ANALYSIS

Relationships between water pollutant discharges per capita (PDCs) and indicators of economic level, water supply and sanitation in developing countries

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ABSTRACT

Water pollutant discharges per capita (PDCs) as indicators to evaluate quantitatively domestic wastewater pollutant discharges to the ambient water were applied to eight international coastal zones and lakeside regions. Statistical analyses were conducted to find the relationships between PDCs and water, sanitation and economic parameters including purchase power parity based gross national income (PPP-GNI) per capita, proportions of access to safe drinking water and appropriate sanitation, domestic water usage amount, and integrated parameters of water, sanitation and economic indicators (WSEI1, 2). Two of the important findings from the regression analyses results were PDC-BOD correlated with PPP-GNI per capita with 3rd-order regression, and PDC-TP correlated with WSEI1 positively with 10% significance, besides smaller adjusted regression coefficients.

t-values of partial regression coefficients between PDC-TP and WSEI2 increased in the most analyses cases compared to those between PDC-TP and WSEI1, which showed improvement of the indices. Empirical estimations were also conducted based on the regression analyses results and distributions of PDCs and PPP-GNI per capita on the graphs. Six components generated by the principle component analysis (PCA) contributed 99% of the parameters. The first component represented access to sanitation, second one represented household connection of safe drinking water, third one represented areal equipment of water supply in urban area, fourth one represented domestic water usage amount, fifth one represented areal equipment of water supply, and sixth one represented income per capita and sanitation.

Although some statistically significances of the multiple linear regression analysis were observed, the relationships between PDCs and the water supply parameters were considered as complicated in regards to areal equipment and household connection, and in whole country and in urban area. Possible chronological relationships between PDC-BOD and water supply equipment were considered based on the results of the multiple linear regression analyses and PCA. Based on the considerations of the water pollutant discharges and the economic related parameters relationships, domestic wastewater treatment facility...
1. Introduction

Water pollution problems in rivers and enclosed coastal zones including lakes and inner bays in developed countries have been alleviated with countermeasures against industry and domestic wastewater pollution. One of the main purposes of wastewater treatment in developed countries is to reduce pollutant discharges. Pollutant discharges derived from domestic, industrial and agricultural wastewater occupied around 80% of total pollutant discharges (UNEP, 2003a).

Various joint efforts of international and domestic corporate organizations have been developed in regards to international water pollution problems. Regional Seas Programme started in 1974 (Table 1), Global Programme of Action (GPA) for the Protection of the Marine Environment from Land-based Activities started in 1995, and the Global International Waters Assessment (GIWA) started in 1999 (UNEP/GPA Coordination Office, 2002; GIWA, 2004; UNEP/RSP, 2006; Tsuzuki, 2004b). Pollutant discharges reduction is included in these programs and activities as one of their purposes.

The changing relationship between per capita income and income inequality was empirically illustrated as the inverted-U shaped curve, which was known as Kuznets (1955) curve. Grossman and Krueger (1995) applied the inverted-U shaped curve to the relationships between economic growth and environmental qualities in 1991, named environmental Kuznets curve (EKC). The relationship was appeared in the World Development Report in 1992 (World Bank, 1992). After that, many investigations have been conducted on EKC. Matsuoka et al. (1998) found that the inverted-U shaped curve was observed only for sulfur oxide (SO$_2$), when several environmental indicators were examined, including per capita emission of SO$_2$, nitrogen oxide (NO$_x$) and carbon dioxide (CO$_2$), accessible ratios of safe water supply and sanitation, and degradation ratio of forest. Bai and Imura (2000) introduced three types of urban environmental issues; (a) poverty-related issues, (b) industrial pollution-related issues and (c) consumption-related issues, after World Bank (1992) (Fig. 1). Yandle et al. (2004) reviewed researches on EKC emphasizing property rights and the roles of law. Shen and Hashimoto (2004) applied EKC to seven pollutants including arsenic, COD, cadmium and mercury in water, sulfur dioxide (SO$_2$), dust fall in air and industrial waste stock in 31 provinces and metropolitans in China. They found the inverted-U shaped curve relationship for four water pollutants and SO$_2$ cases, and the lower income turning points than the earlier empirical studies. They suggested the reasons of the lower income turning points as efficient pollution reduction equipments, the subsidies from developed countries, and the length of the analysis terms, which showed us one of the desirable directions of environmental quality enhancement in developing countries. Ito et al. (2007) analyzed the relationships between water use characteristics and economic related aspects for poor groups and other groups in several villages in Kenya in light of official development assistance (ODA) evaluation scheme.

Most recent studies on EKC have focused on economic model analyses (Tissell, 2001; Chimeli and Braden, 2005; Ranjana and Shortleb, 2007; Chimeli, 2007; Müller-Fürstenbergera and Wagner, 2007; Khanna and Plassmann, 2007; Haight, 2007). Relationships between economic level and CO$_2$ release amount were analyzed using country data in the world (Romero-Ávila, 2007) and country data in the United States (Soytas et al., 2007). Several empirical analyses were conducted with environmental data including water quality related parameters in Shenzhen, China (Liua et al., 2007), air quality related parameters in Spain (Roca and Serrano, 2007), and deforestation related parameters in developing countries (Van and Azomahou, 2007).

