Effective faecal sludge management measures for on-site sanitation systems

Achara Taweesan, Thammarat Koottatep and Chongrak Polprasert

ABSTRACT

Most cities of developing countries in Asia and Africa still employ on-site sanitation systems such as septic tanks or cesspools to treat toilet wastewaters. The septic tank sludge or faecal sludge (FS) which is highly polluted needs to be periodically removed for further treatment and disposal/reuse. However, due to lack of capital, appropriate technologies and management policies, faecal sludge management (FSM) in several cities has been found to be unsatisfactory, causing environmental pollution and health problems. This study aimed to evaluate existing FSM practices, their strengths and weaknesses, and develop FSM indicators responsible for FSM practices which were: collection efficiency, treatment efficiency, benefit/cost ratio and social satisfaction. Based on data collected from 50 cities in Thailand, factors influencing the efficiency of the FSM indicators were identified and simulated using Response Surface Methodology (RSM). An FSM effectiveness diagram was developed and tested with actual data of four cities in Asia having different FSM efficiencies. The findings identified the influencing factors affecting the FSM efficiencies of these tested cities and proposed effective measures for improving FSM practices. The effective FSM measures, as proposed, are recommended for implementation by various cities to minimize environmental pollution and protect public health.

Key words | effective measures, faecal sludge management, influencing factors, on-site sanitation systems

Achara Taweesan (corresponding author)
Thammarat Koottatep
Department of Environmental Engineering and Management,
Asian Institute of Technology,
Bangkok,
Thailand
E-mail: *st108697@ait.ac.th*

Chongrak Polprasert
Department of Civil Engineering, Faculty of Engineering,
Thammasat University,
Bangkok,
Thailand

INTRODUCTION

Most cities of developing countries in Asia and Africa still employ on-site sanitation systems such as septic tanks or cesspools to treat toilet wastewaters (Strande *et al.* 2014), while grey water (or wastewaters from kitchens and bathrooms etc.) is disposed of untreated into nearby storm drains or water courses. It is well known that septic tank sludge or faecal sludge which is highly polluted (Table 1) is often disposed of on public land with or without permission of the landowners (Eawag/Sandec 2006; UNICEF/WHO 2012) causing not only public health problems, but also significant environmental and economic impacts to the nearby communities. In Southeast Asia, for example Bangkok, Thailand, where on-site sanitation systems have been widely used, a large of number of these poorly functioning systems are located in areas with highly impermeable soils (clay) in which the partially treated effluents normally overflow and contaminate nearby canals and river (Ludwig *et al.* 2005). In South Asia, for example Dhaka, Bangladesh, the conventional sewerage system covers only 20–25% of the urban population, while the rest employs mainly on-site sanitation systems which usually cause pollution of the surface water resources (Bill & Melinda Gates Foundation 2011). In other cases, there is evidence of groundwater contamination in Vietnam caused by on-site sanitation systems and outbreaks of diseases, e.g. diarrhoeal diseases (Dan *et al.* 2006). The World Health Organization estimated that over 800,000 premature deaths annually in South and Southeast Asia were attributed to diarrhoeal

doi: 10.2166/washdev.2015.010

Table 1 | Characteristics of faecal sludge

	Faecal sludge sources	
Characterization	**Public toilet**	**Septic tank**
COD (mg/l)	20,000–50,000	<10,000
COD:BOD	2:1–5:1	5:1–10:1
NH_4-N (mg/l)	2,000–5,000	<1,000
TS (mg/l)	≥3.5%	<3%
SS (mg/l)	≥30,000	≈7,000
Helminth eggs (no./litre)	20,000–60,000	≈4,000
Faecal coliforms (cfu/100 ml)	1×10^5	1×10^5

Adapted from Heinss *et al.* 1998; NWSC 2008.

diseases and 90% of them are children under the age of five (UNICEF/WHO 2012). These problems should urge cities to assess ways to increase efficiency of faecal sludge management (FSM) practices. However, due to lack of capital, appropriate technologies and management policies, the FSM problems have become more serious, causing more environmental pollution and health impacts.

