Journal of Global Environment Engineering, Vol. 14, pp.37-46, 2009

ENVIRONMENTAL KUZNETS CURVE (EKC) RELATIONSHIPS BETWEEN POLLUTANT DISCHARGE PER CAPITA (PDC) OF DOMESTIC WASTEWATER AND INCOME INDICATORS

Yoshiaki TSUZUKI [1,2*]

[1]Toyo University
(Izumino 1-1-1, Itakura, Ohra, Gunma 374-0193, Japan)
[2]Shimane University
(Nishikawatsu-cho 1060, Matsue, Shimane 690-8055, Japan)
* E-mail: *tsuzuki.yoshiaki@gmail.com*

Relationships between domestic wastewater pollutant discharges per capita (PDCs) and economic development indicators were discussed in this paper. Chronological relationships of PDCs (COD_{Mn}, TN and TP) with income indicators in the drainage area of Lakes Shinji and Nakaumi in 1955-93 showed statistically significant inverted U-shaped curve, namely environmental Kuznetz curve (EKC). COD_{Mn} discharge per capita (PDC-COD_{Mn}) in 47 prefectures in Japan in 2004 spatially had one-order relationship with an income index, which was regarded as the latter portion of the EKC. However, significant relationships were not observed for TN and TP discharges per capita (PDC-TN and PDC-TP), which should reflect area-specific regulations on the nutrients discharge. Graphical distribution of PDC-BOD and PPP-GNI per capita in developing countries in coastal areas in 2000±2 showed grouping of the coutries by the UNEP Regions. The relationship between BOD discharge per capita (PDC-BOD) and purchase power parity based gross national income (PPP-GNI) per capita showed that PDC-BOD were in wide range when PPP-GNI per capita was smaller and in narrow range when PPP-GNI per capita was larger. The relationship between PDC-BOD and newly introduced water, sanitation and economic parameter (WSEI) showed the same tendency. These relationships were similar to the original Kuznets relationship of economic growth and income inequality. The transition levels were US$ 3,000-4,000 for PPP-GNI per capita and 1.0 for WSEI.

Key Words : *pollutant discharge per capita (PDC); environmental Kuznetz curve (EKC); purchase power parity based gross national income (PPP-GNI); regression analysis; water, sanitation and economic indicator (WSEI)*

1. INTRODUCTION

After implementation of pollutant discharge reduction interventions, water quality in the ambient water has improved in Japan, however, water environment phenomena derived from water quality deterioration including red tide and blue tide are still observed especially in enclosed coastal zones. Pollutant discharge from domestic wastewater contributes much to pollutant load in the ambient water especially in the urban area. Domestic wastewater pollutant discharge reduction interventions include "hard interventions" such as construction of wastewater treatment plants (WWTPs) and *johkasou* (typical Japanese on-site domestic wastewater treatment method) and "soft interventions" such as dissemination of measurements in households by national and local governments and environmental non-government organizations (NGOs).

In the Millennium Development Goals (MDGs), populations of people without safe drinking water and appropriate sanitation are estimated as 1.1 billion and 2.4 billion, respectively, at the beginning of the 21st century, and proportions of these people are targeted to be decreased to half by 2015. Japanese contributions in the sanitation field should include (1) large treatment systems include

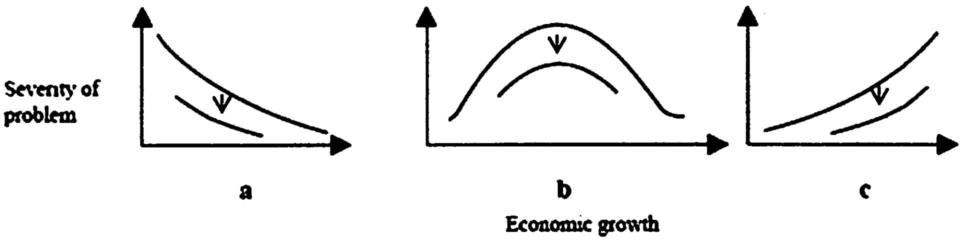

Fig. 1 Three types of the relationships between economic growth and environmental indicators: (a) poverty-related (e.g. proportions of people with accesses to safe drinking water and appropriate sanitation); (b) industrial-related (e.g. suspended particle material (SPM) and sulfur oxides (SO_x) in air); and (c) consumption-related (e.g. carbon dioxide (CO_2) emission, solid waste generation amount). The relation curves should be moved downwards in consideration with the experiences of developed countries [18]. (Prepared by the author based on Bai and Imura (2000)[19]. Original source is World Bank (1992)[17])

WWTPs[1], (2) small scale sanitation[2], and (3) "soft interventions" in the field of environmental education[3]. On-site sanitation includes treatment methods with both black and gray water like a combined *johkasou*[4], and those with only black water like a septic tank. Septic tanks widely prevail especially in developing countries[5),6),7]. Wastewater treatment efficiencies and effects of pollutant discharge reduction should be discussed in consideration with efficiencies of overseas development assistance (ODA) in the sanitation sector.

I have conducted research on pollutant load per capita flowing into the water body (PLC_{wb}) of domestic wastewater as an easily understandable index, in consideration with the effects of measurements in households by ordinary citizens [8),9),10),11),12]. On the contrary, pollutant discharges per capita (PDCs) of domestic wastewater in coastal area of developing countries were found to be related to economic development level and to be depended on the regions[13),14),15]. PDC is calculated with pollutant generation per capita (PGC) and the pollutant removal rate, and PLC_{wb} is calculated with PDC and reaching ratio of the pollutant.

Matsuoka *et al.*[16] is an example of the existing studies on relationships between environment indices and economic development level in Japan. The inverted U-shaped curve relationship, namely environmental Kuznets curve (EKC) relationship, was found only on sulfur oxide (SO_x) among several air and water pollution parameters in their study. The World Bank[17] proposed three types of relationships between severity of environmental problem and economic growth (**Fig. 1**)[18),19].

