Relationship between economic development and pollutant discharge in Southeast Queensland

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Abstract

Some relationships between economic development and pollutant discharge have been found to be represented by inverted U-shaped curves, namely the environmental Kuznets curve (EKC), while S-shaped and N-shaped curves have also been found. There are several hard and soft measures to improve water quality in the rivers in Southeast Queensland. Socio-economic conditions related to river water environment in Australia and Japan have similarities and differences. Comparative investigations have not been conducted so far. In this research, first, qualitative comparisons of the measures to improve the river water environment in Australia and Japan were conducted. Second, the relationships between economic development level and pollutant discharges in Southeast Queensland from 1960 to 2012 were investigated. Pollutant discharges from diffuse sources were estimated based on the existing research results. Effects of precipitation variations were included by introducing the precipitation variation coefficient (PVC) for the diffuse source pollutants. Pollutant discharges from point sources were estimated based on the National Pollutant Inventory (NPI) and the Queensland Government data. The relationship between purchase power parity based gross domestic product (PPP-GDP) per capita and pollutant discharges per capita (PDC) of TN and TP were found to show inverted U-shaped curves especially when the precipitation effects were not included. Higher economic development levels of the inflection points than those of the existing research results suggested that the inflection points in the Brisbane River Catchment found in this research should correspond to the pollutant discharge reductions from point sources in the 2000s. The exceptional inverted U-shaped EKC of PDCs in the Yamato-gawa River Catchment, Japan, on the curvatures of the left and right halves of the curves showed the effectiveness of the hard and soft measures for pollutant discharge reduction.

Keywords

economic development; flood infiltration system; pollutant discharge; precipitation

variation coefficient (PVC); purchase power parity based gross domestic product (PPP-GDP); stormwater harvesting project

Introduction

From water environment conservation perspectives in Southeast Queensland (SEQ), applications of fertilisers and agricultural chemicals, increase of livestock, and land and urban development have caused enormous terrestrial pollutant discharge increases over 100 years including the Brisbane River Catchment (Neil, 1998; Dennison and Abal, 1999; Olley et al., 2006). Therefore, it is worth investigating the relationship between the economic development and pollutant discharges.

An inverted U-shaped curve for the relationship between income level and income inequity has been proposed by Kuznets as a hypothesis (Kuznets, 1955). In the 1990s, the inverted U-shaped curve has been applied to the relationship between economic development level and environmental burdens, and named the environmental Kuznets curve (EKC) (Grossman and Krueger, 1991, 1995; Dasgupta et al., 2002). Because of the extensive concerns and interests in climate change, relationships between economic development and amounts of greenhouse gas (GHG) emission, especially carbon dioxide (CO_2), have been investigated by many researchers with several frameworks of area, location and duration of time. For the relationship between gross domestic product (GDP) per capita and CO_2 emission, log-scales are sometimes applied for the investigations, and symmetric inverted U-shaped curves are not necessarily observed while parabola equations usually apply (Booth et al., 2013; Liao and Cao, 2013).

In the developed countries, the EKC relationship for CO_2 emission and GDP per capita has been found only for southern European countries but not Asian-Pacific and northern European countries (Mazzanti and Musolesi, 2013). Following the economic downturn in the former Soviet Union (FSU) countries, affluence and CO_2 emission has decreased in the 1990–1995 collapse period, and affluence has increased and CO_2 emission has been stable or increased in 1996–2010 (Brizga et al., 2013). For CO_2 and GHG emissions from 22 developing countries in Asia, Sub-Saharan Africa and Latin America, N-shaped relationships have been found for each region and all the countries (Babu and Datta, 2013).

In the energy sector, the results have been divided into countries with and without energy source transformation from fossil sources to nuclear and modern renewable sources (Burke, 2012). For the effects of economic development on the environmental burden related to transportation, the relationship between GDP per capita and sulfur dioxide (SO_2) and suspended particulate materials (SPM) emissions and the number of accidents have resulted in the inverted U-shaped curves. On the contrary, SO_2 and SPM emissions, energy consumption, and the use of private vehicles have been found to monotonically increase with economic development, while nitrogen dioxide (NO_2) emission has been found to decrease

with economic development in Tunisia for 1989–2008 (Mraihi et al., 2013).

The theoretical explanations of the EKC have been investigated for pollutant generation, pollutant-specific generation of industrial sectors, pollutant discharge reduction technologies (Jing et al., 2013), net economic growth effect, scale-technique effect and time-series emission properties (Andreoni and Levinson, 2001; Lai and Yang, 2014). Theoretical considerations based on the EKC research have included private property rights, the role of institutions and rules, respect and enforcement of contracts, the efficiency of the bureaucracy, the efficacy of the rule of law, the extent of government corruption, the risk of appropriation, the not-in-my-backyard (NIMBY) situation and a general model including other "exceptions" than the inverted U-shaped curve (Knack and Keefer, 1995; Ansuategi and Perings, 2000; Yandle et al., 2004). When multiple countries and regions are considered, the concept of the EKC is related to the pollution haven hypothesis (PHH). Liberalisation of trade has been considered to be effective to reduce water pollutant discharges based on a provincial-level analysis of China in 1987–1995 under the conditions of pollutant discharge levy systems (Dean, 2002).

Research into the application of the EKC has been made for free trade and open economies in the 1990s and 2000s. The effects of open economies such as the North America Free Trade Agreement (NAFTA) on environmental pollution have been one of the major concerns in the research related to EKC (Grossman and Krueger, 1991; Cole, 2004). When the EKC exists, economic development of several countries, including both developed countries and developing countries, would lead to decreases of environmental burdens in such countries. Criticism for this hypothesis includes that economic development could lead to more pollution. Some research results show S-shaped or N-shaped curves, an environmental burden decrease after the first inflection point and a further increase after the second inflection point (Yandle et al., 2004; Chen and Wang, 2013; Wang and Wei, in press). These curves have also been discussed in the contexts of the EKC. Other factors which have been considered to explain environmental burden include education and inequity, which have been found to be significant (Hill and Magnani, 2002).

However, there are also results which have not supported the EKC hypothesis (Perman and Stern, 2003). Individual and panel cointegration tests have not supported the EKC hypothesis. Monotonic relationships and U-shaped curves have been observed for some parameters in some existing research (Table 1) (Perman and Stern, 2003; Tsuzuki, 2009a; Mazzanti and Musolesi, 2013; Mraihi et al., 2013). The subject matters of the EKC hypothesis have also included topics other than air pollution, water pollution and solid waste discharge, e.g. the relationships between economic development and deforestation (Bhattarai and Hammig, 2001; Culas, 2007), climate change, biodiversity and ecosystem services in European forests (Ding and Nunes, 2014), economic development and the number of animals killed

(Morris, 2013), CO_2 emission per GDP and the Gini coefficient (Petri and Thomas, 2013), urbanity and direct and indirect CO_2 emissions (Ala-Mantila et al., 2014), human health, irrigation and water sector development and agricultural land-use patterns (Yandle et al., 2004), and ages and CO_2 emission in the USA and France (Chancel, 2014).

Accumulation of empirical evidence is necessary for further theoretical development. For water pollutant discharges, the evidence has still been limited compared to air pollutant emissions such as CO_2 and GHG emissions. Economic development relates to the human and natural causes affecting river water quality. The water environment management in many areas has been improved from technological, regulative and institutional aspects based on the socio-economic conditions. Therefore, evaluations of chronological alterations are necessary to enhance understanding of the relationships between economic development, pollutant discharge and river water quality.

