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WATER QUALITY AND POLLUTANT LOAD IN THE AMBIENT WATER AND DOMESTIC WASTEWATER POLLUTANT DISCHARGES IN THE DEVELOPING COUNTRIES: SURVEY RESULTS IN AUTUMN AND WINTER IN 2006

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ABSTRACT: Domestic wastewater pollutant discharges and water quality in the ambient water were studied in Dhaka, Bangladesh, and Bangkok, Thailand. Water quality measurements with simple kits were identified to illustrate water quality profiles in and around these cities to some extent. Water quality in the Sitalakhaya River, Bangladesh, and in the peri-urban section of the Chao Phraya River, Thailand, vertical homogeneity was observed for parameters measured with a water quality data logger. Estimated pollutant discharges per capita were larger than those in Japan for BOD, TN and TP in Pak Kret Municipality, peri-urban of Bangkok, when seepage and septage from septic tank and leachate from composting ("seepages") were included. Introduction of wastewater treatment methods with larger removal rates should be considered for the ambient water quality improvement together with MDGs perspective of appropriate sanitation.

KEYWORD: Thailand; Bangladesh; domestic wastewater; pollutant load per capita flowing into the water body (PLC_{wb}); pollutant discharge per capita (PDC); seepage and septage from septic tank and leachate from composting ("seepages")

1. Introduction

In the context of the Millennium Development Goals (MDGs), decreasing the proportion of population without access to safe drinking water and appropriate domestic wastewater treatment facilities to half by 2015 was determined as very urgent tasks of the world community. Pollutant load per capita flowing into the water body (PLC_{wb}) was proposed as an appropriate index of the domestic wastewater contribution to the water pollution in the targeted water body based on the pollutant load analyses in the drainage area of the inner-city rivers in Japan (Tsuzuki, 2006b). PLC_{wb} is calculated with pollutant discharge per capita (PDC) and pollutant reaching ratios in the ambient water. PDC is calculated with pollutant generation per capita (PGC) and removal ratio of wastewater treatment facilities. PLC_{wb} was found to be effective to evaluate domestic wastewater pollutant discharge contribution to ambient water pollutant load by wastewater treatment methods and by sub-drainage areas (Tsuzuki, 2006b). In the MDGs perspective, accessible ratios to safety drinking water and appropriate sanitation are emphasized. When we consider on water pollution, we should also focus on pollutant discharge amounts or pollutant discharge reduction function of wastewater treatment facilities. Therefore, researches on the relationships between pollutant discharge and pollutant load or water quality in the ambient water including rivers are important.

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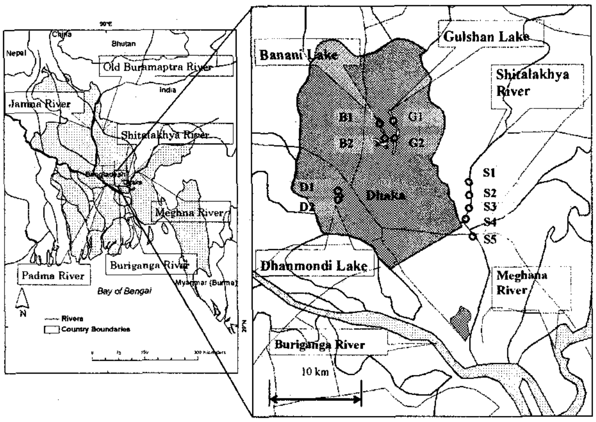


Figure 1. Rivers and lakes in urban and peri-urban areas of Dhaka City, Bangladesh. Sampling points in the Sitalakhaya River (from S1 to S5) and Dhiamondi (D1 and D2), Banani (B1 and B2) and Gulshan Lakes (G1 and G2) are illustrated.

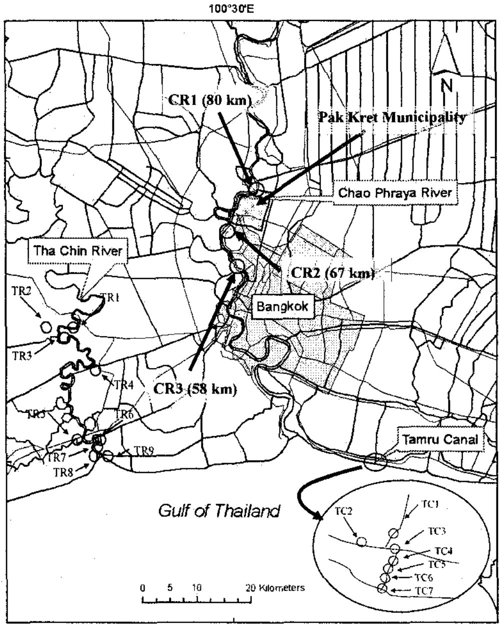


Figure 2. Rivers and canals in urban and peri-urban area of Bangkok, Thailand. Sampling points in the Tha Chin River (TR1-9), the Chao Phraya River (CR1-3) and the Tamru Canal (TC1-3) are illustrated.