There have been a large number of research studies attempting to determine influencing factors affecting FSM practices in cities of developing countries. Several authors have highlighted deficiencies of some or a combination of FSM issues in different countries (Montangero & Strauss 2002; Eawag/Sandec 2006; Kone *et al.* 2007; USAID 2010). These deficiencies included capital and operating costs for achieving financial viability as well as policies, technologies and manpower requirements. For example, the urban areas of Cambodia employ on-site sanitation systems, but the FSM services are commonly ignored or not undertaken properly. Furthermore, due to high transportation costs and absence of faecal sludge (FS) treatment facilities, the collected FS, mostly collected by private operators, is directly discharged into the nearby environment (Frenoux & Tsitsikalis 2014). In general, the success of FSM practices will depend not only on cost-effectiveness, but also the efficiency of FS collection, treatment and positive environmental social impacts. A review of official records of the failure of the FSM practices, as well as previous studies (WHO 2006), indicated that significant environmental pollution and health impact have occurred, suggesting that existing FSM practices in most cities are ineffective. For example, Vietnam is estimated to lose over US$780 million each year in related health, environmental, and economic expenses due to limited local capacity to manage and improve FSM practices (World Bank Water & Sanitation Program 2008).

The objectives of this study were: (i) to evaluate the existing FSM practices of cities in Thailand and neighbouring countries, including their strengths and weaknesses, (ii) to develop FSM indicators and their influencing factors responsible for effective FSM practices, and (iii) to test the proposed effective FSM practices with some cities in Asia and recommend measures for improvement.

METHODOLOGY

At present, there are no established criteria for effective FSM of cities such as number of vacuum trucks per household, number of trained operators per faecal sludge treatment plant, benefit/cost ratio of FSM operation, and people's perception of FSM practices, etc. From published literature on key sanitation management areas (WHO 2000; Balkema *et al.* 2002; Canadian Water & Wastewater Association & the CWWA Water Efficiency Network 2009; Luthi *et al.* 2011; Sabogal *et al.* 2014) and key informants consultation (such as administrators and FSM operators, local leaders and concerned households), the important FSM indicators appeared to be: collection efficiency, treatment efficiency, benefit/cost ratio and social satisfaction. There are several factors influencing the FSM performance indicators, but through key informants consultations and literature reviews (Klingel *et al.* 2002; Montangero & Strauss 2004; WHO 2006; Kone *et al.* 2007; Mbeguere *et al.* 2010; USAID 2010; UN-HABITAT 2011; Bassan *et al.* 2013; Strande *et al.* 2014), the main influencing factors of each FSM indicator were identified as shown in Table 2.

The study collected data of FSM practices of 50 cities located in different regions of Thailand during the period of May 2012–May 2014 (Figure 1). The number of households of each of these cities ranged from 5,000–10,000, representative of most cities in Thailand and Southeast Asian countries. Most data were obtained from official records of FSM practices of the 50 cities which included: (1) FS collection efficiencies (such as number of vacuum trucks, frequency of FS collection services, FS collection

Table 2 | Details of FSM practices assessment criteria

FSM Indicators	Influencing factors
Collection efficiency[a]	- Number of households per city - Number of vacuum trucks per city
Treatment efficiency[b]	- Number of trained operators per treatment plant - Type of treatment technology
Benefit/cost ratio[c]	- Investment and operation costs (US$/cu.m) - Collection fees (US$/cu.m)
Social satisfaction	- Number of health complaints per 1,000 households per year - Number of environmental pollution complaints per 1,000 households per year

routes and distances), (2) FS treatment efficiencies (such as size of treatment plant, type of treatment technology, number of trained operators), (3) benefit/cost ratio (such as FS collection fees, investment and operation and maintenance costs of vacuum trucks and FS treatment facilities) and (4) social satisfaction (such as number of households satisfied with FSM practices and number of complaints). However, about 30% of these cities did not have complete data of the above four categories and the missing data were obtained from field visits, questionnaire surveys and key informants consultation. The attributes of key informants consulted vary considerably but, on average, the number of administrators was 177 (39%), FSM operators were 146 (32%), local leaders were 73 (16%), concerned households were 50 (11%) and others were 9 (2%). The questionnaire surveys were designed to be inclusive of all of the influencing factors of FSM practices listed in (1), (2), (3) and (4) above. All the collected data are summarized in the final report of the Swiss National Centre of Competence in Research (NCCR 2014). The collected data were analysed with respect to important FSM indicators and their respective influencing factors for effective FSM practices. The Response Surface Methodology (RSM) is a statistical tool to simulate the relationships between each FSM indicator and its influencing factors. As shown in Table 2, for each FSM indicator, the RSM plots were developed from data of the influencing factors of the 50 cities in Thailand. The effective FSM levels were classified from the performance data of FSM practices. This tool can be used to identify conditions responsible for effective FSM practices.