Discussions on the EKC include whether the EKC exists or not, and also what the economic development level and environmental burden of the inflection points or turning points actually are (Table 1). The inflection points are usually evaluated with per capita income indicators. In the 1990s and the early 2000s, the inflection points have been calculated to be USD 4,000–5,000 for air pollutants and USD 3,000–10,500 for water pollutants at 1985 prices (Grossman and Krueger, 1991, 1995). Economic levels of the inflection points in most existing research have been USD 3,000–12,700 (Table 1). There have been some exceptional results such as USD 120–5,700 in the Southeast Asian countries (Saboori and Sulaiman, 2013), and USD 400 and 117,000 for the cross-country analysis on SO2 emissions (Perman and Stern, 2003). For water pollutant discharges, USD 13,300 for chemical oxygen demand (COD), USD 5,600 for total nitrogen (TN) and USD 11,600 for total phosphorus (TP) have been found from the chronological investigations in a Japanese catchment (Tsuzuki, 2007, 2009b). For the cross-country investigations of developing countries, USD 2,200–5,100 for biological/biochemical oxygen demand (BOD) and USD 11,000 for TP have been found (Tsuzuki, 2008, 2009a). Pollutant discharge indicators are theoretically more reliable for the EKC analysis because water quality indicators are affected not only by pollutant discharges but also several other natural and socio-economic conditions (Tsuzuki, 2007, 2009b). After reaching the inflection points, the curvatures of right-half curves may be smaller than those of the left-half curves (Figs. 1 and 2 of Burke, 2012; Fig. 1 of Liao and Cao, 2013). This might suggest the curve of the conventional EKC shown in Fig. 1 of Dasgupta et al. (2002). An environmental burden has also been suggested to decrease to the same level with the beginning after the economic development and to continue the small level after that, which is approximated by a third-order equation (Du et al., 2014).

For the relationships between economic development level and pollutant discharge per capita (PDC), chronological relationships in the catchments of Lakes Shinji and

Nakaumi, Japan, between 1955 and 2000 have been found to be of inverted U-shaped curves for COD, TN and TP (Fig. 1) (Tsuzuki, 2007, 2009b). Cross-country panel data analysis for the coastal areas of Asia, Africa and Pacific countries has

Table 1. Inflection points of some existing research on the environmental Kuznets curve (EKC) for the relationships between economic development and environmental burdens

No. Author	Year	Country	Duration	Environment parameters	Socio-economic parameters	Specific sector	EKC was observed (Parameter, area or method)	EKC was not observed (Parameter, area or method)	Inflection point (USD)	Specific methods
1 Wang, Wei	in press	China, 30 major cities	2006-2010	CO_2, Energy consumption			N-shaped curve		N-shape: 12,052 and 12,341	DEA[a] based method
2 Booth, Hui, Alojado, Lam et al.	2013	World	2000	Dioxin			Dioxin emission		9,500	
3 Chen, Wang	2013	China	2001-2010	Urban green space, Urban green space coverage	GDP per capita		Urban green space: N-shaped curve		N-shape: 8,137 and 17,209	
4 Mraihi, Harizi, Alaouia	2013	Tunisia	1989-2008	CO_2, NO_2, SO_2, SPM, energy consumption, accidents, use of private vehicles		Transportation	SO_2, SPM, The number of accidents	Monotonical increase: SO_2, SPM, energy consumption, use of private vehicles; and L-shaped downward curve: NO_2.	SO_2, SPM and the number of accident: 3,400-3,800	
5 Mazzanti, Musolesi	2013	Developed countries		CO_2	GDP per capita		North Europe	Coallition (Asia-Pacific), South Europe	9,900-14,800	
6 Bekhet, Yasmin	2013	Malaysia	1996-2010	CO, NO_2, SO_2, PM_{10}, O_3			CO, PM_{10}, Nemerow Index		5,300	
7 Shahbaz, Ozturk, Afza, Ali	2013	Turkey	1970-2010	CO_2, energy intensity	Economic growth, Globalisation		Long run and short run		4,797	ARDL[b] bounds testing approach, the Granger causality test, and VECM[c].
8 Saboori, Sulaiman	2013	5 ASEAN countries	1971-2009	CO_2, energy consumption			Singapore, Thailand		Indonesia: 657; Malaysia: 116; Phillippines: 1,215; Singapore: 5,731; Thailand: 1,752	ARDL[b] bounds testing approach, the Granger causality test, and VECM[c].
9 Burke	2012	105 countries		CO_2			CO_2		3,640-29,726 (2005 prices)	
10 Tsuzuki	2009	24-42 developing countries	Cross-county, 1990s	BOD, TN, TP	GDP per capita		BOD, TP (Inverted U-shaped curve)	TN (U-shaped curve)	BOD: 5,054; TP: 11,199	
11 Tsuzuki	2008	23 developing countries	Cross-county, 1990s	BOD, TN, TP	PPP-GNI per capita		BOD, TP (Inverted U-shaped curve)		BOD: 2,245[d]; TP: 10,957[d]	
12 Tsuzuki	2007, 2009	Catchment of Lakes Shinji and Nakaumi	1955-1993	COD, TN, TP	Nominal gross prefecture product per capita		COD, TN, TP		COD: 13,283; TN: 5,550; TP: 11,609	
13 Perman, Stern.	2003	74 countries	31 years	SO_2			SO_2	For the indivisual countries and panel cointegration tests, out of the sample range and monotonic emission-income relationship has been implied.	Unrestricted model: 10,795; Pooled mean group restricted model: 15,063; Static fixed effects model: 82,746. Non-OECD countries: Unrestricted estimate: 403; Pooled mean group: 28,792; Fixed effects model: 116,619.	Cointegration analysis
14 Dasgupta, Laplante, Wang, Wheeler	2002	Review		Several air and water pollutants	Income per capita				USD 5,000-8,000	
15 Grossman and Krueger	1995	42 counties	Cross-county	BOD, COD, NO_3-N, T.coli[e], F.coli[f]	GDP per capita		BOD, COD, NO_3-N, T.coli[e], F.coli[f]		BOD: 7,623; COD: 7,853; NO3-N: 10,524; T.coli: 3,043; F.coli: 7,955	
16 Grossman and Krueger	1991	19-42 countries	Cross-county	SO_2, smoke (dark matter), SPM[g]	GDP per capita		SO_2, smoke (dark matter), SPM[g]		SO_2,and smoke (dark matter) 4,000-5,000; SPM[g]: 15,000-16,000	

