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Impacts of housing development on nutrients flow along canals in a peri-urban area of Bangkok, Thailand

R. Honda, Y. Hara, M. Sekiyama and A. Hiramatsu

ABSTRACT

Change of nutrients load and flow according to land-use change induced by housing development was investigated in Bang Yai, Nonthaburi, Thailand, which located in the peri-urban area of Bangkok. Each house in the newly developed residential community was regulated to be equipped with a septic tank to collect night soil. However, greywater and leachate from the septic tank was collected by a community sewage system and discharged into the canals with insufficient treatment, while the canals still function as infrastructure for irrigation and transportation. In the study area, built-up area became 1.4 times and agricultural fields decreased by 13% from 2003 until 2007. Total nutrients load to the canals was increased by 25% as nitrogen and 14% as phosphorus according to the increase of built-up area. Net nutrients load from agricultural fields was largely set off when we evaluated nutrients inflow from the canals to the agricultural field through irrigation. Consequently, nutrients load from domestic wastewater accounted most of net nutrients load into the canal.

Key words | land-use change, nutrients flow analysis, peri-urban development

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INTRODUCTION

Many Asian developing countries face serious environmental problems associated with rapid economic growth. Although there is an urgent need to learn from the experience of industrialized countries that have solved serious pollution problems, existing pollution-control measures must be applied in a manner appropriate to the target region (Takiguchi *et al.* 2007). Bangkok Metropolitan in Thailand is one of the largest expanding cities in Asia. Increase of middle-income citizens promotes their migration from the urban center to the suburban area, where they can own their houses (Hiramatsu *et al.* 2009). Responding to their demand, there is active development of new residential communities found in the urban fringe of Bangkok.

Agriculture on the Chao Phraya Delta is historically developed accompanied by the construction of canals (Takaya 1987). Dense network of the canals still function as their important infrastructure for irrigation, transportation, washing, etc. However, the development of new residential communities in peri-urban area brings about urban–rural mixed land-use and pollution of the canal water. No standard of wastewater discharge was established for a residential community with less than 100 units (National Environmental Board 1994), although development of such small community was brisk in the urban fringe area. The development also brings change in agriculture. The agriculture in the peri-urban area is shifting to suburban agriculture, which requires more intensive fertilizing than rice cropping and traditional fruit cultivation. Increase of wastewater discharge from newly developed residences and such intensive agricultural fields would cause increase of nutrients load and eutrophication of the canals. Since Bangkok and surrounding area locates on the low-flat delta basin, the slow speed of the canals is usually very slow. Therefore, eutrophication of the canals will probably result in bloom of algae, which would impair the functions of the canals.

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To design the appropriate measures for preventing the eutrophication, we need to clarify and quantify the impact of each nutrients source. However, few studies reveal nutrients flow in the peri-urban area in Asian developing cities. The objective of this study is to illustrate and quantify the shift of nutrient flow induced by land-use change in peri-urban development. We estimated change of nutrients load from residential area and agricultural fields in an urban–rural fringe area of Bangkok, Thailand. We also estimated nutrients inflow into agricultural fields by irrigation to investigate nutrients flow mediated by the canals. We evaluated impacts of each land use as net load into canals.

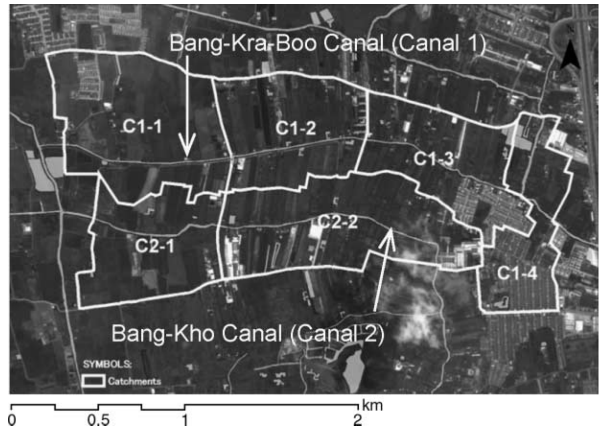

Figure 1 | Study area in Bang Maenang, Nonthaburi, Thailand (ALOS PRISM satellite imagery 2007).