In order to apply the indices and the concept in the developing countries, we conducted information/data collection and field survey in regards to domestic wastewater pollutant discharges and pollutant loads in the rivers, lakes and canals in urban and peri-urban area of Bangkok, Thailand, and Dhaka, Bangladesh in October, November and December, 2006. Purchase power parity based gross national income (PPP-GNI) per capita in Bangladesh was US$ 1,870, that in Thailand was US$ 7,450, and that in Japan was US$ 28,450 in 2003 (World Bank, 2005). The comparison of the domestic wastewater pollution indices were considered to extract some aspects of the domestic wastewater pollutant discharges and wastewater treatment situations in these countries. Some environmental information/data are widely available in the developed countries including Japan. The results of the information/data collection in this study were considered to illustrate the current situations of their availability in these countries.

The purposes of this paper are to illustrate the ambient water quality in urban and peri-urban area of Dhaka and Bangkok based on the existing information/data and the field survey results, to estimate pollutant discharge indices in these countries, and to make comparison of the pollutant discharge indices in these countries and those in Japan. The comparison results will be necessary base information to consider the domestic wastewater treatment situations between these countries and Japan.

Some collected information/data and field survey results were presented in the conferences (Tsuzuki et al., 2007a,b,c,d,e). This paper is mostly based on a Japanese version of a submitted paper. In this paper, some unpublished data including water quality measurement results with simple water quality measurement kits in Thailand were included to describe the effectiveness of the measurement methods, PDC estimation results were updated, and discussion on the relationships between the pollutant indices and economic parameters and water governance in Thailand were also updated.

2. Methods

Information/data collection from the existing literatures including scientific papers, documents and web-sites and field surveys were conducted in regards to water quantity and quality in urban and peri-urban area of Dhaka (Figure 1) and Bankok (Figure 2). The field surveys were conducted from October to December in 2006.

The Sitalakhaya (Shitalakhaya) River flows in the western Narayanganj District, Bangladesh, flowing into the Dhaleshuari River, which flows into the Megha River at Bandar (Figure 1). The Narayanganj District was one of the highest population density district in Bangladesh with more than 2,000 person km^{-2} (Alam ed., 2005). Sampling points from S1 to S5 in the Sitalakhaya River were located in the order from upper to lower reach in the river. There was a river side community on the right bank of the river around S2 and S3, where domestic wastewater was observed to be discharged directly to the river without any treatment. Industrial wastewater effects on the river water quality and annual river water quality deterioration were investigated in the existing research (Alam et al., 2006). Field surveys in Bangladesh were conducted in the Sitalakhya River and three lakes in Dhaka City, namely, Dhanmondi, Banani and Gulshan Lakes.

The Chao Phraya and Tha Chin Rivers in the central area of Thailand are flowing into the Gulf of Thailand. Water quality in the lower sections of these rivers were among the most deteriorated in the ambient water in Thailand (Pollution Control Department (PCD) of Thailand, 2006a). The sampling points, TR2 and TR4, were located at the canals flowing into the Tha Chin River (Figure 2). Field surveys in Thailand were conducted in the Chao Phraya River, the Tha Chin River, the Tamru Canal and the adjoining canals.

In the field surveys, water quality was measured with a water quality data logger, Compact-CTD ® (Alec Electronics, Japan), water quality measurement kits, Pack Test ® (Kyoritsu Chemical Laboratory, Japan), and laboratory measurements. Parameters measured with the water quality data logger were water depth, water temperature, salinity, electricity, EC25 (electricity calibrated at water temperature of 25 °C), density, chlorophyll-a and turbidity. Vertical water profile was measured with the water quality data logger twice at each monitoring point. Parameters measured with the water quality measurement kits were COD_{Mn}, PO_4-P, NO_2-N and NO_3-N. Nitrogen parameters measurements with the water quality measurement kits were conducted only in December. BOD, COD_{Cr}, TN were measured in the laboratory with standardized methods in Thailand.

Pollutant discharges and pollutant loads estimation were conducted only in Thailand in this paper because of data availability. Available water quality and quantity data were very limited in Bangladesh (Ahmed et al., 2005; Ahmed and Ishiga, 2006; Alam et al., 2006). Therefore, we found it important to publish water quality data even if the field survey was within very limited time and area especially in Bangladesh.

