water source of drinking, industry and agriculture. Contaminant derived from factory, household and farm has increased because of growth of cities in these years.

The origin of the pollution load in Kinokawa River was calculated and was compared with actual measurement. The pollutant load was classified into natural, living and industrials by source of pollutions. Japanese government controlled discharged water and kept up sewerage system in the river basin. However, some tributary still has a river water pollution problem. Therefore the purpose of this research is to grasp mechanism of river water pollution for improving water quality and to clear relation between land use and water quality in the Kinokawa basin.

2. RESEARCH AREA AND STUDY METHOD

Figure 1 shows the study area. Kinokawa River basin is located in the middle of Japan near Osaka. The precipitation is 4000 mm in the upper stream of the Kinokawa River basin and 1600 mm in the lower stream. The drainage area of Kinokawa River basin is 1750 km^2. The length of river channel is 75km. Population using the Kinokawa River water is about 700,000 people. Therefore the upper stream of the Kinokawa River basin is important water source and its land use is forest. In the middle stream, main land use is orchard and there are a few small cities. Main orchards are peach, persimmon and mandarin orange. And main industry is fiber industry. In the lower stream, main land use is rice field and housing site with business district.

White circles are sampling points in 2000 and Black box shows water quality observing station of National Land and Transportation Ministry in Fig.1. River water was sampled in July 2000. Major ions (HCO_3^-, Ca^{2+}, SO_4^{2-}, NO_3^-, Na^+, Cl^-) of the sampled water were analyzed by ion exchange chromatography. Moreover, published data of observing station of National Land and Transportation Ministry also used for water quality analysis.

3. DISSOLVED COMPONENT CONCENTRATION CHANGE IN MAIN STREAM

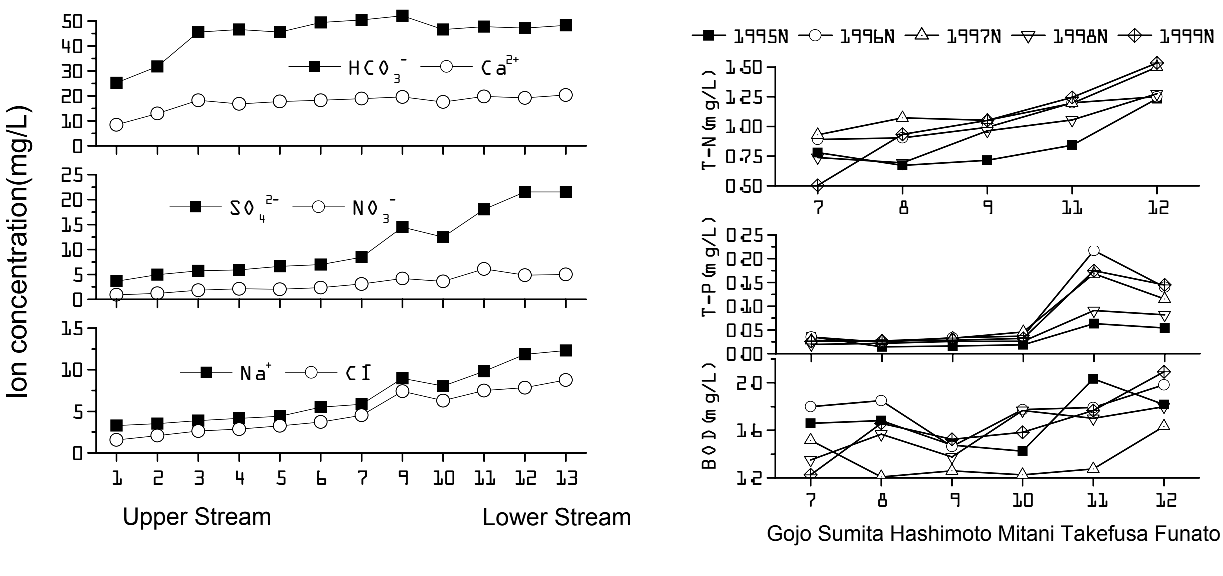

Figure 2. Dissolved component change in main stream (Left: survey in 2000, Right: national observing station)

