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Incremental sanitation improvement strategy: comparison of options for Hanoi, Vietnam

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ABSTRACT

Urban sanitation issues should be tackled strategically, and may be addressed effectively when sewerage development is pursued in conjunction with complementary sanitation measures. Five sanitation improvement scenarios employing sewerage, night-soil collection-and-treatment (NSCT) system, and/or septic-tank improvement by annual desludging were analyzed from the perspective of COD loads, total nitrogen loads, and cost under the conditions found in Hanoi, Vietnam. Compared to the development of sewerage alone, the scenario of developing NSCT systems in a complementary manner with sewerage development was estimated to be the most effective for a rapid decrease of both COD and total nitrogen loads. However, it may be difficult in some cases to replace ordinary water-flush toilets by the micro-flush toilets that are used in NSCT systems. In this case, the scenario employing septic-tank improvement in conjunction with sewerage development may be effective for a rapid decrease of COD in locations where septic tanks are widely used under poor maintenance conditions and nitrogen pollution is not serious compared to COD. It was calculated that the two scenarios above would respectively require cost increases of 16 and 22% over the sewerage development scenario.

Key words | Hanoi, night-soil collection-and-treatment, scenario analysis, septic tank improvement, sewerage

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INTRODUCTION

Background

Although considerable effort has been expended for sewerage development around the world, the coverage of sewerage in developing countries is still low and many developing countries are suffering from serious water pollution and water-borne diseases due to the discharge of untreated domestic wastewater.

Hanoi, the capital of Vietnam, has had a tradition of store and agricultural use of human excreta using vault latrines, which are urine-separation/non-separation double chambers toilets for agricultural use of human excreta. Owing to urbanization and industrialization, water flush toilets are dominant in the city but the coverage by modern sewerage is very limited. Harada *et al.* (2006) showed that the septic tank is one of the few facilities of household-level wastewater treatment, into which 90.5% of the human excreta in urban Hanoi are discharged, and septic-tank effluent is directly discharged into water bodies without any further treatment. However, maintenance conditions of most septic tanks were found to be quite low, especially in terms of desludging. Although the city has a plan of sewerage development, additional measures of urban wastewater management are needed to complement the decades-long development of a modern sewage system in Hanoi.

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Potential measures for urban wastewater management

As sanitation is an urgent issue in Hanoi, we cannot simply wait for the completion of decades-long sewerage development, but also need to employ complementary measures that incrementally improve sanitation conditions. To tackle the issues of urban sanitation in Hanoi, this study focuses on two measures. One alternative is improvement of septic-tank by ensuring frequent desludging. Harada *et al.* (2008) showed that annual desludging can recover the treatment performance of septic tanks in urban Hanoi and eliminate 70% of the effluent COD compared to the current situation. Although private and public system of septage collection and treatment exist in Hanoi, these systems are week. Upgrading septage collection and treatment can contribute the improvement of urban sanitation in Hanoi.

Another option is the development of night-soil collection-and-treatment (NSCT) systems, in which human excreta in pit latrines are collected by suction trucks and treated in night-soil treatment plants. Japan has a unique history of such sanitary improvements. In the past, many Japanese households were equipped with night-soil storage systems, and night soil was collected and used in agriculture. However, this practice had stopped due to the increasing use of chemical fertilizer, and then the country confronted the difficult challenge of excreta management. To overcome the challenge, while still having low coverage by sewers, NSCT systems were implemented and spread across Japan from the 1950s to the 1970s (Inoue 2004). Together with the development of water supply systems and improved nutrient conditions, the NSCT systems contributed to a dramatic reduction in the rate of water-borne disease infection derived from human excreta by the 1970s (Magara 2003). The NSCT systems have been gradually replaced by modern sewerage and advanced septic tank systems recently. At the same time, to enhance comfort, the micro-flush toilet was developed that flushes excreta with a flush-water volume of 200–500 ml per flush, not to flush-and-transport excreta through sewers but to flush-and-drop them into a pit under the toilet. Modern micro-flush toilets are similar in appearance to ordinary water flush toilets.

Many households in Hanoi use septic tanks, receiving toilet wastes only. If the outlets of septic tanks were to be closed, the tanks could be easily used for storing excreta. Also, many people in Hanoi are replacing old flush toilets such as squatting-type one; micro-flush toilets might become a possible option for the replacement if proper excreta-collection systems are developed. Together with the development of night-soil treatment plants, NSCT systems may contribute to the sanitary urban environment in Hanoi.