a: Data envelopment analysis; b: Autoregressive distributed lag; c: Vector error correction method; d: Re-calculated based on the data of the literature; e: Total coliform; f: Escherichia coli; and g: Suspended particulate matter.
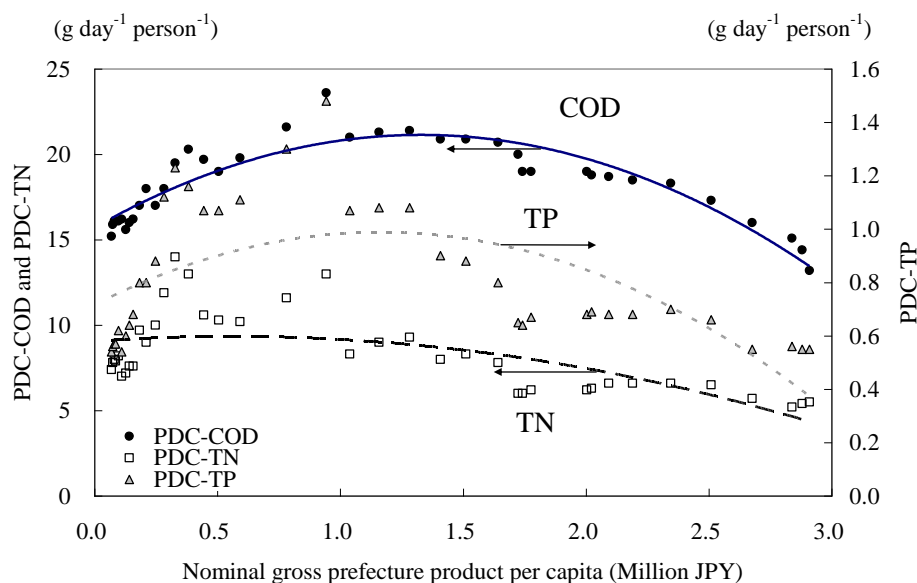
Figure 1. Relationship between economic development and pollutant discharges per capita (PDC) in the catchments of Lakes Shinji and Nakaumi, Japan, from 1955 to1993 (Tsuzuki, 2007, 2009b)

Table 2. Geographic, demographic and meteorological conditions of the subjected catchments

Catchment	Area	Main river/creek length	Population [a]	Population density	Climate	Precipitation	Average daily maximum temperature	Average daily minimum temperature	Monitoring point for precipitation (P) and temperature (T)
	km²	km	'000 person	person km⁻²		mm year⁻¹	°C	°C	
Oxley Creek	260.0	70	152	585	Sub-tropical	1,149	25.5	15.7	Archerfield Airport (P:1972-2013, T:1939-2013)
Norman Creek	29.8	19	90	3,020	Sub-tropical	1,068	26.2	14.3	Brisbane (P:1840-1994, T:1987-1986)
Noosa River	784.0	60	43	55	Sub-tropical	1,484	25.2	15.8	Sunshine Coast Airport
Moreton region (1971)[b]	21,444.0	NA[c]	1,031	48	Sub-tropical	1,149	25.5	15.7	Brisbane (P:1840-1994, T:1987-1986)
Southeast Queensland	22,420.0	NA[c]	3,131	140	Sub-tropical	1,149	25.5	15.7	Brisbane (P:1840-1994, T:1987-1986)
Brisbane River	13,780.0	14,035	2,240	163	Sub-tropical	1,149	25.5	15.7	Brisbane (P:1840-1994, T:1987-1986)
Yamato-gawa River	1,070.0	68	2,102	1,964	Temperate	1,212	20.5	11.7	Sakai (Osaka)
						1,002	20.1	10.0	Nara (Nara)
Lakes Shinji and Nakaumi	1,883.4	153	350	186	Temperate	1,799	19.4	11.1	Matsue (Shimane)

a: Oxley Creek in 1991, estimation was 113,300 in 1996 and 152,181 in 2011. In Noosa Catchment, total number of people in the catchment is almost doubled in the tourism season. Southeast Queensland on 30 June 2010. Yamato-gawa River basin is for 2010.; b: Moreton region was consisted of Brisbane, Gold Coast, Ipswich and Redcliff cities, and Albert, Beaudesert, Boonah, Caboolture, Esk, Gatton, Kilcoy, Laidley, Landsborough, Maroochy, Moreton, Pine Rivers and Redland Shires in 1973; c: Not available.

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showed the EKC relationships for BOD and TP (Tsuzuki, 2008, 2009a). There are differences in socio-economic conditions in the catchments in Japan and Australia (Table 2).

Population density in Southeast Queensland and the Brisbane River Catchment, 140 and 163 persons km^{-2}, are closer to that of the catchments of Lakes Shinji and Nakaumi, 186 persons km^{-2}, than that of the Yamato-gawa River, 1,964 persons km^{-2}, when compared to the catchments in Japan. Among the 60 countries with the largest populations in the world, population density is the smallest in Australia, 2.92 persons km^{-2}, and Japan is the fifth largest, 337 persons km^{-2} (Fig. 2). There are several water environment programs focusing on the rivers and creeks in Australia including the Healthy Waterways and Southeast Queensland (SEQ) Catchments in Southeast Queensland (Q'DERM, 2009; Healthy Waterways, 2012). There are various measures to reduce pollutant discharges and to improve river water quality in these countries (Healthy Waterways, 2012; Tsuzuki et al., 2012). Ambient water quality has been managed with water quality modellings such as the SEQ Receiving Water Quality Model (Q'DERM, 2010; Parslow, 2011). It is questionable whether similar EKC relationships are observed for the relationships of economic development level and pollutant discharges in these countries.
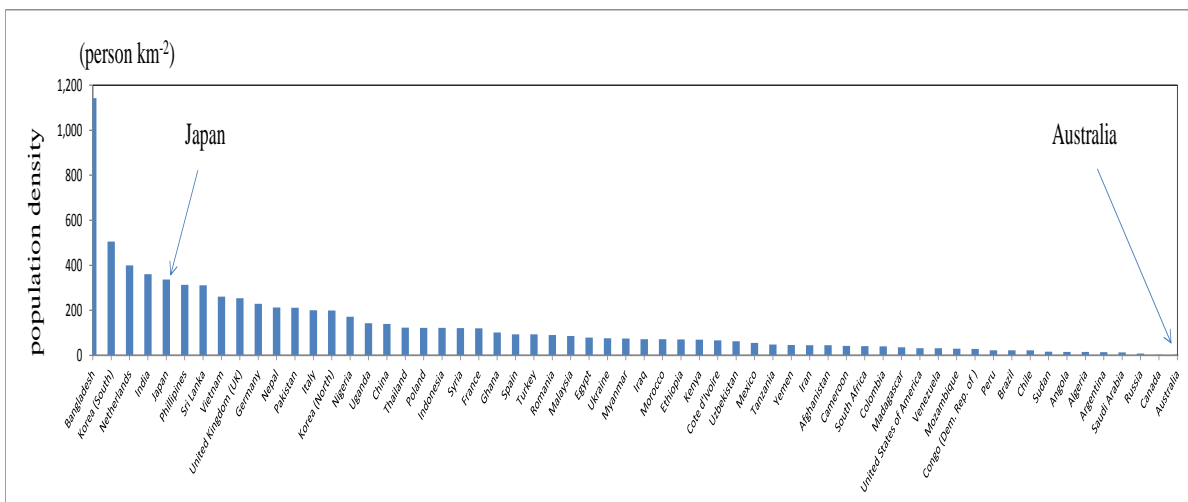

Figure 2. Population densities of 60 countries with the largest populations in 2012 (Prepared by the author based on the World Bank, 2014)

In this paper, first, the hard and soft measures to improve the river water environment in Australia and Japan were qualitatively compared to find the similarities and differences in these measures. Second, the relationship between economic development and pollutant discharge in Southeast Queensland was investigated. Basic trends of pollutant discharge from diffuse sources for TN and TP were estimated based on the pollutant discharge data in 2004 and predictions for 2026 in the Healthy Waterways report (Cavanagh, 2011). Based on the pollutant discharge alteration tendencies from diffuse sources, the effect of annual precipitation was included by developing a precipitation variation coefficient (PVC). Pollutant discharges from point sources were estimated using the data of the National Pollutant Inventory (NPI) (Australian Government Department of Sustainability, Environment, Water, Population and Communities (A'DSEWPC), 2013) and the Queensland Government (Q'DSITIA, 2013).