Tsuzuki and Ogawa (2004) and Tsuzuki (2004a, 2005a,b, 2006a) proposed pollutant loads per capita flowing into the water body (PLC$_{wb}$) as appropriate indices to evaluate domestic wastewater treatment performances and natural purification in the drainage areas. Tsuzuki (2004a, 2005a,c, 2006b) made comparative analyses of PLC$_{wb}$ and pollutant discharge per capita (PDC) with an economic indicator, GDP per capita. Tsuzuki (2006c,d) conducted statistical analyses for BOD discharge per capita (PDC-BOD) with purchase power parity based gross national income (PPP-GNI) per capita and water and sanitation parameters. Tsuzuki (2007) found EKC like inverted-U shaped curve chronological relationships between PDCs of organic carbon, nitrogen and phosphorus and per capita income in the drainage area of Lakes Shinji and Nakai, Japan. The relationships between PDCs and a water, sanitation and economic indicator (WSEI), combinations of indicators such as defined with Eq. (1), were also analyzed (Tsuzuki, 2006e, 2007).

\[
WSEI_i = \frac{a \times 100}{b} \times \frac{d}{c} \times \frac{e}{100} \times 100
\]

(1) where WSEI$_i$: water, sanitation and economic indicator $i$; $a$: PPP-GNI (US$); $b$: proportion of population with access to appropriate sanitation in whole country (%); $c$: proportion of

<table>
<thead>
<tr>
<th>Region</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Sea</td>
<td>South-East Pacific</td>
</tr>
<tr>
<td>Wider Caribbean</td>
<td>South Pacific</td>
</tr>
<tr>
<td>East Africa</td>
<td>West and Central Africa</td>
</tr>
<tr>
<td>East Asia</td>
<td>North-East Pacific</td>
</tr>
<tr>
<td>ROPME* Sea Area</td>
<td>South-West Atlantic</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>Baltic</td>
</tr>
<tr>
<td>North-West Pacific</td>
<td>Arctic</td>
</tr>
<tr>
<td>Red Sea and Gulf of Aden</td>
<td>North-East Atlantic</td>
</tr>
<tr>
<td>South Asia</td>
<td></td>
</tr>
</tbody>
</table>

* Regional Organization for the Protection of the Marine Environment, Kuwait.
population with access to appropriate sanitation in urban area (%); \( d \): proportion of population with access to safe drinking water in whole country (%); \( e \): proportion of population with access to safe drinking water in urban area (%).

Moreover, the relationships between PDCs and GDP per capita in developing countries were statistically analyzed in regards to BOD, TN and TP (Tsuzuki, 2004b). In this paper, some comparative studies between PDCs and economic indicators by use of data in UNEP reports were conducted. PLCwb were considered to be more appropriate parameters to directly show contributions of domestic wastewater to water pollution in the ambient water bodies. However, only PDCs were available for the analyses. Therefore, statistical analyses were conducted with PDCs including PDC-BOD, and total nitrogen and total phosphorus discharges per capita (PDC-TN and PDC-TP). A part of this paper was presented in the 4th International Symposium on Southeast Asian Water Environment, Bangkok, Thailand, in December, 2006 (Tsuzuki, 2006e). The advancements in this paper after Tsuzuki (2006e) were that (1) regression analyses were improved to find empirical estimations between PDCs and PPP-GNI per capita; (2) WSEI was introduced, which included newly introduced parameters, (3) multiple linear regression analysis was conducted with different data combination; (4) principle component analysis (PCA) was conducted with different data combination; (5) discussions were improved with the Millennium Development Goals (MDGs) parameters; and (6) considerations on the relationships between PDC-BOD and water supply parameters were improved.

2. Methods

Regions and the numbers of countries/areas investigated in this paper are shown in Fig. 2. PDC-BOD, PDC-TN and PDC-TP were estimated based on the reports from GPA and GIWA (UNEP/CEP, 1994; UNEP, 1999a,b, 2000a,b, 2003b). PDCs were estimated from domestic wastewater pollutant discharges and equivalent populations. The analyses on PDC-BOD were conducted for 50–65 countries/areas depending on the cases, while those on PDC-TN and PDC-TP were conducted for 33–49 countries/areas because of data availability. Economic, water and sanitation parameters analyzed in this study were PPP-GNI per capita (World Bank, 2002), percentages of population with access to safe drinking water (areal equipment and household connection, and in urban area and in whole country) and appropriate sanitation in urban area and in whole country (WHO/UNICEF, 2004), and water usage amount per capita in households (FAO, 2006). Most pollutant discharges data and

![Image 1](https://example.com/image1)

**Fig. 1**–Types of relationships between economic growth and environmental problems: (a) poverty-related issues (ratios of people lacking access to safe drinking water, or adequate sanitation), (b) industrial pollution-related issues (particulate matter, and sulfur dioxide (SO\(_2\)) in air), (c) consumption-related issues (carbon dioxide (CO\(_2\)) emissions, and solid wastes per capita). It is important to lower the lines of the relationships as indicated in the figures (Tsuzuki, 2006d, 2007; original sources: modified from Bai and Imura, 2000; World Bank, 1992).

