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Factors influencing the performance of faecal sludge management services: case study in Thailand municipalities

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Abstract In most low- and middle-income countries, the service coverage of faecal sludge management is very limited resulting in uncontrolled disposal that directly impacts to water resources and public health. Similar to other countries, Thailand is facing faecal sludge management problems which lead to serious challenge to its local government authorities who are responsible for services provision. Local factors may strongly affect faecal sludge management services. Because of this problem, the management measures should be formulated in responding to significant factors affecting the performance of FSM services. This study aimed to evaluate existing faecal sludge management services in Thailand, their strengths, and weaknesses, and identify the significant factors influencing the performance of services. Based on data collected from 160 municipalities in Thailand, factors influencing the faecal sludge management services were identified using multiple regression analysis. The indicators involving operational efficiency, service performance, and treatment feasibility were used for the assessment of faecal sludge management performance. Significant factors encompassing technical, financial, social, and institutional aspects were identified based on each indicator. The findings identified the significant factors and proposed effective measures for improving faecal sludge management services such as providing technical assistance, implementing awareness programmes for private operators and households, and subsidizing investment and operation costs of faecal sludge management facilities.

Keywords Effective measures · Faecal sludge management · Performance indicators · Significant factors

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1 Introduction

Most low- and middle-income countries suffer from problems related to unsafe faecal sludge (FS) disposal which is very often disposed of untreated into nearby storm drains or water courses (Eawag/Sandec 2006; UNICEF/WHO 2012). These problems have become more serious, causing not only public health problems, but also significant environmental pollution and economic impacts to the nearby communities. Regarding faecal sludge management (FSM) services in Thailand, about 18.5 million cubic metres of FS are produced per year which includes FS from septic tanks and cesspools (Chokewinyoo 2008). Households usually call for FS collection services every 5–10 years and pay their bills for collection services (MOPH 2008). In practices, FS treatment sites are quite limited, which result in untreated faecal sludge being disposed of in landfills, farmlands, and waterways (USAID 2010), causing serious environmental pollution of nearby land and water bodies. There is evidence of groundwater contamination in Thailand caused by poor FSM and outbreaks of diseases most commonly diarrhoeal diseases (Schmoll et al. 2006). The Public Health Act BE 2535 (1992) issued in 1997 by the Thai Ministry of Public Health (MOPH) delegated responsibility for collecting, transporting, and FS disposal to local government authorities. Thai Ministry of Public Health has issued guidelines on FS collection and treatment, but most local government authorities are not able to provide adequate FS collection and treatment facilities due to limited local capacity to manage and improve FSM services (World Bank Water and Sanitation Program 2008). In addition, due to weak regulation enforcements and effective measures, FSM problems have become more serious, causing more environmental pollution and health impacts (USAID 2010; UNICEF/WHO 2012; Strande et al. 2014).

Many studies have identified factors influencing the FSM services in different countries. In Southeast Asia, Hai Phong city, Vietnam, on-site sanitation systems have been widely used, while the FSM services are commonly ignored or not operating properly causing significant impact on public health and the environment (USAID 2010; Bill and Melinda Gates Foundation 2012). Frenoux and Tsitsikalis (2014) documented that in order to improve FS collection services, the government should provide monetary incentives to private sectors to support the country in FSM facilities. Other factors mentioned by other studies are technical support for FSM facilities (Heinss et al. 1998; Klingel et al. 2002), regulatory factors in the country (Bassan et al. 2013), and organization of the private operators (Bill and Melinda Gates Foundation 2012). These factors included policies, technologies, and manpower requirements for achieving functional FSM services. Several authors have identified the stakeholders that may have an interest in effective FSM services such as national and local government authorities (Robbins 2007); municipal authorities (Ludwig and Mohit 2000); private contractors (Frenoux and Tsitsikalis 2014); and households (Klingel et al. 2002). Furthermore, due to high transportation costs and absence of FS treatment facilities, the collected FS mostly done by unlicensed FS collection operators is disposed in unsanitary ways (Bill and Melinda Gates Foundation 2012). In general, the success of FSM practices will depend not only on the efficiency of FS collection services, but also on the efficiency of FS treatment and positive people perception of FSM practices according to their performance (Christoph et al. 2011).

The purposes of this study were to evaluate existing FSM services provided by municipalities in Thailand, their strengths, and weaknesses, and to identify significant factors for improving FSM services.

2 Methodology

Information on the performance of FSM services from various countries was analysed and used in assigning FSM indicators (Boot and Scott 2008; Bill and Melinda Gates Foundation 2012; Bassan et al. 2013; USAID 2010). From published literature on key sanitation management areas (Gaulke 2006; CWWA 2009; USAID 2010; Luthi et al. 2011; Strande et al. 2014) and key informants consultation (such as government authorities, FSM operators, local leaders and concerned households), FSM service indicators were determined to be: operational efficiency, service performance, and treatment feasibility. The operational efficiency indicator is a summative value of the per cent of households that are covered by FS collection services by the municipality. The service performance indicator is a summative value of the per cent of number of FSM complaints per 1000 households per year. The treatment feasibility indicator was measured by the ability of municipalities to manage FS collected at the treatment site(s) operated by trained operator(s) and a monitoring record of satisfactory plant performance. There are several factors influencing FSM service indicators, but through key informants consultations and a reviews of the relevant literature (Gaulke 2006; Kone et al. 2007; Mbeguere et al. 2010; USAID 2010; UN-HABITAT 2011; Strande et al. 2014), the key significant factors of each FSM indicator were identified as presented in Table 1.