Performance data of FSM practices of Asian cities such as Malaysia, Cambodia, Vietnam and Bangladesh were analysed and used in assigning effective FSM levels (Gaulke 2006; USAID 2010; Strande et al. 2014). For cities considered to be effective in FSM practices (such as Fukuoka, Japan and Nonthaburi, Thailand), the FS collection efficiencies of cities were considered 'satisfactory' if FS collected was more than 80% of the FS produced, 'moderate' if the FS collected was between 50–80%, and 'poor' if the FS collected was less than 50% (such as Malang, Indonesia, Kuala Terengganu, Malaysia, and Bangalore, India) (USAID 2010; Bill & Melinda Gates Foundation 2011; Strande et al. 2014). For indicator 2, FS treatment efficiencies indicator, the levels were assigned 'satisfactory' if there were functioning high-type FS treatment plant(s) operated by trained operator(s) and a monitoring record of satisfactory plant performance as shown in the final report of NCCR (2014). The 'moderate' efficiencies were assigned for cities having non-functioning high-type or medium-type FS treatment plant(s) operated by trained operator(s), and without a monitoring record of plant performance. The 'poor' efficiencies were assigned to cities with low-type or without FS treatment plants and without trained operators. According to common financial mechanisms, for indicator 3 (benefit/cost ratio), the levels were assigned 'satisfactory' if the benefit/cost ratio was greater than 1.00, 'moderate' if the benefit/cost ratio was from 0.50 to 1.00 and 'poor' if the benefit/cost ratio was less than 0.50. The social satisfaction indicator was classified into three levels based on results of the questionnaires surveys, similarly to the collection efficiencies.

In this study, FSM practices of a city are considered to be effective if all the four FSM indicators were found to be 'satisfactory'. An FSM effectiveness diagram was developed and tested with actual data of four Asian cities of similar sizes and FSM practices (shown in Table 3) which were Faridpur, Bangladesh; Chachoengsao, Thailand; Kampot, Cambodia; and Patong, Thailand.

The following assumptions were used in plotting the RSM of [a]'collection efficiency': each household should have its FS collection services carried out once yearly; the average capacity of each vacuum truck was 3 m^3. Most cities in this study are in urban areas in which the number of vacuum trucks is more significant in FS collection

Figure 1 | Locations of surveyed and tested cities in Thailand, Bangladesh and Cambodia.

Table 3 | Main characteristics of FSM practices in four tested cities

	Faridpur[a], Bangladesh	Chachoengsao[b], Thailand	Kampot[a], Cambodia	Patong[b], Thailand
Number of households	25,342	8,500	7,922	4,300
Number of population	135,837	39,370	38,819	19,346
Number of vacuum trucks (and capacity, m^3)	2 (1 m^3)	2 (3 m^3)	1 (5 m^3)	5 (3 m^3)
Tank/pit collection frequencies of households	Once every 5 years	Once a year	Once every 4 years	Once a year
FS treatment technology	Anaerobic digestion (not functioning occasionally)	Anaerobic digestion (functioning)	Open dumping	Co-disposal to wastewater treatment plant (functioning)
Collection fees (US$/cu.m.)	9	7	11	10
Investment/operation costs (US$/cu.m.)	40	13	30	47

[a]From Bill & Melinda Gates Foundation (2011).
[b]From survey results.

efficiency than collection routes. For [b]'treatment efficiency', for the cities that have FS treatment plants, the operators having professional training on FSM practices once yearly was found to be more significant than the sizes or capacities of the FS treatment plants; since there are no criteria on level of sludge treatment (Metcalf & Eddy/AECOM 2014), types of treatment technology were assigned according to required levels of investment and operation such as 'high' for anaerobic digestion, controlled aerobic digestion and co-disposal to wastewater treatment plants; 'medium' for sludge drying beds and co-disposal to sanitary landfills; and 'low' for open dumping; the capacities of FS treatment plants were 5–30 m^3/day. For [c]'benefit/cost ratio', the benefit was the FS collection fee or emptying fee, while the investment costs included costs of vacuum trucks, and FS treatment facilities including government subsidies, and the operation costs included manpower, gasoline and maintenance.

RESULTS AND DISCUSSION

The collected data were analysed with respect to the FSM indicators and their respective influencing factors. The relationships between each FSM indicator and its influencing factors were plotted using RSM and are shown in Figures 2–5. The detailed results of these relationships and their application for effective FSM practices are presented below.