![Image 2](https://example.com/image2)

**Fig. 2**–Countries/areas in the regions investigated in this paper.

Normal letters: Only BOD data were available;
Italic (red) letters with underline: BOD, TN and TP data were available.
The numbers in the parentheses indicate the numbers of the countries/areas with pollutant discharge data. (Base map is obtained from UNEP/RSP, 2006)
water, sanitation and economic data were in 1998–2002 depending on the data availability.

Four statistical methods were applied in this study. First, in order to find the relationships between PDCs and PPP-GNI per capita, regression analyses were conducted. The countries investigated were mostly developing countries, however, some large income countries were included because the Wider Caribbean Region and the Middle East countries were included in the analyses. Some extraordinary large values of PDCs were also included in the dataset. Therefore, some cases of the regression analyses were conducted excluding high income countries and the extraordinary PDCs. For PDC-BOD, third-order regression analyses were conducted for the six cases, (1) all countries/areas, (2) without United States of America (USA), (3) without USA and United Arab Emirates (UAE), (4) only countries/areas with PPP-GNI per capita less than US$9266 (border line of high income countries in the statistic data), (5) only countries/areas with PPP-GNI per capita less than US$12666 excluding Cook Islands (extraordinary large value of PDC-BOD comparing to other countries/areas), and (6) without Cook Islands. Fourth-order regression analyses were also conducted for the three cases, (4), (5) and (6). For PDC-TN and PDC-TP, third- and fourth-order regression analyses were conducted for the four cases (1), (2), (3) and (4). Some graphs of PDCs and the economic parameter did not necessarily show the inverted-U shaped curve relationships. Therefore, third- and fourth-order regression analyses were conducted to find more fitted relationship curves. Empirical estimations were also conducted based on the regression analyses results and graphic distributions of PDCs and PPP-GNI per capita. PDCs units in the first set of regression analyses were kg person\(^{-1}\) year\(^{-1}\), and those in the other analyses were g person\(^{-1}\) day\(^{-1}\) for the purpose of comparison with the previous results.

Second, in order to find the relationships between PDCs and WSEIs, regression analyses were conducted for PDCs and WSEIs. In addition to WSEI\(_2\) described in the introduction chapter, WSEI\(_2\) was defined as Eq. (2), which included newly introduced parameters in this paper.

\[
\text{WSEI}_2 = a + \frac{100}{b} + \frac{100}{c} \times \frac{d}{100} \times \frac{e}{100} \times \frac{f}{100} \times \frac{g}{100} \times \frac{h}{100} \quad (2)
\]

where WSEI\(_2\): water, sanitation and economic indicator 2; f: proportion of population with access to safe drinking water with household connection in whole country (%); g: proportion of population with access to safe drinking water with household connection in urban area (%); h: domestic water usage amount per capita (m\(^3\) year\(^{-1}\) person\(^{-1}\)).

Third, PCA was conducted with the water, sanitation and economic parameters in order to find key parameters which determine PDC. The analysis method was varimax rotation method with Kaiser normalization.

Fourth, in order to ensure the key parameters to determine PDC, multiple linear regression analyses were conducted between PDCs and the economic, water and sanitation parameters. In related to the multiple linear regression analyses, relationships between PDCs and each parameter were graphically investigated, and regression coefficients between economic, water and sanitation parameters were analyzed to investigate independence and similarity of the parameters.

Table 2: Regression analyses results between PDCs and PPP-GNI per capita

<table>
<thead>
<tr>
<th>Case</th>
<th>No.</th>
<th>1st-order regression</th>
<th>2nd-order regression</th>
<th>3rd-order regression</th>
<th>4th-order regression</th>
<th>t-value</th>
<th>t-value</th>
<th>t-value</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
<td>e</td>
<td>f</td>
<td>g</td>
<td>h</td>
<td></td>
</tr>
<tr>
<td>BOD, 3rd-order regression</td>
<td>50</td>
<td>0.038</td>
<td>0.170</td>
<td>0.048</td>
<td>0.016</td>
<td>0.003</td>
<td>0.005</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>BOD, 4th-order regression</td>
<td>35</td>
<td>0.053</td>
<td>0.165</td>
<td>0.016</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>TN, 3rd-order regression</td>
<td>33</td>
<td>0.090</td>
<td>0.036</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>TN, 4th-order regression</td>
<td>33</td>
<td>0.089</td>
<td>0.032</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>TP, 3rd-order regression</td>
<td>33</td>
<td>0.098</td>
<td>0.028</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>TP, 4th-order regression</td>
<td>33</td>
<td>0.098</td>
<td>0.028</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
</tbody>
</table>

a: The number of the countries/areas; b: Adjusted multiple regression coefficient; c: Percentage point of T-distribution; d: Without countries/areas with PPP-GNI per capita more than US$9266; e: Constant; f: 1st-, 2nd-, 3rd- and 4th-order of PPP-GNI per capita; g: Not available; and +: 10% significant.
3. Results

Regression analyses results of Case 4 for PDCs (PDC-BOD, PDC-TN and PDC-TP) and PPP-GNI per capita were shown in Table 2. Only some representative regression analyses results were shown in Table 2 to avoid complicatedness of the discussions. The third-order regression analysis result of PPP-GNI per capita for PDC-BOD showed 10% significant correlation. However, adjusted multiple regression coefficient (adjusted $R^2$) was smaller than 0.10 (Table 2). Significant correlations were not observed in other regression analyses with the income.