Figure 2 shows dissolved component from the upper stream to the lower stream of the Kinokawa River basin. Left side figures are survey results in July 2000 and Right side figure is water quality data of national observing station from 1995 to 1999. HCO_3^- concentration is from 20 mg/L to 50 mg/L. HCO_3^- concentration is high from the middle stream to the lower stream. Ca^{2+} concentration is from 10 mg/L to 20 mg/L. SO_4^{2-}concentration is from 5 mg/L to 25 mg/L. NO_3^- concentration is from 0 mg/L to 5 mg/L. Na^+ concentration is from 3 mg/L to 12 mg/L. Cl^- concentration is from 2 mg/L to 10 mg/L. HCO_3^- and Ca^{2+} concentration were uniform from the middle stream to the lower stream. However SO_4^{2-}, NO_3^-, Na^+, Cl^- concentration increased down the stream. T-N concentration increased from the upper stream to the lower stream gradually. However T-P concentration rapidly increased in the lower stream. BOD concentration is low in the middle stream and is high in the lower stream every year. Therefore, T-N concentration change is different form T-P concentration change. Therefore, it is estimated that source of each dissolved components are different and then it is necessary to identify source of dissolved component.

4. ESTIMATION OF COD LOAD IN USING L-Q EQUAION

It is necessary to calculate pollutant load, in order to identify source of dissolved components. Relation between flow rate and pollutant load was calculated by formula (1). Flow rate has not been measured every day in the basin. The pollutant load can be also estimated from flow rate from formula (1), even if concentration is unknown.

$$L = aQ^b \tag{1}$$

L shows Pollutant load. Symbol *a* and *b* show constant number. Q shows flow rate.

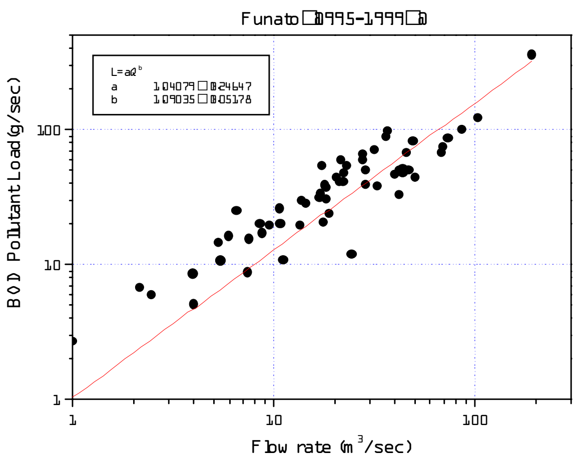

Figure 3. Ration between flow rate and BOD pollutant load

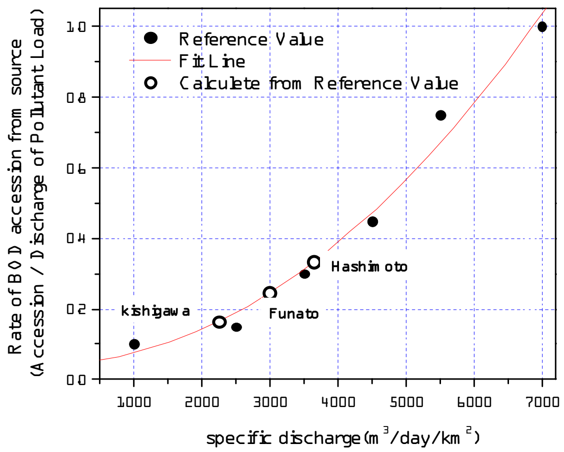

Figure 4. Relation between specific discharge and rate of BOD accession from source

Table 1 rate of accession of load of BOD, T-N and T-P

	hashimoto	fnato	kishi
BOD	0.33	0.25	0.17
T-N	0.78	0.73	0.65
T-P	0.78	0.69	0.54

Figure 3 shows relation between flow rate and BOD pollutant load from 1995 to 1999 at the Funato observing station. Annual BOD load is calculated by L-Q formula. The used BOD data was only measured once a month and did not include BOD values under flood condition. Therefore, annual BOD load also did not include BOD load under flood condition. Pollutant derived from industry, household and farm sources was decomposed and then generally pollutant load decreases down the stream. Therefore, observed load is smaller than load at source point. The rate of accession load is defined as ratio of load at observation point and load at source point. Generally, observation load from source is calculated from source load and rate of accession load. Ukita and Nakanishi in 1985 proposed that the rate of accession load was able to be calculated from specific discharge.