The study collected information of FSM services from 160 municipalities located in different regions of Thailand during the period of May 2012–May 2013, covering 11 City municipalities, 50 Town municipalities, and 99 Subdistrict municipalities (Fig. 1). These municipalities were classified into three levels according to the number of households: City municipalities (each with number of households >10,000); Town municipalities (each with number of households 5000–10,000); and Subdistrict municipalities (each with number of households <5000) (OCS 2003). Most information was obtained from official records and key informants consultation responsible for FSM services of the 160 municipalities and included information about: (1) technical factors (such as areas for FS collection services, number of households, number of vacuum trucks, traffic conditions, operators training, and number of operators); (2) financial factors (such as FS collection fees, investment and operation costs of vacuum trucks and treatment facilities, and budget for FSM services); (3) social factors (such as people's awareness of FSM participation, payment flexibility for FS collection fees, number of households satisfying with FSM services); and (4) institutional aspects (such as policy advocacy to support FSM services, FSM information support, private sector cooperation, regulation enforcements, and designation of responsibility). The attributes of key informants participating in this study varied considerably: government authorities (7 %); private operators (53 %); local leaders (22 %); households (10 %); and others (8 %). The government authorities such as central government authorities and local government authorities (e.g. municipality) are involved in allocating investment and operation costs for FSM services, while municipality has an important role in providing FSM services where FSM is regarded as part of the environmental sanitation management strategy. Private operators are mostly involved through contract arrangements, while local leaders, concerned households, and others (e.g. international agencies and NGOs) have played important roles in participating and supporting FSM services. However, about 25 % of these municipalities did not have complete data of the above four categories and the missing data were obtained from field observations, questionnaire surveys, and key informant consultation.

Table 1 Significant factors influencing the performance of FSM services and application in multiple regression models

Categories	Significant factors and symbol used	Application in multiple regression models
Technical	Areas for FS collection services (area)	Square kilometre
	Number of households (HH)	Number of households/municipality
	Accessibility (access)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important
	Traffic conditions (traffic)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important
	Operators training (training)	Dummy variable (1 = having training; 0 = otherwise)
	Number of vacuum trucks (truck)	Number of vacuum trucks
	Number of operators (operator)	Number of operators
Financial	Subsidies for investment costs (invest)	Dummy variable (1 = investment costs was subsidized by government; 0 = otherwise)
	Subsidies for operation and maintenance costs (O&M)	Dummy variable (1 = operation and maintenance costs was subsidized by government; 0 = otherwise)
	Pricing of land treatment (land)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important
	FS collection fees (fee)	Baht/year
	Budget for FSM services (budget)	Baht/year
Social	People awareness of FSM participation (participate)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important
	Payment flexibility for FS collection fees (payment)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important
	Peoples' satisfaction (SAT)	Strongly dissatisfied to strongly satisfied (five levels)
Institutional	Policy advocacy to support FSM services (advocacy)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important
	Information support (INFOR)	Dummy variable (1 = providing FSM information; 0 = otherwise)
	Private sector cooperation (CO-OPER)	Dummy variable (1 = having private sector cooperation; 0 = otherwise)
	Regulation enforcements (enforcement)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important
	Designation of responsibility (responsible)	0 = not important, 0.25 = less important, 0.50 = important, 0.75 = very important, and 1.00 = most important

Descriptive statistics, particularly percentage distribution, was applied for preliminary analyses and to evaluate existing FSM services in this study. To determine which factors exerted the greatest influence on FSM services, multiple regression analysis was utilized,