Fig. 3 – 1 — Relationship between PDC-BOD and PPP-GNI per capita. 2 — Relationship between PDC-TN and PPP-GNI per capita. 3 — Relationship between PDC-TP and PPP-GNI per capita.
parameter. Fig. 3 shows the relationships between PDCs (PDC-BOD, PDC-TN and PDC-TP) and PPP-GNI per capita. Empirical estimation curves were prepared based on the regression analyses results and distribution of PDCs and PPP-GNI per capita on the graphs (Fig. 3-1, -2 and -3). The units of PDC are kg person\(^{-1}\) year\(^{-1}\) and those of PPP-GNI are US$ person\(^{-1}\) year\(^{-1}\) in the following equations.

\begin{align*}
PDC\text{-BOD} &= -3.609 \times 10^8 \times \text{PPP}\text{-GNI}^4 + 2.173 \times 10^7 \times \text{PPP}\text{-GNI}^3 + 1.922 \times 10^3 \times \text{PPP}\text{-GNI} + 5.180 \quad (0 \leq \text{PPP}\text{-GNI} \leq 10, 000) \\
&= 2.95 \times \exp\left(-\left(\text{PPP}\text{-GNI} + 1000\right)/10000\right) + 2 \quad (\text{PPP}\text{-GNI} \geq 10, 000) \\
PDC\text{-TN} &= 2.50 \times \exp\left(-\left(\text{PPP}\text{-GNI} + 1000\right)/5000\right) + 1 \\
PDC\text{-TP} &= 5.021 \times 10^7 \times \text{PPP}\text{-GNI}^3 - 3.985 \times 10^3 \times \text{PPP}\text{-GNI}^2 + 8.070 \times 10^1 \times \text{PPP}\text{-GNI} + 0.3537.
\end{align*}

Almost all relationships between PDCs and WSEIs were found not to be significant at 10% significance level (Table 3). Adjusted \(R^2\) were below 0.10 for almost all cases except for PCD-TP and WSEI\(_1\). The analyses results with only PDC-TP were shown in Table 3 as examples, which included a result of PDC-TP and first order of WSEI\(_1\) with 10% significance. This only one significant result might show gradual increase of PDC-TP with WSEI\(_1\) increase (Fig. 4(a)). Other relationships between PDCs and WSEIs were not clearly identified (Fig. 4(a) and (b)).

<table>
<thead>
<tr>
<th>Pollutant parameter and WSEI</th>
<th>No.(^a)</th>
<th>(R^{2b})</th>
<th>Partial regression coefficient</th>
<th>t-value</th>
<th>(t(T-k)^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Const., a 1st, b 2nd, c 3rd, d 4th</td>
<td></td>
<td>10% 5% 1%</td>
</tr>
<tr>
<td>PDC-TP and WSEI(_1)</td>
<td></td>
<td></td>
<td>Const., a 1st, b 2nd, c 3rd, d 4th</td>
<td></td>
<td>10% 5% 1%</td>
</tr>
<tr>
<td>1st-order regression</td>
<td>23</td>
<td>0.127</td>
<td>-0.345 0.194+ 0.010 -0.001</td>
<td>-0.422</td>
<td>2.051+ 0.001</td>
</tr>
<tr>
<td>2nd-order regression</td>
<td>23</td>
<td>0.090</td>
<td>0.288 0.021 0.010 0.000 0.000</td>
<td>0.151</td>
<td>0.043 0.370</td>
</tr>
<tr>
<td>3rd-order regression</td>
<td>23</td>
<td>0.042</td>
<td>0.355 -0.010 0.014 0.000 0.000</td>
<td>0.083</td>
<td>-0.006 0.062 0.018</td>
</tr>
<tr>
<td>4th-order regression</td>
<td>23</td>
<td>-0.009</td>
<td>-1.688 1.297 -0.264 0.024 -0.001</td>
<td>-0.163</td>
<td>0.207 -0.204 0.216 -0.219</td>
</tr>
</tbody>
</table>

| PDC-TP and WSEI\(_2\)       |          |         | Const., a 1st, b 2nd, c 3rd, d 4th |         | 10% 5% 1%  |
| 1st-order regression        | 23       | -0.045  | 1.131+ 0.000 0.000 0.000 0.000 | 2.220+  | 0.243 0.001 |
| 2nd-order regression        | 23       | 0.044   | 0.435 0.007 0.000 0.000 0.000 | 0.687   | 1.704 -1.719 |
| 3rd-order regression        | 23       | -0.003  | 0.342 0.009 0.000 0.000 0.000 | 0.449   | 0.932 -0.526 0.231 |
| 4th-order regression        | 23       | -0.058  | 0.299 0.010 0.000 0.000 0.000 | 0.325   | 0.529 -0.237 0.120 -0.091 |