Table 1 shows rate of accession of load of BOD, T-N and T-P. The rate of BOD accession load at the Funato, Hashimoto and Kishi was calculated from specific discharge.

5. RELATION BETWEEN COD AND FLOW BY DISTINCTION OF MESURE INTERVAL

Table 2 COD pollutant Load at Funato Observing Station

COD Pollutant Load	Funato			
	1999	2000	2001	2002
L-Q Formua□1 month□=0.004*Q^1.2	5456	3536	5937	2677
L-Q Formua□1 hour□=0.003*Q^1.4	8894	5258	10271	3590

Table 1 shows COD pollutant Load at the Funato observing station. COD load can be calculated from COD values and flow rate. COD values (1 month COD) measured every month and COD values (1 hour COD) measured every hour were used for analysis and were compared. 1 month COD does not include flood condition and then 1 month COD load is different from the 1 hour COD load. Therefore, it is necessary to calculate pollutant load including flood condition using 1 hour COD. As a result, the pollutant loads using 1 hour COD were from1.2 to 2 times as large as the pollutant loads using 1 month COD.

6. THE POLLUTANT LOAD FROM HOUSING SITE

A pollutant load discharge from housing site can be calculated form a pollutant load per unit person per day and population of the river basin. The treating method of sewage water is various and each ratio is not uniform. Therefore, the pollutant load can be calculated from public sewerage (1), united septic tank (2), singleness septic tank (3), pump up night soil (4) and others (5). Amount of pollutant load of city was calculated from equation (2).

$$Lpl = \sum_i \sum_j (G_L \times P_i \times R_{ij} \times B_j \times \frac{365}{10^6}) \qquad (2)$$

Symbol Lpl (t/year) shows a pollutant load discharge from housing site, Symbol i shows index of city, Symbol j shows index of treatment system form. G_L shows a basic unit of pollutant load (g/people/day). P_i is city i of population (people). R_{ij} is rate of sewage disposal facilities (%). B_j is rate of discharge from sewage disposal facilities (%)

Table 3 shows city of population and rate of sewage disposal facility. This is referenced by homepage of Wakayama prefecture. And this is referenced by department of measures of waste material, department of sewage system and division of agricultural and Forestry in Nara Prefecture.

Table 3 population and rate of sewage disposal facility

	i	P_i	R_{i1}	R_{i2}	R_{i3}	R_{i4}	R_{i5}
Wakayama	1	394095	12.6	43.2	10.5	33.6	0.0
Kainan	2	47203	0.0	9.9	24.1	66.0	0.0
Hashimoto	3	55610	0.0	40.5	36.7	22.7	0.0
Nokami	4	8576	0.0	13.2	18.0	68.8	0.0
Misato	5	4357	0.0	14.7	24.8	60.5	0.0
Utita	6	15253	0.0	19.9	18.7	61.5	0.0
Kokawa	7	17326	0.0	20.8	20.9	58.4	0.0
Naga	8	8996	0.0	11.6	22.5	65.9	0.0
Momoyama	9	8214	0.0	24.0	13.6	62.5	0.0
Kisigawa	10	21840	11.4	26.7	11.7	50.3	0.0
Iwade	11	48146	0.0	25.8	14.7	59.5	0.0
Katsuragi	12	20918	0.0	6.0	33.5	60.4	0.0
Kouyaguchi	13	15817	0.0	6.3	48.2	45.5	0.0
Kudoyama	14	6271	0.0	2.4	39.9	57.7	0.0
Kouya	15	4947	68.8	6.4	4.9	19.8	0.0
Gojo	16	36378	44.1	16.9	2.2	36.8	0.0
Yoshino	17	11561	11.2	30.4	14.4	41.5	2.5
Ohyodo	18	20837	20.2	25.9	35.0	18.9	0.0
Ishimoichi	19	8668	6.7	37.9	9.1	46.3	0.0
Kurotaki	20	1254	0.0	0.0	34.7	65.3	0.0
Nishiyoshino	21	4082	0.0	13.7	6.2	76.4	3.8
Kawakami	22	2660	0.0	69.1	4.1	26.7	0.0
Higashiyoshino	23	3176	0.0	8.3	11.0	80.6	0.0

