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Wastewater Treatment Efficiency of Small and Large–Scale Pig Farms in Vietnam

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Vietnam has experienced a rapid growth in the livestock sector with the increase of large–scale farms (LFs) in addition to existing small–scale farms (SFs). As a result, the country has faced with serious environmental pollutions caused by the production. Although various manure treatment plants (MTPs) have been installed by pig farms, almost they are inappropriate, causing the manure not to be treated effectively. While the improvement in pollutant removal efficiency (PRE) of MTPs is a key factor to solve the environmental pollution, it has been paid little attention by current studies. The purpose of this study is to analyze the characteristics and PRE of alternative MTPs and recommend solutions for SFs and LFs. The study results show that MTPs of LFs have better PRE than those of SFs because these MTPs include the components treating both organic and nutrient matters in the effluents. The study suggests that SFs can improve the PRE by installing biogas digesters and liquid containers, while LFs should construct MTPs comprising biogas digesters, liquid containers, and bio–ponds. Although such MTPs do not incur high unit abatement costs, they occupy large land; thus, the government should control the minimum land area needed to install the MTPs with sufficient capacity according to the quantity of pigs at the farms. The study also indicates that reducing water use can improve PRE of the MTPs; therefore, advanced technology for saving water should be introduced to the pig farms.

Key words: manure treatment plant, manure management, large–scale farm, small–scale farm, developing countries

INTRODUCTION

Developing countries in Asia have experienced rapid population growth, rising income levels, urbanization, and lifestyle changes, further compounded by a shift in dietary patterns high in meat and dairy products that reflects intensified livestock production (IAEA, 2008). Consequently, the volume of livestock waste emitted is increasing (Tetsuo *et al.*, 2018), challenging waste management in these countries. Without proper manure treatment practices, livestock waste is one of the biggest sources of pollution in the agriculture sector. It is estimated that only around 60% of animal waste is treated in Vietnam, and the remainder is discharged directly into the environment without treated (i.e., dumping on land, fishponds, canals, and rivers) (Dinh, 2017). As a result, this leads to soil, water, and air pollution, which has adverse effects on public health and agricultural sustainability (Dinh, 2017; Terry & Khatri, 2009).

To meet the increasing demand for meat and milk, livestock production patterns have changed to intensive production systems with the increasing number of large–scale farming (Dinh, 2017; Huynh *et al.*, 2006). According to Vietnam's regulation on livestock farm size, large–scale pig farms (LFs) are defined as farms raising at least 20 sows/batch or 100 fattening pigs/batch, the others are defined as small–scale farms (SFs) (Dinh, 2017). Over the past decade, the number of pig producers has been declining in Vietnam, while the number of LFs are increasing. In 2008, SFs produced 85% of total pig population and the remainder came from LFs, while in 2014, 70% of pig heads and 60% of pork products were produced by SFs, while LFs contributed the remainder (Dinh, 2017).

Pig farms in Vietnam have adopted various MTPs, but such MTPs are irrelevant, causing severe environmental pollution. Owing to different production features, SFs and LFs require distinct MTPs; however prior studies have investigated manure management practices and proposed solutions for only SFs (Hai *et al.*, 2016; Roubík *et al.*, 2018; Thien Thu *et al.*, 2012; Vu *et al.*, 2015; Vu *et al.*, 2007). Although study of Huong *et al.* (2020) compared the manure treatment and pollution levels of SFs and LFs, and examined the factors affecting pollutant concentrations in the effluents, but it did not investigate the pollutant removal efficiency (PRE) of MTPs. The improvement in the PRE is found to be the main factor to reduce the environmental pollution derived from livestock production. Therefore, this study aims to analyze the PRE of the MTPs used by SFs and LFs to find the appropriate solutions to manure management for each farm type. As Vietnam and other developing countries in Asia face similar economic and environmental problems, this study provides the governments of these countries information on the current situation, problems faced, and potential solutions for sustainable livestock production.