In regards to pollutant loads in the Chao Phraya River in Thailand, flow rate was measured in the field survey, however, flow rates of the exiting data were applied in the estimation because of the existence of flow rate fluctuations by the tidal effect and the seasonal flow rate variation. COD_{Cr} loads and BOD loads were estimated using TOC laboratory analyses results and correlation coefficients between TOC and COD_{Cr}, and COD_{Cr} and BOD. The former correlation was estimated from the empirical relationship, and the latter was estimated from water quality data in the rivers in Thailand (PCD of Thailand, 2006c).

Pollutant discharge estimation was conducted in Pak Kret Municipality. Pak Kret District (Amphoe) (area: 89.0 km^2, population: 201,399 person in 2004, population density: 2,297 person km^{-2}) was located at northeast of Notanburi Province, north of Bangkok, Thailand. Pak Kret Municipality was consisted of five urban communities (Tambon) in the twelve communities in Pak Kret District (Sinsupan, 2004). Most of domestic wastewater was treated with septic tanks in Pak Kret Municipality. Opposite side of Pak Kret Municipality across the Chao Phraya River was not so populated. Total pollutant discharge from Pak Kret Municipality and pollutant discharge per capita (PDC) of domestic wastewater were estimated based on the material flow analysis (MFA) results (Sinsupan, 2004). In the MFA, material flows were analyzed between the processes including peri-urban agriculture, household, wastewater treatment plants (WWTP), market, collecting/sorting of solid wastes, septic tank and composting with system boundary including atmosphere, landfill, groundwater, surface water and soil. In the PDC estimations, *seepage and septage from septic tank and leachate from composting* ("seepages") were found to be large contributors to the pollutant discharges. Therefore, two kinds estimations were conducted in this paper, i.e. with "seepages" and without "seepages".

Information collection on water governance in Thailand was also conducted to consider the possibility of community participation in the fields of water environment improvement..

3. Results and Discussions

3.1 Ambient water quality in and around Dhaka, Bangladesh

The water quality measurement results of COD_{Mn} with the water quality measurement kits in the Sitalakhaya River and the three lakes (Figure 3), the vertical bars in the figures indicated the measurement results were in these ranges. The measurement results showed water quality deterioration near the river side community at the sampling points S2, S3 and S4. Natural purification or dilution in the sampling point S5 was also observed. Dhanmondi Lakes (D1, D2) was in the residential area and used for recreation including boating and taking a walk by the people, however, Banani (B1, B2) and Gulshan Lakes (G1, G2) were in the office and commercial areas. Some wastewater was observed to be discharged directly to these lakes. One of the reasons for the relatively better water quality in Dhanmondi Lake was considered as the differences of these characteristics of the lakes in urban area of Dhaka. The water quality profiles with the water quality data logger measurements in the Sitalakhaya River were vertically homogeneous (Figure 4). Observation of ebb flow and flood flow in the river was reported (BCEOM/EPC, 1991), which was considered to be a reason for the vertical homogeneity of the water quality parameters.

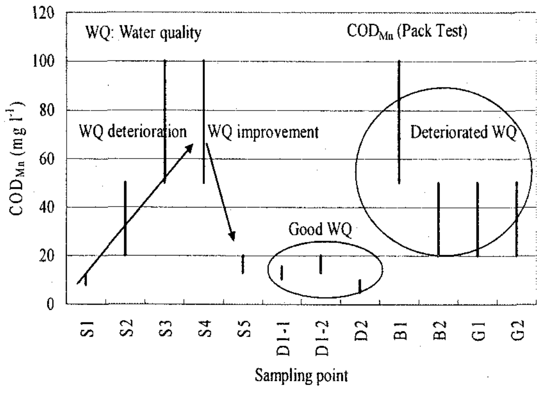


Figure 3. Water quality measurement results with the water quality measurement kit in the Shitalakhya River and the three lakes in urban and peri-urban areas of Dhaka, Bangladesh. The reaction color of the water samples of the water quality measurement kits sometimes indicated between the standard color indications. The vertical bars indicate that the reaction color were between the standard color indications. (Modified from Tsuzuki et al., 2007a,b,c,d,e)

Water quality in the road side waterways in the residential areas was observed as deteriorated (Tsuzuki, 2007a). One of the reasons for such water quality deterioration was considered to be domestic wastewater discharges, especially gray water discharges. Taking the lower domestic wastewater treatment around 30 % in Dhaka City into consideration, gray water treatment and domestic wastewater pollutant discharge reduction measurements in the households were considered to be necessary to reduce pollutant discharges and to improve the ambient water quality especially in the residential area.