Collection efficiency indicator

The relationships between FS collection efficiency, the number of households per city and the number of vacuum trucks per city are shown in Figure 2. It can be seen that 44 of the 50 surveyed cities were considered to have 'poor' FS collection efficiency, 5 of the 50 surveyed cities were considered to have 'moderate' FS collection efficiency, only one

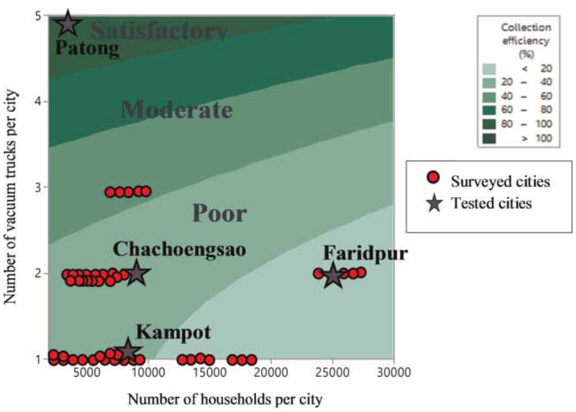

Figure 2 | RSM plot of FS collection efficiencies.

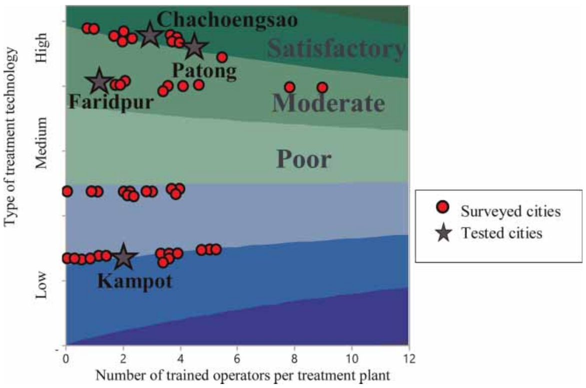

Figure 3 | RSM plot of FS treatment efficiencies.

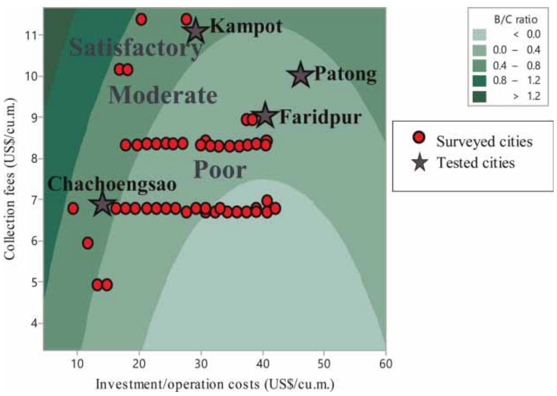

Figure 4 | RSM plot of benefit/cost ratio.

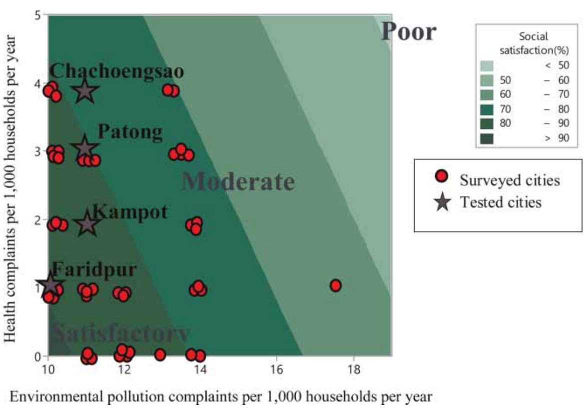

Figure 5 | RSM plot of social satisfaction.

surveyed city was found to have 'satisfactory' FS collection efficiency. From the RSM plot of Figure 2, a city should have at least 1 vacuum truck per 1,000 households to achieve satisfactory FS collection efficiency of more than 80%. The 'moderate' and 'poor' FS collection efficiencies of about 50% and less than 20% would occur for cities having the ratios of the number of vacuum trucks per households of 1:4,300 and 1:10,000, respectively. It was found that most of the surveyed cities in Thailand did not have an adequate number of vacuum trucks (with inadequate maintenance) for satisfactory FS collection services. Similar results were documented by Kone *et al.* (2007), USAID (2010) and Strande *et al.* (2014), where the number of vacuum trucks is usually too limited to provide effective FS collection services.