I have studied relationships between PDC and economic development level in this paper. First, chronological relationship between economic development in 1950's-1990's was studied. Second, PDC and economic level was studied in 47 prefectures in Japan. Third, PDC and economic development level was studied in 26 areas/cities of developing countries in seven regions. This paper is the translated English version of Tsuzuki[20], which was mainly based on Tsuzuki[21].

Table 1 PDC of several domestic wastewater treatment methods in the drainage area of Lakes Shinji and Nakaumi (Estimated by the author based on Nakamura *et al.*[22])

	WWTP^a	AVWTF^b	CJ & CP^c	SJ^d	NST^e
COD	2.2	8.1	5.9	20.8	17.8
TN	3.6	5.2	5.6	10.5	2.8
TP	0.53	0.78	1.03	1.17	0.44

a: wastewater treatment plants; b: agriculture village wastewater treatment facility; c: combined *johkasou* and community plant; d: simple *johkasou*; and e: night soil treatment.

2. METHODS

Relationships between PDC and economic development level were studied for (1) chronological relationship in an area; (2) spatial relationship at a time in Japan; and (3) spatial relationship at a time in developing countries. Statistical analysis methods and data are different in each study because of available data when the studies were conducted.

First, PDC data in the drainage area of Lakes Shinji and Nakaumi were from Nakamura *et al.*[22] (**Table 1**). Compensation of employment per capita and nominal gross prefecture product per capita as economic indices were from Doi[23]. Second-order regression analysis was conducted supposing the EKC inverted U-shaped curve. Chemical oxygen demand (COD_{Mn}), total nitrogen (TN) and total phosphorus (TP) were water quality parameters analyzed in this case.

Second, PDC in 47 prefectures in Japan in 2004 was estimated from administrative data on populations served with domestic wastewater treatments[24),25] and pollutant discharge per capita by

Table 2 PPP-GNI per capita, proportion of people with access to safe drinking water and appropriate sanitation, domestic water usage amount per capita and BOD discharge per capita (PDC-BOD) of domestic wastewater in developing countries/areas in coastal zones.

Region	Country	PPP-GNI[a] (U.S.$ 1,000) 2000	Access to sanitary facilities, household[b] Total (%) 2002	Urban (%) 2002	Access to safe drinking water, household[b] Total (%) 2002	Urban (%) 2002	Water usage for households per capita[c] (m^3 $person^{-1}$ year) 1998-2002	WSEI[d]	Pollutant discharge per capita[e] (kg yr^{-1} $person^{-1}$) BOD
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Pacific Islands	Papua New Guinea	2.3	45	67	11	61	7.2	0.04	1.6
South China Sea	Cambodia	1.4	16	53	6	31	4.3	0.01	18.2
	China	3.9	44	69	59	91	31.8	2.22	16.4
	Indonesia	2.8	52	71	17	31	30.5	0.12	14.8
	Malaysia	8.4	96	94	95	96	63.4	5.36	13.1
	Philippines	4.2	73	81	44	60	60.2	1.13	11.9
	Thailand	6.3	99	97	34	80	34.9	0.62	15.9
	Viet Nam	2.0	41	84	14	51	69.0	0.29	18.2
PORME Sea Region	Iran	5.9	84	86	87	96	72.9	4.97	0.5
	Kuwait	9.3	100	100	100	100	81.9	7.59	0.3
	Saudi Arabia	11.1	86	100	89	97	72.3	8.02	1.6
West and Central African (WACAF) Region	Northern WACFA	1.6	35	53	27	46	15.5	0.17	3.6
	Middle WACFA	1.0	40	53	14	27	13.5	0.02	1.7
	Southren WACFA	0.7	29	44	30	53	3.9	0.03	0.6
Caspian Sea	Azerbadjan	2.8	55	73	47	76	100.0	2.46	11.5
	Iran	5.9	84	86	87	96	72.9	4.97	10.8
	Kazakhstan	5.5	72	87	61	88	38.2	1.80	1.1
	Russian Federation	8.0	87	93	81	92	99.8	7.38	4.6
	Turkmenistan	4.0	62	77	52	81	87.4	3.12	4.0
Eastern African Region	Mombasa, Kenya	1.0	48	56	29	56	14.9	0.09	9.9
	Tanga, Tanzania	0.5	46	54	16	44	14.5	0.02	12.2
	Dar es Salaam, Tanzai	0.5	46	54	16	44	14.5	0.02	4.4
	Seychelles	7.3	100	100	87	100	2.0	0.13	19.5
	Madagascar	0.8	33	49	5	14	24.9	0.01	2.2
	Comoros	1.5	23	38	25	47	6.4	0.13	6.0
Red Sea and Gulf of Aden	Jeddah, Saudi Alabia	11.1	86	100	89	47	72.3	3.89	1.3

a: World Bank, 2002, World Development Report 2002;

b: World Resource Institute (2006) Earth Trend Environmental Information (available on http://earthtrends.wri.org/searchable_db, accessed in April, 2006) Source: World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2004. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation; Meeting the MDG drinking water and sanitation target: a mid-term assessment of progress;

c: Estimated from population and domestic water use in Food and Agriculture Organization of the United Nations (FAO) Land and Water Development Division. 2005. AQUASTAT Information System on Water and Agriculture: Online database. Rome: FAO. Available on-line at http://www.fao.org/ag/agl/aglw/aquastat/dbase/index.stm;

d: Water, sanitation and economy index defined by equation (1); and

e: Calculated by authors based on the reports from UNEP (Tsuzuki, 2004).

treatment methods from Nakamura *et al.*[22] (**Table 1**). Income per capita in each prefecture was from administrative data[26]. Regression analysis was conducted to find the relationships between PDC and the income index. Proliferation of wastewater treatment methods was considered to be affected not only by the economic index in the year of analysis but also by that in the past years. Therefore, the income index in 2003 and average of the income index in 1991-2003 were both applied in this study. COD_{Mn}, TN and TP were also analyzed in this case.