Table 4 basic unit of arises from living and rate of sewage disposal facility of discharge

	G_L	B_1	B_2	B_3	B_4	B_5
BOD	58.0	7.0	80.0	10.0	67.5	10.0
T-N	11.0	61.0	76.7	49.0	16.9	49.0
T-P	1.3	39.0	50.0	65.0	31.0	64.0

Table 4 shows basic unit of arises from housing site and rate of sewage disposal facility of discharge.

The pollutant load of discharge from housing site is calculated from formula (2).

7. THE POLLUTANT LOAD FROM INDUSTRY

Pollutant load of discharge from industry is calculated from formula (3).

$$D_I = \sum_i \sum_j (G_{Ij} \times M_{ij} \times C_{ij} \times 365/10^6) \qquad (3)$$

D_I shows a pollutant load discharge from industry, Symbol i shows index of city, j shows category index of industry. G_{Ij} shows a category index j of basic unit of pollutant load (g/day/million Yen). M_{ij} shows city i of industry j of shipment value (million Yen). C_{ij} shows City i of category j of rate for amount of business place.

Table 5 basic unit of discharge from industry (G_{lj})

(Index) assortment	BOD	T-N	T-P
	basic unit (g/day/million Yen)		
(12) foods	38.78	5.26	0.83
(13) drink/fodder	14.05	1.42	0.20
(14) fabric	38.44	13.15	1.89
(15) apparel	7.73	1.09	0.10
(16) wood	3.68	0.18	0.03
(17) furniture/accessory	2.25	0.10	0.06
(18) pulp/peper	7.47	0.80	0.02
(19) print	1.71	0.10	0.03
(20) chemistry	24.71	9.75	1.28
(21) oil/coal	3.20	0.28	0.11
(22) plastic	5.17	0.27	0.15
(23) rubber	1.50	0.14	0.26
(24) tannage	216.72	13.32	1.55
(25) ceramic industry/soil and stone	2.70	0.24	0.05
(26) iron and steel	1.34	0.38	0.03
(27) nonferrous metal			
(28) metalware	2.88	0.88	1.24
(29) general machinery	1.66	0.76	0.78
(30) electric machine	7.06	0.73	0.42
(31) information-communication machine	7.08	1.13	1.04
(32) precision instrument	2.25	0.52	0.13
(34) others	29.82	9.72	9.54

Table 5 shows basic unit of pollutant load from industry (G_{lj}). The basic unit of pollutant load from industry (G_j) is calculated from formula (4).

$$G_j = \frac{\sum_k J_k \times K_k}{\sum_k M_k} \qquad (4)$$

Symbol k is category j of fine sort. J_k is fine sort k of water quality of industrial waste water (mg/L). Symbol K_k is fine sort k of amount of industrial waste water (m^3/day). Symbol M_k is fine sort k of shipment value (million Yen). Basic unit in Table 5 is calculated from raw data from factories. When amount of discharged water was less than $50m^3/s$, actual concentration was utilized. However, when amount of discharged water was over $50m^3/s$ and actual concentration was satisfied with Japanese Water Pollution Control Law, actual concentration was adopted but when actual concentration was over than Japanese Water Pollution Control Law, Japanese Water Pollution Control Law was adopted.

8. THE POLLUTANT LOAD FROM VEGETATION

Table 6 basic unit f arises from vegetation

	paddy	farm land	orchard	forest
				(kg/km^2/year)
BOD	7078	1694	1694	1586
T-N	1280	6710	9827	440
T-P	165	72	125	34

Table 6 shows basic unit of pollutant load discharge from vegetation. Multiplying the area (km^2) by the basic unit of pollutant load discharge from vegetation (kg/km^2/year) gives the annual pollutant load.