Purpose

This study focuses on NSCT and septic-tank improvement by annual desludging to incrementally improve urban sanitation in Hanoi in conjunction with modern sewerage development. Sewerage development, NSCT system development, septic-tank improvement and combinations of these approaches were evaluated as measures for sanitation improvement in urban Hanoi. Although there are various determinants which influence the viability of the approaches, this study compared them from the perspective of the pollution loads of COD and total nitrogen, and cost.

METHODOLOGY

Five scenarios using approaches such as sewerage, NSCT, and/or septic-tank improvement were compared from the perspective of pollution loads and cost based on conditions in urban Hanoi.

Scenarios

Five scenarios were set up as follows:

(1) *Scenario A (sewerage development)*: Developing conventional sewer coverage and realizing extensive treatment within 30 years.
(2) *Scenario B (annual desludging from septic tanks and septage treatment)*: Start with improving desludging practice (annually) of all septic tanks within five years. Septic tanks receive toilet wastes only and the effluent is discharged into water bodies without any further treatment. Greywater is not treated. Septage is

collected by suction trucks and treated in night-soil treatment plants employing the high-loading denitrification process.

(3) *Scenario C (Combined approach of sewerage development and annual desludging)*: Developing conventional sewerage employing secondary treatment within 40 years, in conjunction with starting annual desludging of all septic tanks within five years. Population served by sewerage stops annual desludging.

(4) *Scenario D (NSCT system development)*: Developing NSCT systems within five years. Toilet waste is collected by suction trucks and treated at night-soil treatment plants employing the high-loading denitrification process. Greywater is not treated.

(5) *Scenario E (Combined approach of sewerage development and NSCT system development)*: Developing sewerage within 40 years in conjunction with developing NSCT systems within five years. Population served by sewerage stops receiving the service of NSCT.

In scenarios C and E, we assume that sewage sludge treatment facilities could be used to treat night-soil, septage and/or sewage sludge to avoid the construction of similar facilities such as night-soil/septage treatment plants and sewage sludge treatment facilities; the treatment performance of sewage sludge treatment facilities would be at the same level as night-soil treatment plants. The population transitions in each scenario are presented in Figure 1. In all scenarios, 90.5% of the total population have septic tanks, which are not desludged annually, and the rest have no services of wastewater treatment facilities at Year 0.

For the five scenarios above, the three unit systems, NSCT, septage collection and treatment, and sewerage, are described in Table 1. The setup of Unit system A, NSCT, was based on the dominant NSCT system in Japan in which excreta are discharged through micro-flush toilets that have been specially developed for the NSCT system. Details of the treatment technology used by night-soil treatment plants are described by Matsui *et al.* (2006). The setup of Unit system C, sewerage, was based on the standard sewerage in Japan (JSWA 1999). Average removal ratios of pollutants for each system are summarized in Table 2. In Unit systems A and B greywater is directly discharged into drains and water bodies. In Unit system C greywater is collected.

Pollution load calculations

The annual pollution loads of each scenario were calculated for both COD and total nitrogen as follows:

$$L_{annual-total} = L_{annual-non} + L_{annual-sw} + L_{annual-non-desl} + L_{annual-desl} + L_{annual-nsct} \quad (1)$$

$$L_{annual-non} = P_{non} \times (u_{excr} + u_{grey}) \quad (2)$$

$$L_{annual-sw} = P_{sw} \times (u_{excr} + u_{grey}) \times R_{sw} \quad (3)$$

$$L_{annual-non-desl} = P_{non-desl} \times u_{excr} \times R_{non-desl} + P_{non-desl} \times u_{grey} \quad (4)$$

$$L_{annual-desl} = P_{desl} \times u_{excr} \times R_{desl} + P_{desl} \times u_{grey} \quad (5)$$

$$L_{annual-nsct} = P_{nsct} \times u_{excr} \times R_{nsct} + P_{nsct} \times u_{grey} \quad (6)$$