Third, relationship between PDC and income index, and those between PDC and water, sanitation and economic indices were analyzed in developing countries in coastal areas, because the MDGs water and sanitation parameters and domestic water usage amount were considered to affect PDC as discussed below (**Table 2**). PDC was estimated with total domestic wastewater discharge and estimated population in the subjected areas. Explanation variables included purchase power parity based gross national income (PPP-GNI), proportions of population with access to safe drinking water and appropriate sanitation in urban areas and whole country, and domestic water usage amount per capita which was estimated from water usage amount and proportion of household water usage[27),28),29)]. Independence of the six variables was examined with regression coefficients and their significance, and principle component analysis.

Biological oxygen demand (BOD) discharge per capita (PDC-BOD) was analyzed with the water, sanitation and economic indices, because the number of the available data was larger for BOD than those of TN and TP. Three kinds of analyses were conducted: (1) third-order regression analysis with PPP-GNI, (2) relationship between PDC-BOD and water, sanitation and economic index (WSEI) defined as Eq. (1), and (3) multiple regression analysis of PDC with eight indices: first, second and third power of PPP-GNI, access ratios of water and sanitation in urban and whole country areas, and household water usage amount per capita. Analysis methods of multiple variables in Eq. (1) was determined by making reference to Goda[30)].

$$WSEI = a \times \frac{100}{b} \times \frac{100}{c} \times \frac{d}{100} \times \frac{e}{100} \times f \times 10^{-6} \quad (1)$$

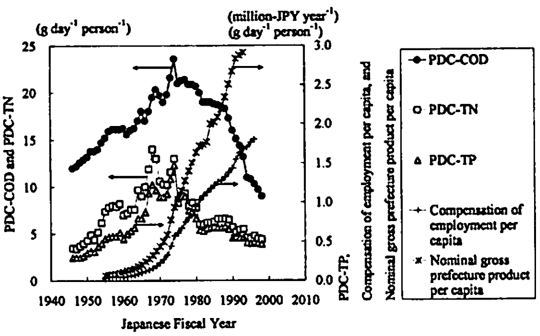

Fig. 2 Annual alternations of PDCs and economic indicators in the drainage area of Lakes Shinji and Nakaumi

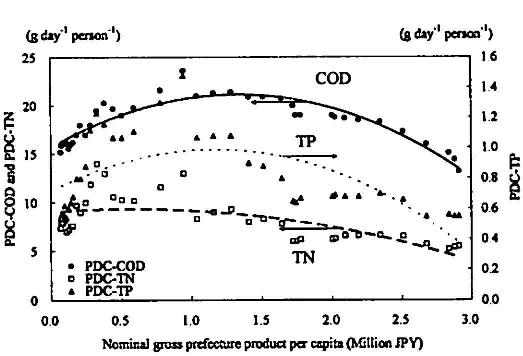

Fig. 3-1 Second-order regressions of PDCs and an economic indicator in the drainage area of Lakes Shinji and Nakaumi in 1955-93

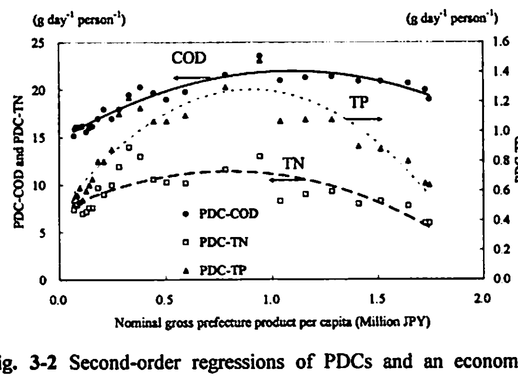

Fig. 3-2 Second-order regressions of PDCs and an economic indicator in the drainage area of Lakes Shinji and Nakaumi in 1955-82

where *WSEI* is water, sanitation and economic index (10^{-6} US\$ m^3 $person^{-2}$ $year^{-2}$); *a* is PPP-GNI per capita (US\$ $person^{-1}$ $year^{-1}$); *b* is proportion of appropriate sanitation access in whole country (%); *c* is proportion of appropriate sanitation access in urban area (%); *d* is proportion of safe drinking water access in whole country (%); *e* is proportion of safe drinking water access in urban area (%); and *f* is household water usage amount (m^3 $person^{-1}$ $year^{-1}$).

3. RESULTS AND DISCUSSIONS

(1) PDCs in Drainage area of Lakes Shinji and Nakaumi

Second-order regressions of PDCs with two economic parameters showed similar results. The results with nominal gross prefecture product per capita is explained in this paper. Two economic parameters increased in 1950's-1990's, however, PDC increased from 1940's, had peak values in 1968-1974, i.e. COD_{Mn} discharge per capita (PDC-COD_{Mn}) in 1974, TN discharge per capita (PDC-TN) in 1968 and TP discharge per capita (PDC-TP) in 1974, and decreased after the peak years (**Fig. 2**). Regression analysis of PDCs and the income parameter in 1955-93 found that different tendencies before and after 1982 especially for PDC-TN and PDC-TP (**Fig. 3-1** and **Table 3**). Therefore, regression analyses in 1955-82 were also conducted (**Fig. 3-2** and **Table 3**).

The relationships between PDCs and the income parameter were found to be the EKC inverted U-shaped curve. Regression analysis results of PDC-COD_{Mn} and the income parameter showed large correlation both in 1955-93 and 1955-82, and both one-order and second-order coefficients were 1% significance. On the contrary, adjusted multiple regression coefficient of PDC-TN and PDC-TP were relatively smaller, 0.408-0.525 for TN and 0.355-0.822 for TP, respectively. However, regression coefficient of PDC-TN in 1955-82 and those of PDC-TP in 1955-93 and 1955-82 were 1% significance.

Comparison of the results (**Fig. 3**) showed the tendency that domestic wastewater nutrients discharge did not decrease as the rates of the period before 1982 in the period after 1983 even with the economic development. There should be some technological and economical difficulties in removing the nutrients from domestic wastewater.