Treatment efficiency indicator

The effects of number of trained operators and type of treatment technology on FS treatment efficiency are shown in Figure 3. It can be seen from the RSM plot of Figure 3 that 27 of the 50 surveyed cities were considered to have 'poor' FS treatment efficiency, 11 of the 50 surveyed cities were considered to have 'moderate' FS treatment efficiency, and 12 of the surveyed cities were found to have 'satisfactory' FS treatment efficiency. The results of Figure 3 suggested the significance of type of treatment technology which had direct effects on the FS treatment efficiencies; less effect on the FS treatment efficiencies was observed with the number of trained operators per treatment plant. For example, a FS treatment plant employing anaerobic digestion (high treatment technology) to treat 15 m^3/day employed only three trained operators per treatment plant to achieve satisfactory efficiencies; while another city employing sludge drying beds (medium treatment technology) to treat 8 m^3/day of FS had to employ four trained operators per treatment plant and achieved only moderate efficiency. A similar finding was reported by USAID (2010) which suggested that in choosing the most appropriate FS treatment technology option, consideration should be given to type of treatment technology and its compatibility with available local resources and conditions.

Benefit/cost ratio indicator

The effects of investment and operation costs and the collection fees of FS collection services on benefit/cost ratio, shown in Figure 4, indicate that all the 50 surveyed cities were operating at a loss in which the FS collection fees were less than the investment and operation costs. From the survey results, the FS collection fees of most cities were in the range of US$ 5–9 per cu.m which could cover mainly the collection and transportation costs, but not the FS treatment operation which was about US$ 40 per cu.m for anaerobic digestion. Due to the current regulations and limited household incomes, it might not be practical to increase the collection fees to cover the investment and operation costs. Although there are some subsidies provided by the central government, many cities do not put high priority on FSM, resulting in less budget and manpower for this purpose. Previous studies by Kone *et al.* (2007) and CSE (2011) emphasized the need for both central and local government agencies to give high priority to FSM practices to reduce environmental pollution and health impacts due to inappropriate FS disposal. For example, Malaysia has achieved effective FSM practices because the central government provides large subsidies to improve FS collection services and treatment plant operation, while the households are able to pay appropriate FS collection and treatment fees (Strande *et al.* 2014).

Social satisfaction indicator

The effects of environmental pollution and health complaints on the level of social satisfaction are shown in Figure 5 which indicates that 34 of the 50 surveyed cities had households satisfied with the FSM practices, while the 'moderate' level of social satisfaction was found with 16 out of the 50 surveyed cities. There were no cities that were assigned a 'poor' level of social satisfaction with FSM practices. From the RSM plot of Figure 5, environmental pollution complaints were found to be more influential on the social satisfaction level than health complaints. For example, the Nonthaburi city in central Thailand which had more than 80% (satisfactory) social satisfaction for FSM received about 1 health complaint per 1,000 households per year, but more than 10 environmental pollution complaints per 1,000 households per year. For a city having the level of social satisfaction of 50–80% (moderate), the number of environmental pollution and health complaints were found to be 18 and 5 or less, respectively. From the survey results, it was found that the major reason for environmental pollution complaints was illegal disposal of the collected FS to public areas, resulting in serious pollution of nearby land and water bodies. Odour problems resulting from improper FS handling and disposal practices were the main reason for health complaints. Although people were infected with waterborne diseases, this kind of health problem could not be related directly to improper FSM, making the number of health complaints less influential on the level of social satisfaction than the number of environmental pollution complaints. Since people in developing countries, including Thailand, Cambodia and Bangladesh (USAID 2010; Bill & Melinda Gates Foundation 2012), are usually more concerned with the FS collection services and the collection fees, they are less concerned with the environmental and health impacts of the FSM practices; hence, among the 50 surveyed cities, there was no 'poor' level of social satisfaction with FSM practices. In this respect, there should be programmes to raise people's awareness about environmental and health impacts of FSM practices.

Measures to enhance effective FSM practices

An FSM effectiveness diagram was plotted (Figure 6) using the four FSM indicators; the scales of the collection efficiency, treatment efficiency and social satisfaction were from 0 to 100%, while the benefit/cost ratio scale was from 0.00 to 1.00. A city is considered to have effective FSM practices if the four FSM indicators were equal to or more than the 'satisfactory' level. The proposed effective FSM practices were tested with actual data of four cities in Asia (Faridpur, Bangladesh; Kampot, Cambodia; and

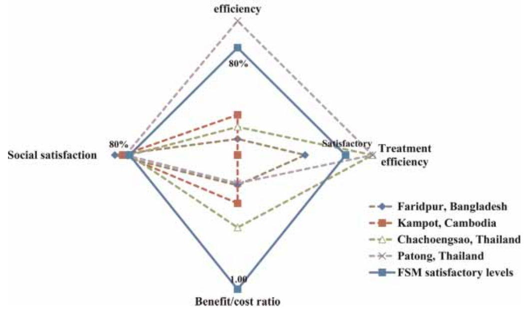

Figure 6 | FSM effectiveness diagram.