MATERIALS AND METHODS

Study area

We targeted Bang Maenang District in Nonthaburi Province as a study area, and focused on the area along the two canals in the district, Bang-Kra-Boo Canal (Canal 1) and Bang-Kho Canal (Canal 2). We chose these canals because development of new residential area was seen in many places along the canals, and because progress in development was different between along the two canals. Basins of Bang-Kra-Boo Canal and Bang-Kho Canal were defined in the following way: (i) the area was divided in lots through on-screen visual interpretation of ALOS PRISM satellite imagery; (ii) the lot bounded on the either of the canal was defined as the basins of the neighboring canal; (iii) the lot which was not bounded on the either of the canals was defined as the basins of the closer canal; (iv) the lot bounded on the both canals was divided in two parts to connect boundaries of the basins in the neighboring lots; and (v) if wastewater of the lot was found to be discharged to the either of the canals in field survey, the lot was defined as the basin of the corresponding canal. The defined basins were divided for descriptive purposes as C1-1 to C1-4 and C2-1 to C2-2, respectively (Figure 1). Total area of the study area was 3.05 km^2.

Land-use change and population

Land-use change due to urban development in the target area between 2003 and 2007 was spatially investigated using GIS software (ArcGIS, ESRI). The 2003 urban planning base map in vector format with a scale of 1:4000 (Department of Public Works and Town & Country Planning, Ministry of Interior, Thailand) was obtained and used for GIS analysis. The map for 2007 was constructed by editing 2003 vector map through on-screen visual interpretation of ALOS PRISM satellite imagery observed in 2007. An area of a residential land use, the number of houses, an area of rice fields and vegetable fields in each year and their changes were calculated by overlaying the 2003 and the 2007 maps. Population was extrapolated from the national average household size: 3.4 persons/household (National Statistical Office of Thailand 2001).

Nutrients load and flow

Agricultural fields

Load and flow of nitrogen and phosphorus in the target area (Figure 2) was quantified based on field survey.

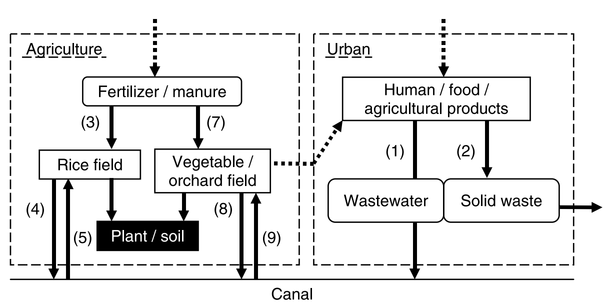

Figure 2 | Nutrients flow along canal in the study area. (The flow was numbered for reference in below discussion).

Amount of applied nutrients by fertilizer in rice and vegetable fields was estimated according to the results of interview survey to the farmers. Amount of irrigation water and discharged water into/from agricultural fields were calculated from the monitoring data of water level and precipitation. Water level in agricultural fields was monitored by water level loggers (HOBO Water Logger U20-001-04, Onset, USA), which were placed at two sites in rice fields and one site in vegetable field. Precipitation was monitored by a precipitation logger (HOBO Data Logging Rain Gauge RG3-M, Onset, USA). Rate of water level decline by evapotranspiration and penetration was estimated as 4.0 mm/day in rice fields and as 5.0 mm/day in vegetable fields by water level decline observed in continuous clear conditions. In the monitoring data, water level decline larger than the evapotranspiration and penetration rate was considered as an event of water discharge from the agriculture fields. Water level rise without precipitation was considered as an event of water irrigation. Total nitrogen and total phosphorus concentrations of irrigation water and discharged water were determined from average concentration of monitoring data of water in canal, rice and vegetable fields. Total nitrogen concentration was calculated from TKN, NH_4-N, NO_2-N, and NO_3-N, analyzed by

