Chapter 2
Pollutant Load and Water Quality

Pollutant load per capita flowing into water body (PLC_{wb}) is an index to evaluate contribution of municipal wastewater pollutant discharge in pollutant load flowing into ambient water body such as coastal zones, bays and lakes. PLC_{wb} is not commonly applied in water pollution fields, however, PLC_{wb} should be more widely applied because of its easily understandable characteristics especially for comparison purposes among wastewater treatment methods or systems, among river sub-basins, and among countries, for miscellaneous stakeholders including policy makers, professionals of water environment and wastewater treatment and ordinary citizens.

PLC_{wb} is different by wastewater treatment methods and sub-river basins. For example, PLC_{wb}-BOD has been estimated to be 0.83 g person^{-1} day^{-1} (gpd) for WWTPs populations, 0.8–2.4 gpd for combined *johkasou* populations, 8.3–24 gpd for simple *johkasou* populations, and 7.8–21 gpd for night soil treatment system populations in a river basin of Japan (Tsuzuki 2006). The pollutant discharge calculator should be prepared for each sub-river basin and for each municipal wastewater treatment method. The pollutant discharge calculators can be utilised to enhance community involvement in water environment preservation and improvement.

Pollutant discharge per capita (PDC) is an index to simply indicate pollutant discharge amount to ambient water. PDC of municipal wastewater is a function of pollutant generation per capita (PGC) and treatment efficiencies of municipal wastewater treatment systems. The Millennium Development Goals (MDGs) sanitation indicator is 100 % in Japan. However, there have still been some municipal wastewater pollutant discharge problems. One of the key indices in sanitation and wastewater treatment in Japan is population with flush toilets. On the contrary, in Thailand, the MDGs sanitation indicator is 99–100 %, however, PDCs in Thailand are larger than those in Japan (Tsuzuki et al. 2009c). Therefore, more improvement of municipal wastewater treatment is necessary to improve the ambient water quality in Thailand. These situations may be similar in other developing countries with large MDGs sanitation indicator or on truck country.

In this chapter, estimation methods of PLC_{wb} and their results are explained. Water quality profiles in the past and present are explained to consider the relationships

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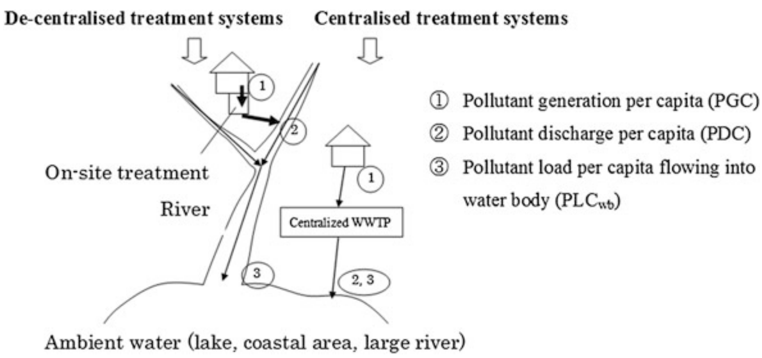

Fig. 2.1 Water pollutant indicators in centralized and on-site wastewater treatment systems (Modified from Tsuzuki 2005). (Copyright permissions have been obtained from JECES and Nova Science Publishers)

between pollutant discharges and the ambient water quality. The sub-river basin basis analysis of PLC_{wb} has been firstly conducted in the Miyako-gawa River Basin, Chiba Prefecture, Japan, which flows into the Tokyo Bay (Tsuzuki 2006). The indicator, PLC_{wb}, has been quantitatively evaluated by sub-river basin and wastewater treatment method. An example of pollutant discharge calculator of municipal wastewater shows the quantification concept and method of the soft intervention effects on pollutant discharge reductions and ambient water quality improvement.

2.1 Pollutant Load per Capita Flowing into Water Body (PLC_{wb})

In this section, the municipal wastewater pollutant indicators and their relationships with ambient water are discussed and explained. There are several indicators on water pollutant discharges and environmental water quality (Fig. 2.1):

1. Pollutant generation per capita (PGC);
2. Pollutant discharge per capita (PDC);
3. Pollutant load per capita flowing into water body (PLC_{wb}); and
4. Water quality.

The water body is considered as the ambient water especially bay or coastal areas in Fig. 2.1. Analysis of PLC_{wb} and Pollutant discharge calculator of municipal wastewater is conducted for several on-site and centralised municipal wastewater treatment systems in Japan (Fig. 2.2).