In Equations (1–6), $L_{annual\text{-}total}$: annual total pollution load (mg/year); $L_{annual\text{-}non}$, $L_{annual\text{-}sw}$, $L_{annual\text{-}non\text{-}desl}$, $L_{annual\text{-}desl}$ and $L_{annual\text{-}nsct}$: annual pollution load from population without any treatment system, population covered by sewage treatment, population using septic tanks not desludged annually, population using septic tanks desludged annually, and population covered by NSCT systems (mg/year); P_{non}, P_{sw}, $P_{non\text{-}desl}$, P_{desl} and P_{nsct}: population without any treatment system, population covered by sewage treatment, population using septic tanks not desludged annually, population using septic tanks desludged annually, and population covered by NSCT systems (persons); u_{grey} and u_{excr}: unit pollution loads of greywater and human excreta (mg/person/year); R_{sw}, $R_{non\text{-}desl}$, R_{desl} and R_{nsct}: removal ratios of pollution through sewage treatment, septic tank treatment not desludged annually, septic tank treatment desludged annually, and night-soil treatment (-). In this calculation, greywater was treated only in the case of sewerage; it was discharged without any treatment in the other cases and thus the

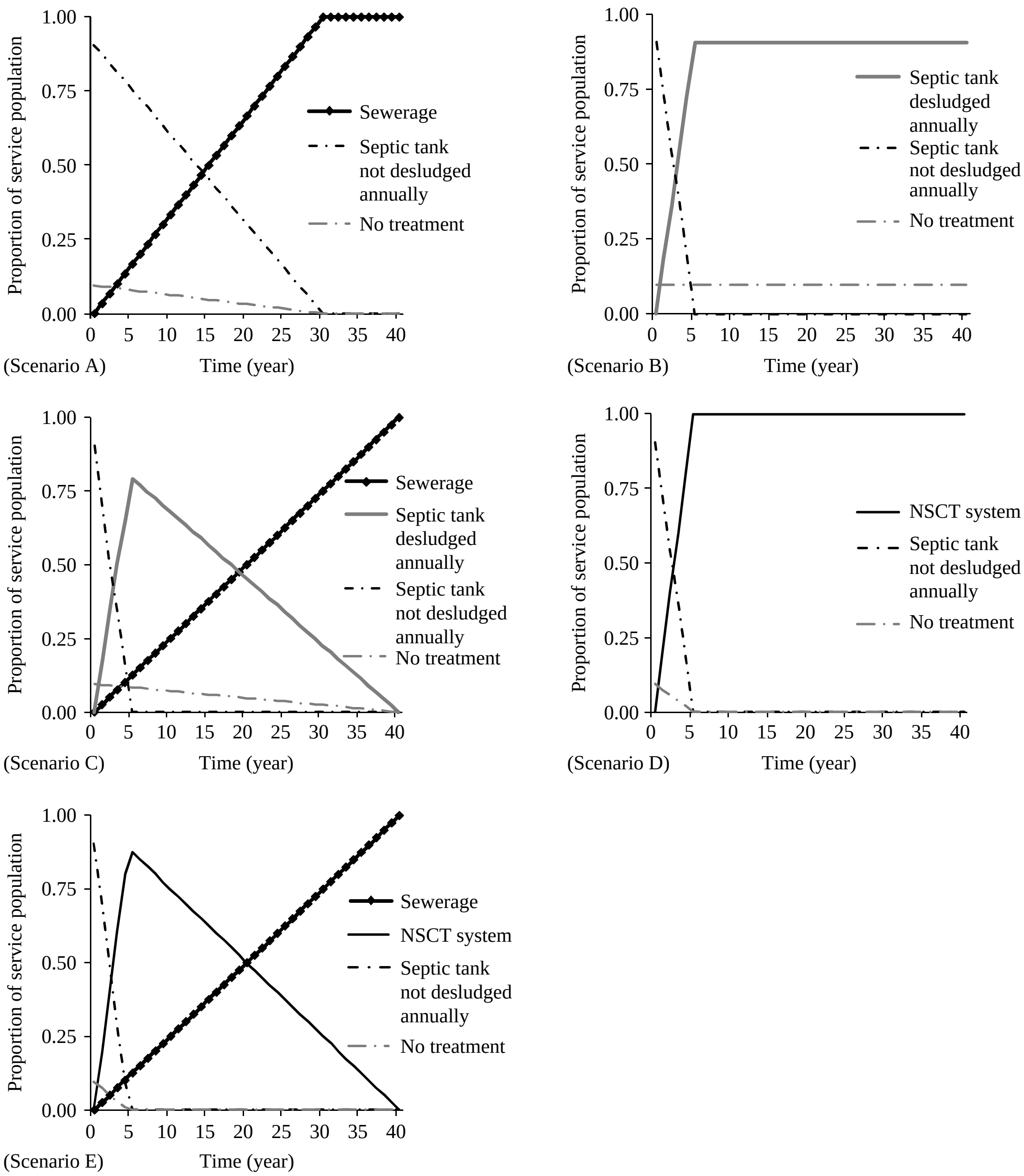

Figure 1 | Population transitions in five scenarios over 40 years.

pollution load of greywater is included in the annual pollution load without any removal of pollution.