(2) PDCs in 47 prefectures in Japan

For PDCs in 47 prefectures in 2004, relationships with the income parameters in 2003 and average of the income parameter in 1990-2003 were examined. The two results were similar and the latter result is explained in this paper. Relationships of PDCs in 2004 and average compensation of employee per capita in prefecture in 1990-2003 are shown in **Fig. 4**. The result of PDC-COD_{Mn} was 1% significant first-order relationship, however, the results of PDC-TN and PDC-TP were not 10% significant. The result should show the relationships between PDCs and economic level in economically developed area.

Table 3 Second-order regressions of PDCs and an income index in the drainage area of Lakes Shinji and Nakaumi

	R2[a]	Partial regression coefficient			Standard error			T-value			t(T-k)[b]	
		Const.[c]	First[d]	Second[d]	Const.[c]	First[d]	Second[d]	Const.[c,e]	First[d,e]	Second[d,e]	5%	1%
COD, 1955-93	0.843	15.719	8.169	-3.075	0.291	0.594	0.215	53.949	13.745	-14.330	2.024	2.712
COD, 1955-82	0.911	14.776	13.220	-6.071	0.273	1.002	0.580	54.085	13.199	-10.475	2.060	2.787
TN, 1955-93	0.408	9.067	0.999	-0.900	0.541	1.103	0.398	16.772	0.906	-2.259	2.024	2.712
TN, 1955-82	0.525	7.332	10.372	-6.553	0.564	2.068	1.197	13.000	5.016	-5.477	2.060	2.787
TP, 1955-93	0.355	0.716	0.469	-0.202	0.063	0.129	0.047	11.329	3.634	-4.328	2.024	2.712
TP, 1955-82	0.822	0.466	1.816	-1.009	0.044	0.162	0.094	10.547	11.220	-10.770	2.060	2.787

a: Adjusted multiple regression coefficient; b: Percentage points of T-distribution; c: Constant; d: First-, Second-order of gross prefectural product per capita in Shimane Prefecture; e: Percentage points of T-distribution.

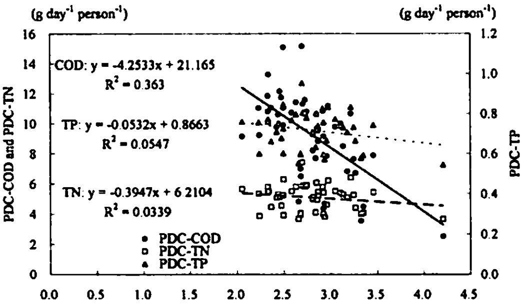

Fig. 4 Relationships between PDCs in 2004 and an income index in 1990-2003 in 47 prefectures in Japan

The reasons for the differences between organic carbon and the two nutrient parameters should be comparative differences of technological and economical difficulty of nutrient removal from wastewater and the targeted water bodies have been limited to enclosed coastal water bodies and lakes in the existing nutrient parameter regulation scheme.

The first-order relationships, the results of the analyses, are categorized in (a) poverty-related parameters in **Fig. 1**. World Bank categorized proportions of water and sanitation access as poverty-related parameters[17]. Therefore, it should be reasonable that PDC-COD_{Mn} is categorized in this category.

Chronological relationships of PDCs and economic parameter were found to be the EKC inverted U-shaped curve, which are categorized in (b) industry-related parameters[17] in **Fig. 1** as described in the previous section. However, PDC in this study is a pollution parameter from households. One of the possible reasons for the difference is the income level. Compensations of employment per capita in 47 prefectures are above JPY 2.0 millions in **Fig. 4**, whereas income range in the drainage area of Lakes Shinji and Nakaumi in 1955-93 was JPY 0.1-2.9 millions in **Fig. 3**, in which PDCs decreased in the income range above JPY 1.5 millions.

Based on the results in this and the previous two sections, it was found that the relationships between PDC and economic development is the EKC inverted U-shaped curve and the peak values of income indicators are JPY 0.8-1.5 millions.

(3) PDC-BOD in developing countries in coastal areas

Relationship between PDC-BOD and PPP-GNI per capita is shown in **Fig. 5-1**. Third-order regression analysis of PDC-BOD with PPP-GNI of developing countries in coastal areas shown in **Table 2** resulted in Eq. (2).

$$y = 0.0185\,x^3 - 0.5711\,x^2 + 3.8565\,x + 3.7872 \quad (2)$$

(0.0456) (0.7754) (3.5629) (3.7855)
(0.4055) (-0.7364) (1.0824) (1.0004)
(R^2 = 0.4237, Adjusted R^2 = 0.0676)

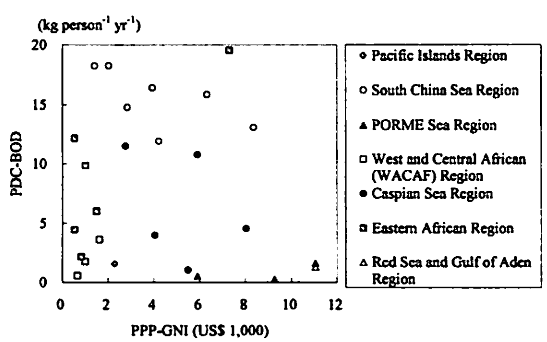

Fig. 5-1 PDC-BOD and PPP-GNI per capita in developing countries in coastal areas

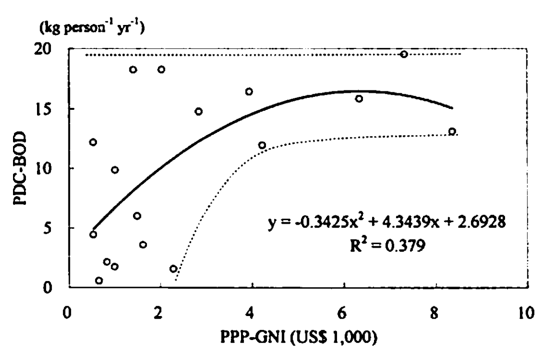

Fig. 5-2 PDC-BOD and PPP-GNI per capita in developing countries/areas in Asian, Pacific and African Regions

Table 4 Third-order regression analysis results of PDC-BOD and PPP-GNI per capita with dummy variables to find the most appropriate grouping of the Regions with countries/areas analyzed among the four cases.