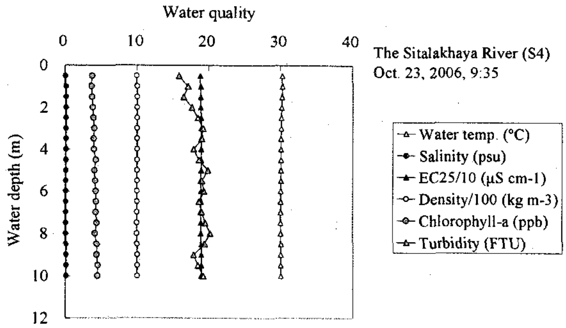


Figure 4. An example of vertical water quality profiles at the sampling point S4 in the Shitalakhya River, Bangladesh (Modified from Tsuzuki et al., 2007e)

In Bangladesh, available water quality and quantity data were very limited. Therefore, some water quality and quantity monitoring plans and implications, and their dissemination should be considered especially in the academia and administrative sectors.

3.2 Ambient water quality in and around Bangkok, Thailand

The water quality kits measurement results in the rivers and canals in Thailand also showed the characteristics of the ambient water quality (Figure 5). In the Tamru Canal, relatively high concentrations of COD_{Mn} and PO_4-P were observed. COD_{Mn} was 20-100 mg-O l^{-1}, and PO_4-P was from non-detective (less than

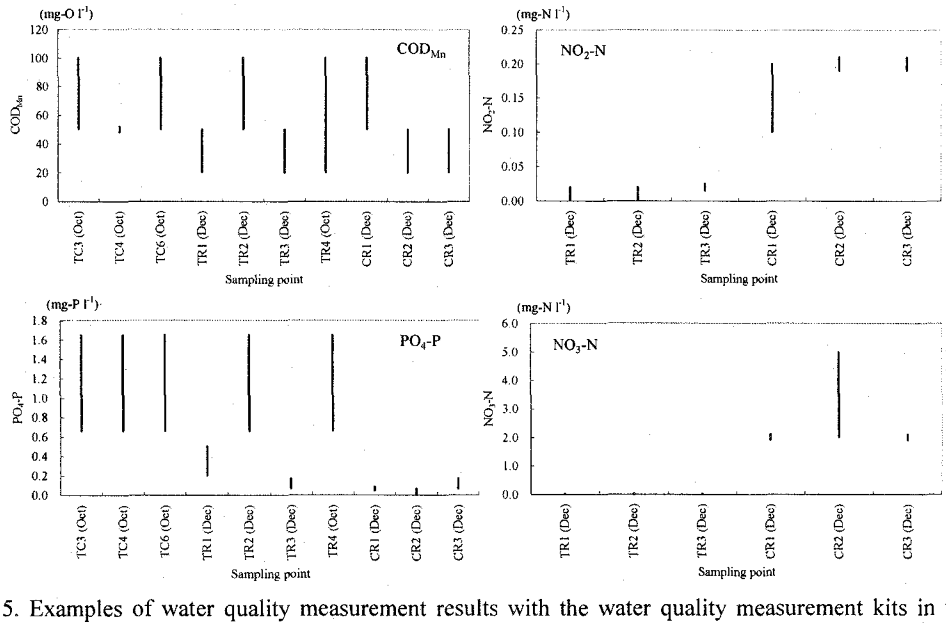


Figure 5. Examples of water quality measurement results with the water quality measurement kits in the Tamru Canal (TC3, 4, 6), the Tha Chin River (TR1-4) and the Cho Phraya River (CR1-3), Thailand. The measurements were conducted in October (Oct) and in December (Dec). The indications of the vertical bars are same as Figure 3.

0.066 mg-P l^{-1}) to 0.66-1.6 mg-P l^{-1} in the Tamru Canal. In the Tha Chin River, TR2 and TR4 were located in the canals flowing into the Tha Chin River, where relatively high concentrations of COD_{Mn} and PO_4-P were observed. Water quality deterioration was found more severe in these canals than the large rivers.

NO_2-N and NO_3-N was relatively higher concentration in the Chao Phraya River, 0.1-0.2 mg-N l^{-1} of nitrite and 2-5 mg-N l^{-1} of nitrate, than those in the Tha Chin River (Figure 5). In the Tha Chin River, nitrite was from non-detective (less than 0.02 mg-N l^{-1}) to 0.02 mg-N l^{-1} and nitrate was non-detective (less than 0.02 mg-N l^{-1}). The difference of the nitrogen oxides concentrations implied that nitrification should occur around the sampling points in the Chao Phraya River but around the sampling points in the Tha Chin River. Dissolved oxygen at surface and 3 m depth at these sampling points were around 1.0 mg-O l^{-1}. Further investigation will be necessary to find the situations of nitrification to consider on nitrogen mass-balances and possibility of eutrophication in these rivers.