Unit pollution loads of COD and total nitrogen for greywater and human excreta are calculated based on the daily pollution loads in Table 3. Pollution removal ratios are based on Table 2. Two different removal ratios were determined for septic tank treatment desludged annually and septic tank treatment not desludged annually.

Cost calculations

Cost of sewerage, NSCT system, septage collection-and-treatment was calculated for a given population with a period of 40 years. In this study, we assumed that although the cost is calculated using unit costs and cost functions developed based on conditions in Japan, we can relatively, not absolutely, compare the cost of each scenario as a

Table 1 | Description of the unit systems

Type of treatment system	Explanation
Unit system A: NSCT system	
Interface	Micro-flush toilet (200–500 ml/flush) and a watertight excreta vault under the toilet
Treated object	Toilet waste, not greywater or rainwater
Transportation	Suction truck for conveying excreta to a treatment facility
Treatment process	High-loading treatment (pretreatment, high-loading nitrification-and-denitrification process, coagulation, final sedimentation, chlorination, and incineration for excess sludge)
Unit system B: septage collection and treatment at a night-soil treatment plant	
Interface	Flush toilet connected to septic tank
Treated object	Toilet waste treated by septic tanks, not greywater or rainwater. Septage collected and then treated
Transportation	Same as NSCT system above
Treatment process	Same as NSCT system above
Unit system C: sewerage	
Interface	Flush toilet
Treated object	Toilet wastes and greywater, not rain water
Transportation	Conventional separate sewer without pump station
Treatment process	Secondary treatment (pretreatment, primary sedimentation, the standard activated sludge process, final sedimentation, chlorination, and digestion and incineration for excess sludge)

proportion of the total cost of scenario A (sewerage development). As such, the calculations were made based on the cost functions developed in Japan in the same manner as Harada *et al.* (2006), as follows:

$$C_{Sew-total} = C_{C-STP} + C_{C-Sew} + C_{OM-STP} + C_{OM-Sew} \quad (7)$$

$$C_{N-total} = C_{C-NSTP} + C_{OM-NSTP} + C_{OM-NSC} \quad (8)$$

$$C_{Sep-total} = C_{C-SepTP} + C_{OM-SepTP} + C_{OM-SepC} \quad (9)$$

In Equations (7–9), $C_{Sew\text{-}total}$: total cost of sewerage (Yen); $C_{C\text{-}STP}$: construction cost of sewage treatment plants (Yen); $C_{C\text{-}Sew}$: construction cost of sewers (Yen); $C_{OM\text{-}STP}$: operation and maintenance (O&M) cost of sewage treatment plants (Yen); $C_{OM\text{-}Sew}$: O&M cost of sewers (Yen); $C_{N\text{-}total}$: total cost of NSCT systems (Yen); $C_{C\text{-}NSTP}$: construction cost of night-soil treatment plants (Yen); $C_{OM\text{-}NSTP}$: O&M cost of night-soil treatment plants (Yen); $C_{OM\text{-}NSC}$: O&M cost of night-soil collection (Yen); $C_{Sep\text{-}total}$: total cost of septage collection and treatment (Yen);

Table 2 | Removal ratios of COD and total nitrogen in several types of treatment

	COD			Total nitrogen		
	Influent (mg/L)	Effluent (mg/L)	Removal rate (-)	Influent (mg/L)	Effluent (mg/L)	Removal rate (-)
Sewerage*	99.6	10.1	0.90	35.5	12.3	0.65
NSCT system*	5,200	12	0.998	2,700	19	0.993
Septic tank desludged annually			0.794†			0
Septic tank not desludged annually (at seven-year interval‡)			0.441†			0

*COD values are based on COD_{Mn}.
†Removal rates of a septic tank were calculated by using the septic-tank performance function, which was developed by Harada *et al.* (2008), according to a frequency of desludging.
‡Seven year is the median non-desludging period of septic tanks in urban Hanoi (Harada *et al.* 2008).
Source: Data based on Japanese statistics JSWA (2002) and Harada *et al.* (2008).

Table 3 | Daily pollution loads of excreta and greywater in Hanoi

	COD (g/person/day)	Total nitrogen (g/person/day)
Excreta	35	6.3
Greywater	37	1.0
Total	72	7.3

Source: Busser *et al.* (2006).