	Group 1	Group 2	Square of multiple regression coefficient, R^2	Adjusted R^2	t-value of dummy coefficient
Case 1	Sounth China Sea Caspian Sea region East African Region	Pacific Islands PORME Region WACAF Region Red Sea and Gulf of Aden	0.6807	0.3612	3.3332
Case 2	Sounth China Sea East African Region	Pacific Islands PORME Region WACAF Region Caspian Sea Region Red Sea and Gulf of Aden	0.7934	0.5589	5.0497
Case 3	Sounth China Sea	Pacific Islands PORME Region WACAF Region Caspian Sea Region East African Region Red Sea and Gulf of Aden	0.7398	0.4610	4.1302
Case 4	Sounth China Sea WACAF Region Caspian Sea Region East African Region	Pacific Islands PORME Region Red Sea and Gulf of Aden	0.6404	0.2978	2.8657

where y is PDC-BOD (kg person^{-1} year^{-1}); x is PPP-GNI per capita in 2000 (US$ 1,000); R^2 is square of regression coefficient; value in the upper parenthesis is standard error; and value in the lower parenthesis is t-value.

The relationship between PDC-BOD and PPP-GNI per capita was not clearly identified and not significant. Adjusted square of regression coefficient was small, 0.0676, and absolute t-values of partial regression coefficients were 0.41-1.08, which were smaller than 5% significant t-value of 2.07 with degree of freedom of 22. The countries/areas data made a grouping by the UNEP Regions, which should reflect the similarity of PDC-BOD and PPP-GNI per capita in countries/areas in each Region besides the general insignificance as described above.

One of the reasons for the insignificance of Eq. (2) was considered to be differences of economic, natural and social conditions in these countries. Therefore, I examined the relationship of only countries/areas in Asia, Pacific and Africa Regions which have similarity in climate, water resource availability and economy (**Fig. 5-2**). PDC-BOD was in wide range, i.e. 0.6-18.2 kg person^{-1} year^{-1}, when PPP-GNI per capita was below US$ 3,000-4,000. PDC-BOD was in narrow range, i.e. 12-20 kg person^{-1} year^{-1}, when PPP-GNI per capita was above US$ 3,000-4,000. This relationship is similar to the original Kuznets' relationship of income level and income inequality presented in 1955 [31]. The relationship was later applied correspondingly to those of economic level and severity of environmental problems, which is called as the EKC inverted U-shaped curve.

Dummy coefficient method was applied to make grouping of similar Regions to two groups with third-order regression of PDC-BOD and PPP-GNI per capita (**Table 4**). Four combination cases were analyzed and the combination with largest significance was found to be Case 2, i.e. South China Sea Region and East African Region as Group 1 and other Regions as Group 2. Multiple regression coefficient, R^2, was 0.793, and adjusted R^2 was 0.559, both of which were largest in the four cases. The grouping results of all four cases were 1% significant (1% significant t-value is 2.83 with degree of freedom of 21). In Case 2, PDC-BOD in South China Sea and East African Regions was found to be comparatively larger than that in other Regions (**Fig. 5-2**). If we focus on pollutant discharge reduction function of sanitation, PDC-BOD should be important factors to determine priority areas/countries of sanitation. Then, countries in South China Seas and East African Regions were found to be with most priority of sanitation improvement with pollutant discharge reduction. In this paper, I am focusing on pollutant discharge function of sanitation. On the contrary, in the MDGs sanitation scheme, decreasing infectious diseases and improving lifestyles are more focused and important functions of sanitation. The MDGs sanitation target is considered to be hard one to be achieved by 2015. We should pursue to achieve the MDGs target and pursue also to decrease domestic wastewater pollutant discharge. Natural and social conditions of ambient water and coastal areas are different in countries/areas subjected in this study. Therefore, actual priority of pollutant discharge reduction should be further identified in consideration with these conditions.

(4) Relationship between WSEI's and PDC-BOD

Pearson's regression coefficients between six variables consisting WSEI were 0.54-0.92, and 1% significant in all combinations (**Table 5**).

Principle component analysis resulted in 1st component explaining 80% of variables, 2nd component explaining 9% and 3rd component explaining 6% (**Table 6**). Factor loadings of each variable in the component 1 were 0.73-0.94 and all the variables contributed positively. For the component 2, factor loading of domestic water usage amount was positive and absolutely largest, which means that domestic water usage amount is most strong parameter in the component 2.

Graphical distribution of PDC-BOD and WSEI showed data of countries/areas in each Region made a group on the graph (**Fig. 6-1**), which was similar to the result of PDC-BOD and PPP-GNI per capita

Table 5 Coefficients of correlation of explanation variables in developing countries

	(a)	(b)	(c)	(d)	(e)	(f)
(a)	1.0000					
(b)	0.8730	1.0000				
(c)	0.9018	0.9213	1.0000			
(d)	0.8926	0.8415	0.7951	1.0000		
(e)	0.7005	0.7670	0.7378	0.8410	1.0000	
(f)	0.6084	0.5741	0.6610	0.6257	0.5397	1.0000

(a)-(f): water, sanitation and economic parameters shown in Table 2.
All the relationships are significance with 1 % significant level.

(**Fig. 5-1**). Relationship between PDC-BOD and WSEI in countries/areas in Asia, Pacific and African countries was identified with second-order regression analysis as Eq. (3) (**Fig. 6-2**).

$$y = -1.1597x^2 + 7.0905x + 8.0907 \quad (3)$$

(0.8701) (4.4951) (1.9374)
(-1.3328) (1.5774) (4.1761)
(R^2=0.1750, Adjusted R^2=0.0571)

where x is WSEI (10^{-6} US\$ m^3 $person^{-2}$ $year^{-2}$); other parameters and values are the same as Eq. (2).