RESEARCH METHODS AND DATA COLLECTION

Data collection

Over the past few years, livestock production has gradually moved from densely to less populated areas, forming new livestock production clusters. These

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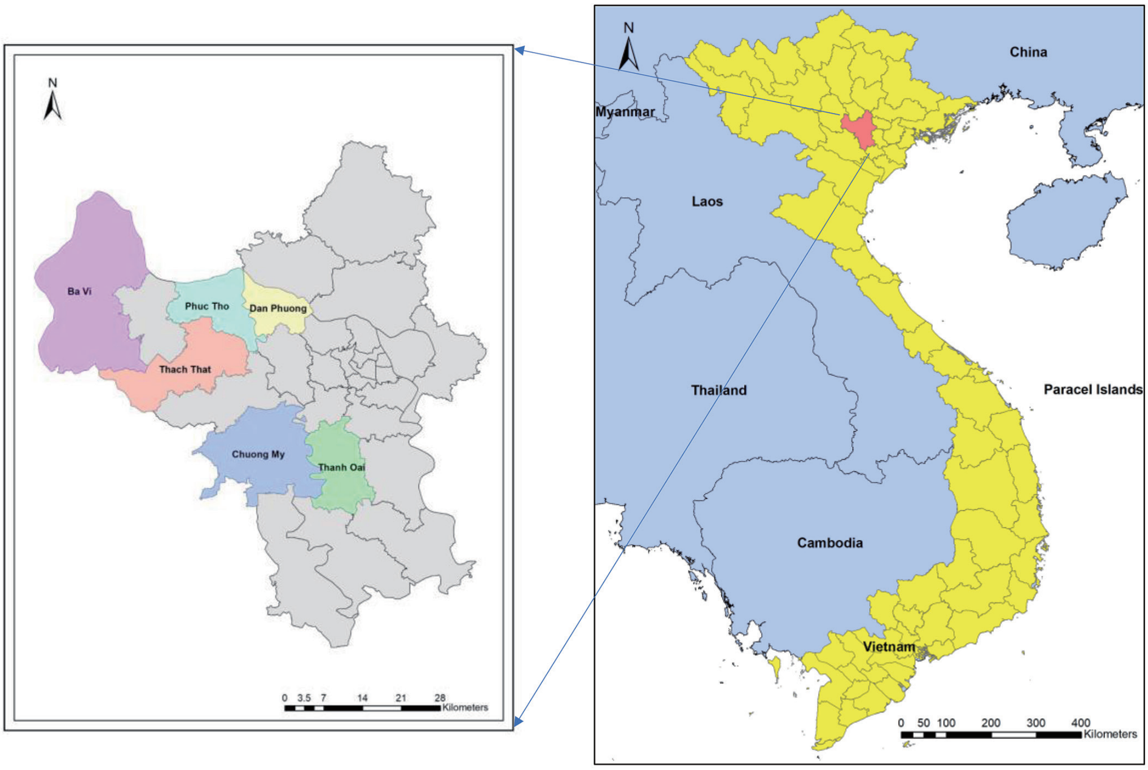

Fig. 1. Study site.

dynamics can be observed in areas around big cities (i.e., Hanoi and Ho Chi Minh) (Dinh, 2017). This research was carried out in Hanoi, which produces the largest pork quantity in Vietnam at 168,475 tons and accounts for 5.8% of total pig population of Vietnam (GSO, 2018). Hanoi can be representative for Vietnam pig production since it includes SFs and LFs and various MTPs.

Hanoi Veterinary Department provided us lists of all pig producers in the Hanoi. According to the list in May 2018, there were 101,813 pig owners in the area. We conducted in–depth interviews with officials at the Department about the location and quantity of SFs and LFs there. Based on the interview, we choose six districts for the survey: Ba Vi, Phuc Tho, Thach That, Dan Phuong, Chuong My, and Thanh Oai (see Fig. 1). We randomly selected 45 farms of each district for the farm-heads interview. After surveying by questionnaires with 270 farms, we randomly drawn 59 farms for collecting wastewater samples to calculate the PRE of MTPs.

Analysis method

The samples were collected and analyzed in the laboratory of Faculty of Environment, Vietnam National University of Agriculture. Four parameters analyzed in the wastewater samples include chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (TN), and total phosphorus (TP). The BOD and COD values were calculated by the dilution and seeding method (ISO, 1989)[2] the dichromate method (Cr6+) (American Public Health Association (APHA), 1992)[3] and the filtration through glass–fiber filters method (ISO, 1997)[4], respectively. The concentrations of TN and TP were determined according to the Kjeldahl method (SMEWW4500.Norg.A.B.C) and the APHA Method 4500–P (American Public Health Association, 1992), respectively. The analyses were conducted twice, with the relative deviation of the duplicate values being usually <5%.