PDC and PLC_{wb} are calculated with Eqs. 2.1 and 2.2

$$(PDC(POL_j))_i = PGC_j \times \frac{(100 - WTE_{i,j})}{100} \tag{2.1}$$

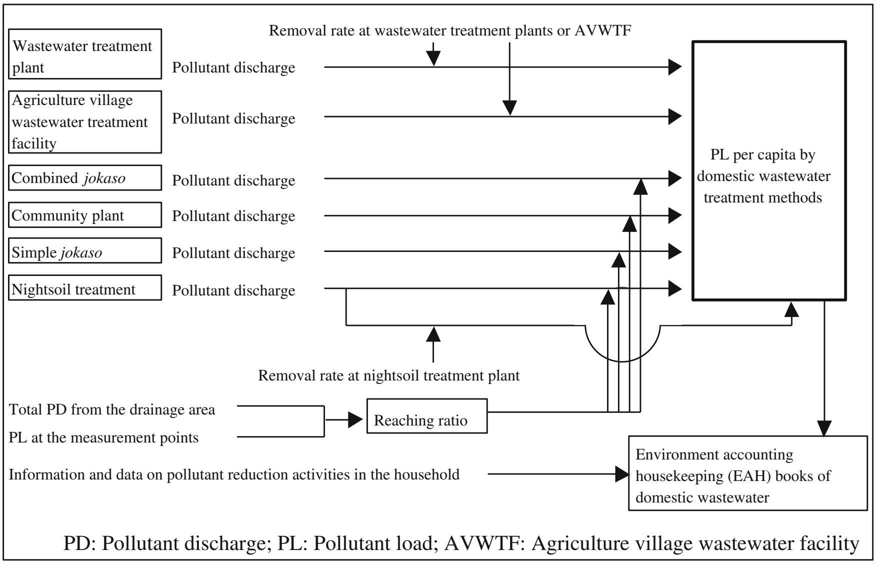

Fig. 2.2 Flow chart of the analysis of pollutant load per capita flowing into the water body (PLC_{wb}) and pollutant discharge calculator for municipal wastewater. (Tsuzuki 2006) (Removal rate is pollutant removal efficiency. Reaching ratio is pollutant yield rate). (Copyright permissions have been obtained from Elsevier and Nova Science Publishers)

where $(PDC(POL_j))_i$ is pollutant discharge per capita (PDC) of pollutant j with municipal wastewater treatment method i (g person^{-1} day^{-1}); PGC_j is pollutant generation per capita (PGC) of pollutant j (g person^{-1} day^{-1}); and $WTE_{i,j}$ is wastewater treatment efficiency of pollutant j with municipal wastewater treatment method i (%).

$$(PLC_{wb}(POL_j))_i = (PDC(POL_j))_i \times \frac{PRY_j}{100} \tag{2.2}$$

where $(PLC_{wb}(POL_j))_i$ is pollutant load per capita flowing into water body (PLC_{wb}) of pollutant j with municipal wastewater treatment method i (g person^{-1} day^{-1}); and PRY_j is pollutant runoff yield of the pollutant j (%).

Pollutant discharge within a sub-river basin, $PD_{ka,j}$ (g day^{-1}), is calculated for the area above the monitoring point using Eq. 2.3 (Tsuzuki 2006).

$$PD_{ka,j} = PD_{k,j} \times \frac{A_{ka}}{A_k} \tag{2.3}$$

where $PD_{k,j}$ is pollutant discharge of pollutant j in the sub-river basin k (g day^{-1}), A_{ka} is land area above the monitoring point in the sub-river basin k (km^2) and A_k is total land area in the sub-river basin k (km^2).

For sub-river basins downstream of the other sub-river basin(s), pollutant load used for the calculation of pollutant runoff yield is calculated with Eq. 2.4, and corresponds to pollutant discharge.

$$PL_{k,j} = PL_{k-1,j} + PD_{k,j} \times \frac{A_{ka}}{A_k} \tag{2.4}$$

where, $PL_{k,j}$ is pollutant load of pollutant j in the rivers at the monitoring points in the sub-river section k (g day^{-1}).

For river basins with a riverside purification facility, the pollutant discharge of the river basin has been calculated using the removal efficiency of a pollutant in the river water purification facility, and the treated and untreated river water volumes in the river water purification facility (Eq. 2.5).

$$PL_{kb,j} = PL_{k,j} \times \frac{\{(1 - \frac{RE_v}{100}) \times Q_t + Q_u\}}{Q_t + Q_u} \tag{2.5}$$

where, $PD_{kb,j}$ is pollutant load of pollutant j below the river water purification facility v in the sub-river section k (g day^{-1}), $PD_{k,j}$ is pollutant load of pollutant j above the river water purification facility v in the sub-river section k (g day^{-1}), RE_v is removal efficiency of the riverside purification facility v (%), Q_t is treated river water volume in the river water purification facility (m^3 day^{-1}), and Q_u is untreated river water volume in the river water purification facility (m^3 day^{-1}).

In Eq. 2.5, it is assumed that only one river water purification facility is developed in the corresponding sub-river section. When there are more than one river water purification facilities in the sub-river section k, there are two calculation methods. One is calculations using Eq. 2.5 for the number of times of the facilities. Another is one-time calculation supposing the effects of several river water purification facilities into one specific removal efficiency with pollutant loads at the most upper and the lowest points of these river water purification facilities.

Figure 2.3 shows some places in Japan explained in this book. Tokyo Bay is surrunded by Chiba and Kanagawa Prefectures and Tokyo Metropolitan.