First- and second- orders coefficients were not 5% significant. PDC-BOD was in wide range, 0.3-19.5 kg $person^{-1}$ $year^{-1}$, when WSEI was smaller than 1.0 and in narrow range, 12-16 kg $person^{-1}$ $year^{-1}$, when WSEI was larger than 1.0. The relationship was similar to the relationship of economic growth and income inequality which was originally presented by Kuznetz[31]. PDC-BOD should be dependent on regional conditions including economical, natural and social conditions when WSEI was smaller, and gradually reach certain amount when WSEI was larger.

Multiple regression analysis of PDC-BOD with the eight variables resulted in insignificance of all the variables at 5% significance (**Table 7**). Most significant variable in these less significant results was the proportion of appropriate sanitation access in urban area, followed by household water usage

Table 6 Principle component analysis result of explanation variables of PDC-BOD in developing countries

Parameter	Factor loading		
	Component 1	Component 2	Component 3
(a) PPP-GNI per capita	0.936	-0.086	-0.226
(b) Access to sanitary facilities (household connection in whole country)	0.937	-0.161	-0.159
(c) Access to sanitary facilities (household connection in urban area)	0.941	-0.015	-0.231
(d) Access to safe drinking water (household connenction in whole count	0.937	-0.102	0.146
(e) Access to safe drinking water (household connection in urban area)	0.858	-0.179	0.454
(f) Domestic water usage per capita	0.733	0.676	0.071
Percentage of variance (%)	79.9	8.9	6.0
Cumulative contribution of variance (%)	79.9	88.7	94.8

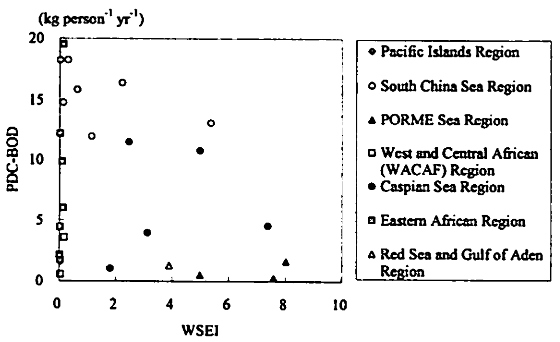

Fig. 6-1 PDC-BOD and WSEI in developing countries

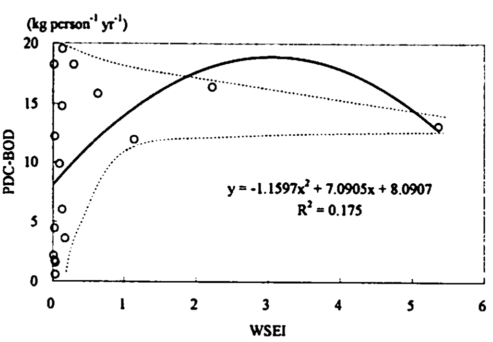

Fig. 6-2 PDC-BOD and WSEI in Asian, Pacific and African countries

Table 7 Multiple regression analysis result of PDC-BOD in developing countries in coastal zones

	Coefficient	Standard error	t-value	Significance probability
PPP-GNI	1.063	4.684	0.227	0.823
$(PPP\text{-}GNI)^2$	-0.148	1.100	-0.134	0.895
$(PPP\text{-}GNI)^3$	-0.005	0.067	-0.076	0.941
Access to sanitary facilities, household, total	-0.166	0.183	-0.906	0.377
Access to sanitary facilities, household, urban	0.456	0.256	1.782	0.093
Access to safe drinking water, household, total	0.023	0.142	0.160	0.875
Access to safe drinking water, household, urban	-0.040	0.116	-0.348	0.732
Water usage for households per capita	-0.081	0.058	-1.387	0.183
Constant	-9.625	10.777	-0.893	0.384

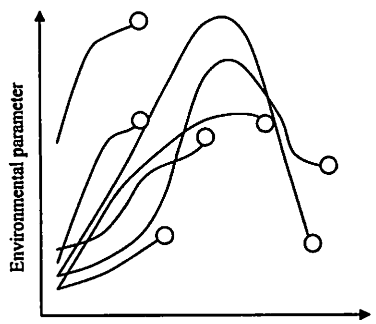

Fig. 7 Chronological relationship between an economic index and an environmental problem parameter. Blank circles indicate the relationships at certain time. There is a hypothesis that the development ways should be different in several countries and the relationship at certain time should not show clear and significant relationship.

amount per capita. We already know the importance of sanitation facilities in urban areas which should be made up with domestic water usage amount increase in our experience. The principle component analysis result was in accordance with the experience. However, the result was insignificant, which showed PDC-BOD was not necessarily simply explained with income, water and sanitation indices. The results of regression analyses with PPP-GNI and WSEI and multiple regression analyses showed PDC-BOD should be determined by complicated economic, social and natural conditions in countries/areas. Original data from the United Nations Environment Programme (UNEP)[13)] should be further investigated.

(5) Time scale of development

I have tried to explain PDC with economic, water and sanitation parameters in this paper. We have discussed on time-scale of development in the Developing Countries Sub-Committee of the Global Environmental Committee, Japan Society of Civil Engineers (JSCE). There are two sides on the time-scale of development: (1) time-scale of development is dependent on the countries and areas and there should be difficulty in explaining environment related indices only with economic indices (**Fig. 7**); and (2) environment related indices should be explained only with economic indices to some extent. For the former hypothesis, economic development ways should be different in countries/areas. Therefore, even the development way in each country/area should be EKC like inverted U-shaped curve, there may be difficulty to find the EKC like relationship for many countries/areas at certain time (**Fig. 7**). Therefore, I have applied not only economic indices but also water and sanitation indices to explain PDC-BOD in the analyses of developing countries to try to make the analysis results more meaningful.