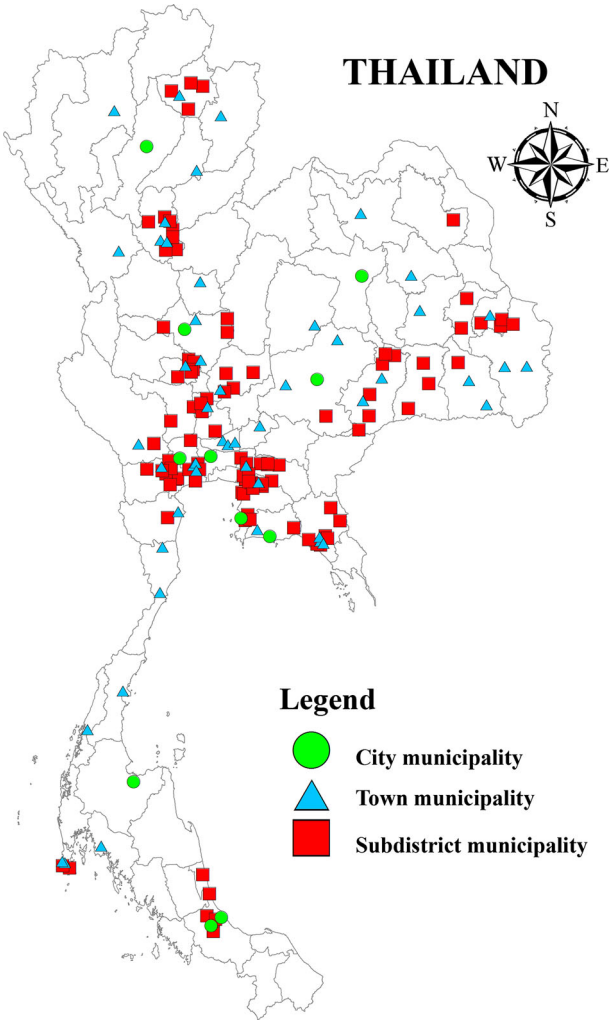

Fig. 1 Locations of surveyed municipalities in Thailand

by assigning survey data as independent variables and assessment results of each FSM indicator as dependent variables. Table 1 provides the details of the 20 factors within the four groups that were selected for multiple regression analysis. Multiple regression analysis is a statistical tool to determine the significant factors of each FSM indicator, which could be used to identify conditions to achieve effective FSM services (Hardy and Bryman 2004). Models with a high adjusted R^2 (representing a high correlation between dependent and independent variables) and significant response as determined using an F test (measuring the reliability of the model) were selected for proposed effective measures to improve FSM services. The Cronbach alpha was also applied to measure how well a set of factors measures a single unidimensional latent construct or a coefficient of reliability of factors of the questionnaires in this study. Cronbach alpha values were in the range of

0.80–0.85 which exceed Nunnally's (1978) recommended threshold of 0.7, indicating high reliability for an internal consistency among factors within a group.

3 Results and discussion

3.1 Existing situation of FSM services in Thailand

Results related to technical background regarding FS collection services showed that 28 % of the respondents were served by municipalities and 72 % by private operators. Municipalities had only 25 % appropriate treatment sites; of which, treatment technologies were anaerobic digestion (12 %), controlled aerobic digestion (1 %), co-disposal to wastewater treatment plants (3 %), sludge drying beds (4 %), and co-disposal to sanitary landfills (5 %) as shown in Fig. 2. In municipalities that had no treatment system (75 %), 22 % of the collected FS were disposed in orchard and rice fields, and 53 % were discharged into public land or vacant lots. Thai Ministry of Public Health reported that 70 % of FS collected from on-site sanitation systems in the country is disposed of in landfills, agricultural fields, and waterways as reported by USAID (2010).

Regarding financial issues of FSM services, most of the municipalities face financial constraints to support FSM services for both FS collection and treatment facilities. Although there are some subsidies provided by the authority, many municipalities do not put high priority on FSM services, resulting in smaller budgets for this purpose. From the survey results, only 4 % of municipalities subsidized investment costs on FSM services and only 3 % subsidized for operation and maintenance costs by the central government, which usually cause insufficient fund to provide efficient FS collection services. With regard to incomes from FSM services, they are directly generated from FS collection fees, if operated by municipalities and from the permit fees, if operated by authorized private operators. The FS collection fees of most municipalities were in the range of 5–9 US$/cu.m. which could cover mainly the collection and transportation costs, but not FS treatment operation which was about 40 US$/cu.m. for anaerobic digestion. Due to current regulations and limited household incomes, it might not be practical to increase the collection fees to cover the investment and operation costs. The present permit rate for private operators is around US$ 65–350/year/enterprise, as reported by the authority, depending mainly on mayor policies and local conditions. Even with these income-generating

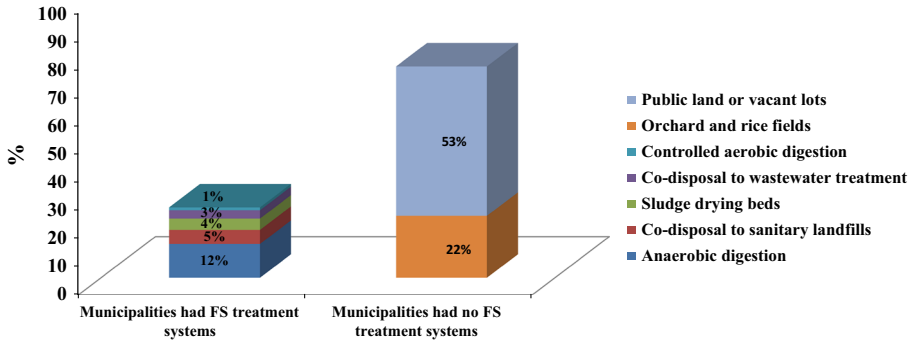

Fig. 2 Percentage of FS treatment in Thailand

mechanisms, it is not adequate for municipalities to further develop and invest for FS treatment facilities.

3.2 Factors influencing FSM services

The collected data were analysed with respect to each FSM indicator and their respective significant factors for FSM services. The relationships between each of these indicators and its significant factors were identified using multiple regression analysis as shown in Eqs. (1)–(9). The detailed results of these relationships are presented below.

3.2.1 City municipalities

Model C_{OE}, C_{SP}, and C_{TF} represented the assessment of FSM services based on operational efficiency indicator, service performance indicator, and treatment feasibility indicator, respectively, of 11 City municipalities [Eqs. (1)–(3); Fig. 3a]. More importantly, the adjusted R^2 from the models for City municipalities was found to be rather high which exceed Hardy and Bryman (2004) documented threshold of 0.6, indicating highly reliable models.