Horizontal water quality profiles in the Chao Phraya River were summarized from the administrative data (PCD of Thailand, 2006c) (Figures 6). Bi-annual average of BOD in 1999-2000 at 50-350 km of the Chao Phraya River was 1.0-2.0 mg l^{-1} (hereafter, bi-annual averages were mentioned as representative water quality parameters), increased to 4.1 mg l^{-1} at 30 km, then decreased to 2.8 mg l^{-1}. DO was larger than 5.0 mg l^{-1} at

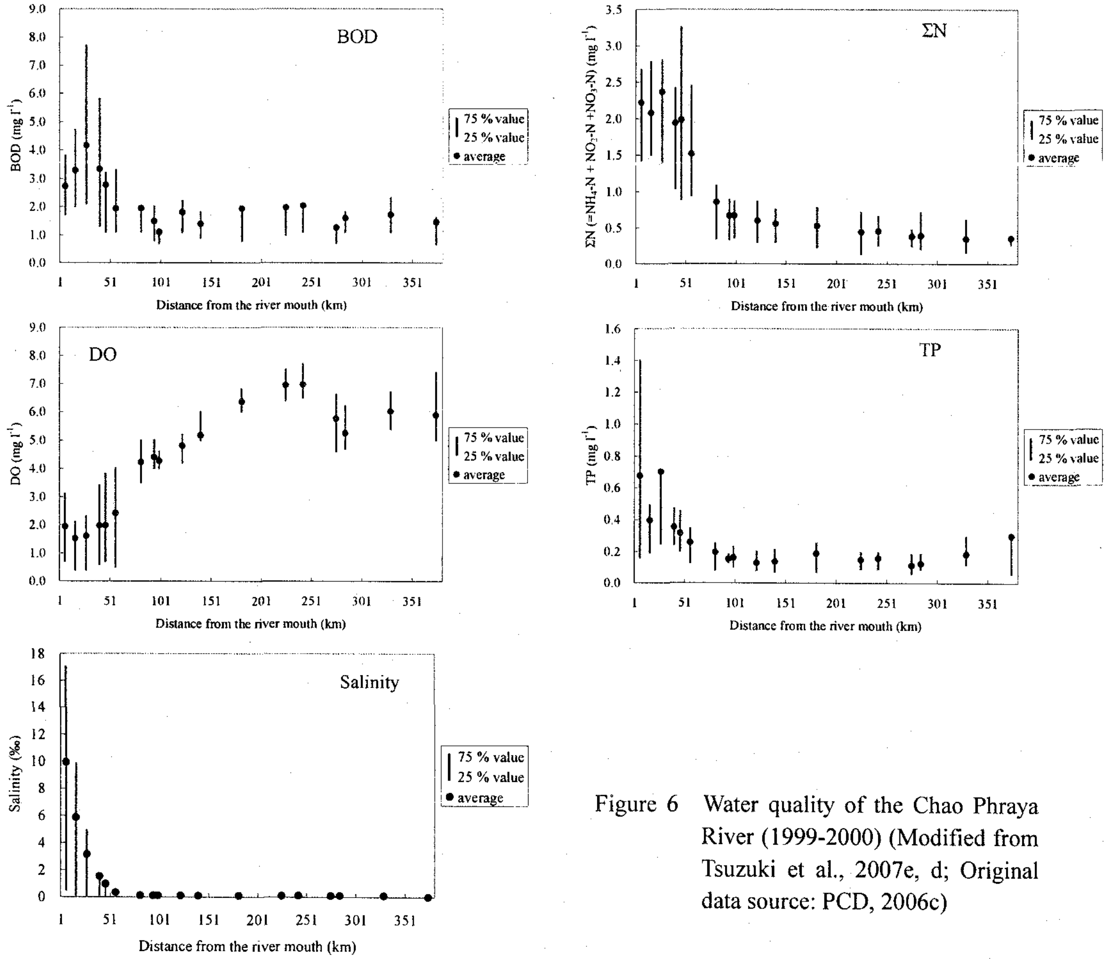


Figure 6 Water quality of the Chao Phraya River (1999-2000) (Modified from Tsuzuki et al., 2007e, d; Original data source: PCD, 2006c)

150-350 km, and smallest as 1.5 mg l^{-1} at 15 km. Estuarine zone in the Chao Phraya River was considered to be 0-50 km from the river mouth judging from the bi-annual average of salinity. Summation of ammonium, nitrite and nitrate nitrogen (ΣN) was lower concentration at 150-350 km. In this river section, ΣN increased gradually with down-flow in the range of 0.4 to 0.6 mg l^{-1}. ΣN increased to 2.1-2.4 mg l^{-1} near the river mouth. TP was also lower concentration at 150-350 km, fluctuated around 0.1-0.3 mg l^{-1}, and increased to 0.4-0.7 mg l^{-1} near the river mouth.