Prior to analysis, the data were rechecked to ensure accuracy. If information was inconsistent, the interviewer contacted the farm and surveyed the farmer again. If reliable data could not be obtained, the information was omitted from the data analysis. Questionnaires and wastewater parameters were input into the computer and analyzed using the statistical software package STATA 14.

The four main pollutants usually analyzed for livestock effluents in Vietnam are COD, BOD, TN, and TP (MONRE, 2016). A hierarchical cluster analysis was applied to better evaluate the PRE of the wastewater treatment processes (Zhang *et al*., 2019). Cluster analysis is a technique to categorize farms into several clusters based on the PRE of the four pollutants. The PRE are calculated as $E_i=(I_i–O_i)/I_i$. E_i is the i^{th} PRE; I_i is the i^{th} pollutant load in the influent flowing into the MTPs (kg); O_i is the i^{th} pollutant load in the effluent flowing

[2] ISO (1989). Water quality–determination of biochemical oxygen demand after 5 days (BOD5)–dilution and seeding method.
[3] American Public Health Association (1992). Standard method for examination of water and wastewater. 18th edition, Washington D.C.
[4] ISO (1997). Water quality–determination of suspended solids by filtration through glass–fiber filters method.

out from the MTPs (kg).

Cluster analysis was carried out in two steps. First, principal component analysis (PCA) was used as a dimension–reduction tool for the four PRE and to identify the major groups. The Kaiser criterion (Ford *et al.*, 1986), which retains all the factors with eigenvalues greater than 1, was used to determine the number of components to be retained, resulting in two components. In our study, the components explain a total of 89.7% of the variance. Only factors with loadings greater than 0.30, that is, meeting the minimum practical significance level, are interpreted (Hair *et al.*, 2009). Second, cluster analysis based on a PCA usually results in a clear delineation of clusters compared to only a cluster analysis. In this step, the object scores determined by the PCA were used as the input to an agglomerative hierarchical cluster analysis. We applied the Ward–linkage method based on the Euclidean distance. This step led us to define four PRE clusters. For further analysis, these clusters are linked to types of MTPs and other attributes.

RESULTS AND DISCUSSIONS

Types of MTP

We found five types of MTP in the study site, which is presented in Fig. 2. In MTP 1, the slurry stored in a lagoon flows out into the environment if the lagoon capacity exceeds. The lagoons are shallow with about 2 m in depth and large surface area. In MTP 2, the slurry is pushed into biogas digesters and wastewater from the digesters flows out into the environment. The biogas digesters are made from brick, composite, or plastic materials. In MTP 3, the slurry flows into biogas digesters, wastewater from the digesters is stored in containers and later discharges into the environment when it exceeds the container volume. The container is a hole with small surface area, functioning to settle the undigested material and non–degradable solids. MTP 4 is nearly similar to MTP 3, but the containers are substituted by bio–ponds. MTP 5 captures all the components of other processes, in which the slurry drains into biogas plants, wastewater from the biogas plants flows into containers, and flows out into bio–ponds and is finally discharged into the environment. In the ponds, several plants such as water hyacinth and spinach are grown to break down nutrient matters (TN and TP). In the biogas digesters and liquid containers, anaerobic processes take place to remove BOD and COD (Van Duy & Vu Dinh, 2010), while bio–ponds function aerobic processes to remove TN and TP (Tilley, 2014). In the slurry lagoons, the anaerobic and aerobic processes occur in the bottom and surface, respectively (Park & Craggs, 2007).

The distribution of MTPs by farm types and its characteristics are shown in Fig. 3 and Table 1, respectively. All the LFs installs MTPs while some of the SFs discharge untreated manure to the environment. MTP 1 is mainly used by LFs (72.2%) because these farms are often located far from residential areas and have large land area for the lagoons. On average MTP 1 occupies 2034 m^2, which is much larger than the others do. MTP 2 and 3 are preferred by SFs because of their low construction costs and low land use. Almost all biogas digesters of MTP 2 and 3 are placed under the ground, so it occupies insignificant land area. Whereas MTP 4 and 5 are mainly selected by LFs to treat a large amount of manure. MTP 5 is installed by only LFs who are affordable for high construction costs (US $13454.6) and maintenance costs (US $113.6) and own large land size. It incurs considerable maintenance costs because its biogas digesters are all made from plastic materials which are easily broken. Unlike brick and composite biogas digesters, the plastic one cover significant land area because it is constructed on the ground.