\(a\): The number of the countries/areas; \(b\): Adjusted multiple regression coefficient; \(c\): Percentage point of \(T\)-distribution; \(d\): Constant; \(e\): 1st, 2nd, 3rd and 4th power of WSEI\(_1\) and WSEI\(_2\), WSEI\(_1\) and WSEI\(_2\) were defined as Eqs. (1) and (2); and \(+\): 10% significant.

Fig. 4 – Relationships between PDC and water, sanitation and economic indexes, (a) WSEI\(_1\) and (b) WSEI\(_2\) (legends: circle: PDC-BOD; square: PDC-TN; and triangle: PDC-TP).
The relationships between two pairs of components, i.e., components 1 and 2, and components 3 and 4, and PDC-BOD, PDC-TN and PDC-TP were illustrated in Fig. 5, respectively. The results of multiple linear regression analyses showed some parameters were significantly correlated with PDCs (Table 5). Two safe drinking water parameters correlated positively with PDC-BOD and other two safe drinking water parameters correlated negatively with PDC-BOD. However, the relationship between PDC-BOD and each parameter did not necessarily show clear relationship (Fig. 6).

In regards to regression coefficients between the economic, water and sanitation parameters, two parameters of safe drinking water with household connection correlated positively with 10% significance, and two sanitation parameters correlated positively with 10% significance (Table 6). Other four cases were found with 20% significance.

### 4. Discussions

In the Millennium Development Goals (MDGs) of water and sanitation sectors, to half the proportions of population of people without safe drinking water and appropriate sanitation by 2015 is targeted. Figs. 7 and 8, which were prepared using UNDP data (UNDP, 2007), showed the relationships between the ranks of Human Development Indicator Rank (HDIRANK), GDP per capita (GDPC), proportions of people with access to safe drinking water (ACCWAT) and appropriate sanitation (ACCSANI). There were many countries with less than US $10,000 person$^{-1}$ year$^{-1}$ GDP per capita, and with wide range of accessibilities to safe drinking water and appropriate sanitation. Therefore, it is meaningful to consider the relationships between the economic indicators and the water and sanitation parameters especially for low-income countries with GDP per capita less than US$10,000 person$^{-1}$ year$^{-1}$.

In regards to the results of the regression analyses between PDCs and PPP-GNI per capita, all of the t-values were lower than percentage point of 5% significance in Case 4 (Table 2). In Case 5, regression curve of the fourth-order regression for PDC-BOD was similar to those of third-order regression in the range below US$8000 person$^{-1}$ year$^{-1}$ of PPP-GNI per capita (Fig. 3-1). The third-order regression curves go up and fourth-order regression curves go down above US$9200 person$^{-1}$ year$^{-1}$ of PPP-GNI per capita. However, more realistic curve line of the relationship between PPP-GNI per capita and PDC-BOD in the latter range of PPP-GNI per capita was considered to gradually decrease with income increase because of domestic wastewater treatment improvement in larger income countries/areas.

Although larger significance of regression relationship curves were not observed in this study, an empirical relationship of EKC inverted-U shaped curve with a vague peak around US$2100–2600 person$^{-1}$ year$^{-1}$ of PPP-GNI per capita was estimated for the relationship of PPP-GNI per capita and PDC-BOD (Fig. 3-1).

In regards to the nutrient parameters, an EKC inverted-U shaped curve was observed for PDC-TP, but not for PDC-TN (Table 2 and Fig. 3-2 and -3). Besides low significance of the correlations, PDC-TN was suggested to gradually decrease with PPP-GNI per capita increase. PDC-TP was suggested to increase in the range below US$14,000 person$^{-1}$ year$^{-1}$ of PPP-GNI per capita and to decrease above US$14,000 person$^{-1}$ year$^{-1}$ of PPP-GNI per capita. The analyses results of Tsuzuki (2004b) with smaller number of countries/areas showed the same tendencies for PDCs and GDP per capita relationships (Figs. 9 and 10). GDP per capita of the peaks of the estimated curves were US$4000 and US$10,000 for PDC-BOD and PDC-TP, respectively. Possible reasons for the differences of these peak values between the results were considered to be the differences of the subjected countries/areas and the economic parameters. PPP-GNI in developing countries are generally larger than GDP per capita in developing countries, which explained the difference in PDC-TP analyses results. In regards to BOD, the third-order regression curve of PDC-BOD and PPP-GNI in this study swiftly increased in the range above US$10,000 person$^{-1}$ year$^{-1}$ PPP-GNI per capita (Fig. 3-1). The reason for the increase was considered as addition of the Wider Caribbean Region countries.
especially those with US$8800–12,800 person$^{-1}$ year$^{-1}$ of PPP-GNI per capita and 6.1–14.3 kg person$^{-1}$ year$^{-1}$ of PDC-BOD. This dataset update might cause the regression curve alternation, which was considered to move the first peak forward to smaller range of PPP-GNI from the previous results (Fig. 9).
Table 5 – Multiple linear regression analyses results of PDCs with the water, sanitation and economic parameters