In this study, significant EKC like inverted U-shaped curves were found in the relationships between PDCs and income parameters in the drainage areas of Lakes Shinji and Nakaumi. The results of 47 prefectures in Japan showed first-order negative relationships which were identified as the latter portion of the EKC. The World Bank categorized sanitation access percentage as a poverty-related parameter, which decreases with economic development (**Fig. 1**). However, PDC was found to be categorized in the World Bank's industrial-related parameter. The reasons for which should be necessity of certain economic development to start and proliferate domestic wastewater treatment, and delaying interventions against environmental problem because environmental deteriorations are unobvious in the early stage of development. These kinds of phenomena should be in accordance with environmental problems during the high economic growth of Japan.

The relationship between PDC-BOD and PPP-GNI and that of PDC-BOD and WSEI were insignificant. One of the reasons for the insignificance should be that wastewater treatment conditions are different by country/area. For example, the proportion of people with access to appropriate sanitation is 97% countrywide and 99% in urban areas in Thailand in 2002, however, the most popular on-site domestic wastewater treatment methods are a septic tank and an anaerobic filtration which are corresponding to simple *johkasou* in Japan treating only black water. One of the interesting findings in this study is that the relationships between PDC-BOD and water, sanitation and economic indicators were similar to the original Kuznets relationship of economic growth and income inequality.

Some results in this study were 5% insignificant. Some reasons for the results include (1) conventional wastewater treatment methods and pollutant discharge amounts are dependent on countries/areas, and (2) national and local governments policies, intergovernmental policies and ordinary citizens' will should form investments in centralized and de-centralized wastewater treatment systems. These factors including governance should be considered in further research.

4. CONCLUSIONS

Relationships between PDCs and water, sanitation and economic indices were analyzed with the existing data. The conclusions of this study are:

1) Relationships between PDCs (COD_{Mn}, TN and TP) and income parameters in the drainage areas of Lakes Shinji and Nakaumi in 1955-93 were 1% significant EKC like inverted U-shaped curve;
2) Relationship between PDC-COD_{Mn} of 47 prefectures in Japan in 2004 was 1% significant first-order negative relationship, whereas those of PDC-TN and PDC-TP were insignificant. These results should correspond to the latter portion of the EKC. Insignificance of nutrient parameters should reflect that nutrient regulations have been conducted in specific areas and technologically comparable difficulties in nutrient removal from wastewater;
3) Relationship between PDC-BOD and PPP-GNI and PDC-BOD and water, sanitation and economic parameters including WSEI in the developing countries in coastal areas were insignificant. Focusing on only Asian, Pacific and African countries/areas, PDC-BOD was in wide range when PPP-GNI and WSEI were smaller, and in narrow range when PPP-GNI and WSEI were larger. The transition values of PPP-GNI and WSEI were US$ 3,000-4,000 and 1.0, respectively. These relationships were similar to the original Kuznets' relationship of economic growth and income inequality; and
4) The relationships of PDCs and economic level in Japan were found to be the EKC inverted U-shaped curve, which are corresponding to industrial-related relationships in the World Bank's categories. PDC-BOD in developing countries was difficult to explain only with water, sanitation and economic indices. Possible reasons for the latter result should be that domestic wastewater related conditions including wastewater generation amount, pollutant generation amount, treatment methods, overall treatment conditions are different by country/area.

ACKNOWLEDGMENT: A part of this research was conducted in the Developing Countries Sub-Committee of the Global Environmental Committee, Japan Society of Civil Engineers (JSCE). A part of this research was funded by Japan Education Center for Environmental Sanitation. Mr, James Heather, Lecturer at Regional Development Studies, Toyo University, kindly conducted English proofreading of the former version of the manuscript. The author is solely responsible if there is any misunderstanding or mistake in the manuscript.

REFERENCES

1) Institute for International Cooperation/Japan International Cooperation Agency (2007) Approaches for systematic planning of development projects: Water pollution, 160p.
2) Katayama, Tohru (2004) Development of *joukasou* system in abroad, Journal of *Jouhkasou* -Small Domestic Wastewater Treatment Systems-, Vol.338, pp.4-9. (in Japanese)
3) Global Environment Center Foundation (2004) Demonstration Project of Environmental Preservation Activities with Community Participation in Lamphun Municipality, Thailand (http://gec.jp/gec/gec.nsf/en/Activities-International_Environmental_Cooperation_Projects-Thailand-2003)
4) Xu, Kaiqin, Inamori, Yuhei, Sudo, Ryuichi (2006) Policy on de-centralized wastewater treatment systems in the United States of America, Journal of *Jouhkasou* -Small Domestic Wastewater Treatment Systems-, Vol.365, pp.4-11. (in Japanese)
5) Yamamoto, Mitsuhiro (2004) Current situations of domestic wastewater treatment and possibility of proliferation of *jouhkasou* in Vietnum, Journal of *Jouhkasou* -Small Domestic Wastewater Treatment Systems-, Vol.339, pp.14-18. (in Japanese)
6) Sakai, Akira (2004) Toilet and sanitation conditions in Bangladesh, Journal of *Jouhkasou* -Small Domestic Wastewater Treatment Systems-, Vol.365, pp.19-23. (in Japanese)
7) Harada, Hidenori, Matsui, Saburou, Hoang Thi Trung Hieu, Pham Anh Tuan, Nguyen The Dong (2006) A study of the household-wastewater management in Hanoi City of Vietnam focusing on septic tank, Proceedings of 14th Symposium of Global Environment (JSCE), pp.171-176. (in Japanese with English abstract)