Methods

Definitions of pollutant discharge indicators

A water pollutant is sometimes treated at a generated place and the effluent is discharged into ambient water. The per capita amount of the pollutant generated at the pollutant source is defined as the pollutant generation per capita (PGC) and that of pollutant discharged to ambient water is known as the PDC (Tsuzuki et al., 2012; Tsuzuki, 2014). The PGC usually increases with economic development. On the contrary, such relationships are often observed that PDCs increase with economic development at the beginning, and decrease with further economic development because of the introduction of measures to decrease pollutant discharges.

Comparison of water environment improvement measures including community involvement programs in Australia and Japan

TN and TP concentrations have been improved in the Lower Brisbane River Catchment in 1975–2012 (Tsuzuki, 2013a). For the water quality improvements, several hard and soft measures have been conducted in these countries (Q'DERM, 2009; Healthy Waterways, 2012; Tsuzuki et al., 2012). The Social Experiment Program in the Yamato-gawa River Catchment has been successful in water quality improvement and has achieved the water quality criteria of BOD concentration in the river, 5 mg l^{-1} of annual average and 75% percentile, while that was once more than 20 mg l^{-1} in the early 1970s (Tsuzuki et al., 2012). A qualitative comparison of the measures to improve river water environment was conducted between Australia and Japan.

Relationship between economic development of Australia and pollutant discharge from the Brisbane River Catchment in 1960–2010

The chronological relationships between economic development and pollutant discharges in Southeast Queensland were investigated for TN and TP. Purchase power parity based gross domestic product (PPP-GDP) in Australia was calculated from the government statistical data of quarterly GDP data, population data and the consumer price index (CPI) based in 2009 (Australian Bureau of Statistics (ABS), 2013). Australian dollar (AUD) and Japanese Yen (JPY) were converted to USD or AUD prices supposing AUD 1 equalled USD 0.93, AUD 1 equalled JPY 94 or USD 1 equalled JPY 101.

Long-term alteration tendencies of pollutant discharges from diffuse sources were firstly estimated based on the Healthy Waterways report (Cavanagh, 2011). Secondly, effects of precipitation were included in pollutant discharge estimation by introducing PVC (Eq. 1) (Tsuzuki, 2013a; 2013b).

$$PD_{i,j,2} = PD_{i,j,1} + \frac{PRE_j - PRE_{ave}}{PRE_{ave}} \times \frac{PD_{i,ave}}{PVC} \qquad (1)$$

where $PD_{i,j,2}$ is pollutant discharge of pollutant i in year j with the effects of precipitation (t year^{-1}); $PD_{i,j,1}$ is pollutant discharge of pollutant i in year j without the effects of precipitation (t year^{-1}); PRE_j is precipitation of year j (mm year^{-1}); PRE_{ave} is yearly average precipitation (mm year^{-1}); $PD_{i,ave}$ is yearly average pollutant discharge (t year^{-1}); PVC is PVC (dimensionless).

The estimation results were compared with the pollutant discharge data in the existing literature (Queensland Co-ordinator-General's Department, 1973; Eyre and McKee, 1999; Stevens et al., 2005; Abal et al., 2005; Maxwell et al., 2007; SEQHWP, 2007; Rogers et al., 2013) and pollutant discharge estimations based on the spatial data and pollutant discharge per land area in Southeast Queensland (Abal et al., 2005; Queensland Government, 2013). Areas for the pollutant discharge estimations in the existing literature were the Moreton Bay Catchment before 2000 and Southeast Queensland in 2000–2010.

Pollutant discharges from point sources were estimated based on the National Pollutant Inventory (NPI) (A'DSEWPC, 2013) and pollutant discharge data obtained from the Queensland Government (Q'DSITIA, 2013). Most pollutant discharge data of the NPI and the Queensland Government are only after 1999. Therefore, pollutant discharge estimations from point sources before 1999 were conducted by the following two methods. First, point source pollutant discharges before 1999 were assumed to be constant. Second, those were assumed to be proportional to population for pollutant discharges from sewage treatment plants (STPs), and proportional to PPP-GDP for those from industries.

Relationship between economic development of Japan and municipal wastewater pollutant discharge from the Yamato-gawa River Catchment, Japan, in 1955–2010

The relationship between PPP-GDP per capita of Japan and municipal wastewater pollutant discharge from the Yamato-gawa River Catchment, Japan, in 1955–2010 was recalculated based on the existing literature applying the government statistical data of GDP and deflator, population and BOD discharge per capita from municipal wastewater (Tsuzuki and Yoneda, 2012; Cabinet Office of Japan, 2014; Ministry of Internal Affairs and Communications of Japan, 2014). Municipal wastewater has contributed 80% of BOD discharge in the catchment. Therefore, chronological estimations of municipal wastewater PDC are considered to explain most of the pollutant discharge alterations in the catchment.

Results

Comparison of water environment improvement measures in Australia and Japan

Water environment improvement measures in Australia and Japan were compared as shown in Table 3. There are similarities and differences in both hard and soft measures between these countries. Hard measures have similarities such as centralised and on-site wastewater treatment and prevention of sedimentation loss in forest and agriculture lands. Rice fields are typical of the Japanese agricultural sector and a range of measures to decrease pollutant discharges have been developed (Takeda and Fukushima, 2006; Somura et al., 2012; Chono et al., 2012). In the rivers and canals, installation of logs, flood infiltration systems, stormwater harvesting project such as the South Bank Stormwater Harvesting and Recycling Centre (SHARC) project and bush care activities are typical measures in Australia (Bunn et al., 1999; Mitchell, 2006; Hamlyn-Harris and Pickering, 2008; Sarker et al., 2008; Strang, 2008; Arthington, 2012; Healthy Waterways, 2012) while river water purification facilities are typical in Japan (Tsuzuki et al., 2012). The soft measures in households have been typical ones in Japan to improve river water quality by community involvement while disseminations of information about environment-friendly lifestyles have also been conducted in Australia.

Table 3. A comparison of Australian and Japanese measures to improve river water environment

Category	Australia	Japan
Hard measure		
Wastewater	Centralised wastewater treatment On-site wastewater treatment	Centralised wastewater treatment On-site wastewater treatment
Forest	Prevention of sedimentation loss	Prevention of sedimentation loss
Agriculture	Decrease of fertiliser usage amounts Prevention of sedimentation loss	Decrease of fertiliser usage amounts Prevention of sedimentation loss Water management in rice fields
River/canal	Installation of logs in the river Bush care activity Stormwater harvesting project Flood infiltration system	River water purification facility
Soft measure		
Lifestyles in households	Dissemination of environment-friendly lifestyle	Social Experiment Program (Soft measures in households)
Outdoor lifestyles	Dissemination of environment-friendly lifestyle	Cleaning up activity

White column: Similar measures; and Grey column: Different measures.