<table>
<thead>
<tr>
<th>Water, sanitation and economic parameter</th>
<th>Partial regression coefficient</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BOD</td>
<td>TN</td>
</tr>
<tr>
<td>Constant</td>
<td>60.817</td>
<td>44.925</td>
</tr>
<tr>
<td>PPP-GNI</td>
<td>0.857</td>
<td>0.239</td>
</tr>
<tr>
<td>Water supply (whole country, areal equipment)</td>
<td>0.824</td>
<td>0.159</td>
</tr>
<tr>
<td>Water supply (whole country, household connection)</td>
<td>-1.038</td>
<td>-0.076</td>
</tr>
<tr>
<td>Water supply (urban area, areal equipment)</td>
<td>-1.354</td>
<td>-0.464</td>
</tr>
<tr>
<td>Water supply (urban area, household connection)</td>
<td>0.959</td>
<td>0.167</td>
</tr>
<tr>
<td>Sanitation (whole country)</td>
<td>-0.434</td>
<td>0.024</td>
</tr>
<tr>
<td>Sanitation (urban area)</td>
<td>0.256</td>
<td>-0.267</td>
</tr>
<tr>
<td>Domestic water usage amount</td>
<td>0.166</td>
<td>-0.006</td>
</tr>
<tr>
<td>The number of the countries/areas</td>
<td>37</td>
<td>22</td>
</tr>
<tr>
<td>Adjusted regression coefficient, $R^2$</td>
<td>0.186</td>
<td>0.202</td>
</tr>
<tr>
<td>Percentage point of t-value, 10%</td>
<td>n.a a</td>
<td>n.a a</td>
</tr>
<tr>
<td>Percentage point of t-value, 5%</td>
<td>n.a a</td>
<td>n.a a</td>
</tr>
<tr>
<td>Percentage point of t-value, 1%</td>
<td>n.a a</td>
<td>n.a a</td>
</tr>
</tbody>
</table>

a: Not available; **: 1% significant; *: 5% significant; and +: 10% significant.

The exponential curve estimations in Fig. 3-1 and -2 implied that PDC-BOD and PDC-TN should reach around 2 kg-BOD person-1 year-1 and 1 kg-N person-1 year-1 with economic development in the matured societies. These values were estimated from several statistical analyses results and distribution of PDC and PPP-GNI per capita on the graphs, however, the estimations were still considered to be rather arbitrary. Fig. 3-1 and -2 did not show necessarily all the countries/areas data were in line with these empirical estimation curves, which showed the existence of other factors than income levels which determined PDCs. Therefore, further investigations of other factors were considered to be necessary to clarify the key factors on PDC.

In the regression analyses with WSEI, the only one significant relationship was found between PDC-TP and WSEI1 (Table 3, Fig. 4). Countries/areas in the Wider Caribbean Region, newly added countries/areas in this study, were wide variety of the countries from the point of view of economic, water and sanitation related conditions. For example, PPP-GNI per capita was from US$2390 to US$34,260. By means of introduction of WSEIs, significances of regression analyses results could be enhanced besides slightly less than 10% significance (Table 3). The increase of the countries/areas data could increase the reliability of the analyses results. More increase of the countries/areas data with PPP-GNI per capita less than US$1000 person-1 year-1 should be conducted in further research.

Possible reasons for the smaller significance of the regression analyses results are considered to be (1) actually less significant relationships between PDCs and the income parameters or WSEIs, (2) difficulty of the dataset preparation of PDCs because of data availability on PDCs, and (3) possible difference of the accuracy and reliability of PDCs data between countries/areas. These points will be addressed in further research.

Six components were generated by PCA, which account for 99% of total variances (Table 4, Fig. 5-1 and -2). The six components successfully distinguished the parameters with their characteristics in relation to PDC as described in the results chapter. Component 1 represented sanitation equipment. Therefore, PDCs were considered to decrease with component 1 increase. In the same manner, PDCs were considered to increase with components 2, 3 and 4 increases, because components 2 and 3 represented water supply equipment, and component 4 represented water usage amount, respectively. However, such simple relationships between PDC and the components were not observed (Fig. 5-1 and -2). The reasons for these vague relationships were considered that the relationships between PDC and water, sanitation and economic parameters were complicated, and there were various countries/areas in the dataset. Moreover, four parameters of safe drinking water did not necessarily show the same tendency of the relationships with PDCs, which suggested some complicated effects of safe drinking water parameters on PDCs. When the countries/areas were limited within Asia, Pacific and Africa, wider range of PDC-BOD in the range below US$3000 person-1 year-1 should be conducted in 1 year.