8) Tsuzuki, Yoshiaki (2004) Proposal of Environmental Accounting Housekeeping (EAH) Books of Domestic Wastewater Based on Water Pollutant Loads per capita: A Case Study of *Sanbanze* Tidal Coastal Zone, *Tokyo* Bay, Journal of Global Environment Engineering, Vol.10, pp.187-196.
9) Tsuzuki, Yoshiaki (2004) Performances of Domestic Wastewater Treatments in Japan and Environmental Accounting Housekeeping (EAH) Books for Domestic Wastewater Pollutants Reduction: from the Perspective of Countermeasures against Coastal Zone Water Pollution, Proceedings of the Second International Symposium on Southeast Asian Water Environment, Hanoi, Vietnam, pp.461-468.
10) Tsuzuki, Yoshiaki (2005) Water pollution loads per capita flowing into *Sanbanze, Tokyo Bay*, and environmental accounting housekeeping (EAH) books of domestic wastewater for dissemination and environmental education, Journal of Japan Society on Water Environment, Vo.28, No.1, pp.49-54. (in Japanese with English abstract)
11) Tsuzuki, Yoshiaki (2005) Performances of Domestic Wastewater Treatments in Japan and Environmental Accounting Housekeeping (EAH) Books for Domestic Wastewater Pollutants Reduction: from the Perspective of Countermeasures against Coastal Zone Water Pollution, in Global Environmental Committee of JSCE ed. Systematization of whole philosophy in civil engineering related to environment, Research Report in JFY 2003, 344p., pp.2-38~67, 2005.
12) Tsuzuki, Yoshiaki (2005) Domestic wastewater treatment in the drainage areas of Lakes Shinji and Nakaumi: Treatment efficiency and dissemination for ordinary citizens, LAGUNA (coastal environment research), No.12, pp.53-61. (in Japanese with English abstract)
13) Tsuzuki, Yoshiaki (2004) Water pollutant load per capita running into coastal area and lakes, and economic development level of developing countries, Proceedings of 12th Symposium of Global Environment (JSCE), pp.129-134. (in Japanese with English abstract)
14) Tsuzuki, Yoshiaki (2005) Final Report of Research Sub-Committee on Developing Countries, Global Environmental Committee, JSCE, in JFY 2003: Literature review on environmental alternation in developing countries and comparison with development progress, *in* Global Environmental Committee of JSCE ed. Systematization of whole philosophy in civil engineering related to environment, Research Report in JFY 2003, 344p., pp.2-5~14, 2005. (in Japanese)
15) Tsuzuki, Yoshiaki (2005) A preliminary assessment of pollutant load per capita flowing into public water body: a comparative study of several river basins in Japan and coastal areas in other countries., Oral Presentation Proceedings of the 3rd International Symposium on Southeast Asian Water Environment, pp.9-16, Dec. 6-8, 2005, Bangkok, Thailand.
16) Matsuoka, Shunji, Matsumoto Reishi and Kochi, Ikuho (1998) Economic growth and environmental problem in developing countries: The environmental Kuznets curve do exist?, Environmental Science, Japan Society of Environmental Science, Vol.11 (4), pp.349-362. (in Japanese with English abstract)
17) World Bank (1992) World development report 1992, New York, Oxford University Press, 308p.
18) Tsuzuki, Yoshiaki (2006) An index directly indicates land-based pollutant load contributions of domestic wastewater to the water pollution and its application, Science of the Total Environment, Vol. 370, pp.425-440.
19) Bai X, Imura H. (2000) A Comparative study of urban environment in East Asia: Stage model of urban environmental evolution. International Review for Environmental Strategies, Vol.1 (1), pp.135-158.
20) Tsuzuki, Yoshiaki (2007) Relationships between pollutant discharges per capita (PDC) of domestic wastewater and the economic development indicators, Journal of Environmental Systems and Engineering (*Dobokugakkai Ronbunsyu* Category G, JSCE), Vol.63, No.4, pp.224-232. (in Japanese with English abstract)
21) Tsuzuki, Yoshiaki (2006) Pollutant loads per capita flowing into public water bodies and pollutant discharges per capita in the coastal regions including developing countries, Proceedings of 14th Symposium of Global Environment (JSCE), pp.121-126. (in Japanese with English abstract)
22) Nakamura, Yoshiyuki, Ishino, Akira, Takao, Akira (2006) Study on the long-term variations of pollutant load to Lakes Shinji and Nakaumi Basin, Abstract proceedings of 40th annual meeting of Japan Society on Water Environment, pp.117-117. (in Japanese)
23) Doi, Takerou (2000) Databank of Economics and Financial (http://www.econ.keio.ac.jp/staff/tdoi/pfdata.html)
24) Ministry of Land, Infrastructure and Transport, Japan (2005) Domestic wastewater treatment situations in Japan in JFY 2004 (http://www.mlit.go.jp/kisha/kisha05/04/040822_3_.html) (in Japanese)
25) Ministry of the Environments, Japan (2006) Statistics on environment (http://www.env.go.jp/doc/toukei/ contents/) (in Japanese)
26) Cabinet Office (2006) Statistics of prefecture economics account in JFY 2003 (http://www.esri.cao.go.jp/jp/sna/kenmin/h15/main.html) (in Japanese)
27) Food and Agriculture Organization of the United Nations (FAO) Land and Water Development Division (2005) AQUASTAT Information System on Water and Agriculture: Online database. Rome: FAO. (http://www.fao.org/nr/water/aquastat/dbase/index.stm)
28) World Bank (2002) World Development Report 2002: Building Institutions for Markets, 228p.
29) World Resource Institute (2006) Earth Trend Environmental Information (http://earthtrends.wri.org/searchable_db) Original source: United Nation's Children's Fund (UNICEF). 2005. Meeting the MDG Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress (http://www.unicef.org/wes/mdgreport/who_unicef_WESestimate.pdf). New York: UNICEF. Data were originally collected under the UNICEF-World Health Organization (WHO) Joint Monitoring Program.
30) Goda, Takeshi (1981) Mutual correlation of lake eutrophication indexes and the significance of physiographical properties, *in* National Institute for Environmental Studies ed. Applicability of Trophic State Indices for Lakes, Research Report from the National Institute for Environmental Studies, No.23, pp.33-48. (in Japanese)
31) Kuznets, Simon (1955) Economic growth and income inequality, American Economic Review, Vol. 45, No.1, pp.1-28.

(Accepted in Japanese for Doboku Gakkai Ronbunsyuu G, Vol.63, No.4, pp.224-232, JSCE, August 10, 2007)
(Received in English for JGEE, September 29, 2008)
(Received in English in revised form, February 5, 2009)
(Accepted in English for JGEE, February 23, 2009)