$C_{\text{C-SepTP}}$: construction cost of septage treatment plants (Yen); $C_{\text{OM-SepTP}}$: O&M cost of septage treatment plants (Yen); and $C_{\text{OM-SepC}}$: O&M cost of septage collection (Yen).

Key functions and treatment amounts are summarized in Tables 4–6. Cost of construction and O&M for sewage treatment plants and night-soil/septage treatment plants was calculated according to plant scales. The cost of construction and O&M for sewers and the cost of O&M for night-soil/septage collection were calculated based on a household density, which was set at 2,650 households per km^2. Since septage was assumed to be collected and treated in the same manner as in NSCT systems, the cost of septage collection and treatment was calculated in the same manner as for NSCT systems. Inflation is not included in the calculations.

RESULTS AND DISCUSSION

Pollution load analysis

Annual COD loads for each scenario are presented in Figure 2. Scenarios A, C and E, which comprise sewerage development, show 90% reduction in annual load between Year 0 and Year 40, while scenarios B and D do 18 and 35%, respectively. Since greywater accounted for 65% of the original COD load and greywater COD load is not eliminated at all in scenarios B and D as shown in Figure 3, the reduction were limited in these scenarios. However, focusing on the early period of 40 years, compared to scenario A, scenario B and D presented compatible and superior performances to eliminate annual COD load, respectively, in the early period of 40 years. The reason is due to the shot-term establishment of NSCT systems and annual desludging.

In scenarios E, which is a combined approach of sewerage development and NSCT system development, as indicated in Figure 2, the calculated annual COD shows a rapid and considerable decrease; scenario E surpass scenario A in annual COD load at Year 22, when the original annual load at Year 0 is already eliminated by 65%. In addition, from the viewpoint of overall reduction of COD, the total COD load over 40 years in scenario E estimated to be smaller than scenario A (91%), as illustrated in Figure 4. It can therefore be concluded that, even though sewerage development is delayed partially, the combined approach of NSCT systems and sewerage even contributes to a rapid and overall reduction of COD load.

For the other combined scenario (C), in which annual desludging is executed in conjunction with sewerage development, although the total load over 40 years was estimated to be compatible (103%) with scenario A, scenario C shows smaller annual COD load until Year 15. It is thus concluded that the combined scenario of annual desludging and sewerage development perform effectively in term of the rapid reduction of COD load. This should be emphasized because of the urgency of sanitation improvement.

Unlike COD loads, a sharp drop of total nitrogen loads was found for scenarios D and E, which employ NSCT, during the first five years as shown in Figure 5. This considerable decrease is due to the great reduction of blackwater nitrogen loads as indicated in Figure 6.

Table 4 | Key functions for the calculation of NSCT system cost

Calculated item	Unit	Function	Reference	Note
Initial construction cost of treatment plant of NSCT system	Yen	$8.3851 \times 10^7 \times S_{\text{NSTP}}^{0.7719}$	Harada *et al.* (2006)	S_{NSTP}
Volumetric O&M cost of treatment plant of NSCT system	Yen/litre	9.275	Harada *et al.* (2006)	
Volumetric excreta-collection cost of NSCT system	Yen/litre	$14.5489 \times D^{-0.3143}$	Harada *et al.* (2006)	D

S_{NSTP}, Scale of night-soil treatment plant (m^3/day); D, Density of households (household/km).

Table 5 | Key functions for the calculation of sewerage cost

Calculated item	Unit	Function	Reference	Note
Construction cost of sewage treatment plant	Yen	$7.7847 \times 10^6 \times Q_m^{0.7206}$	JSWA (1999)	Q_m
Annual O&M cost of sewage treatment plant	Yen/year	$1.1134 \times 10^5 \times Q_a^{0.7984}$	JSWA (1999)	Q_a
Unit sewer length (L_u)	m/household	$5,454.4 \times D^{-0.8006}$	Harada *et al.* (2006)	D
Construction cost of sewer	Yen	$75,000 \times L_u \times H$	JSWA (1998)	H
Annual O&M cost of sewer	Yen/year	$80 \times L_u \times H$	JSWA (1998)	H

Q_m, Daily maximum amount of sewage (m^3/day); Q_a, Daily average amount of sewage (m^3/day); D, Density of households (household/km^2); H, Household numbers (household).