Chachoengsao and Patong, Thailand). These four tested cities were selected because they employ on-site sanitation systems such as septic tanks or cesspools to treat toilet wastewaters (Klingel *et al.* 2002; USAID 2010; Bill & Melinda Gates Foundation 2012). The details of FS collection, treatment, financial data and background information of these four tested cities, given in Table 3, were used to plot the FSM effectiveness diagram (Figure 6) to determine the FSM effectiveness of each tested city. The effective measures for improving FSM practices were then deduced from Figures 2–5. A city is considered to have effective FSM practices if all the four indicators were more than the FSM satisfactory levels.

It can be seen from Figure 6 that among the four tested cities, none of them had all the four FSM indicators meeting the 'satisfactory' levels. Although the four tested cities had 'satisfactory' level for social satisfaction, the opposite occurred for the benefit/cost ratio and treatment efficiency indicators. More details of these analyses and the proposed measures for effective FSM practices are given below.

For the collection efficiency indicator, most cities were found to be 'poor' or less than 50% of the FS collected, except for Patong in Southern Thailand which was 'satisfactory' (Figure 6). From the survey results, it was found that Patong city has subsidies from the central and local governments to support the FSM practices in both FS collection and treatment. In addition, Patong city provides tax incentives to private sectors to support the city in FS collection. The main reason for the poor collection efficiencies of the other three tested cities was the inadequate number of vacuum trucks for FS collection services. According to Figure 2, to achieve satisfactory FS collection efficiencies, the cities of Faridpur, Chachoengsao and Kampot should have at least five, four and four vacuum trucks, respectively. This lack of an adequate number of vacuum trucks could lead to propagation of unlicensed FS collection operators which usually dispose of the collected FS in unsanitary ways. A similar finding was documented by the Bill & Melinda Gates Foundation (2011) showing that the FS collection services in Bangladesh and Cambodia were undertaken predominantly with unlicensed informal operators, who subsequently disposed of the collected FS at illegal dumping sites.

The FS treatment efficiencies of Kampot and Faridpur were found to be 'poor' and 'moderate', respectively, which were still unsatisfactory. The main reason for the poor treatment efficiency of Kampot was the low treatment technology which was open dumping. Although Faridpur had the high treatment technology, anaerobic digestion, the digesters failed to function occasionally, but the digested slurry was kept in holding ponds not contaminating the nearby environment, therefore the treatment efficiency level was assigned as 'moderate'. The FS treatment technologies of Chachoengsao and Patong were anaerobic digestion and co-disposal to wastewater treatment plant, respectively, which functioned properly resulting in a 'satisfactory' level of treatment efficiencies. The satisfactory FS treatment efficiencies of these Thai cities were also due to stringent environmental regulations, strict enforcements, subsidies from the central government and political wills of the local administrators in implementing the FS treatment programmes, as previously reported by USAID (2010). These supporting factors were not available in the tested cities of Kampot and Faridpur, contributing to their FS treatment efficiency levels being less than 'satisfactory'.

It is evident from Table 3 and Figure 4 that the FSM practices of these four tested cities had benefit/cost ratios less than 1.00 or unsatisfactory. The main reason for the benefit/cost ratio indicator to be less than 'satisfactory' was the high investment and operation costs of the vacuum trucks, FS treatment plants, gasoline and maintenance which were 13–47 US$/cu.m, while the FS collection fees were only 7–11 US$/cu.m. As it was stated earlier that it was not practical to increase the FS collection fees in these cities, to make the benefit/cost ratio indicator satisfactory, there should be more subsidies provided by both central and local governments in the investment and operation costs of the FSM practices. From the survey results, it was found that the largest operating cost of these four tested cities was gasoline, making up about 40% of the operation costs.