Generally basic unit of COD and unit of BOD in lake can be presented by equation (5) and (6) because both basic unites are directly proportional to specific discharge from empirical results. As rain wash out substances such as fertilizer in soil, rain strength increases with increase of discharged substances from soil. Discharged water finally flows into lake. Formula (5) shows relation between COD load per basic unit and specific discharge, Formula (6) shows and relation between BOD load per basic unit and specific discharge.

$$\text{COD}\square\ Gn = 0.1486 \times q^{0.8763} \times 365 \qquad (5)$$

$$\text{BOD}\square\ Gn = 0.0702 \times q^{0.9671} \times 365 \qquad (6)$$

Symbol Gn is basic unit of pollutant load discharge (kg/km^2/year). Symbol q is specific discharge (L/km^2/s). So the specific discharge at the Funato observing station is 25.7L/km^2/s, COD load per basic unit discharge is 11110 kg/km^2/year, and BOD load per basic unit discharge is 7048 kg/km^2/year. COD and BOD basic units are used only for lake. These values are not directly able to be utilized. COD basic unit is only published for each land use. Then BOD basic unit was calculated from COD basic unit using the ratio of 7048/11110. The estimated BOD basic units for paddy, farm orchard, and forest were shown in table 6.

T-N and T-P loads per basic unit discharge from paddy, farm and forest are average in Japan. T-N and T-P loads per basic unit discharge from orchard are calculated from used amount of fertilizer of orange, peach, Japanese persimmon.

9. RESULT OF POLLUTANT LOADS PER BASIC UNIT METHOD

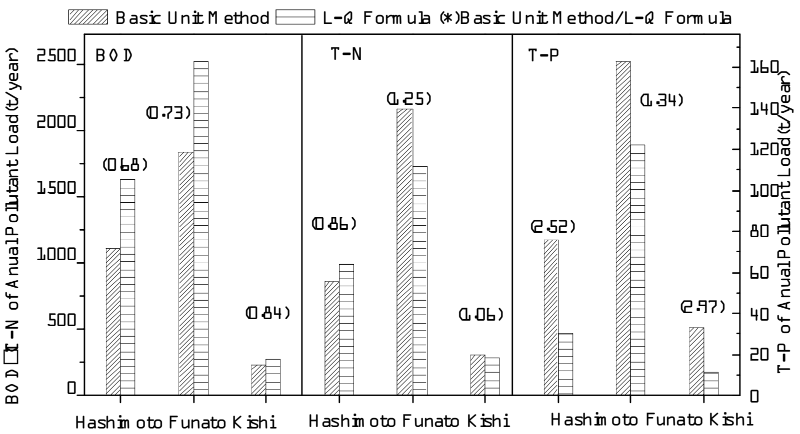

Figure 5. Comparing pollutant loads per basic unit method with L-Q formula

Figure 5 shows comparison of results from pollutant loads per basic unit method with results from L-Q Formula. Each of Loads of L-Q formula is calculated from flow rate in the Hashimoto, Funato and Kishi. Each of pollutant loads per basic unit method is calculated from sum of discharged loads of upper stream of area. As a result, BOD, T-N Load is similar with loads calculated from L-Q formula. T-P Load is 2 times as large as loads calculated from L-Q formula. Pollutant load in the Funato is highest and that in the Kishi is the minimum from both methods.