Model C_{OE} shown a strong relationship (adjusted $R^2 = 0.98$) between a set of selected factors and operational efficiency indicator (Eq. 1). When an alpha level of at least 0.01 was used as the significance benchmark, two significant factors were indicated in the regression model: number of vacuum trucks and perception of designation of responsibility. The survey results revealed that most of the surveyed municipalities did not have an

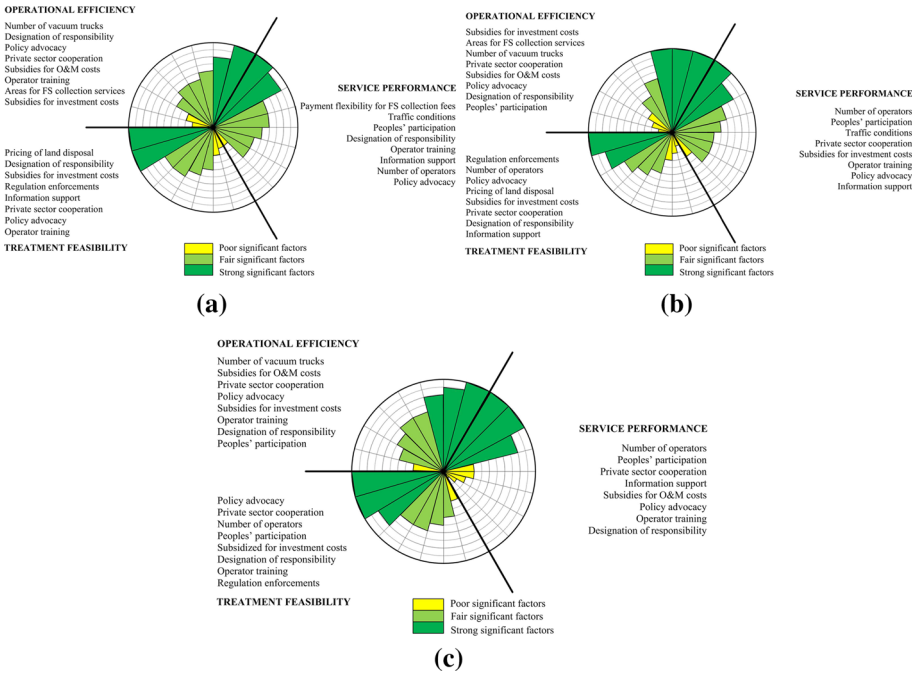

Fig. 3 FSM performance diagrams. **a** City municipalities. **b** Town municipalities. **c** Subdistrict municipalities

adequate number of vacuum trucks and adequate maintenance for the vacuum trucks used. This reduce FS operational efficiency and causes high operation and maintenance costs as reported by USAID (2010), Bill and Melinda Gates Foundation (2012) and Frenoux and Tsitsikalis (2014). In addition, perception of designation of responsibility strongly contributed to higher operational efficiency of City municipalities. In practices, FSM systems involve a large number of different stakeholders, but often it is seen only as a responsibility of local government authorities. A similar finding was remarked by Chokewinyoo (2008) that common causes for the poor FS collection services in low- and middle-income countries, including Thailand, are the lack of clearly defined roles and responsibilities of different stakeholders.

$$\begin{aligned} C_{\mathrm{OE}} = {} & 35.107 + 0.687(\mathrm{TRUCK}^{***}) + 0.434(\mathrm{RESPONSIBLE}^{***}) + 0.244(\mathrm{ADVOCACY}^{**}) \\ & + 0.277(\mathrm{CO\text{-}OPER}^{**}) + 0.201(\mathrm{O\&M}^{**}) + 0.288(\mathrm{TRAINING}^{**}) \\ & + 0.200(\mathrm{AREA}^{*}) + 0.160(\mathrm{INVEST}^{*}) \end{aligned} \tag{1}$$

Model C_{SP} provided a set of significant factors correlated with service performance (adjusted $R^2 = 0.96$) (Eq. 2), where C_{SP} is service performance for City municipalities. Two significant factors were indicated in the regression model ($p < 0.01$): perception of payment flexibility for FS collection fees and traffic conditions. From the survey results, the majority of households were unsatisfied with the rate of FS collection fees and traffic conditions affecting FS collection efficiency, resulting in complaints from surrounding communities. Previous studies by USAID (2010) reported that many municipalities of low- and middle-income countries are more concerned with the delay in FS collection services and collection fees than with the negative environmental and health impacts caused by inadequate FSM services.

$$\begin{aligned} C_{\mathrm{SP}} = {} & 330.959 + 1.434(\mathrm{PAYMENT}^{***}) + 0.786(\mathrm{TRAFFIC}^{***}) + 1.591(\mathrm{PATICIPATE}^{**}) \\ & + 0.823(\mathrm{RESPONSIBLE}^{**}) + 1.845(\mathrm{TRAINING}^{**}) + 0.441(\mathrm{INFOR}^{**}) \\ & + 0.852(\mathrm{OPERATOR}^{**}) + 0.243(\mathrm{ADVOCACY}^{*}) \end{aligned} \tag{2}$$