Relationship between PPP-GDP per capita in Australia and PDC in the Brisbane River Catchment in 1960–2010

Chronological alterations of PPP-GDP per capita were calculated based on the Australian and Japanese government statistics (Fig. 3) (ABS, 2013; Cabinet Office of Japan, 2013).
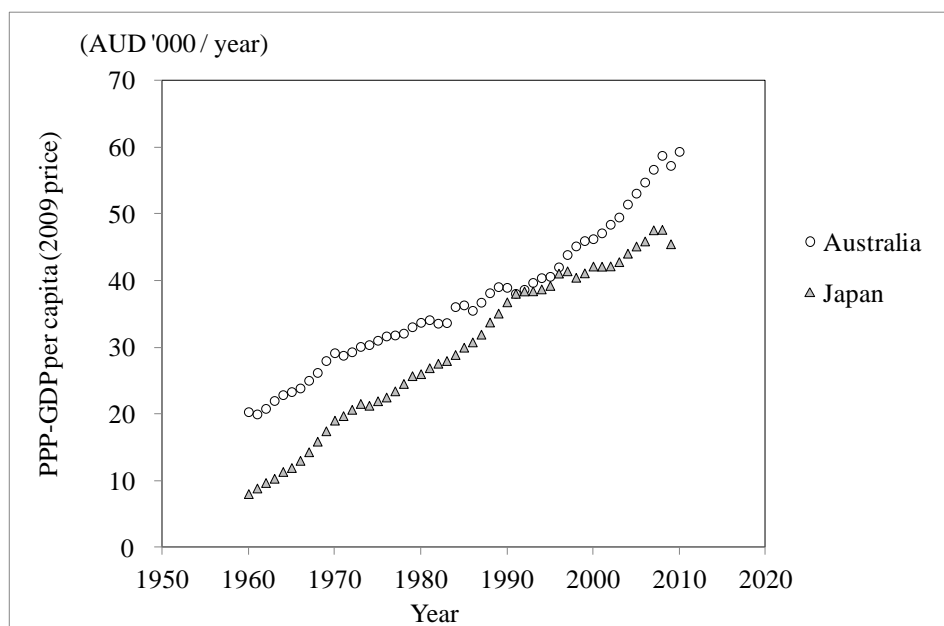

Figure 3. PPP-GDP in Australia and Japan (2009 price) (Prepared by the author based on ABS, 2013; and Cabinet Office of Japan, 2013)

For the pollutant discharge estimation results, only the second results are shown in Fig. 4, where pollutant discharges from point sources before 1999 were assumed to be proportional to population for pollutant discharges from STP and PPP-GDP for those from industries, respectively. Explanations of the first results with the constant assumption are described in the texts. Pollutant discharges from point sources have been decreased substantially in the 2000s. Pollutant discharges from diffuse sources with PVC were estimated to fluctuate during the investigation term. The ratios of discharge amounts from point sources to those from diffuse sources were 40.6–44.8% in 1960–2010 and 26.1–37.9% in 1999–2010 for TN, and 23.3–26.6% in 1960–2010 and 25.3–36.5% in 1999–2010 for TP. Therefore, pollutant discharges from both diffuse and point sources were considered to contribute significantly in the catchment for many years. However, the ratios decreased to 5.0–7.2% for TN and 8.0–11.5% for TP in 2010. These tendencies were similar in the results with the constant assumption while pollutant discharges from point sources were constant in 1960–1999. The pollutant discharge estimation of TP was relatively larger than the major range of the existing research data, however, the estimation results were considered to be comparable with the existing research and pollutant discharge

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estimations from the spatial data (Fig. 5). The comparison results showed large effects of precipitation on the pollutant discharges from the catchment, which were inconsistent with the common understanding in Southeast Queensland (Eyre, 1997; Bunn etal., 1999; Dennison and Abal, 1999; SEQHWP, 2007; Q'DERM, 2009, 2010; Cavanagh, 2011; Rogers, 2013).
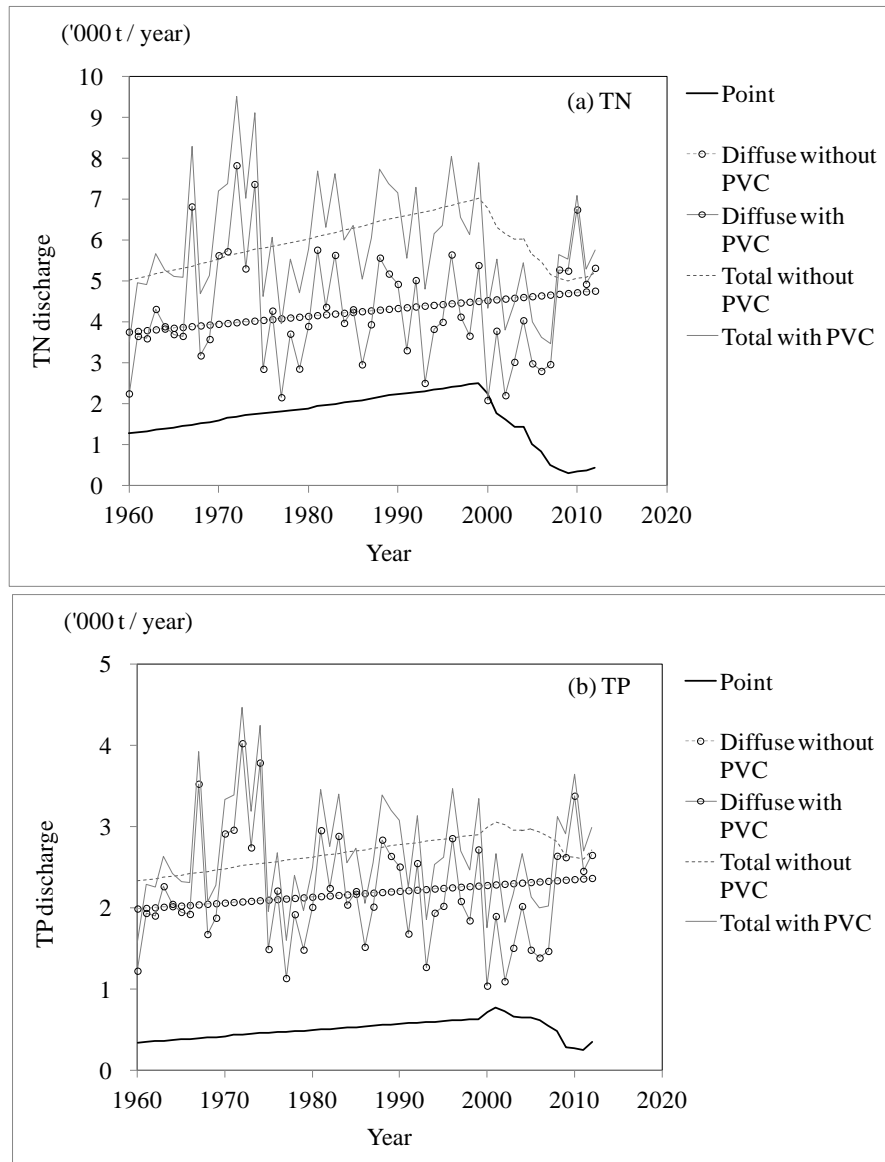