The exponential curve estimations in Fig. 3-1 and -2 of PPP-GNI per capita was from US$2390 to US$34,260. By means of introduction of WSEIs, significances of regression analyses results could be enhanced besides slightly less than 10% significance (Table 3). The increase of the countries/areas data could increase the reliability of the analyses results. More increase of the countries/areas data with PPP-GNI per capita less than US$1000 person-1 year-1 should be conducted in further research.

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The multiple linear regression analysis result suggested complicated relationships between PDC-BOD and safe drinking water parameters (Table 5), which was also suggested by the PCA result as described above. The results suggested that increase of access to safe drinking water household connection in whole country and areal equipment in urban area should positively correlated with decrease of PDC-BOD (Tsuzuki, 2006e). The multiple linear regression analysis was based on the data around 2000, therefore the relationships between water supply parameters and PDC-BOD were spatial relationships at a time. If these relationships could be expanded to chronological relationships, the estimated relationships would be as shown in Fig. 11. Deployment of water supply infrastructures is generally considered to be conducted in the order of (1) areal equipment in urban area, (2) household connection in urban area, (3) areal equipment in whole country, and (4) household connection in whole country. The
Fig. 6 – Relationships between PDC-BOD and water, sanitation and economic parameters.
multiple linear regression analysis and PCA results suggested that in the early stage of the development with (1) areal equipment in urban area, PDC-BOD should decrease to some extent. In the middle stage with (2) household connection in urban area and (3) areal equipment in whole country, PDC-BOD should increase with the development. In the later stage with (4) household connection in whole country, PDC-BOD should decrease with the development. Simple regression analysis between PDC-BOD and the safe drinking water parameters resulted in less significant negative correlations (Fig. 6(b), (c), (d) and (e)). Therefore, these possible chronological relationships were considered to be accompanied with other related development to reduce pollutant discharges (Fig. 11). Further analyses would be required on this point with the dataset update in further research. PLCwb was proposed as an appropriate indicator for domestic wastewater treatment performance including natural purification effect in the ambient water. Analyses on the relationships between PLCwb and the safe drinking water parameters resulted in less significant negative correlations (Fig. 6(b), (c), (d) and (e)). Therefore, these possible chronological relationships were considered to be accompanied with other related development to reduce pollutant discharges (Fig. 11). Further analyses would be required on this point with the dataset update in further research. PLCwb was proposed as an appropriate indicator for domestic wastewater treatment performance including natural purification effect in the ambient water. Analyses on the relationships between PLCwb and the safe drinking water parameters resulted in less significant negative correlations (Fig. 6(b), (c), (d) and (e)). Therefore, these possible chronological relationships were considered to be accompanied with other related development to reduce pollutant discharges (Fig. 11). Further analyses would be required on this point with the dataset update in further research. PLCwb was proposed as an appropriate indicator for domestic wastewater treatment performance including natural purification effect in the ambient water. Analyses on the relationships between PLCwb and the safe drinking water parameters resulted in less significant negative correlations (Fig. 6(b), (c), (d) and (e)). Therefore, these possible chronological relationships were considered to be accompanied with other related development to reduce pollutant discharges (Fig. 11). Further analyses would be required on this point with the dataset update in further research. PLCwb was proposed as an appropriate indicator for domestic wastewater treatment performance including natural purification effect in the ambient water. Analyses on the relationships between PLCwb and the safe drinking water parameters resulted in less significant negative correlations (Fig. 6(b), (c), (d) and (e)). Therefore, these possible chronological relationships were considered to be accompanied with other related development to reduce pollutant discharges (Fig. 11). Further analyses would be required on this point with the dataset update in further research. PLCwb was proposed as an appropriate indicator for domestic wastewater treatment performance including natural purification effect in the ambient water.

| Table 6 – Regression coefficients between the water, sanitation and economic parameters |
|-----------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 PPP-GNI                                    | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 2 Water supply (whole country, areal equipment) | 0.667 | 0.778 | 1   | 0.698 | 1   | 0.755 | 1   | 1   |
| 3 Water supply (whole country, household connection) | 0.799 | 0.816 | 0.925 | 0.613 | 0.672 | 1   | 0.920 | 1   |
| 4 Water supply (urban area, areal equipment) | 0.799 | 0.715 | 0.743 | 0.613 | 0.672 | 1   | 0.920 | 1   |
| 5 Water supply (urban area, household connection) | 0.518 | 0.659 | 0.739 | 0.597 | 0.716 | 0.743 | 0.613 | 0.672 | 1   |
| 6 Sanitation (whole country)                  | 0.838 | 0.715 | 0.743 | 0.613 | 0.672 | 1   | 0.920 | 1   |
| 7 Sanitation (urban area)                    | 0.838 | 0.659 | 0.739 | 0.597 | 0.716 | 0.743 | 0.613 | 0.672 | 1   |
| 8 Domestic water usage amount                | 0.699 | 0.591 | 0.706 | 0.484 | 0.560 | 0.648 | 0.608 | 1   |

*: 10% significance, and #: 20% significance with Pearson examination.