Table 6 | Treatment amounts

Item	Amount	Unit	Note
Night soil			
Unit amount	2.24	L/p/d	MOE (2004)
Annual amount collected from entire population	81,800	m^3/year	
Septage			
Average individual tank volume	5.4	m^3/tank	Harada *et al.* (2006)
Average household size	4.27		HSO (2006)
Annual amount collected from entire population	103,000	m^3/year	
Sewage			
Daily average amount	170	L/p/d	Busser *et al.* (2006)
Daily maximum amount	227	L/p/d	1.33-fold of the average

This is because most nitrogen loads are not derived from greywater but from excreta (Table 3), and the removal ratio of nitrogen through NSCT is much higher than sewage treatment (Table 2). This high removal ratio can be explained by the high influent concentration of nitrogen in NSCT. Although the influent concentration of NSCT is much higher than that of sewage treatment, the effluent concentrations of nitrogen are almost equal in the two treatments, resulting in the high removal ratio of nitrogen in the NSCT system (Table 2).

Even though the nitrogen load from greywater is not eliminated at all, the total nitrogen load over 40 years in scenario D, thus, accounted for only 37% of that in scenario A as shown in Figure 7. Moreover, the annual nitrogen load in scenario E increases after Year 5 (Figures 5 and 6) when the population of NSCT systems are gradually replaced by that of sewerage (scenario E in Figure 1); and then the blackwater are treated by sewerage treatment plants at a lower removal ratio than night-soil treatment plants. It can be concluded that NSCT systems are superior to sewerage for reduction of the nitrogen load and a transition from NSCT systems to sewerage even increases the load.

Cost analysis

As shown in Figure 8, the annual costs of scenarios C and E were higher than other scenarios, especially at the early

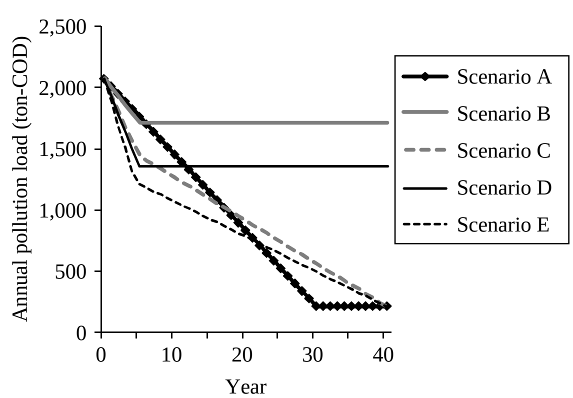

Figure 2 | Transition of annual pollution loads of COD in five scenarios.

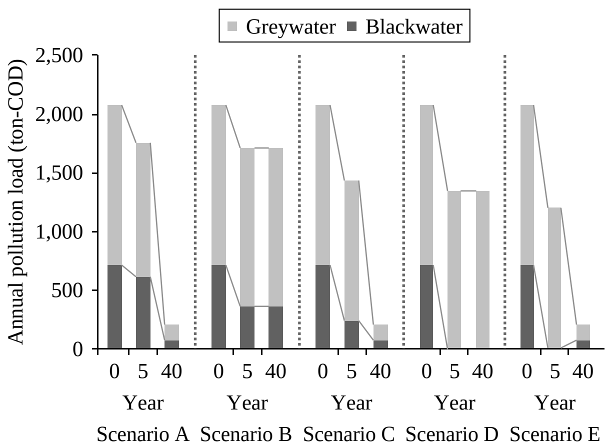

Figure 3 | Annual pollution load of COD by blackwater and greywater in five scenarios.

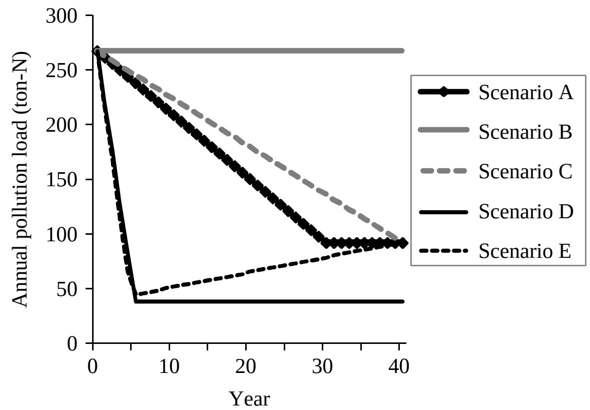

Figure 5 | Transition of annual pollution loads of total nitrogen in five scenarios.

period of 40 years, where sewerage and NSCT/annual-desludging were served together. The maximum annual costs for scenarios C and E are found at Year 5, and are respectively 20 and 11% higher than the cost of scenario A. Shown in Figure 9 is the total cost over 40 years. scenarios C and E, respectively, require a cost increase of 22 and 16% compared to scenario A; most cost in these scenarios is composed of sewerage treatment and sewage transport including construction and O&M cost. It can be concluded that the combined scenarios with annual desludging or NSCT require higher annual and total costs, especially in the early period of 40 years.