Table 1 | Basic units used in estimation of nutrients load and flow in this study

Basic unit	Value	Unit	Reference
Rice fields			
Amount of irrigation water from canals into rice fields	1.65	m/year	This study
Nitrogen concentration in irrigation water into rice fields	2.34	mgN/L	This study
Phosphorus concentration in irrigation water into rice fields	0.43	mgP/L	This study
Amount of water discharge from rice fields	2.08	m/year	This study
Nitrogen concentration in water discharge from rice fields	2.4	mgN/L	This study
Phosphorus concentration in water discharge from rice fields	0.51	mgP/L	This study
Amount of nitrogen in fertilizer used in rice fields	9.61	g/m^2/year	This study
Amount of phosphorus in fertilizer used in rice fields	2.04	g/m^2/year	This study
Vegetable fields			
Amount of irrigation water from canals into vegetable fields	3.17	m/year	This study
Nitrogen concentration in irrigation water into vegetable fields	2.47	mgN/L	This study
Phosphorus concentration in irrigation water into vegetable fields	0.43	mgP/L	This study
Amount of water discharge from vegetable fields	3.31	m/year	This study
Nitrogen concentration in water discharge from vegetable fields	2.8	mgN/L	This study
Phosphorus concentration in water discharge from vegetable fields	0.48	mgP/L	This study
Amount of nitrogen in fertilizer used in vegetable fields	6.67	g/m^2/year	This study
Amount of phosphorus in fertilizer used in vegetable fields	2.06	g/m^2/year	This study
Residences (wastewater)			
Number of residents per household	3.4	Persons/household	This study
Amount of domestic wastewater	279	L/person/day	This study
Nitrogen concentration in domestic wastewater	45.5	mgN/L	–*
Phosphorus concentration in domestic wastewater	4.2	mgP/L	–*
Residences (solid waste)			
Amount of municipal solid waste generation	346	kg/household/year	–†
Nitrogen content in municipal solid waste	4.02	%	This study
Phosphorus content in municipal solid waste	0.19	%	This study

*Modified from Lee & Wong (2003), considered treatment by septic tanks.
†Hiramatsu et al. (2009).

Table 2 | Removal ratio of nitrogen and phosphorus by septic tank (%)

Nitrogen	Phosphorus	Reference
5–14	11–27	Montangero & Belevi (2007)
<30	<35	Von Sperling & De Lemos Chernicharo (2005)
10–30	–	Seabloom *et al.* (2004)
9	–	Chulalongkorn University (2003)
3.7	–	Schaffner *et al.* (2006)

macro-Kjeldahl method, titrimetric method, colorimetric method, nitrate electrode method (Eaton *et al.* 2005), respectively. Total phosphorus concentration was analyzed by vanadomolybdophosphoric acid colorimetric method (Eaton *et al.* 2005). The water level was monitored from June 2007 until December 2007; canal water quality was monitored twice a month from February 2007 until February 2008; water quality in agricultural fields was monitored from September 2007 until February 2008 (Table 1).

Residences

The sewer systems in residential communities in the target area were combined systems. However, the sewer system in each community was too small to monitor amount and water quality of discharged sewage. Therefore, the amount of nutrients discharged from residences was calculated by multiplying amount of wastewater discharged from residences and nutrients concentrations of the wastewater. Wastewater discharge from residences was assumed to be equal to amount of water usage, 279 L/person/year. The value was average amount of water usage calculated by using monthly data from October 2005 until September 2006, which was obtained at Water Management Association in Nonthaburi Province.