We can estimate contributions of municipal wastewater discharges to ambient water quality (Table 2.1). PLC_{wb}(BOD) has been found to be different by sub-river basin even with the same municipal wastewater treatment method in a case study in Chiba City, Japan (Fig. 2.4) (Tsuzuki 2006). Contribution of pollutant discharge to the Tokyo Bay can be estimated for each sub-river basin and municipal wastewater treatment method. Then, effects of pollutant discharge reduction measures or soft measures in households can be estimated for each sub-river basin and municipal wastewater treatment method (Table 2.1). PLC_{wb} depended on sub-river basin even with the same wastewater treatment method.

Along with economic development, PGC should increase to some extent with increase of foods, chemicals and materials amounts used in people's lives and industries. PDC should increase with PGC increase when appropriate wastewater treatment systems are not applied, and decrease after wastewater treatment system

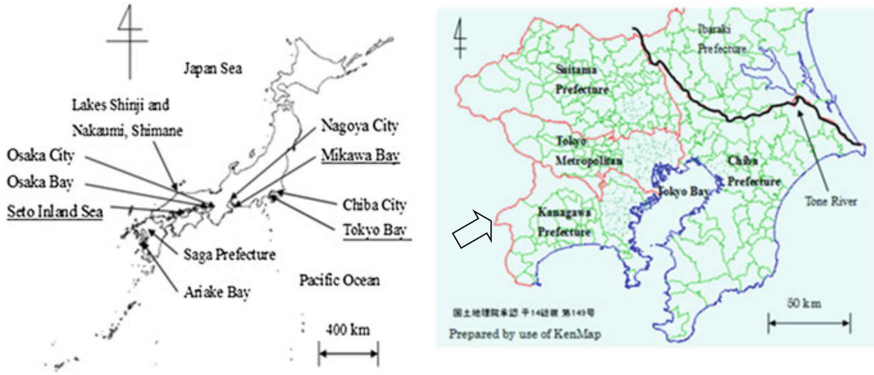

Fig. 2.3 Some specific places described in this book in Japan and around Tokyo Bay. There is the Tone River between Ibaraki and Chiba Prefectures, and most pollutants flowing into the Tokyo Bay are from Saitama, Chiba and Kanagawa Prefectures and Tokyo Metropolitan

development. PGC and PDC can be decreased with soft interventions. PLC_{wb} reflects PGC, PDC, pollutant removal efficiency of the wastewater treatment systems, and natural purification effect in ambient water. Water quality, which is commonly applied as the water environment indicator, is a function of pollutant load and water amount or flow rate in ambient water. Monitored water quality would be a base dataset to estimate PGC, PDC and PLC_{wb}. Water quality itself is important to make judgment for the appropriateness of the water usage for many purposes including water supply sources, irrigation, navigation, fishery, recreation, swimming and hydro power generation.

2.2 Roles of Fishery for Water Environment

How are pollutants discharged to coastal area decreased? Natural purification, discharging to neighbouring water body and removal by fishery are major possible reasons for pollutants reduction in coastal areas. Removal amounts of organic carbon (COD_{Mn} in this case), total nitrogen (TN) and total phosphorus (TP) by fishery have been estimated in the Tokyo Bay for the three periods of 1935, 1960, and 1997–2001 as shown in Fig. 2.5 (Tsuzuki 2004). Annual fishery amounts in the Tokyo Bay has been largest in 1960 among the three periods and decreased after industrialization and water pollution in the sea area. Total pollutant discharge amounts have been regulated in major enclosed sea areas in Japan, i.e. the Tokyo Bay, Mikawa Bay and Seto Inland Sea (Fig. 2.3). The Mikawa Bay is adjacent to Nagoya City and Seto Inland Sea includes the Osaka Bay. The concept of total pollutant discharge control in Japan is similar to total maximum daily load (TMDL) regulations in the USA. However, the number of subjected areas in Japan is limited. In the fifth total pollutant discharge reduction plan in Tokyo Bay area in

Table 2.1 An example of environmental accounting housekeeping (EAH) books or pollutant discharge calculators for municipal wastewater: population served with simple johkasou (SJ) and the river basin No. 1, upper river basin of the Miyakogawa River, Chiba City, Japan (Tsuzuki 2006) (see Fig. 2.4). The pollutant discharge calculators are prepared for wastewater treatment methods and sub river basins. Pollutant load decrease flowing into Tokyo Bay is estimated by applying the pollutant discharge calculators. (Copyright permissions have been obtained from Elsevier and Nova Science Publishers)