Scenario D required the least annual and total cost in five scenarios; the total cost in scenario D accounted for 66% of that in scenario A. With focus on annual collection cost in scenarios A, B and D at Year 40, as indicated in Figure 9, the collection cost of sewage (0.42 as a total cost ratio) was much higher than those of night soil (0.14) and septage (0.11). The higher collection cost of sewage in scenario A was mainly due to the construction cost of sewers. Scenario B showed higher annual and total cost than scenario D in Figures 8 and 9. This is because, although the unit septage/night-soil treatment and collection costs were same, the amount of septage collected in scenario B (5.4 m^3/year/household) was less than that of night-soil collected in scenario D (3.49 m^3/year/household). These amounts are calculated based on the unit septage and night-soil amounts in Table 6.

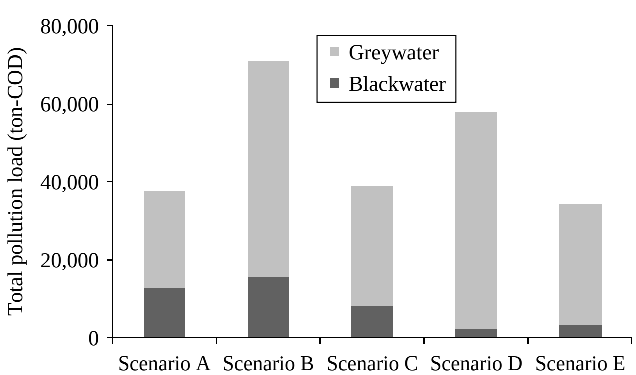

Figure 4 | Total pollution load of COD over 40 years in five scenarios.

Possibility of incremental sanitation improvement

The combined approach with the development of NSCT system in conjunction with sewerage development was

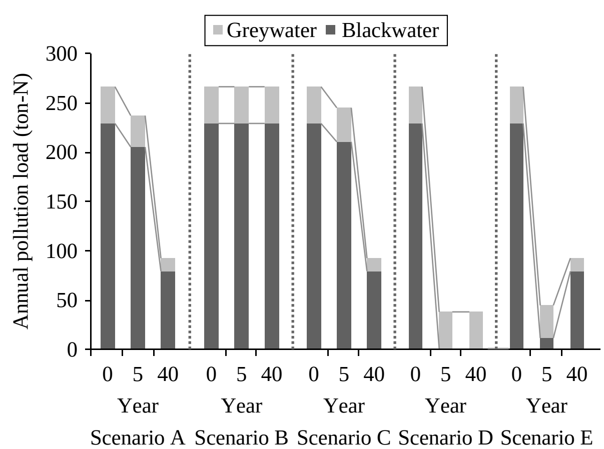

Figure 6 | Annual pollution load of total nitrogen by blackwater and greywater in five scenarios.

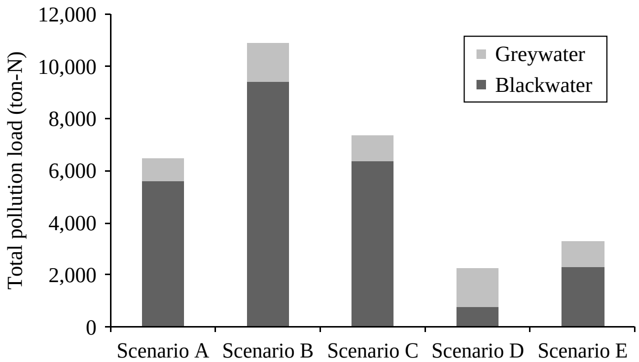

Figure 7 | Total pollution load of COD over 40 years in five scenarios.