Figure 4. Chronological pollutant discharges of TN and TP in the Brisbane River Catchment (Pollutant discharge data of point sources were obtained from the Australian Government (A'DSEWPC, 2013) and the Queensland Government (Q'DSITIA, 2013))
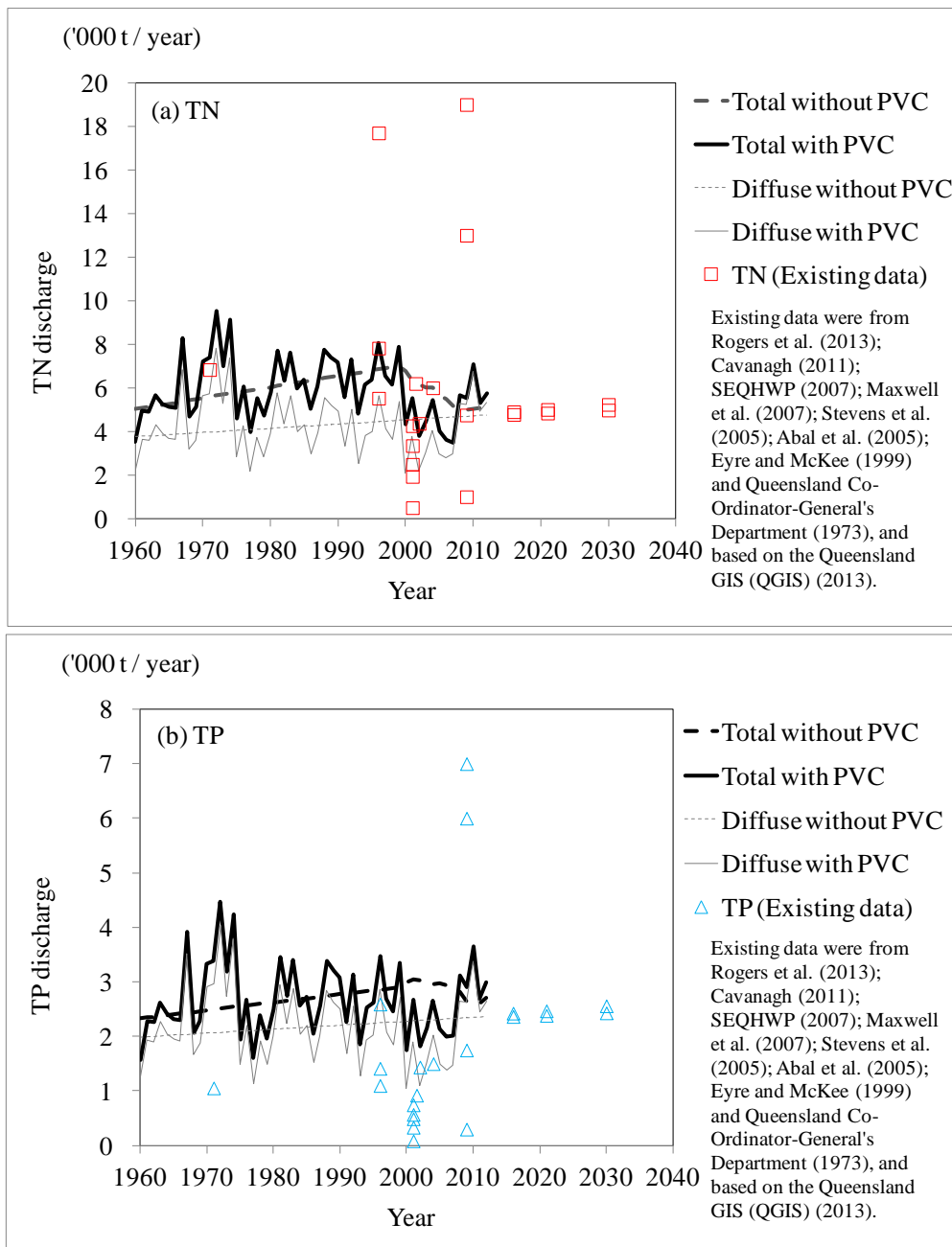
Figure 5. Comparisons of the pollutant discharge estimations of this research, existing data, and those based on the Queensland Government spatial data

The relationship between PPP-GDP per capita and pollutant discharges in the Brisbane River Catchment were expressed as second-order equations, especially when the effects of precipitation were not included (Fig. 6, Table 4). When the effects of precipitation were included, the correlation was less than the relationship without the precipitation effects.
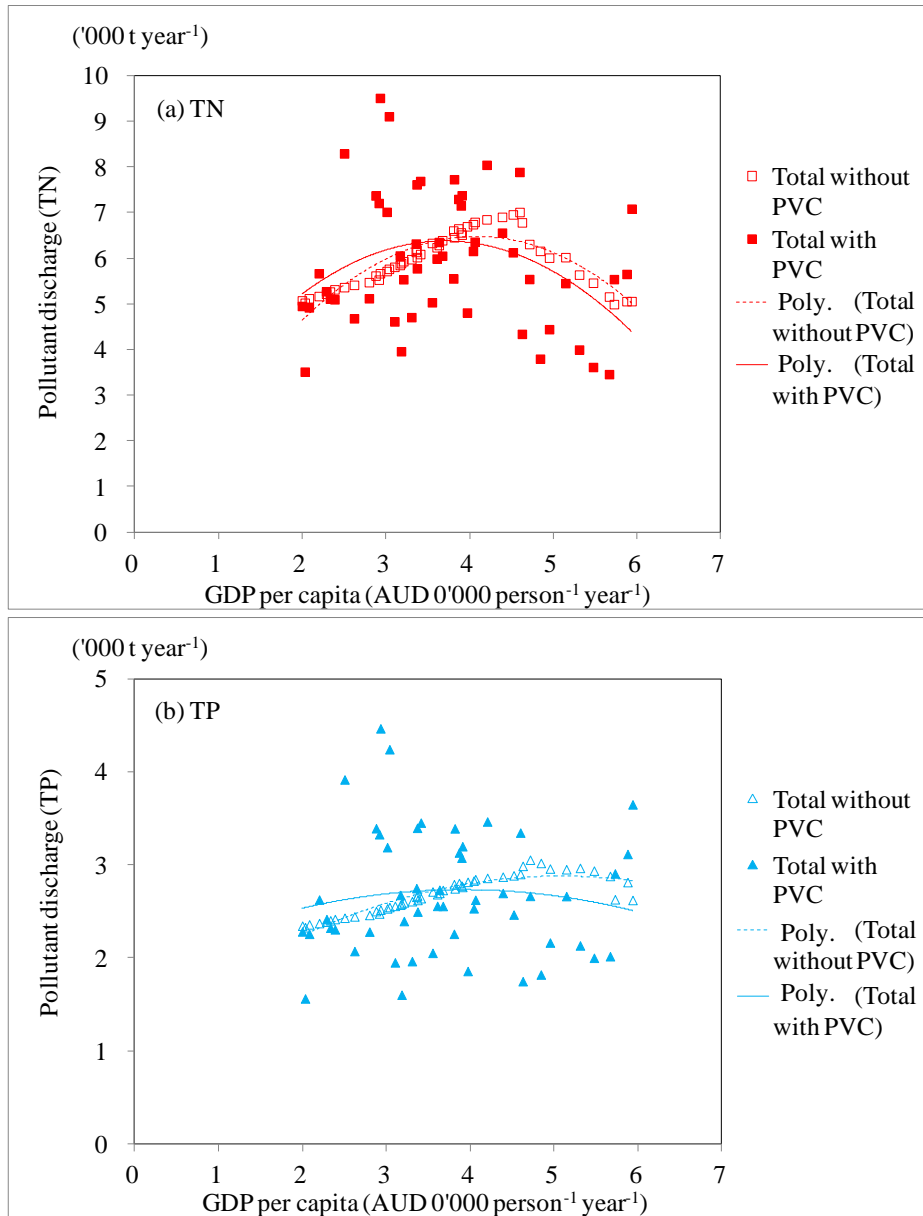
Figure 6. Relationship between GDP per capita in Australia and pollutant discharge in the Brisbane River Catchment (Pollutant discharge data of point sources were obtained from the Australian Government (A'DSEWPC, 2013) and the Queensland Government (Q'DSITIA, 2013)