Miyakogawa River, upper drainage area Simple *jokaso*	Pollutant load ratio[a]				Pollutant load flowing into public water body and pollutant reduction effects[b]				Daily life				A month, 30 days				Estimation for calcualtion
	BOD %	COD %	TN %	TP %	BOD mg	COD mg	TN mg	TP mg	BOD mg	COD mg	TN mg	TP mg	BOD g	COD g	TN g	TP g	
Nightsoil[c]					840	3120	2640	300									
Bath[c]	(20)	(15)	(20)	(60)	1530	1740	130	80	460	520	39	24	14	16	1.2	0.7	
Decrease shampoo and soap[d]					460	520	39	24	460	520	39	24	14	16	1.2	0.7	The decrease effect to be 30 %
Kitchen[c]	(60)	(70)	(50)	(30)	4590	8110	330	40	320	570	70	2	10	17	2.1	0.1	
No use of detergent[d]					530	1780	35	0									The previous used amount to be 5 ml $person^{-1}$ day^{-1} (2 g-BOD, 2 g-COD, 80 mg-TN and 0 g-TP $person^{-1}$ day^{-1})
Decrease detergent[d]					265	890	18	0									Decrease to half
Do not drain rice washing water[d]					530	1780	11	1									Pollutant loads of rice washing water to be 2 g-BOD, 2 g-COD, 24 mg-TN and 2 mg-TP $person^{-1}$ day^{-1}
Use paper filter for kitchen[d]					320	570	70	2	320	570	70	2	10	17	2.1	0.1	Removal rate: BOD:7 %, COD:7 %, T-N:21 %, and TP: 4 %
Use net for kitchen[d]					140	240	50	1									Removal rate: BOD:3 %, COD:3 %, T-N:15 %, and TP: 2 %
Treatment during and after cooking[d]					2300	4060	170	20									Removal rate: 50 %
Do not drain residual liquid																	
Dressing 5ml[d]					2940	n.a.[e]	n.a.	n.a.									BOD: 660,000 mg l^{-1}, and waste amount: 5 ml

(continued)

Table 2.1 (continued)

Miyakogawa River, upper drainage area Simple *jokaso*	Pollutant load ratio[a]				Pollutant load flowing into public water body and pollutant reduction effects[b]				Daily life				A month, 30 days				Estimation for calcualtion
	BOD %	COD %	TN %	TP %	BOD mg	COD mg	TN mg	TP mg	BOD mg	COD mg	TN mg	TP mg	BOD g	COD g	TN g	TP g	
Chinese noodle soup 50ml[d]					1160	n.a.	n.a.	n.a.									BOD: 26,000 mg l^{-1}, and waste amount: 50 ml
Used edible oil 10ml[d]					14900	n.a.	n.a.	n.a.									BOD: 1,670,000 mg l^{-1}, and waste amount: 10 ml
Washing clothes[c]	(20)	(15)	(30)	(10)	1530	1740	200	10									
Decrease detergent to half[d]					690	780	90	5									The contributions of detergent to be 90 % of pollutant loads by washing clothes
Total pollutant loads[f]	(100)	(100)	(100)	(100)	8500	14700	3300	430	7720	13610	3191	404	232	408	95.7	12.1	
Decrese of pollutant load per capita									780	1090	109	26	23	33	3.3	0.8	
Decrese of pollutant load for a family of four													94	131	13.1	3.1	

[a] Pollutant load ratios without nightsoil, determined by the author based on the data in Chiba Prefectural Institute for Water Quality Preservation (1980)
[b] Pollutant load by households activities calculated at the measurement point nearest the river mouth, and corresponding pollutant reduction effects of measures in the households
[c] Pollutant load flowing into the water body by pollutant load discharge categories in the households
[d] Pollutant load reduction measures in the households and their effect estimations calculated by use of pollutant load per capita flowing into the water body or reaching ratio
[e] Not available because of data or information dificiency
[f] Total pollutant load per capita flowing into the water body, PLC-FW

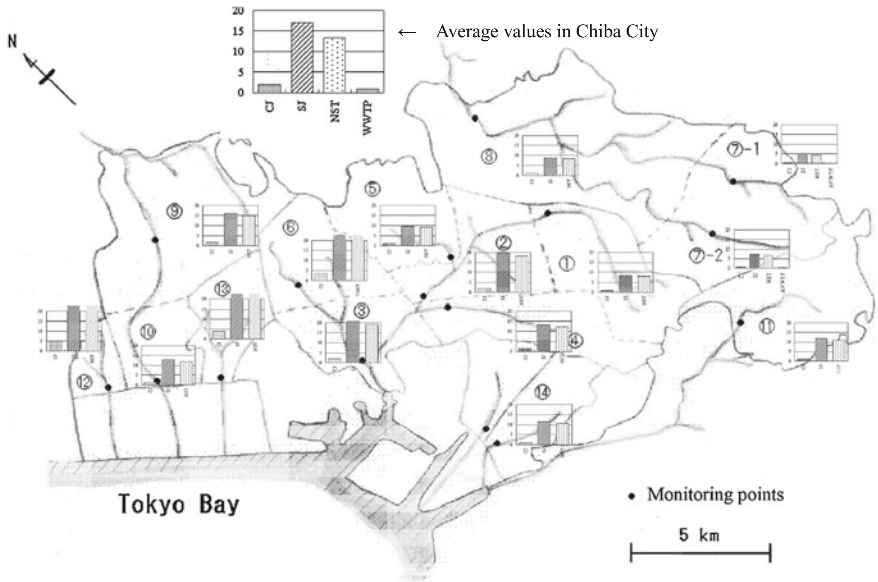

Fig. 2.4 PLC_{wb}(BOD) by sub-river basins and wastewater treatment methods in Chiba City, Japan (g-BOD $person^{-1}$ day^{-1}) (Tsuzuki 2006). (Copyright permissions have been obtained from Elsevier and Nova Science Publishers)