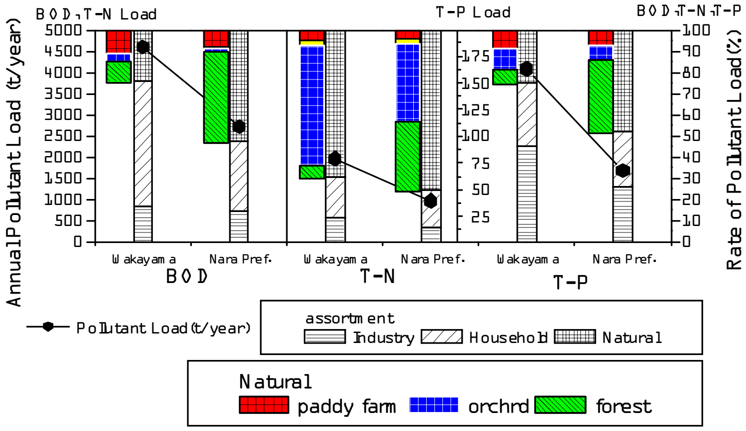

Figure 6. The result of pollutant loads per basic unit method

Figure 6 show the result of pollutant load per basic unit method. The pollutant load source was estimated from pollutant loads per basic unit method. Main sources of BOD, T-N, and T-P in the Kinokawa River basin were estimated to be domestic sewage, orchard and industrial wastewater respectively. Comparing the lower and the upper stream of the Kinokawa River basin, main sources of BOD and T-P in the upper stream were forest. Main sources of BOD and T-P in the lower stream were domestic sewage and industrial wastewater. Main source of T-N in the middle stream was orchard.

10. CONCLUSION

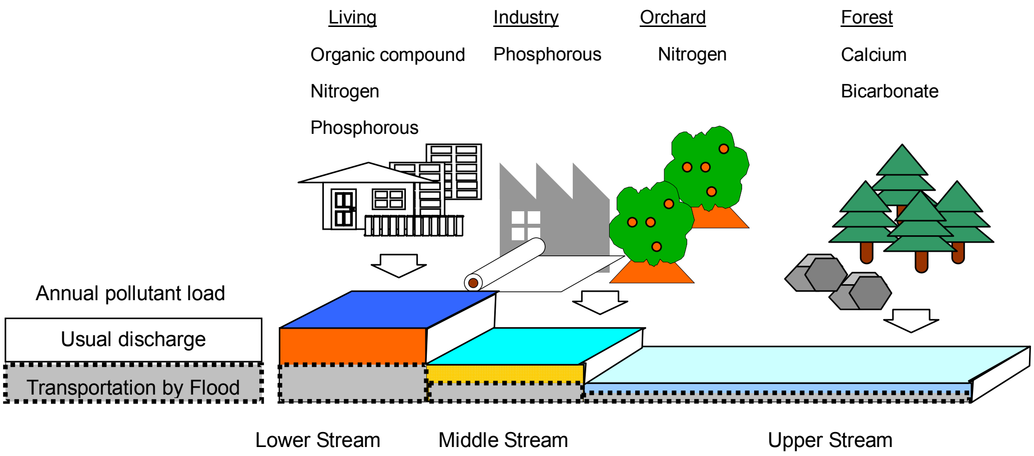

Figure 7. The contour of Pollutant Load ambulation in Kinokawa River Basin

Pollutant loads for organic matter, nitrogen and phosphorus were estimated in the Kinokawa River basin in central Japan. Kinokawa River Basin have problem for water quality. As a result, the COD load calculated by the 1 hour measurement was about 2 times as large as the COD load calculated by the 1 month measurement. Therefore the flood loads is very large in the Kinokawa River.

Then, origins of pollution in the Kinokawa River were analyzed by L-Q equation and pollutant load per unit production using a field survey result and the previous data. As a result, BOD and T-N values calculated from L-Q method were in good agreement with those calculated from pollutant load unit production method. The T-P loads calculated from the pollutant load per unit production was 2 times as large as the T-P loads calculated by L-Q equation. Pollutant load source was estimated by pollutant loads per basic unit method. Main sources of BOD, T-N, and T-P in the Kinokawa River basin were estimated to be domestic sewage, orchard and industrial wastewater respectively. Comparing the lower and the upper stream of the Kinokawa River basin, main sources of BOD and T-P in the upper stream were forest. Main sources of BOD and T-P in the lower stream were domestic sewage and industrial wastewater. Main source of T-N in the middle stream was orchard. In particular, T-N, T-P load in middle stream is high in Kinokawa River Basin. Therefore, it is necessary to make improvements water quality in middle stream of Kinokawa River Basin.

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