Table 4. Comparison of the coefficient, constant, R-squared and inflection points of the regression analyses of this research and some existing literature on water pollutant discharges

Area	Parameter	Conditions	Unit of explanatory variable	Third-order coefficient	Second-order coefficient	First-order coefficient	Constant	R^2	GDP at the peak[a] USD person^{-1} year^{-1}	PD at the peak[b] g person^{-1} day^{-1}	Reference
Brisbane River	TN	Without PVC	AUD 10,000	NA[e]	-0.4240	3.4631	-0.5948	0.8187	43,912	8.6	This research
		With PVC	AUD 10,000	NA[e]	-0.3994	2.9598	0.8923	0.1332	39,842	6.7	This research
	TP	Without PVC	AUD 10,000	NA[e]	-0.0671	0.6824	1.1439	0.8619	54,677	2.1	This research
		With PVC	AUD 10,000	NA[e]	-0.0546	0.4270	1.8984	0.0105	42,046	1.0	This research
Coastal area in the world	BOD	PPP-GNI per capita	USD 1,000	NA[e]	-0.1996	0.8882	19.0300	0.0721	22,249	20.0	Tsuzuki (2008)[c]
	BOD	PPP-GNI per capita	USD	NA[e]	NA[e]	NA[e]	NA[e]	NA[e]	4,000	NA[e]	Tsuzuki (2008)
	BOD	PPP-GNI per capita	USD	NA[e]	NA[e]	NA[e]	NA[e]	NA[e]	2,100 – 2,600	NA[e]	Tsuzuki (2008)
	TP	GDP per capita	USD 1,000	NA[e]	-0.0128	0.2805	0.3597	0.2184	10,957	1.9	Tsuzuki (2008)[c]
	TP	PPP-GNI per capita	USD	NA[e]	NA[e]	NA[e]	NA[e]	NA[e]	10,000	NA[e]	Tsuzuki (2008)
	TP	PPP-GNI per capita	USD	NA[e]	NA[e]	NA[e]	NA[e]	NA[e]	13,000 – 14,000	NA[e]	Tsuzuki (2008)
Developing countries	BOD	GDP per capita	USD	NA[e]	-0.0900	0.9098	22.2220	0.0443	5,054	24.5	Tsuzuki (2009a)
	TN	GDP per capita	USD	NA[e]	0.0194	-0.7329	7.6962	0.2932	18,889	0.8	Tsuzuki (2009a)
	TP	GDP per capita	USD	NA[e]	-0.0181	0.4054	0.3726	0.2840	11,199	2.6	Tsuzuki (2009a)
Lakes Shinji and Nakaumi, Japan	COD[d]	GDP per capita	JPY million	NA[e]	-3.0750	8.1690	15.7190	0.8430	13,283	21	Tsuzuki (2007, 2009b)[c]
	TN	GDP per capita	JPY million	NA[e]	-0.9000	0.9990	9.0670	0.4080	5,550	9.3	Tsuzuki (2007, 2009b)[c]
	TP	GDP per capita	JPY million	NA[e]	-0.2020	0.4690	0.7160	0.3550	11,609	1.0	Tsuzuki (2007, 2009b)[c]
42 countries	DO	GDP per capita	USD 1,000	0.004	-0.127	1.33	NA[e]	0.209 [f]	2,703	NA[e]	Grossman and Krueger (1995)
	BOD	GDP per capita	USD 1,000	-0.022	0.335	1.41	NA[e]	0.039 [f]	7,623	NA[e]	Grossman and Krueger (1995)
	COD	GDP per capita	USD 1,000	0.015	0.498	-19.66	NA[e]	0.352 [f]	7,853	NA[e]	Grossman and Krueger (1995)
	NO3-N	GDP per capita	USD 1,000	-0.007	0.188	-1.16	NA[e]	0.663 [f]	10,524	NA[e]	Grossman and Krueger (1995)
	T.coli	GDP per capita	USD 1,000	-0.016	0.473	-3.71	NA[e]	0.479 [f]	3,043	NA[e]	Grossman and Krueger (1995)
	F.coli	GDP per capita	USD 1,000	-0.0038	0.110	-0.85	NA[e]	0.003 [f]	7,955	NA[e]	Grossman and Krueger (1995)

a: PPP-GDP per capita at the peak of the second-order function; b: Pollutant discharge at the peak of the second-order function; c: Re-calculated based on the literature; d: Chemical oxygen demand; e: Not available; and f: P-value (income only).

Relationship between PPP-GDP per capita in Japan and PDC in the Yamato-gawa River Catchment in 1955–2010

The relationship between GDP per capita and BOD discharge per capita from municipal wastewater in the Yamato-gawa River Catchment in 1955–2010 was calculated based on the existing literature (Fig. 7) (Tsuzuki, 2007, 2009b). The relationship was found to show the EKC inverted U-shaped curve. The proximate square-equation lines of the inverted U-shaped curves are usually bilaterally symmetrical because of the mathematical method of regression analysis, however, the tendencies of the actual data might be different in the samples. Symmetry of the inverted U-shaped curves of the EKC are sometimes observed and suggested as smaller curvatures in the right half of decreasing curves rather than the left half of the increasing curves (Dasgupta, 2002; Burke, 2012; Liao and Cao, 2013). S-shaped and N-shaped curves which are approximated with third-order equations have also been hypothesised (Du et al., 2014). The results of the Yamato-gawa River Catchment exhibited a larger curvature in the right half than the left half of the inverted U-shaped curve. The environmental burden at the right end or in the 2000s was smaller than that at the right end in the 1950s. This curve was considered to be exceptional comparing to the existing concepts and research results, which showed the effectiveness of the hard and soft measures in the catchment.

The equation shown in the figure:

$$y = -0.0641x^2 + 3.1369x + 5.117$$
$$R^2 = 0.7756$$

x: GDP per capita ('000 AUD person⁻¹ year⁻¹)
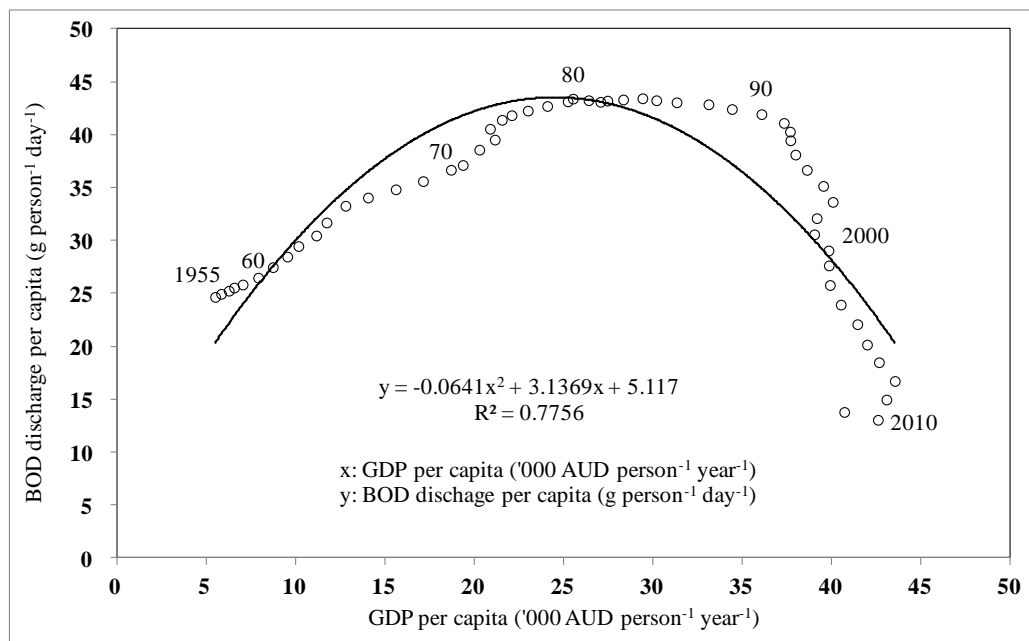y: BOD dischage per capita (g person⁻¹ day⁻¹)