The regression analysis results for model C_{TF} (adjusted $R^2 = 0.99$) are presented in Eq. (3), where C_{TF} is treatment feasibility for City municipalities. Two significant factors were indicated in the regression analysis ($p < 0.01$): perception of designation of responsibility and pricing of land treatment. Bassan et al. (2013) stated that land characteristics (e.g. availability and cost of land) are the important factors affecting the feasibility of FS treatment. A similar finding was documented by Strande et al. (2014) that suggested that in choosing the most appropriate FS treatment technology options, consideration should be given to type of treatment technology and its compatibility with available local resources and conditions.

$$\begin{aligned} C_{\mathrm{TF}} = {} & 145.274 + 0.684(\mathrm{RESPONSIBLE}^{***}) + 0.454(\mathrm{LAND}^{***}) + 0.162(\mathrm{INVEST}^{**}) \\ & + 0.110(\mathrm{ENFORCEMENT}^{**}) + 0.109(\mathrm{INFOR}^{**}) + 0.151(\mathrm{CO\text{-}OPER}^{**}) \\ & + 0.112(\mathrm{ADVOCACY}^{*}) + 0.081(\mathrm{TRAINING}^{*}) \end{aligned} \tag{3}$$

3.2.2 Town municipalities

Model T_{OE}, T_{SP}, and T_{TF} represented the assessment of FSM services based on operational efficiency indicator, service performance indicator, and treatment feasibility indicator, respectively, of 50 Town municipalities [Eqs. (4)–(6]; Fig. 3b]. The adjusted R^2 from the models for Town municipalities was in the range of 0.60–0.82 which exceed Hardy and Bryman (2004) recommended threshold of 0.6, indicating highly reliable models.

From Eq. (4), model T_{OE} shown operational efficiency for Town municipalities (adjusted $R^2 = 0.82$). Three significant factors strongly contributed to higher operational efficiency of Town municipalities ($p < 0.01$): subsidies for investment costs, areas for FS collection services, and number of vacuum trucks. This finding implied that operators who had performed FSM services need to be aware of the relative costs of manpower and equipment to implement FSM services. A similar finding was documented by Kone et al. (2007) and CSE (2011), showing that investment and operation costs should be supported by the central government to increase the operational efficiency. In contrast, areas for FS collection services negatively influenced operational efficiency for Town municipalities. Perhaps this is because the inadequate number of vacuum trucks for FS collection services and longer distance to these services reduce the probability of operational efficiency in accordance with the finding for City municipalities.

$$\begin{aligned} T_{OE} = {} & 36.905 + 0.334(\text{INVEST}^{***}) - 0.270(\text{AREA}^{***}) + 0.625(\text{TRUCK}^{***}) \\ & + 0.152(\text{CO-OPER}^{**}) + 0.150(\text{O\&M}^{**}) + 0.122(\text{ADVOCACY}^{*}) \\ & + 0.127(\text{RESPONSIBLE}^{*}) + 0.126(\text{PATICIPATE}^{*}) \end{aligned} \quad (4)$$

From Eq. (5), model T_{SP} provided a set of significant factors correlated with service performance indicator, where T_{SP} is service performance for Town municipalities (adjusted $R^2 = 0.60$). It can be seen that number of operators and perception of people awareness of FSM participation strongly contributed to higher service performance in Town municipalities ($p < 0.01$). These findings suggested that the service performance of Town municipalities need adequate number of operators dealing with complaints in a given period. In smaller municipalities, one operator may operate both wastewater management and FSM, resulting in inadequate manpower in implementing the FSM (Omran 2011). Not surprisingly, perception of people awareness of FSM participation strongly contributed to higher service performance of Town municipalities. In this respect, there should be programmes to motivate people in the perception of their FSM problems and understanding the importance of people's participation in FSM programmes.

$$\begin{aligned} T_{SP} = {} & 32.239 + 0.332(\text{OPERATOR}^{***}) + 0.298(\text{PATICIPATE}^{***}) + 0.240(\text{TRAFFIC}^{**}) \\ & + 0.218(\text{CO-OPER}^{**}) + 0.199(\text{INVEST}^{**}) + 0.198(\text{TRAINING}^{**}) \\ & + 0.207(\text{ADVOCACY}^{**}) + 0.185(\text{INFOR}^{*}) \end{aligned} \quad (5)$$

Based on treatment feasibility (Eq. 6), the number of operators and perception of administrator awareness of regulation enforcements strongly contributed to higher treatment feasibility in Town municipalities ($p < 0.01$; adjusted $R^2 = 0.74$). From the survey results, a FS treatment plant employing sludge drying beds to treat 8 m^3/day of FS had to employ four operators per treatment plant to appropriate FS disposal. These

findings suggested that the significance of number of operators has direct effects on the FS treatment feasibility in Town municipalities. Another factor strongly contributing to higher treatment feasibility in Town municipalities was perception of administrator awareness of regulation enforcements for illegal disposal of the collected FS to public areas. Although the 1992 Public Health Act in Thailand delegates the main responsibilities for providing adequate FS treatment facilities to local governments, most of the local governments have not been able to support FS treatment facilities and weak enforcement for this purpose, causing more environmental pollution and health impacts (MOPH 2008).