Vertical water quality profiles in the Chao Phraya River at 67 km (Wat Tumnuktai, Figure 7a, b) and 80 km (Wat Potongbon, Figure 7c, d) from the river mouth was found to be rather homogeneous. Chlorophyll-a was 5.0-5.5 ppb at almost all the depth at both monitoring points. Vertical water quality homogeneity was observed at the sampling points except for near the river mouths and canal mouths. Salinity was lower in the measurement results, however, flood flow and ebb flow was observed near the sampling points. The tidal effects were considered to be one of the reasons for the vertical homogeneity of the water quality parameters in the Chao Phraya River also.

The vertical water quality homogeneity suggested that surface water quality parameters should be applied as representative values in the vertical direction when pollutant loads in the river section was calculated. Therefore, surface water quality values were applied to estimate pollutant loads in the next section.

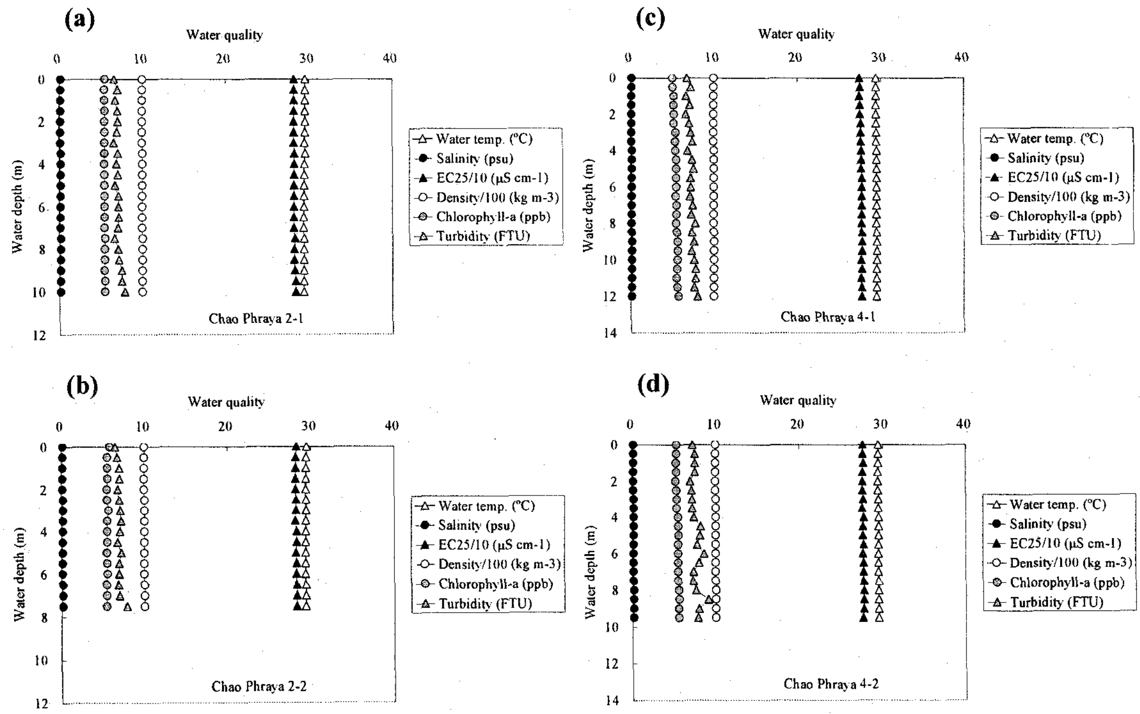


Figure 7 Vertical water quality profile at 58 km (a and b) and 67 km (c and d) from the river mouth in the Chao Phraya River on Dec. 10, 2006

3.3 Domestic wastewater pollutant discharge and pollutant load in the river in Thailand

Total pollutant discharges and PDC of the Pack Kret Municipality were estimated based on the MFA results (Sinsupan, 2004) (Table 1). BOD discharge per capita (PDC-BOD) was estimated as 48.4 g-BOD person^{-1} day^{-1} with "seepages", and 29.2 g-BOD person^{-1} day^{-1} without "seepages". These estimated PDC were comparable with the previous PDC estimation in Thailand based on the UNEP report, 43 g-BOD person^{-1} day^{-1} (Tsuzuki, 2006b), and pollutant generation per capita (PGC) applied in World Bank (2001), 35 g-BOD person^{-1} day^{-1}. The PDC estimation results revealed that relatively large amounts of "seepages" pollutant discharges should contribute pollutant discharges from domestic wastewater.

Pollutant loads in the Chao Phraya River were estimated with the water quality field survey results and flow rates in the literature (Lohani et al., 1980) (Table 2).

Reaching ratios of BOD and TN estimated from the results shown in Tables 1 and 2 exceeded 100 %, when the increases of pollutant loads in 67-80 km from the river mouth were considered to be explained with pollutant discharges from Pak Kret Municipality. For example, total BOD discharge from Pak Kret Municipality was estimated as 11.9 t day^{-1}, whereas BOD load increase in the section was estimated as 20.6 t day^{-1}. Therefore, PLC_{wb} estimation should be considered further.