On the contrary, the level of social satisfaction regarding FSM practices of these four tested cities was found to be more than 80% or 'satisfactory'. This result implies that, in many developing countries, environmental pollution and health impacts are not directly associated with the level of social satisfaction. Minor complaints about FSM practices were regarding the delay in FSM collection services and odours emanating from FS disposal sites. To address these problems, the FS haulage routes should be properly planned to provide efficient FS collection services and minimize odour problems (Montangero & Strauss 2002).

To further demonstrate its applicability, the FSM effectiveness diagram (Figure 6) is suggested to be tested with actual data from other cities having similar socio-economic conditions as the four tested cities listed in Table 3. However, the FSM measures (Figures 2–5) are recommended for implementation by cities in developing countries to minimize environmental pollution and protect public health.

SUMMARY CONCLUSIONS

Due to rapid population growth, most cities especially in developing countries would continue to employ on-site sanitation systems to treat toilet wastewaters. Therefore, the FS problems need to be properly managed to minimize environmental pollution and health impacts. The relationships between the FSM indicators and their influencing factors developed in this study could be used to identify conditions to achieve effective FSM practices for each city. The FSM effectiveness diagram could assess whether a city has effective FSM practices or not and identify the FSM indicators that need improvement.

Based on the results obtained from this study, the following conclusions are made:

1. Most of the surveyed cities were found to have poor collection efficiency (due to inadequate number of vacuum trucks), poor to moderate treatment efficiency (due to inappropriate type of FS treatment technology), unsatisfactory benefit/cost ratio (due to high investment and operation costs and low collection fees), and moderate to satisfactory social satisfaction.
2. Relationships between the FSM indicators and their respective influencing factors were developed from data of 50 cities in Thailand, which could be used to identify conditions to achieve effective FSM practices.
3. An FSM effectiveness diagram was developed based on the proposed four FSM indicators (Figure 6). A city is considered to have an effective FSM practice if all the four FSM indicators were more than the FSM satisfactory levels. The FSM effectiveness diagram was tested with the FSM practices data of four Asian cities and the results revealed that none of them had all the four FSM indicators meeting the 'satisfactory' levels.
4. Specific measures to improve FSM practices of the tested cities were recommend such as increasing the number of vacuum trucks to be 1/1,000 households, choosing high-type FS treatment technologies (e.g. anaerobic digestion and co-disposal to wastewater treatment plant), subsidies, political will of central and local governments, and more programmes to raise people's awareness about environmental and health impacts of FSM practices.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge support from the Swiss National Centre of Competence in Research (NCCR) North-South, Research Partnerships for User Driven Sanitation, co-funded by the Swiss National Science Foundation (SNSF), the Swiss Agency for Development and Cooperation (SDC), and the participating institutions. Special thanks are due to Mr. Krailak Fakkaew for the technical support on RSM.

REFERENCES

Balkema, A., Preisig, H. A., Otterpohl, R. & Lambert, F. J. D. 2002 Indicators for the sustainability assessment of wastewater treatment system. *Urban Water* **4** (2), 153–161.

Bassan, M., Mbeguere, M., Tchonda, T., Zabsonre, F. & Strande, L. 2013 Integrated faecal sludge management scheme for the cities of Burkina Faso. *Journal of Water, Sanitation and Hygiene for Development* **3** (2), 216–221.

Bill, Melinda Gates Foundation 2011 *Regional Synthesis Report Asia: FSM Landscape Analysis and Business Model Assessment*.

Bill, Melinda Gates Foundation 2012 *Business Analysis of Faecal Sludge Management: Emptying and Transportation Services in Africa and Asia*. Draft Final Report.

Canadian Water, Wastewater Association, the CWWA Water Efficiency Network 2009 *Water Conservation and Efficiency Performance Measures and Benchmarks within the Municipal sector: An Identification of Current Practices and Assessment of the Feasibility of Expanding their Use*. A Report Produced for the Ontario Ministry of Environment.

CSE 2011 *Policy Paper on Septage Management in India*. Report of the Centre for Science and Environment. Centre for Science and Environment, New Delhi, India.

Dan, N. P., Thanh, B. X. & Truong, B. D. 2006 Case studies of groundwater pollution in Southeast Vietnam. *International Review for Environmental Strategies* **6** (2), 361–372.

Eawag/Sandec 2006 *Urban Excreta Management-Situation, Challenges, and Promising Solutions*. Report of the Swiss Federal Institute for Environmental Science and Technology, Department of Water and Sanitation in Developing Countries. Eawag/Sandec, Dubendorf, Switzerland.