$$\begin{aligned} T_{\mathrm{TF}} = {} & 159.507 + 0.492(\mathrm{ENFORCEMENT}^{***}) + 0.217(\mathrm{OPERATOR}^{***}) \\ & + 0.211(\mathrm{ADVOCACY}^{**}) + 0.169(\mathrm{INVEST}^{**}) + 0.173(\mathrm{CO\text{-}OPER}^{*}) \\ & + 0.153(\mathrm{RESPONSIBLE}^{*}) + 0.157(\mathrm{INFOR}^{*}) \end{aligned} \quad (6)$$

3.2.3 Subdistrict municipalities

Model S_{OE}, S_{SP}, and S_{TF} represented the assessment of FSM services based on operational efficiency indicator, service performance indicator, and treatment feasibility indicator, respectively, of 99 Subdistrict municipalities [Eqs. (7)–(9); Fig. 3c]. The adjusted R^2 from the models for Subdistrict municipalities was in the range of 0.35–0.57. Although the low values of adjusted R^2 generated for these groups, the combination showed the most appropriate group in factor analysis.

From Eq. (7), model S_{OE} shows operational efficiency for Subdistrict municipalities (adjusted $R^2 = 0.54$). Three significant factors strongly contributed to higher operational efficiency in Subdistrict municipalities: number of vacuum trucks, subsidies for operation and maintenance costs, and private sector cooperation ($p < 0.01$). A similar finding was documented by the Ludwig and Mohit (2000) showing that inadequate number of vacuum trucks could lead to propagation of unlicensed FS collection operators. For example, Bangladesh and Cambodia were undertaken predominantly with unlicensed informal operators, who subsequently disposed of the collected FS at illegal dumping sites (Bill and Melinda Gates Foundation 2012). Another factor strongly contributing to higher operational efficiency in Subdistrict municipalities was subsidizing from the central government in operating the FS collection services, as previously reported by the Strande et al. (2014). For example, Malaysia has achieved effective FSM services because the central government provides large subsidies to improve FS collection services and treatment plant operation (USAID 2010).

$$\begin{aligned} S_{\mathrm{OE}} = {} & 37.648 + 0.486(\mathrm{TRUCK}^{***}) + 0.275(\mathrm{O\&M}^{***}) + 0.205(\mathrm{CO\text{-}OPER}^{***}) \\ & + 0.176(\mathrm{ADVOCACY}^{**}) + 0.163(\mathrm{INVEST}^{**}) + 0.154(\mathrm{TRAINING}^{**}) \\ & + 0.156(\mathrm{RESPONSIBLE}^{**}) + 0.139(\mathrm{PATICIPATE}^{*}) \end{aligned} \quad (7)$$

For service performance indicator (Eq. 8), three significant factors strongly contributed to higher service performance in Subdistrict municipalities (adjusted $R^2 = 0.57$): the number of operators, perception of people awareness of FSM participation, and private sector cooperation ($p < 0.01$). It was also clear that the number of operators and perception of people awareness of FSM participation were regarded as being important factors to reduce the number of complaint regarding inefficiency in both Town and Subdistrict municipalities. Similar results were documented by Bill and Melinda Gates Foundation (2012),

where the number of operators is usually limited to implement the FSM services. Strande et al. (2014) indicated that the involvement of the private sector and social conditions (e.g. the attitudes of people in FSM participation) are the important factors for the success of FSM practices.

$$S_{SP} = 54.225 + 0.503(\text{OPERATOR}^{***}) + 0.306(\text{PATICIPATE}^{***}) + 0.203(\text{CO-OPER}^{***}) + 0.175(\text{INFOR}^{*}) + 0.130(\text{O\&M}^{*}) + 0.155(\text{ADVOCACY}^{*}) + 0.126(\text{TRAINING}^{*}) + 0.134(\text{RESPONSIBLE}^{*}) \quad (8)$$

Regarding treatment feasibility (Eq. 9), three significant factors strongly contributed to higher treatment feasibility in Subdistrict municipalities ($p < 0.01$): policy advocacy to support FS treatment facilities, private sector cooperation, and number of operators (adjusted $R^2 = 0.35$). Interestingly, policy advocacy to support FS treatment facilities contributed to higher treatment feasibility in Subdistrict municipalities. USAID (2010) reported that most FS treatment projects in Thailand have failed to achieve a desired output for the communities due to lack of political wills of the local administrators in implementing the FS treatment programmes. Another factor strongly contributing to higher treatment feasibility in Subdistrict municipalities was the involvement of private sectors in FS operation. It is possible that the positive relationship between authority and private operators could be encouraged in investment FS treatment systems. Conditions for treatment provision are also included the number of operators in implementing the FS treatment programmes and obligation to have a private contractors in providing legal dumping sites for FS collected.

$$S_{TF} = 70.706 + 0.575(\text{ADVOCACY}^{***}) + 0.343(\text{CO-OPER}^{***}) + 0.229(\text{OPERATOR}^{***}) + 0.229(\text{PATICIPATE}^{**}) + 0.233(\text{INVEST}^{**}) + 0.190(\text{RESPONSIBLE}^{**}) + 0.203(\text{TRAINING}^{**}) + 0.151(\text{ENFORCEMENT}^{*}) \quad (9)$$