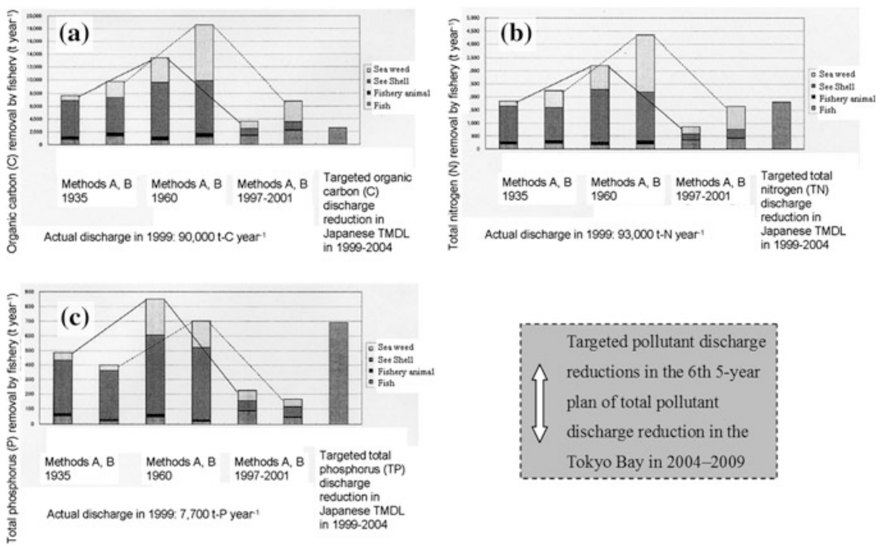

Fig. 2.5 Pollutant removal amounts by fishery in Tokyo Bay in 1935, 1960 and 1997–2001 **a** Organic carbon (C) **b** total nitrogen (TN), and **c** total phosphorus (TP) (Modified from Tsuzuki 2004)

1999–2004, targeted pollutant discharge reduction amounts have been 19 t-COD_{Mn} day^{-1}, 5 t-TN day^{-1}, and 1.9 t-TP day^{-1}, or 6,900 t-COD_{Mn} year^{-1}, 1,800 t-TN year^{-1} and 690 t-TP year^{-1} (Table 2.2). Targeted reduction amounts of COD_{Mn}, TN and TP discharged into the Tokyo Bay in 2004–2009 in the 6th Plan have been within the same order as those in the 5th Plan. The actual discharged amounts of COD_{Mn}, TN and TP have been less than the targeted amounts in the 5th Plan, and the Plan has been considered to be achieved in a quite good extents. For example, COD_{Mn} discharge amount has been targeted to be 228 t day^{-1} in 2004 in the 5th Plan schemes, and the actual discharged amount has been 211 t day^{-1} in 2004 (Table 2.2).

These targeted amounts are almost the same range of yearly organic carbon, TN and TP removal amounts by fishery in 1960 (Fig. 2.5). Pollutant removal by fishery is not neglectable amount in regards to pollutant discharge and removal in the Tokyo Bay area.

Table 2.2 Pollutant discharge regulated amounts in the 5th and 6th total pollutant discharge reduction plan in Tokyo Bay area in 1999–2004 and in 2004–2009.

2.3 Relationship Between Pollutant Discharge and Water Quality: Perturbation or Hysteresis

When the amounts of pollutants discharged to the ambient water including the rivers, lakes and coastal areas, water quality of the ambient water is generally considered to deteriorate and vice versa. The relationship between pollutant discharge amounts and ambient water quality is generally considered to be something like linear or first-order relationship. Miscellaneous measures are conducted to reduce pollutant discharge and to improve ambient water quality.

On the contrary, BOD in the Yamato-gawa River, Japan, has been found to deteriorate more than expected when pollutant discharge has rapidly increased in the late 1960s and early 1970s (Figs. 2.6 and 2.7) (Tsuzuki 2013). In phase I (Fig. 2.7d), original relationship between pollutant discharge and water quality has been considered to be a linear, however, water quality has deteriorated because of rapid increase of pollutant discharge over a threshold level in the river basin (Phase II). After several years, water quality has improved besides continuous increase of pollutant discharge, water quality has improved and the relationship has become close to the original linear relationship with pollutant discharge decrease (Phase IV), and the relationship has returned to the original linear relationship (Phase V). It has taken long time when water quality has once deteriorated cause by rapid pollutant discharge increase or pollutant discharge excess a threshold level. The relationship is similar to perturbation or dynamic equilibrium change of stable conditions in the fields of ecosystems.