Frenoux, C. & Tsitsikalis, A. 2014 Domestic private fecal sludge emptying services in Cambodia: between market efficiency and regulation needs for sustainable management. *Journal of Water, Sanitation and Hygiene for Development* **5** (1), 143–155.

Gaulke, L. S. 2006 On-site wastewater treatment and reuses in Japan. *Proceedings of the Institute of Civil Engineers. Water Management* **159** (2), 103–109.

Heinss, U., Larmie, S. A. & Strauss, M. 1998 *Solids Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropics*. In: Sandec Report No. 05/98. Eawag/Sandec, Dubendorf, Accra.

Klingel, F., Montangero, A., Kone, D. & Strauss, M. 2002 *Fecal Sludge Management in Developing Countries: A Planning Manual, 1st Edition, April 2002*. Eawag/Sandec, Dubendorf, Switzerland.

Kone, D., Strauss, M. & Saywell, D. 2007 Towards an Improved Faecal Sludge Management. In: *Proceedings of the 1st International Symposium and Workshop on Faecal Sludge Management Policy*, Dakar, Senegal.

Ludwig, H. F., Fennerty, H., Sow, K. L. & Mohit, K. 2005 *Textbook of Appropriate Sewerage Technology for Developing Countries*. South Asian Publishers Pvt Ltd, New Delhi, India.

Luthi, C., Panesar, A., Schutze, T., Norstrom, A., McConville, J., Parkinson, J., Saywell, D. & Ingle, R. 2011 *Sustainable Sanitation in Cities: A Framework for Action*. Papiroz Publishing House, Rijswijk, Netherlands.

Mbeguere, M., Gning, J. B., Dodane, P. H. & Kone, D. 2010 Socio-economic profile and profitability of faecal sludge emptying companies. *Resources, Conservation and Recycling* **54**, 1288–1295.

Metcalf, Eddy/AECOM 2014 *Wastewater Engineering: Treatment and Resource Recovery*, Fifth Edition (Vol. 1 and 2). McGraw-Hill Education, New York.

Montangero, A. & Strauss, M. 2002 *Faecal Sludge Management: Review of Practices, Problems and Initiatives*. Report of the Swiss Federal Institute for Environmental Science and Technology, Department of Water and Sanitation in Developing Countries. Eawag/Sandec, Dubendorf, Switzerland.

Montangero, A. & Strauss, M. 2004 *Faecal Sludge Treatment*. Report of the Swiss Federal Institute for Environmental Science and Technology, Department of Water and Sanitation in Developing Countries. Eawag/Sandec, Dubendorf, Switzerland.

NCCR 2014 *User Driven Sanitation: Gender and the Challenge for Sanitation Demand*. Draft Final Report. Swiss National Centre of Competence in Research (NCCR) North-South, Bern, Switzerland.

NWSC 2008 *Kampala Sanitation Program: Feasibility Study for Sanitation Master in Kampala, Uganda*. Report of the National Water and Sewerage Corporation, Kampala.

Sabogal, R. I., Medlin, E., Aquino, G. & Gelting, R. J. 2014 Sustainability of water, sanitation and hygiene interventions in Central America. *Journal of Water, Sanitation and Hygiene for Development* **4** (1), 89–99.

Strande, L., Ronteltap, M. & Brdjanovic, D. 2014 *Faecal Sludge Management*. IWA Publishing, London.

UN-HABITAT 2011 *Status and Strategy for Faecal Sludge Management in the Kathmandu Valley*. Report of the United Nations Human Settlements Programme (UN-HABITAT).

UNICEF/WHO 2012 Progress on Drinking Water and Sanitation. 2012 Update. UNICEF/WHO Joint monitoring Program for Water Supply and Sanitation. http://www.unicef.org/media/files/JMPreport2012.pdf.

USAID 2010 *A Rapid Assessment of Septage Management in Asia: Policies and Practices in India, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam*. Report of the US Agency for International Development. AECOM publishing, S.I.

WHO 2000 *Tools for Assessing the O&M Status of Water Supply and Sanitation in Developing Countries*. Report of the World Health Organization. World Health Organization, Geneva, Switzerland.

WHO 2006 *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater – Volume IV: Excreta and Greywater Use in Agriculture*. Report of the World Health Organization. World Health Organization, Geneva, Switzerland.

World Bank Water, Sanitation Program 2008 *Economic Impacts of Sanitation in Vietnam*. Research Report. World Bank, Jakarta.

First received 31 January 2015; accepted in revised form 1 June 2015. Available online 13 July 2015