Based on different municipality levels, categorized to the number of households, into City, Town, and Subdistrict municipalities, the key significant factors of each FSM indicator were identified as shown in Fig. 3, and indicated the significance of number of vacuum trucks which caused direct effects on the FS operational efficiency for all municipality levels. Inadequately, budgets are often more apparent for FSM implementation, particular in smaller municipalities as Subdistrict municipalities. Likewise, in some cases there are sufficient funds to manage public facilities, such as water supply provisions and flood preventions, but none are allocated to implement FSM services due to lack of interest in FSM from local government authorities and concerned people. Several effective measures were recommended for improving FS operational efficiency including (1) subsidy to support investment and operation costs for FS collection services; (2) monetary incentives and tax reductions for the encouraging private sector cooperation; and (3) technical assistance for building human resource capability (Table 2). For example, providing tax reductions can improve FS operational efficiency by attracting operators to implement an alternative operation and maintenance system with lower long-term costs. In addition, monetary incentives (e.g. interest, loans, and compensatory goods) can also be applied to encourage private contractors to invest in FS collection services.

Table 2 Summary of proposed effective measures for improving FSM services

FSM indicators	Municipality levels			Respond to	Effective FSM measures
	City	Town	Subdistrict		
Operational efficiency indicator					
Areas for FS collection services	P	S		Inadequate number of vacuum trucks	Subsidies
Number of vacuum trucks	S	S	S	Inadequate budgets for FS collection services	Tax reductions
Subsidies for investment costs	P	S	F	Lack of financial support in investment costs	Monetary incentives
Subsidies for operation and maintenance costs	F	F	S	Lack of financial support in operation and maintenance costs	Monetary incentives
Private sector cooperation	F	F	S	Lack of private sector cooperation for FS collection services	Tax reductions
Designation of responsibility	S	P	F	Building human resource capability	Technical assistance
Service performance indicator					
Number of operators	F	S	S	Increasing local capacity to manage and improve FSM services	Improving networking with voluntary organizations
Traffic conditions	S	F		Reducing traffic condition problems	Optimizing FS collection routes
Peoples' participation in FSM	F	S	S	Increasing awareness of people to FSM problems	Education programmes
Payment flexibility for FS collection fees	S			Insufficient incomes from FS collection services	Information dissemination
Private sector cooperation		F	S	Lack of private sectors cooperation to operate FSM services	Strict enforcements
Treatment feasibility indicator					
Number of operators		S	S	Inadequate number of operators in implementing the FS treatment programmes	Subsidies
Pricing of land treatment	S	F		Perception of land pricing problems	Subsidies
Policy advocacy	P	F	S	Lack of interest in FS treatment programmes of government authorities (e.g. central government local government authorities, politician)	Awareness campaigns

Table 2 continued

FSM indicators	Municipality levels			Respond to	Effective FSM measures
	City	Town	Subdistrict		
Private sector cooperation	F	P	S	Awareness of private operators to legally disposed FS collected	Strict enforcements
Regulation enforcements	F	S	P	Inadequate enforcement programmes	Strict enforcements
Designation of responsibility	S	P	F	Inadequately capabilities of responsible agencies	Technical training

P, poor significant factors ($p < 0.10$); F, fair significant factors ($p < 0.05$); S, strong significant factors ($p < 0.01$)

It was furthermore found that inadequate number of operators and awareness of people to FSM problems significantly affected service performance in Town and Subdistrict municipalities. Likely due to the introduction of a decentralization policy in Thailand in 1999, aimed at empowering and transferring authorities from the central to the local levels, local government authorities are forced to take on several roles, resulting in inadequately operators in implementing the FSM services. Improving networking with voluntary organizations is critically needed for increasing local capacity to manage and improve FSM services. In addition, because working for FSM programmes is a voluntary job with no monetary incentive for encouraging people to participate in FSM programmes, it resulted in poor FSM participation among concerned people. Education programmes should be conducted in order to motivate people with FSM problems to understand the importance of improving FSM services. As a consequence, perception of payment flexibility for FS collection fees and traffic conditions could be the main causes for the poor service performance in City municipalities. Optimizing FS collection routes should be properly planned to provide efficient FS collection services in City municipalities as documented by USAID (2010). Information dissemination should be conducted in order to promote the benefit of improved FSM services. However, fees for FS collection services should be generated covering the collection, transportation, and treatment costs (Strande et al. 2014).

The significance of number of operators was highly effective for improving FS treatment feasibility in Town and Subdistrict municipalities, less affecting the City municipality. From the survey results, it was found that the success of FS treatment practices in most of the surveyed City municipalities in Thailand was due to subsidies from the central government and political wills of the local administrators to support the FS treatment programmes. These supporting factors were not available in the surveyed municipalities of Town and Subdistrict, contributing to poor performance of their FS treatment. Furthermore, due to high investment and operation costs of FS treatment facilities, FS treatment programmes in several municipalities have been found to be unsatisfactory. To address these problems, there should be more subsidies provided by both central and local government authorities in the investment and operation costs of the FS treatment programmes.