Figure 7. Relationship between GDP per capita of Japan and BOD discharge per capita in the Yamato-gawa River Catchment in 1955–2010 (Recalculated from Tsuzuki, 2007, 2009b)

Discussion

The TN and TP concentrations in the Lower Brisbane River Catchment have been gradually decreased in 1975–2010 (Tsuzuki, 2013a). Therefore, pollutant discharges from diffuse and point sources were not necessarily considered to affect proportionally these water qualities. The relationship between the pollutant discharges and water quality concentrations are only briefly discussed in this paper. For TN and TP discharges from the Brisbane River Catchment, point sources were more influential in regards to socio-economic development than diffuse sources in the catchment during the investigation period when gradual decreases (improvements) of TN and TP concentrations in the Lower Brisbane River Catchment was observed in this decade (Fig. 4) (Tsuzuki, 2013a).

Because of the relatively large precipitation in recent years, total and diffuse pollutant discharges for TN and TP in 2008–2010 were larger than those in 2001–2007 (Figs. 4 and 5). During the decade, although TN and TP pollutant discharges from point sources decreased, total and diffuse pollutant discharges with PVC increased in the late 2000s. The tendencies of pollutant discharges and water quality were considered to be reasonable when the spatial distributions of pollutant sources are taking into account. The diffuse sources spread across all the catchment including the upper and middle sub-catchments, and most of the point sources are placed in the Lower Brisbane River Catchment where long-term water quality decreases (improvements) for TN and TP were observed (Tsuzuki, 2013a).

The relationships between economic development and pollutant discharges were found to be inverted U-shaped curves especially without PVC (Fig. 6, Table 4). Correlation coefficients were smaller for the PDCs with PVC. Socio-economic effects are considered to be related to both point and diffuse sources. For the pollutant discharges and water quality tendencies in some catchments around the Brisbane River, in the Richmond River Catchment, northern New South Wales (NSW), phosphate concentration has been found to be in a similar level besides a 2.5 fold phosphorus discharge increase in 50 years (Eyre, 1997). In the Moreton Bay Catchment, where the Brisbane River Catchment is included, fertiliser applications have been increased while the land areas of sown pasture and cropland have decreased after 1960 (Neil, 1998; Dennison and Abal, 1999). Further be more precise and longer-term investigations of pollutant discharges including the effects of the flood infiltration systems and stormwater harvesting projects.

Yandle et al. (2004) have summarised economic indicators at the inflection or turning points of the EKC. There have been many research results on air pollutants from SO_2, NO_x to CO_2 and GHG since the 1990s. Some existing results on the inflection points for water quality parameters were summarised as well as recalculated results based on the existing research to compare with the results in this paper (Tables 1 and 4). The inflection points for pollutant discharges without the precipitation effects occurred around the year 1999. These were affected by pollutant discharge

tendencies from point sources (Figs. 4 and 6). PPP-GDP per capita at the inflection points were AUD 37,053–50,849 (USD 39,842–54,677) person^{-1} year^{-1}, which were larger than those in the existing literature, USD 2,100–22,249 person^{-1} year^{-1} (Table 4) (Grossman and Krueger, 1995; Tsuzuki, 2007, 2008, 2009a, 2009b). PPP-GDPs per capita at the inflection points in this research were larger than those in the existing research including those on other environmental parameters such as CO_2 and GHG emissions (Table 1). In the Brisbane River Catchment, there might be other inflection points with the smaller PPP-GDP per capita for the investigation period of 1960–2010, which should correspond to the traditional water quality improvement measures and regulations. Therefore, the relationship curves might be four- or two-dimensional depend on the chronological data of pollutant discharges in further research. The inflection points found in this research might also be caused by the estimation methods due to the data availability and should be investigated further in detail.

TN and TP discharge amounts estimated in this research for the Brisbane River Catchment, 6.7–8.6 g-N person^{-1} day^{-1} and 1.0–2.1 g-P person^{-1} day^{-1}, were considered to be comparable with those in the existing research of the Japanese catchments and coastal areas of developing countries, 0.8–9.3 g-N person^{-1} day^{-1} and 1.0–2.6 g-P person^{-1} day^{-1}, while the results of the Japanese catchments have been of only municipal wastewater pollutant discharges (Tsuzuki, 2007, 2009b). The hard and soft measures in the Yamato-gawa River were also reassured to be effective measures for pollutant discharge reduction (Fig. 7).

Agriculture and mining are the important primary industries in Queensland, Australia (Battellino, 2010; Eady et al., 2013; Porter et al., 2013; Patterson et al., 2013; Ivanova, 2014;). These industries have potentials to affect the river water environment because of their pollutant discharges. In this paper, specific quantifications and investigations of these pollutant discharges were not conducted, and some effects of agriculture including fertilisers were considered to be included in the pollutant discharge from diffuse sources (Queensland Co-ordinator-General's Department, 1973; Eyre and McKee, 1999; Stevens et al., 2005; Abal et al., 2005; Olley, 2006; Maxwell et al., 2007; SEQHWP, 2007; Rogers et al., 2013). More specific investigations of pollutant discharges including the effects of these industries would be considered in further research.

The relationships between economic development and pollutant discharges have been represented not only by the inverted U-shaped curves but also by S-curves and N-curves (Table 1) (Chen and Wang, 2013; Wang and Wei, in press). The results of the S-curves and N-curves have suggested environment improvement should not occur automatically with the certain level of economic development. Water quality in the Brisbane River has been considered to be worse than that of more than 50 years ago (Dennison and Abal, 1999). Decreasing pollutant discharges is considered to be necessary for water quality improvement and conservations of the precise water

environment. Desirable combinations of technologies, regulations and governances are considered to be effective for pollutant discharge management. The quantitative evaluation on the effects of these policies and measures would be possible by such methods as the EKC and benefit-cost analyses.

Conclusions

Based on the existing literature and data including government statistics, the relationships between economic development and pollutant discharges in Southeast Queensland in 1960–2012 were investigated. Inverted U-shaped curves of the EKC were found for the relationships in the Brisbane River Catchment. The inflection points were found around the year 1999. Their PPP-GDPs per capita at the inflection points were found to be larger and PDCs were found to be in the similar ranges comparing to the existing literature. The reasons for the larger PPP-GDPs per capita were considered to be that the inflection points should correspond to the measures to reduce pollutant discharges from the point sources in the 2000s in the Brisbane River Catchment. The hard and soft measures in the Yamato-gawa River Catchment were reassured to be effective for pollutant discharge reduction. Further detailed investigations would enhance understanding of these measures and water quality in Australia and Japan.

Acknowledgements

Biography

Yoshiaki Tsuzuki is a PhD student at The University of Queensland and a collaborative researcher at Shimane University. His background is environmental engineering, and is interested in engineering and natural science aspects and socio-economic aspects of water environment, ecological economics, water and sanitation, and environmental history.

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