Wastewater discharged from a residence to a sewer system in the target area consisted of greywater and leachate of a septic tank, which was equipped at each residence. We assumed nitrogen and phosphorus concentrations in wastewater without septic-tank treatment as 50 mgN/L and 5 mgP/L, respectively, according to Lee & Wong (2003). Past studies reported that 90–93% of nitrogen and 75–88% of phosphorus was originated from black water (Vinneras *et al.* 2001; Gray & Becker 2002; Vinneras & Jonsson 2002*a*,*b*). We assumed that black water contributes 90% and 80% of nitrogen and phosphorus in the wastewater, and that removal ratio of total nitrogen and phosphorus by a septic tank as 10% and 20%, respectively, according to past studies (Table 2). Consequently, we determined nitrogen and phosphorus concentration in wastewater from residences to the sewer system as 45.5 mgN/L and 4.2 mgP/L, respectively.

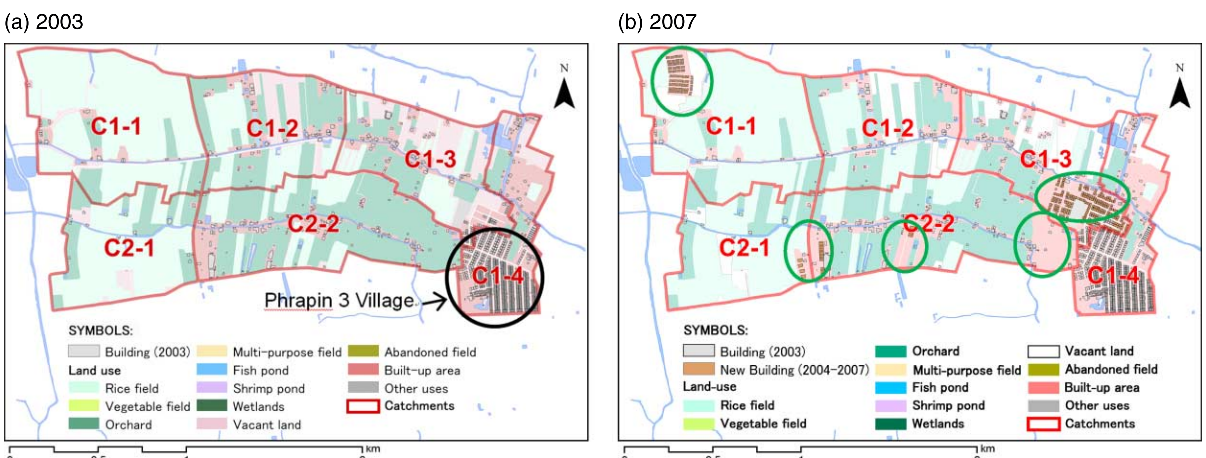

Figure 3 | Land-use change in the study area from (a) 2003 until (b) 2007.

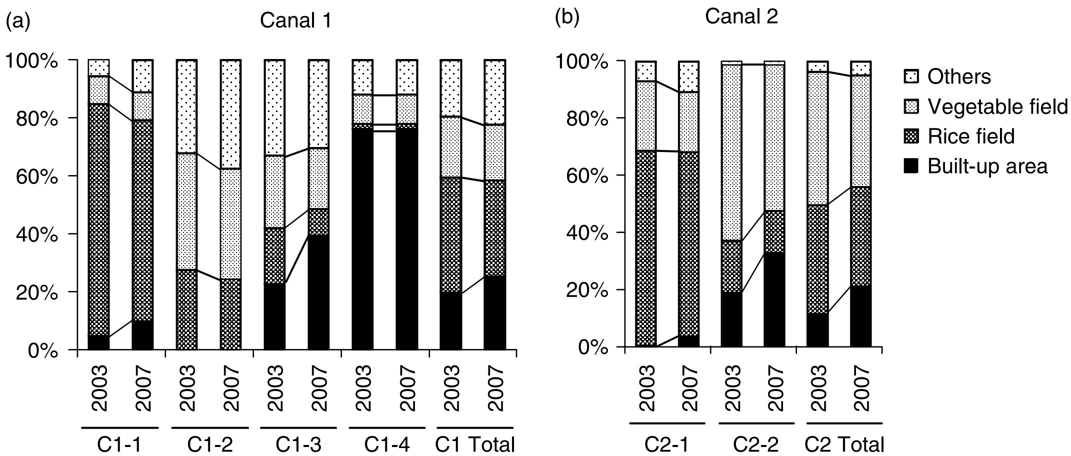

Figure 4 | Land-use change in the basin along Canals 1 and 2.