Table 2.2 Pollutant discharge regulated amounts in the 5th and 6th total populant discharge reduction plan in Tokyo Bay area in 1999–2004 and in 2004–2009

Logal government	Unit	COD_{Mn}				TN				TP			
		5th Plan		6th Plan		5th Plan		6th Plan		5th Plan		6th Plan	
		Discharge in 1999	Target in 2004	Discharge in 2004	Target in 2009	Discharge in 1999	Target in 2004	Discharge in 2004	Target in 2009	Discharge in 1999	Target in 2004	Discharge in 2004	Target in 2009
Chiba Prefecture	t day^{-1}	51	46	42	36	45	43	36	33	3.4	3.0	2.7	23
Tokyo Metropolitan	t day^{-1}	73	70	61	58	101	100	78	76	7.7	12	6.0	5.8
Kanagawa Prefecture	t day^{-1}	30	28	27	26	42	41	33	31	3.5	32	2.5	2.0
Saitama Prefecture	t day^{-1}	93	84	81	73	66	65	61	59	6.5	5.8	4.1	3.8
Total of 4 local gov.	t day^{-1}	247	228	211	193	254	249	208	199	21.1	19.2	15.3	13.9
Reduction in 1999–2004	t day^{-1}		19				5				1.9		
Reduction in 1999–2004	t year’$^{-1}$		6900				1800				690		
Reduction in 2004–2009	t day^{-1}				18				9				1.4
Reduction in 2004–2009	t $year^{-1}$				6600				3300				510

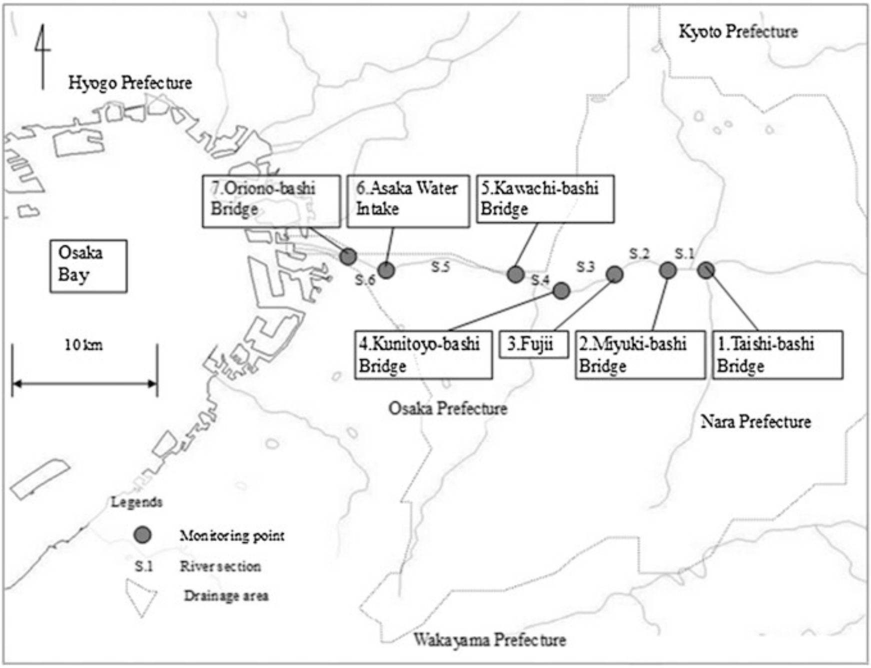

Fig. 2.6 Yamato-gawa River Basin, Japan (Tsuzuki et al. 2010a). (Copyright permission has been obtained from Elsevier)

It has been also observed that the relationship between pollutant discharge and water quality has not in accordance with a linear relationship in a short-term rainfall events in a mountainous catchment in Kyoto-Fu, Japan (Fujii et al. 2006), and in the Richmond River, Australia (McKee et al. 2000). The short-term relationship between pollutant discharge and water quality which is not in accordance with a linear relationship is called hysteresis.

2.4 Natural Purification of BOD in the River Sections

Natural purification effects in ambient water including the rivers are generally well known. For example, a classical relationship between BOD and DO has been proposed (Eqs. 2.6 and 2.7) (Streeter and Phelps 1925; Toda 2001; Tsuzuki et al. 2010a).