4 Conclusions

Due to a high rate of population growth, most cities especially in low- and middle-income countries are continuously facing unsafe FS disposal that cause detrimental effects to water resources and public health. FS problems should be properly managed to minimize significant impact on public health and the environment. Relationships among FSM indicators (operational efficiency, service performance, and treatment feasibility) and its significant factors were identified by multiple regression analysis in this study. Factors encompass technical, financial, social, and institutional aspects. Results of the assessment, through operational efficiency indicator, showed that operational efficiency could be improved by addressing these significant factors: number of vacuum trucks, subsidies for investment and operation costs of the vacuum trucks, private sector cooperation, and designation of responsibility. Specific measures to improve operational efficiency were proposed such as subsidizing investment and operation costs of FS collection services, monetary incentives and tax reduction, and technical assistance. For service performance indicator, inadequate number of operators, traffic conditions, perception of people awareness of FSM

participation, payment flexibility for FS collection fees, and private sector cooperation were found to be influential on the service performance. In order to address these findings, specific measures such as improving networking with voluntary organizations, optimizing FS collection routes, introducing education programmes to raise people's participation in FSM, information dissemination, and strict enforcements for illegal FSM implementation were high potential measures for improving service performance. For treatment feasibility indicator, there are several significant factors that acts as barriers to improvement FS treatment feasibility, including inadequate number of operators in implementing FS treatment programmes, pricing of land treatment, policy advocacy, private sector cooperation, regulation enforcements, and designation of responsibility. Specific measures to enhance treatment feasibility included providing subsidies to support FS treatment plant operation, awareness campaigns to motivate administrators in the perception of their FSM problems, strict enforcements, and technical training.

In addition, significant factors and the assessment methods used in this study could be applied to identify conditions to achieve effective FSM services for other countries. Although conducted in the context of FSM services in Thailand, this study could have broader applications, providing insights into both practical and research challenges. The systematic approach to identifying significant factors and application of potential measures which has been used in this study is expected to be valid and beneficial for other key FSM problems, particular where FSM programmes have been implemented and need to improve their performance. Therefore, more study is required to cope with not only local factors but also regional and global factors, in order to achieve sustainable environmental sanitation solutions.

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References

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. (2012). Business analysis of faecal sludge management: Emptying and transportation services in Africa and Asia. Draft Final Report.

Boot, N.L.D., & Scott, R.E. (2008). Faecal sludge management in Accra, Ghana: Strengthening links in the chain. Report of the 33rd WEDC International Conference, Accra, Ghana.

Canadian Water and Wastewater Association and 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.

Chokewinyoo, P. (2008). *Lessons learned and strategies on Septage Management in Thailand.* Paper Presented at the Regional Symposium-cum-Training Workshop on Sustainable Septage Management in Asia and Pacific. Asian Institute of Technology, Bangkok, Thailand.

Christoph, L., Panesar, A., Schutze, T., Norstrom, A., McConville, J., Parkinson, J., et al. (2011). *Sustainable sanitation in cities: A framework for action*. Rijswijk: Papiroz Publishing House.

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.

Eawag/Sandec. (2006). Urban excreta management-situation, challenges, and promising solutions. 1st International Faecal Sludge Management Policy Symposium and Workshop. Report of the Swiss

Federal Institute for Environmental Science and Technology, Department of Water and Sanitation in Developing Countries. Eawag/Sandec, 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.
Hardy, A. M., & Bryman, A. (2004). *Handbook on data analysis*. London: SAGE.
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. Swiss Federal Institute for Environmental Science and Technology (Eawag), Department of Water and Sanitation in Developing Countries (Sandec), 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., & Mohit, K. (2000). Appropriate technology for municipal sewerage/excreta management in developing countries: Thailand case study. *The Environmentalist, 20*, 215–219.
Luthi, C., Panesar, A., Schutze, T., Norstrom, A., McConville, J., Parkinson, J., et al. (2011). *Sustainable sanitation in cities: A framework for action*. Rijswijk, Netherlands: Published by Papiroz Publishing House.
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.
MOPH. (2008). *Factsheet on environmental health: Managing night soil in Subdistricts*. Thailand (in Thai): Report of the Ministry of Public Health.
Nunnally, J. (1978). *Psychometric theory*. New York: McGraw-Hill.
OCS. (2003). Municipality Act (Vol. 12, B.E.2546). Report of the Office of the Council of State, Thailand.
Omran, A. (2011). Factors influencing water treatment management performance in Malaysia: A case study in Pulau Pinang. *International Journal of Engineering*, *6*, 53–62.
Robbins, M.D. (2007). Septage management guide for local governments: A step-by-step practical guide to developing effective Septage Management programs for cities and municipalities.
Schmoll, O., Howard, G., Chilton, J., & Chorus, I. (2006). *Protecting groundwater for health: Managing the quality of drinking-water sources*. London: Report of the World Health Organization.
Strande, L., Ronteltap, M., & Brdjanovic, D. (2014). *Faecal sludge management*. London: IWA Publishing.
UN-HABITAT. (2011). *Status and strategy for faecal sludge management in the Kathmandu Valley*. Nepal: HPCIDBC Publishing.
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. USAID.
World Bank Water and Sanitation Program. (2008). Economic impacts of sanitation in Vietnam. Research Report.