Unit abatement cost (depreciation of construction costs and maintenance costs per pig) is highest in MTP 2 (US $ 0.8/pig) because its biogas digesters are made

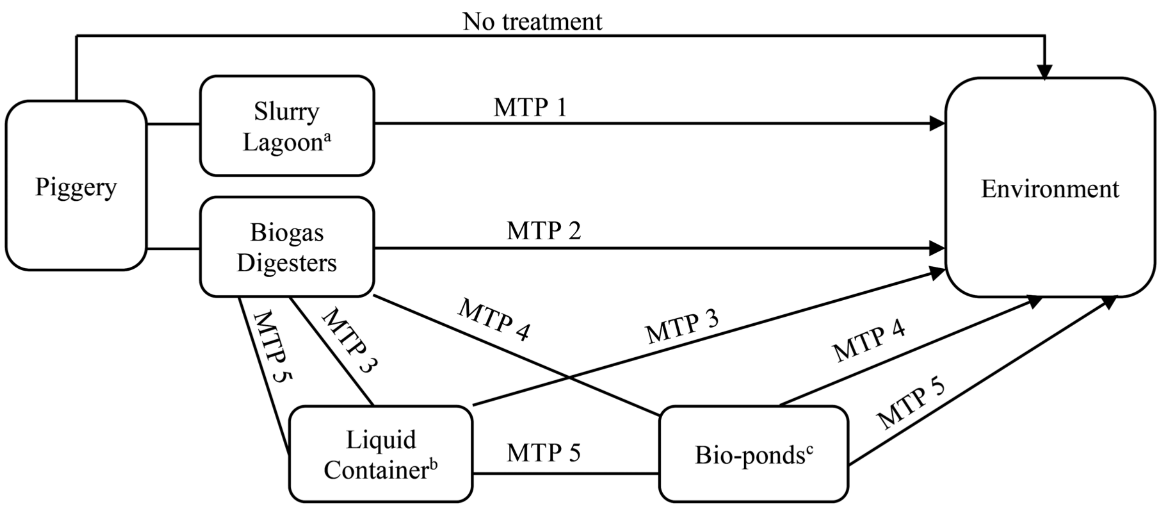

Fig. 2. Types of manure treatment plant (MTP).
[a] Slurry lagoon is used to store the untreated slurry.
[b] Liquid container stores the wastewater from biogas digesters.
[c] Bio–pond is used to continue treating the wastewater from the previous facilities.

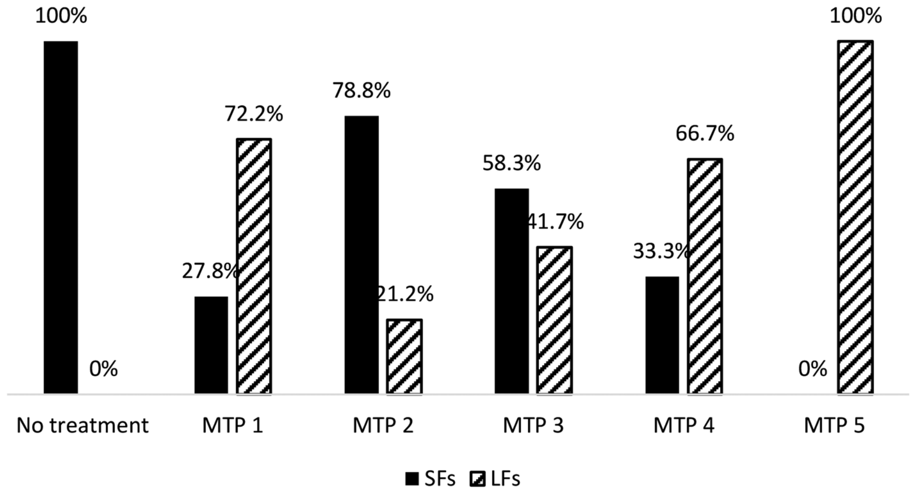

Fig. 3. Distribution of MTPs by SFs and LFs.

Table 1. Mean values of costs and land occupation of MTPs

	MTP 1	MTP 2	MTP 3	MTP 4	MTP 5
Construction cost (US $)	4058.1 (3242.7)	1170.0 (3504.6)	2324.6 (2951.2)	7197.0 (5717.6)	13454.6 (9977.2)
Maintenance costs (US $)	0.0 (0.0)	6.3 (30.1)	11.2 (29.2)	3.8 (6.6)	113.6 (173.5)
Abatement costs (US $/pig)	0.2 (0.6)	0.8 (1.0)	0.5 (0.4)	0.3 (0.1)	0.4 (0.3)
Land occupation (m^2)	2034.0 (4419.9)	22.7 (96.4)	186.6 (420.7)	863.2 (703.6)	1260.2 (530.0)

Standard deviations are given in parentheses.

from brick or composite that incur higher construction costs than plastic ones.