Amount of solid waste discharge and nutrients contents in the waste were obtained by field survey on municipal solid waste generation which targeted on randomly selected 24 households in Bang Maenang District (Hiramatsu *et al.* 2009). Amount of municipal solid waste generation was 346 kg/household/year, and the average nitrogen content was 4.02% (Hiramatsu *et al.* 2009).

RESULTS AND DISCUSSION

Land-use change

Housing development was more active in the eastern area, which is closer to the urban center. Increase of built-up area in downstream (eastern) area was larger than upstream (western) area (Figures 3 and 4). However, there was little land-use change in C1-4, in which housing development had been saturated. The land-use change was more active along Canal 2, which was less developed than along Canal 1. Built-up area along Canal 2 in 2007 became 1.8 times of that in 2003, while it increased to 1.3 times along Canal 1. Agricultural fields had lost 13–14% of its share along Canals 1 and 2, respectively. In addition to the built-up area, vacant land, which is categorized as 'Others' in Figure 4, also increased in all the basins. This implies the future increase of built-up area.

Nutrients load

Increase of built-up area induced increase of total nutrients load into Canal 1. Most of the nutrients load increase was contributed by built-up area along Canal 1 (Figure 5 and Table 3). On the other hand, the load into Canal 2 decreased, probably because of shift of agricultural fields to vacant land. According to larger amount of unit load per area, share of nutrients load into the canals from domestic wastewater was estimated larger than that of land-use. Along Canal 1, the load from domestic wastewater accounted 74% as nitrogen and 58% as phosphorus in 2003; it increased to 83% and 71% in 2007, respectively. The load from agricultural fields decreased accompanied by decrease of agricultural fields.

Nutrients flow mediated by the canals

Net load of nutrients from agricultural fields was largely reduced when we evaluated nutrients flow from the canals

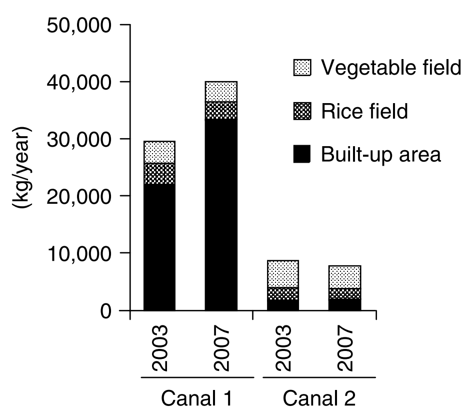

Figure 5 | Total nitrogen load into Canals 1 and 2.

by irrigation. Approximately 85% of nutrients load from agricultural fields was set off by nutrients inflow by irrigation (Table 3). Although phosphorus load was larger from agricultural fields than from domestic wastewater, the major net load of phosphorus along Canal 1 was from domestic wastewater, which accounted for more than 85%, when we consider phosphorus inflow from the canals by irrigation. The major net load of nitrogen was domestic wastewater along both canals. Nutrients load from residential area in 2007 became 1.5 times as much as in 2003 along Canal 1.