$$\text{BOD}: u\frac{dB}{dx} = -k_bB - k_pB + L_B \tag{2.6}$$

$$\text{DO}: \ u\frac{dD}{dx} = -k_bB + k_r(D^* - D) - L_D \tag{2.7}$$

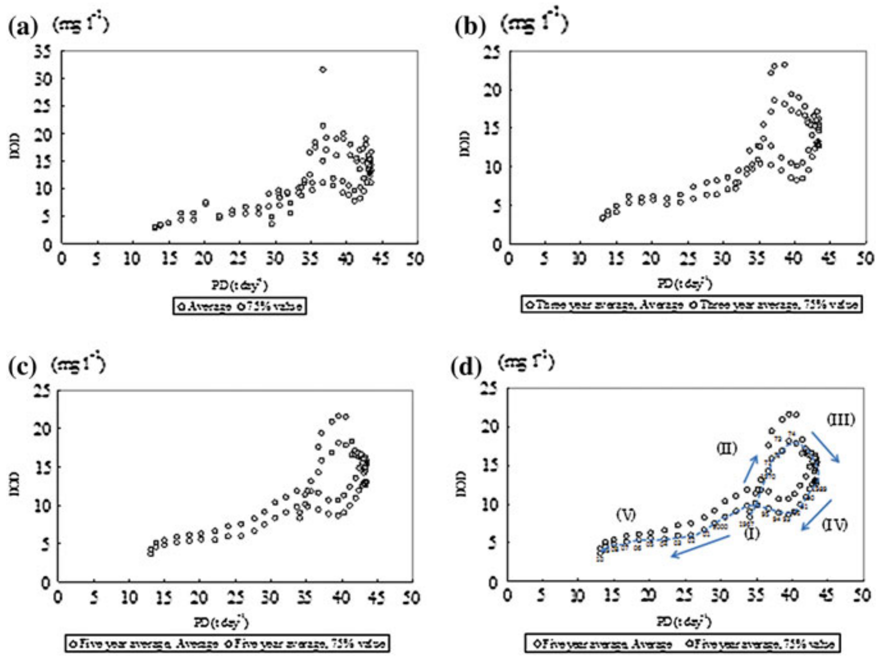

Fig. 2.7 Chronological relationship between BOD discharge in the Yamato-gawa River Basin and BOD quality in the river, **a** average and 75 percentile, **b** 3 year average of average and 75 percentile, **c** 5 year average of average and 75 percentile, and **d** 5 year average of average and 75 percentile with explanation of Phases (Tsuzuki et al. 2013). (Copyright permission has been obtained from Springer)

where B is BOD concentration (g m^{-3}); D is DO concentration (g m^{-3}); x is distance (m); u is advection velocity (m s^{-1}); k_b is biological oxygen consumption rate (min^{-1}); k_p is BOD removal rate with physical and chemical reaction (s^{-1}); L_B is BOD loading (g m^{-3} s^{-1}); k_r is re-aeration coefficient (s^{-1}); D^* is saturation oxygen concentration (g m^{-3}); and L_D is oxygen consumption rate with other reaction than biological (g m^{-3} s^{-1}).

The Streeter-Phelps equation has been applied to BOD and DO concentrations in the six sections of the Yamato-gawa River, and the values of k_b, biological oxygen consumption rate, and k_p, BOD removal rate with physical and chemical reaction have been investigated to evaluate the magnitude of natural purification effects of these river sections (Tsuzuki et al. 2010a). The magnitude of natural purification effects has been in accordance with the existing research (Kusuda 1986; Shimomura et al. 2008). The effects the soft measures in households have been quantified based on the results (Fig. 2.8). When all the households in the river basin are assumed to introduce and continue the soft measures, BOD concentration at the monitoring point nearest to the river mouth has been estimated to improve 25 %, from 4.1 to 3.1 mg-BOD l^{-1}.

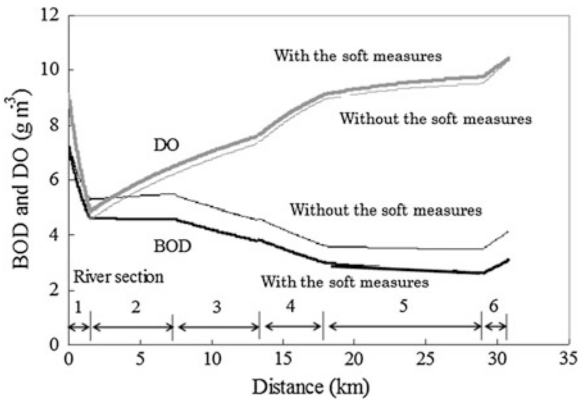

Fig. 2.8 BOD and DO estimation results of the Streeter-Phelps one dimensional water quality model with and without soft measures in households. (Modified from Tsuzuki et al. 2010a). (Copyright permission has been obtained from Elsevier)

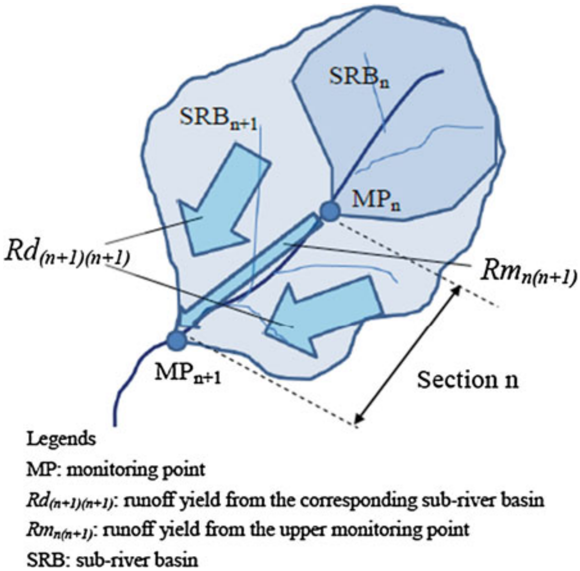

Fig. 2.9 Pollutant runoff yield from corresponding sub-river basin, $Rd_{(n+1)(n+1)}$, and that from upper monitoring point, $Rm_{n(n+1)}$ (Tsuzuki and Yoneda 2011). (Copyright permission has been obtained from Elsevier)