Pollutant removal efficiency (PRE)

PRE of SFs and LFs are given in Table 2. In general, PRE of the surveyed farms are low, except TP with 61.8%. There is no significant difference in PRE of COD and BOD between these farm types but the PRE of TN and TP of LFs are significantly higher than that of SFs. The differences in the PRE might derive from the types of MTP. LFs mostly install MTP 4 and 5 that include bio–ponds functioning nutrient removal as TN and TP.

PRE of different types of MTP are presented in Table 3. In general, PRE of COD and BOD are low in all MTPs, of which MTP 1 have the lowest efficiencies, and MTP 5 have the highest. PRE of TN and TP are fair in all MTPs, of which MTP 5 have the highest PRE than the others do.

Cluster analysis results

We employ a cluster analysis technique to categorize the farms into some PRE clusters and examine the relationships the clusters and factors. The results of the cluster analysis provide us four clusters, namely poor, organic, nutrient, and high PRE (Table 4). Cluster "poor PRE" has lower PRE of COD, BOD and TN than the others. Cluster "nutrient PRE" has high PRE of TP and TN with 96.5% and 75%, respectively but PRE of COD and BOD are low at 10.1% and 7.6%, respectively. Cluster "organic PRE" is described by PRE of COD and BOD being high at 55% and 44.2%; however, its PRE of TP and TN are low at 37.5% and 0.7%, respectively. Cluster

Table 2. Pollutant removal efficiency by farm types

(Unit: %)

Pollutants	Pooled	SFs	LFs	t–value[(1)]
COD	29.0 (30.9)	28.5 (27.0)	29.2 (32.3)	–0.7
BOD	24.0 (29.4)	17.9 (26.0)	25.9 (30.3)	–8.0
TP	61.8 (39.4)	6.6 (24.9)	77.6 (27.2)	–7.83***
TN	25.1 (33.2)	11.1 (27.9)	30.8 (33.6)	–2.90***

(1) Two sample t–tests with unequal variances were conducted for comparing PRE between SFs and LFs. ** and *** are statistically significant at 5% and 1% level, respectively.

"high PRE" has PRE of all pollutants are generally higher than other clusters.

There is a statistical relationship between the clusters and farm types, which is shown in Table 5. Broadly, LFs have better PRE than SFs do. The percentage of LFs in the poor PRE cluster is 40%, that is lower than that of SFs (57.1%). There are no SFs in the nutrient PRE cluster, while LFs comprise 20% of the cluster. In the organic PRE cluster, the percentage of SFs is 35.7%, double that of LFs. Conversely, in the high PRE cluster, the percentage of LFs is 24%, much higher than that of SFs (7%).

The characteristics of the clusters are described in Table 6. All MTP 1 is in the poor and nutrient PRE clusters with the percentage of 44.4% and 55.6%, respectively. Almost all MTP 2 falls into poor PRE cluster (60%), the remainders are in nutrient and organic PRE clusters with each being 20%. Although majority of MTP 3 is in the poor and organic PRE clusters (78.3%), there are some being in high PRE cluster (21.2%). All MTP 4 is in the nutrient PRE cluster; and all MTP 5 is in the high PRE cluster.

Pig density is also the factors associated with the PRE clusters. The ratio of pig to treatment volume in poor PRE cluster is highest (4.2 pig/m^3), followed by nutrient PRE cluster (3.6 pig/m^3) while it is only 0.7 pig/

Table 3. Pollutant removal efficiency by MTPs

(Unit: %)

Pollutants	MTP 1	MTP 2	MTP 3	MTP 4	MTP 5
COD	6.4 (8.9)	11.6 (21.0)	34.8 (31.2)	16.4 (23.2)	71.7 (14.3)
BOD	3.4 (5.7)	7.0 (17.5)	28.9 (29.6)	11.0 (15.6)	67.1 (19.8)
TP	81.5 (31.4)	44.1 (43.7)	55.1 (39.3)	97.3 (1.2)	92.4 (9.4)
TN	40.3 (39.2)	15.6 (32.9)	14.7 (25.7)	78.6 (14.2)	63.9 (15.2)

Standard deviations are given in parentheses.