Fig. 7 – Relationships between Human Development Indicator Rank (HDIRANK), GDP per capita (GDPC), proportion of population with access to appropriate sanitation (ACCSANI) and safe water (ACCWAT) in 2004 (prepared by the author using UNDP data: UNDP, 2007).
and the economic, water and sanitation related parameters will be conducted in further research.

Regression coefficients between water, sanitation and economic parameters showed relatively large correlations between specific pairs of parameters (Table 6). Significant correlation with 10% significance between two water supply household connection parameters showed household connection in urban and in whole country was conducted in parallel to some extent. Significant correlation with 10% significance between two sanitation parameters showed also in parallel equipment of sanitation in urban and in whole country. Moderate significance with 20% significance between PPP-GNI per capita and water and sanitation parameters showed water and sanitation equipments should increase with income increase.

The relationships between economic parameters and pollution parameters are not only limited to EKC inverted-U shaped curve (Fig. 1). Therefore, we might focus on preservation of environment and reduction of pollutant loads, especially in the low-income countries “at earlier stages of development than previously been the case” as stated by Grossman and Krueger (1995) taking the relationships into account.

In regards to pollutant loads of domestic wastewater, linear correlation was observed between PDC-BOD and accessible

\[
\text{Without Nation A: } R^2 = 0.0788 \\
Y = 3 \times 10^{-12} \cdot X^3 - 9 \times 10^{-2} X^2 + 0.0001 \cdot X + 7.619
\]

\[
\text{With Nation A: } R^2 = 0.0696 \\
Y = 1 \times 10^{-11} \cdot X^3 - 3 \times 10^{-7} X^2 + 0.002 \cdot X + 6.5345
\]

(X: GDP per capita, Y: BOD load per capita)

Fig. 9 – Relationship of GDP per capita with PDC-BOD (Tsuzuki, 2004b).
ratio to high efficiency sanitation including wastewater treatment plants, agriculture village wastewater treatment facilities (rural community wastewater treatment facilities), and combined jokaso (sometimes written as jokasou) in some drainage areas in Japan (Tsuzuki, 2005a,c, 2006a). Jokaso is an on-site domestic wastewater treatment system in Japan. Combined jokaso treats all wastewater from households including wastewater from kitchen, bath, toilet and washing clothes (International Environmental Planning Center (INTEP)/The University of Tokyo, 1996). Simple jokaso treats only wastewater from toilet. Currently, newly installation of jokaso is limited only to combined jokaso by the regulations in Japan because of its overall high treatment efficiency. The treatment efficiency of advanced combined jokaso is comparative to wastewater treatment plants (Japan Education Center of Environmental Sanitation, 2003). Therefore, increasing accessible ratios of high efficiency sanitation will enhance water quality of the ambient water bodies in developing countries by decreasing pollutant discharges. In addition to achieving the water and sanitation MDGs, pollutant discharge reduction strategies should be also considered in the early stage of the development even in developing countries. Several measurements in the households, e.g. using environmental accounting housekeeping (EAH) books (Tsuzuki and Ogawa, 2004; Tsuzuki, 2004a, 2005a,b, 2006a), will also contribute to pollutant discharge reduction flowing into the ambient water bodies including coastal zones and lakes.

5. Conclusion

At the beginning of the study on the relationships between water pollutant discharges and economic related parameters, such kinds of relationships were estimated, i.e. PDCs would decrease with sanitation facility parameters, increase with water supply parameters, increase with economic parameter in the first stage and decrease in the next stage, and so on. The analyses results of the four statistical methods showed that the relationships between PDC and water, sanitation and economic parameters were not so simple and clear relationships were not necessarily observed. However, the increase of the countries/areas data and parameters after the previous studies could enhance the reliability of the analyses results.

The empirically estimated relationship between PDC-BOD and PPP-GNI per capita was inverted-U shaped curve with a vague peak in the range of US$2100–2600 person−1 year−1 of PPP-GNI per capita. PDC-TN gradually decreased with PPP-GNI per capita increase. The empirically estimated relationship between PDC-TP and PPP-GNI per capita was EKC inverted-U shaped curve with a peak in the range of US$13,000–14,000 person−1 year−1 of PPP-GNI per capita.

Two of the important findings in the regression analyses results were PDC-BOD correlated with third-order regression of PPP-GNI per capita, and PDC-TP correlated with WSEI1 positively with 10% significance. Introduction of WSEI2 could increase significance of the regression analyses results between PDC-TP and WSEI besides less than 10% significance. The multiple linear regression analyses results suggested complicated relationships between PDC-BOD and safe drinking water parameters, which was also suggested by the PCA.
result as illustrated in Fig. 11. Many analyses results were less significant than 10%. Therefore, further investigation with updated dataset would be desirable. Consideration on \( PLC_{wb} \) would also be necessary in future research.

It was considered to be meaningful to find the relationships between FDC and water, sanitation and economic parameters especially for low-income countries with GDP per capita less than US$1000 person \(^{-1}\) year \(^{-1}\). Increasing accessible ratios to high efficiency sanitation and other measurements to decrease pollutant discharges will enhance water quality of the ambient water bodies in developing countries by decreasing pollutant discharges.

Acknowledgement

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