Necessity of appropriate control of wastewater from residential area

Eutrophication is one of the possible concerns to deteriorate the functions of the canals, because flow speed of the canal is very slow since they are located in the low-flat Chao Phraya River Basin. Along Canal 1, increase of nutrients load into the canal was brought by increase of load from domestic wastewater. In addition, the net load of nutrients was also dominated by domestic wastewater. Therefore, control of domestic wastewater from newly development

Table 3 | Nutrients flow in the study area

Land-use	Flow*	Canal 1 2003	Canal 1 2007	Canal 2 2003	Canal 2 2007	Note
(a) Nitrogen (kg/year)						
Built-up area	(1) Wastewater	21,866	33,288 (+52%)	1,827	1,890 (+3%)	
	(2) Solid waste	19,283	29,355	1,612	1,667	
Rice field	(3) Fertilizing	7,448	6,178	4,039	3,679	
	(4) Discharge	3,867	3,208	2,097	1,910	
	(5) Irrigation	2,991	2,481	1,622	1,478	
	(6) Net	876	726 (−17%)	475	433 (−9%)	(4) − (5)
Vegetable fields	(7) Fertilizing	2,708	2,518	3,434	2,869	
	(8) Discharge	3,766	3,501	4,776	3,990	
	(9) Irrigation	3,177	2,954	4,029	3,366	
	(10) Net	589	548 (−7%)	747	624 (−16%)	(8) − (9)
Total load to canal		29,499	39,997 (+37%)	8,701	7,791 (−10%)	(1) + (4) + (8)
Net load to canal		23,331	34,562 (+48%)	3,049	2,947 (−3%)	(1) + (6) + (10)
(b) Phosphorus (kg/year)						
Built-up area	(1) Wastewater	2,018	3,073 (+52%)	169	175 (+3%)	
	(2) Solid waste	918	1,398	77	79	
Rice field	(3) Fertilizing	3,908	3,242	2,120	1,931	
	(4) Discharge	821	681	445	406	
	(5) Irrigation	550	456	298	272	
	(6) Net	271	225 (−17%)	147	134 (−9%)	(4) − (5)
Vegetable fields	(7) Fertilizing	836	777	1,060	886	
	(8) Discharge	646	601	819	684	
	(9) Irrigation	553	514	701	585	
	(10) Net	93	87 (−7%)	119	99 (−16%)	(8) − (9)
Total load to canal		3,486	4,355 (+28%)	1,433	1,265 (−11%)	(1) + (4) + (8)
Net load to canal		2,383	3,385 (+43%)	434	494 (−6%)	(1) + (6) + (10)

*The numbering of the flow is corresponding to Figure 3.

communities is necessary to sustain canal water environment, which is still utilized for purpose of irrigation, transportation, bathing, washing, etc.

The number of houses in most of the newly developed communities in the study area was smaller than 100 houses. Therefore, most of these new communities were supposed to have no treatment facilities except septic tanks equipped at each house, because there were no standards of wastewater discharge for residential community with less than 100 units (National Environmental Board 1994). Only eastern part of Phrapin 3 village, which was the largest community in the target area, had two oxidation pond processes as community-based treatment facilities. However, one did not work at all because there was no discharge point of treated water; the other also had low treatment performance probably due to lack of proper maintenance and operation. To prevent the deterioration of canal water environment and functions in the study area, the following measures should be taken by national and/or local government: (i) application of standards on wastewater discharge regardless of community size, which enables control of wastewater from small residential communities; and (ii) monitoring of discharged water, which enforces the proper management and maintenance of wastewater treatment facility in the communities.

CONCLUSIONS

Total nutrients load to the canals in the study area was increased by 25% as nitrogen and 14% as phosphorus from 2003 until 2007. Net nutrients load from agricultural fields was largely set off when we evaluated nutrients inflow from the canals to the agricultural field through irrigation. Consequently, nutrients load from domestic wastewater accounted for most of net nutrients load.

Control of nutrients load from domestic wastewater discharged from newly developed and existing residential area is required to prevent eutrophication of the canals. In reality this means (i) application of standards of discharged wastewater quality, which was currently applied only for a residential community with more than 100 units, regardless of the community size and (ii) monitoring by local government which enforces appropriate management of wastewater treatment facility built in the community were required.

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