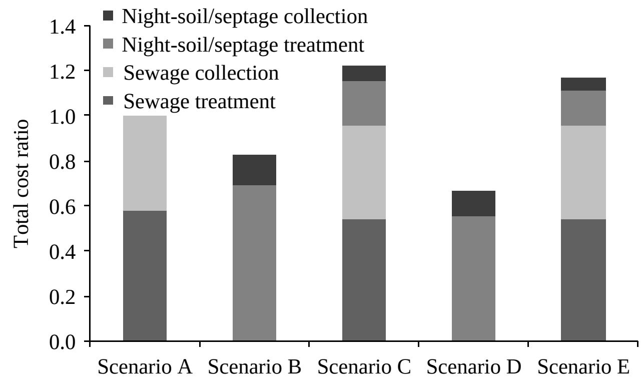

Figure 9 | Ratio of total cost over 40 years in each scenario by cost types to that in scenario A.

considered as the best scenario to reduce the pollution load of COD; and the development of NSCT and the combined approach mentined above were remarkably effective scenarios to eliminate total nitrogen load. ICEM (2007) showed that domestic sources contribute 89.6% of total organic pollution loads (BOD) in Nhue-Day river basis where most part of urban Hanoi is located. According to this organic load, the combined approach could eliminate the total organic pollution by 37% at Year 5, 44% at Year 10, 56% at Year 20, 81% at Year 40, while sewerage development alone (scenario A) could do 13% at Year 5, 27% at Year 10, 54% at Year 20, 81% at Year 40. Thus, this combined approach may contribute to the betterment of water environment in the area.

On the other hands, this approach require an increase of 16% in the total cost over 40 years compared to sewerage development alone (scenario A); and the development of NSCT system cost the least in five scenarios. In this study, sewerage cost accounted for main part of the total cost in all scenarios employing sewerage development. As the cost calculation of sewerage was based on the Japanese conventional sewerage (JSWA 1999), simplified sewerage (e.g. Mara 1996; IDIJ 2007) may reduce the cost of systems employing sewerage and alleviate difficulties in affordability. Transition of the sanitation system is also one of important perspectives. Scenario B that is the performance improvement of existing facilities, septic tanks, may be the most feasible compared to other scenarios, while scenario E requires modification of septic tanks to store excreta as pits and install micro-flush toilets. From this perspective, the other combined approach, annual desludging in conjunction with sewerage development, may be effective for a rapid decrease of COD in locations where septic tanks are widely used under poor maintenance conditions and nitrogen pollution is not serious.

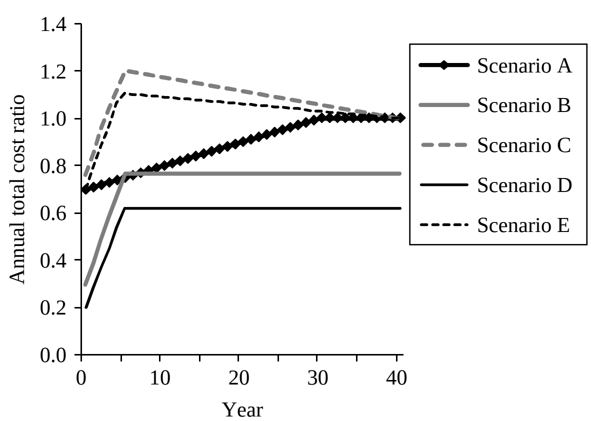

Figure 8 | Transition of the ratio of annual cost in five scenarios to that in scenario A at Year 40.

CONCLUSIONS

Five sanitation improvement scenarios employing sewerage, NSCT systems, and/or annual desludging were evaluated from the perspective of COD load, total nitrogen load, and overall cost under the conditions of Hanoi, Vietnam. As a result, the combined approach of NSCT systems and sewerage is the most effective from the perspective of reducing pollution loads of COD and total nitrogen. Considering difficulties in the transition of systems, the other combined approach, annual desludging and sewerage development, may be effective, especially in locations where septic tanks are widely. These combined approaches, however, require increase of 16 and 22% in total cost over 40 years. To realize the combined approach, the reduction of sewerage cost, which is a large part of total cost, is crucial.

Although all the cost calculation was based on the Japanese situation in this study, Low-cost sanitation technology for developing countries should be considered in further studies. This study had the assumption of modification of septic tanks to store excreta and of replacement of old flush toilets by modern micro-flush toilets; the feasibility of this system transition should be practically examined. For the further development of combined sanitation approach, the co-treatment of excreta/septage, sewage sludge, and also possibly organic waste might contribute to the reduction of treatment cost and also enhance the possibility of resource recovery. Nevertheless, it is notable that several combined approaches could be evaluated from the aspect of both pollution loads and cost. It is therefore concluded that combined approaches of NSCT or annual-desludging with sewerage has a considerable possibility as urban sanitation measures for incremental sanitation improvement in conjunction with sewerage development.

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