2.5 Pollutant Runoff Yields in Sub-Catchments

Some parts of the pollutants discharged to ambient water are purified and cleaned in the ecosystems, e.g. being uptaken biologically by organisms including fish, plankton, invertebrates and microorganisms, and physically settling to the bottom of the rivers, lakes and coastal areas, or attaching to particles. Pollutant runoff yield is a coefficient to indicate the ratio of pollutant load in the river and pollutant discharged to the catchment or river basin (Fig. 2.9) (Tsuzuki and Yoneda 2011). Pollutant runoff yield at monitoring point, MP_{n+1}, has been attributed to that from

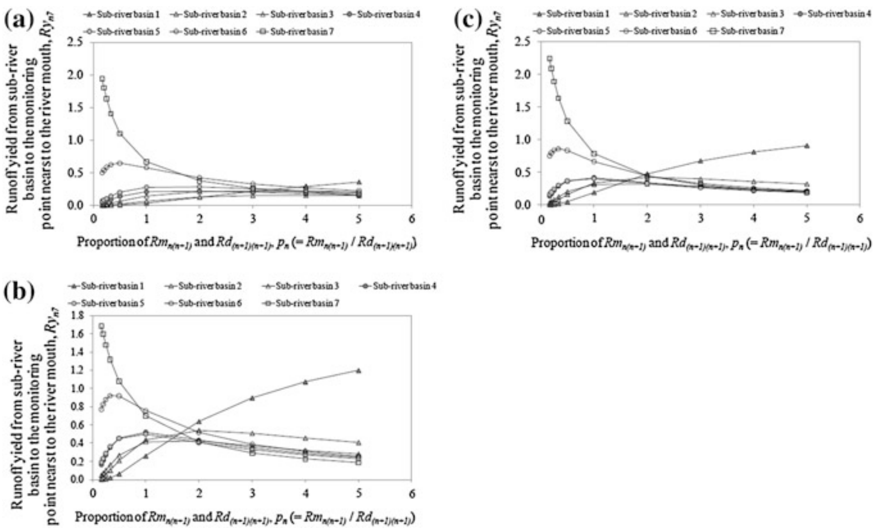

Fig. 2.10 Pollutant runoff yields from sub-river basins n to monitoring point 7, Ry_{n7}, as functions of the proportion, p_n (= $Rm_{n(n+1)}$ /$Rd_{(n+1)(n+1)}$) for **a** BOD **b** TN and **c** TP (Tsuzuki and Yoneda 2011). (Copyright permission has been obtained from Elsevier)

the corresponding sub-river basin, $Rd_{(n+1)(n+1)}$, and that from the upper monitoring point, $Rm_{n(n+1)}$. Pollutant runoff yield from MP_n to MP_{n+1} is described as Eq. 2.8. Pollutant runoff yields from sub-river basins (from 1 to 7) to monitoring point nearest to the river mouth, Ry_{n7}, have been calculated with Eq. 2.9.

$$Rm_{n(n+1)} = \frac{(POLloading)_{MP(n+1)} - (POLdisch)_{SRB(n+1)} \times Rd_{(n+1)(n+1)}}{(POLloading)_{MP(n)}} \quad (2.8)$$

where $Rm_{n(n+1)}$ is runoff yield from monitoring point MPn to MPn+1 (%) ($POLloading$)$MP_{(n+1)}$ is pollutant loading at monitoring point MP_{n+1} (kg day^{-1}) ($POLdisch)SRB_{(n+1)}$ is pollutant discharge in sub-river basin MP_{n+1} (kg day^{-1}); $Rd_{(n+1)(n+1)}$ is pollutant runoff yield from sub-river basin n+1 to MPn+1 (−).

$$\begin{aligned} Ry_{n7} &= Rd_m \times Rm_{n(n+1)} \times \cdots \times Rm_{n7} \; (1 \le n \le 6) \\ &= Rd_{77} \qquad\qquad\qquad (n = 7) \end{aligned} \quad (2.9)$$

where Ry_{n7} is pollutant runoff yield from sub-river basin n to monitoring point, MP_7 (%).

Pollutant runoff yields from sub-river basins to the monitoring point 7, Ry_{n7}, are expressed as functions of the proportion, p_n (Fig. 2.10). P_n is the ratio of $Rm_{n(n+1)}$ and $Rd_{(n+1)(n+1)}$ (Eq. 2.10). The results of BOD show Ry_{n7} increases with *pn* increase when *pn* is small in sub-river basins 1–6. When p_n is larger than the corresponding value to the each curve peak of Ry_{n7}, Ry_{n7} decreases with p_n increase. The corresponding values of Ry_{n7} peaks for BOD are 4.0 for sub-river basin 2, 3.0 for sub-river basin 3, 2.0 for sub-river basins 4 and 5, and 0.5 for sub-river basin 6 (Fig. 2.10a). Rr_{17} always increases when p_n is from 0.17 to 5.0. On the contrary, for sub-river basin 7, pollutant runoff yield from sub-river basin 7, Ry_{77} (= Rd_{77}), decreases with p_n increase. Tendencies of Ry_{77} are the same for TN and TP besides the corresponding values for Ry_{n7} curves are different by pollutant (Fig. 2.10b and c).

$$P_n = \frac{Rm_{n(n+1)}}{Rd_{(n+1)(n+1)}} \tag{2.10}$$

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