Table 4. Summary of the clusters of pollutant removal efficiency

(Unit: %)

Cluster name	COD	BOD	TP	TN
Poor PRE	4.0 (6.9)	1.0 (3.0)	47.3 (40.3)	2.6 (9.5)
Nutrient PRE	10.1 (12.1)	7.6 (8.5)	96.5 (2.1)	75.0 (10.8)
Organic PRE	55.0 (14.5)	44.2 (21.2)	37.5 (36.8)	0.7 (2.6)
High PRE	71.6 (11.1)	65.8 (14.2)	91.7 (6.5)	60.7 (16.4)

Standard deviations are given in parentheses.

Table 5. Summary of the clusters of pollutant removal efficiency and farm types

	Poor PRE		Nutrient PRE		Organic PRE		High PRE	
	N	%	N	%	N	%	N	%
SFs	8	57.1	0	0.0	5	35.7	1	7.1
LFs	18	40.0	9	20.0	7	15.6	11	24.4

N is number of farms.
% is percentage within SFs and LFs.
Fisher's exact = 0.068

Table 6. Characteristics of clusters of pollutant removal efficiency

Characteristics		Unit	Clusters			
			Poor PRE	Nutrient PRE	Organic PRE	High PRE
Treatment processes[(1)]	MTP 1	%	44.4	55.6	0.0	0.0
	MTP 2	%	60.0	20.0	20.0	0.0
	MTP 3	%	48.5	0.0	30.3	21.2
	MTP 4	%	0.0	100.0	0.0	0.0
	MTP 5	%	0.0	0.0	0.0	100.0
Ratio of pigs to treatment volume[(2)]		pig/m^3	4.2[a]	3.6[ac]	0.9[b]	0.7[b]
Daily washing water[(2)]		liter/pig	191.5[a]	43.6[b]	312.0[c]	60.0[d]

[(1)] Fisher tests were conducted for MTPs with Fisher's exact is 0.000.
[(2)] Pairwise comparison of means with unequal variances were conducted.
[a, b, c, d] In each row, the superscripts represent statistically significant differences in the pair.

m^3 and 0.9 pig/m^3 in high and organic PRE clusters, respectively.

Amount of daily washing water is also found to be related to the PRE clusters. Poor and organic PRE clusters are associated with the large volume of water consumption being 191.5 l/pig and 312 l/pig, respectively. Whereas, nutrient and high PRE clusters have a relationship to low amount of water used with 43.6 l/pig and 60 l/pig, respectively.

Discussion

MTPs

To the deal with the pig manure, some MTPs have been used in Vietnam such as slurry lagoon, biogas digester, liquid container, and stabilization pond, which are like MTPs in other Asian countries. In Sri Lanka, SFs treat the slurry by a simple treatment method that uses a soakage pit, while medium and large–scale farms install advanced treatment methods such as biogas plants (Fernando, 2017). In Thailand, pig farmers install bio–ponds, anaerobic filter tank systems, and biogas plants (Kashyap, 2017). Biogas digesters are commonly used in Vietnam (78%), but it is rarely installed in Thailand (6%). Conversely, the bio–ponds are mainly constructed by LFs in Thailand (42%) (Kashyap, 2017), but rarely used by LFs in Vietnam (7.8%). The ponds are low–cost conventional method in Thailand with some advantages such as easy maintenance and operations, low capital cost, and high removal efficiency; however, it needs a large area (Kashyap, 2017). Therefore, it is often preferred by LFs who own sizable land. Slurry lagoons are used by few small– and medium–sized farms in Thailand (7%) (Kashyap, 2017), whereas they are installed by some LFs in Vietnam. Although the slurry lagoons incur low construction costs, they are not effective at treating the slurry.

PRE

The PRE of pig farms in Vietnam are much lower than those in some Asian countries. For example, in LFs of Vietnam, PRE for COD, BOD, TP and TN are 29.2%, 25.9%, 77.6% and 30.8%, respectively, while they are 88.4%, 89.8%, 67.7% and 64.7% in Thailand (Kashyap, 2017). Similarly, PRE for the same pollutants in Vietnamese SFs are 28.5%, 17.9%, 6.6% and 11.1%, while they are 77.4%, 82.7%, 66.3% and 57.0% in Thailand (Kashyap, 2017). Because Thailand's livestock sector experienced a period of rapid development, that is, much earlier than Vietnam, environmental regulations and waste treatment technologies were developed prior to Vietnam. Thus, MTPs in Thailand are better than in Vietnam, resulting in better PRE.