In regards to the assumption of the relationship between total pollutant discharge from Pak Kret Municipality and pollutant load increase in the Chao Phraya River section, it was considered to be rather realistic for rough estimation because the opposite side across the river was not so populated and less pollutant discharge from the opposite bank of the river were supposed. For more accurate estimation, we should consider pollutant discharge from the opposite side and those from the riverside industry and commercial wastewater. Lots of water hyacinths were found on the surface of rivers (Photo 1). The effects of

Table 1 Pollutant discharge from the Pak Kret Municipality estimated based on the MFA results (Modified from Tsuzuki et al., 2007d,e)

Pollutant	Polllutant discharge from households without "seepages"[a]	Polllutant discharge from households with "seepages"[b]	Total polllutant discharge without "seepages"[a]	Total polllutant discharge with "seepages"[b]	PDC[c] without "seepages"[a]	PDC[c] with "seepages"[b]
	kg day^{-1}	kg day^{-1}	kg day^{-1}	kg day^{-1}	g person^{-1} day^{-1}	g person^{-1} day^{-1}
BOD	7,099	11,752	9,660	15,202	29.2	48.4
TN	1,166	3,021	2,020	3,922	4.8	12.4
TP	221	577	506	868	0.91	2.38

a: without seepage and septage from septic tank and leachate from composting, ; b: including seepage and septage from septic tank and leachate from composting; c: pollutand discharge per capita. (Source: Estimated by the authors based on Sinsupan, 2004)

Table 2 Pollutant load in the Chao Phraya River calculated with the field survey results and the secondary data of flow rate (Tsuzuki et al., 2007d,e)

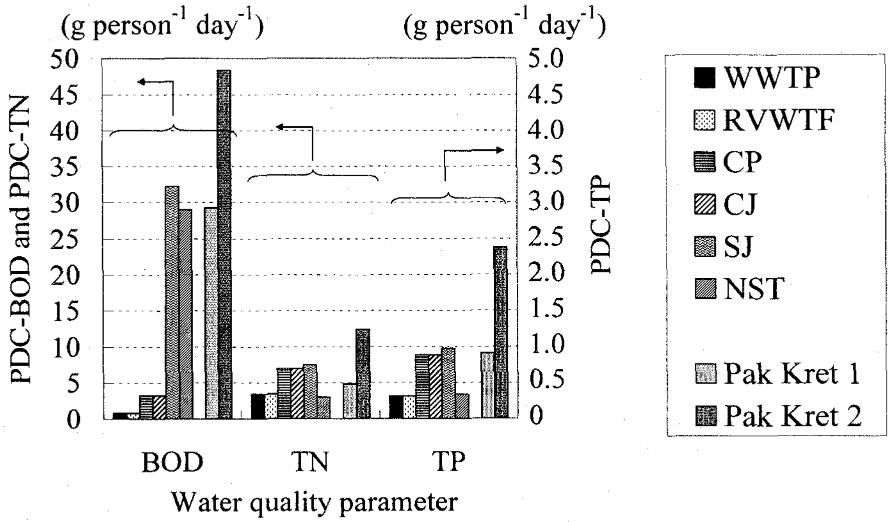
	Distance from the river mouth	Flow rate[a]	TOC	TN	CODcal[b]	BODcal[c]
	km	m^3 s^{-1}	t day^{-1}	t day^{-1}	t day^{-1}	t day^{-1}
Pibulsongkram Pier	58	1,082	581	117	1,453	88.6
Wat Tumnuktai	67	955	523	97	1,308	79.8
Wat Potongbon	80	784	388	78	971	59.2

a: Lohani et al. (1980); b: CODcal=2.5*TOC; c: BODcal=0.061*CODcal planktons, water hyacinths and other organisms should also be further considered with the relationships between nutrients pollutant discharges and nutrients pollutant loads in the rivers and canals (Mahujchariyawong and Ikeda, 2001).

Photo 1 Water plants including water hyacinths in the Chao Phraya River

When "seepages" were included, PDC in Pak Kret Municipality was estimated as larger than PDC in Japan (Tsuzuki, 2006b) even in comparison with PDC of lower efficiency treatment methods including simple *johkasou* (*jokaso*) (SJ) or night soil treatment systems (NTS) for all the water quality parameters: BOD, TN and TP (Figure 8). Introduction of wastewater treatment methods with larger removal rates including combined *johkasou* (CJ) or community plant (CP) would decrease domestic pollutant discharges, and lead to the ambient water quality improvement. In regards to the nutrient parameters, nitrogen and phosphorus removal improvement has been achieved in recent studies (Okumura et al., 2006). Such larger nutrient removal treatment facilities should be introduced to decrease nutrient discharges.

When "seepages" were not included, PDC-BOD in Pak Kret Municipality was almost the same as those of SJ and NST in Japan. For the nutrient parameters, nitrogen discharge per capita (PDC-TN) was between those of centralized (WWTP and RVWTF) and decentralized (CP, CJ, SJ) treatment methods. Phosphorus discharge



WWTP: Wastewater treatment plant; RVWTF: Rural village wastewater treatment facility; CP: Community plant; CJ: Combined *johkasou*; SJ: Single *johkasou*; NST: Night soil treatment; Pak Kret 1: without "seepages"; Pak Kret 2: with "seepages".

Figure 8 Pollutant discharge per capita (PDC) in Japan estimated based on the existing treatment facilities in Chiba City (Tsuzuki, 2006c) and those in Pak Kret Municipality estimated in this study per capita (PDC-TP) was almost the same with those of decentralized methods (CP, CJ and SJ). These PDC estimation results would be base data for estimation of PLC_{wb} in further research.

PDC and PLC_{wb} were also more effective indicators of domestic wastewater pollutant discharges and their contribution on water pollution in the ambient water than ambient water quality parameters especially in consideration with the economic indices (Tsuzuki, 2007b). PPP-GNI in Thailand was almost one fourth of that in Japan in 2003 (World Bank, 2005). Therefore, some economically affordable wastewater treatment methods with larger pollutant discharge reduction would be desirable to improve the ambient water quality. The MDGs parameters of water and sanitation are important from the perspectives of hygiene, health and life-style improvements. Together with the MDGs parameters, pollutant discharge reduction function of wastewater treatment systems should be considered more to improve the ambient water quality using indices including PLC_{wb} and PDC.

3.4 Water governance in Thailand

Pollutant discharges have been investigated in Thailand especially with MFA methods (Sinsupan, 2004). The river water quality including basic parameters including organic carbon, nitrogen, phosphorus, bacterial parameters, and heavy metals have been monitored periodically by PCD of the Thai government (PCD of Thailand, 2006a, b, c). Water pollution control program by the Thai government has been consisted of 1) wastewater treatment and disposal, 2) waste minimization, 3) cleaner production, 4) legal framework, 5) institutional and financial management, 6) monitoring and enforcement, 7) cooperation with related agencies and local communities, and 8) river basin management approach (Simachaya, 2000). Integrated water resources management (IWRM) has been also researched in Thailand (Lekphet et al., 2004). Environmental education program has been conducted, for example, in the drainage area of the Tha Chin River (Thongnopphakun, 2006). Information dissemination has been conducted by the Thai government using the web-site (PCD of Thailand, 2006b).

The results and the concept of this research would be necessary base information for the environmental education and dissemination including pollutant discharge reduction measurements in the households. Possibility of introduction of environmental accounting housekeeping (EAH) books of domestic wastewater (Tsuzuki, 2006b) should be considered in further research.

4. CONCLUSIONS

Water quality kits measurement results effectively illustrated the water quality in the rivers, lakes and canals in Bangladesh and Thailand. Vertical water quality profiles were rather homogeneous in the rivers except for sampling points near the river/canal mouths, one of the reasons for which were considered to be the existing tidal effects.

In regards to pollutant discharge indices, necessary data were not obtained during the research periods in Bangladesh. Institutional arrangements for water quality and quantity data monitoring especially by the academia and administrative, and their dissemination procedures and methods should be considered in Bangladesh.

PDC-BOD in Pak Kret District, north of Bangkok, Thailand, was estimated as 48.4 g-BOD $person^{-1}$ day^{-1} with "seepages" and 29.2 g-BOD $person^{-1}$ day^{-1} without "seepages" based on the existing MFA research results, which was comparable to the existing figures of PDC and PGC. PDC-BOD in Pak Kret Municipality, where septic tanks were dominant domestic wastewater treatment methods, were larger than those in Japan including those with lower efficiency treatment methods. Introduction of domestic wastewater treatment methods with smaller PDC would improve the ambient water quality through pollutant discharge reduction. In regards to nutrients, advanced CJ with larger removal rates and smaller PDC of nutrients would be an alternative to reduce nutrient pollutant discharges. Together with the MDGs perspective of accessible ratios to safe drinking water and appropriate sanitation, pollutant discharge reduction would be important to improve the ambient water quality. The indices, PDC and PLC_{wb}, would be effective to illustrate the pollutant discharge and its contribution to the ambient water pollution.

IWRM has been widely advocated among the researchers and governments, and MFA has also been conducted in Thailand. Community participation was also introduced in the field of water environment. These situations on water environment in Thailand suggested the possibility of introduction of policy measurements including EAH books of domestic wastewater to reduce pollutant discharges. The results and the concept in this paper would be among the necessary base information for water environment improvement in the countries together with these advanced water environment related researches, policies and implications.

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