LFs have higher PRE than SFs do because they have better MTPs that consist of more components to treat both nutrient and organic matters in the effluents. The findings are consistent with those of Kashyap (2017) in Thailand. Cluster analysis results on PRE introduce four clusters: poor, nutrient, organic, and high PRE, of which 24.4% of LFs and only 7.1% of SFs are in the high PRE cluster. In the high PRE cluster, there are all LFs installing MTP 5 and one SFs constructing MTP 3. Therefore, MTP 5 is the best one, followed by MTP 3. However, even when using the same MTP 3, farms could be categorized into three clusters: poor, organic, and high PRE. In fact, the quality of biogas digesters plays an important role in reducing pollutants, but some farms have experienced problems with the biogas digesters such as leakages in a reactor and solid digestate incrustation floating in the main tank, or breakdown of the anaerobic digestion process (Roubík *et al.*, 2016), all of which reduce the PRE of the MTPs.

Pig density was found to be related to the PRE clusters, of which the high PRE cluster has the lowest ratio of pig to treatment volume with 0.7 pig/m^3. Higher pig density makes MTPs overloaded by large volume of manure, resulting in lower PRE (Roubík *et al.*, 2016; Thien Thu *et al.*, 2012). Hence, keeping the density at appropriately low level is a solution to improve the PRE.

The study results also indicates that the farms in high PRE cluster use less water for washing and cooling pigpens than those in other PRE clusters with the exception of nutrient cluster. This finding confirms the result indicated by Thien Thu *et al.* (2012) that high ratio of water to manure causing low retention times in the MTPs and low PRE. In fact, the methods of cleaning pigpen significantly affect the water use. For example, indoor manure separation and artificial cooling system can reduce the water consumption (Liang *et al.*, 2017; Muhlbauer *et al.*, 2011). In Vietnam, because farmers do not scrape the manure from the pigpen floor before hosing, they require more water to washing and must stop adding the water after the manure being completely removed (Thien Thu *et al.*, 2012). The cleaning method consumes significant water, causing the MTPs overloaded.

CONCLUSIONS

Like other developing countries in Asia, Vietnam has faced with environmental pollution from rapid growth in livestock production. In the intensification trend, the number of large–scale livestock farms (LFs) is increasing, while small–scale farms (SFs) are still the dominant forms in Vietnam. Although the farms there have applied various treatment methods, animal manure has not been treated properly. With different production features, the SFs and LFs need to find their own waste treatment processes. This study contributes to literature and practice by comparing the pollutant removal efficiency (PRE) of different types of pig manure treatment plant (MTP) in the LFs and SFs and suggest the appropriate plants to each farm type.

A cluster analysis categorizes the farms into four clusters: poor, nutrient, organic and high PRE. This study indicates that LFs have higher PRE than SFs do because their MTPs include more components to decompose both nutrient and organic matters in the effluents. In addition, the MTPs consisting of biogas digester, liquid containers and bio–ponds belong to the high PRE cluster. There are 21.2% of MTP with biogas digester and liquid containers in the high PRE cluster. The findings suggest that for SFs owing small land area, the MTP with biogas digester and liquid containers should be installed, the MTPs consisting of biogas digester, liquid containers and bio–ponds is appropriate for LFs who have sizable land and capital sufficiency.

The study results also point out that low pig density and using less water for washing and cooling have close relationship to high PRE cluster. The results imply that keeping pig density at appropriate level and reducing water use are the solutions to improve PRE. In doing so, the government should control minimum land area needed for installing MTPs with sufficient capacity and introduce the technologies for cutting down water consumption at the farms.

AUTHOR CONTRIBUTIONS

Le Thi Thu Huong formed the research idea, designed the questionnaire for survey, collected, analyzed the data, and drafted the manuscript. Yoshifumi Takahashi supervised the research and made critical revisions to the manuscript. Do Kim Chung, Cao Truong Son edited the manuscript. Luu Van Duy collected the secondary and primary data and edited the manuscript.

Mitsuyasu Yabe suggested the research idea, supervised the research, commented on manuscript, and provided fund for this work. All authors read and approved the final manuscript.

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