Challenges and Potentials of Ecological Sanitation: Experiences from the Cases in Vietnam and Malawi

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Abstract

The world's sanitation systems must be up to the challenge of addressing the global crises of water shortages and food insecurity in the face of a growing population. To help address these problems, ecological sanitation (Ecosan), which typically involve the use of urine-diverting dry toilets (UDDTs) and the application of excreta in agriculture, can be employed. This paper discusses the challenges and potentials of the Ecosan approach in terms of 3 essential requirements—continuous defecation use, reduction of health risk, and use of excreta—by examining 3 cases of Ecosan use in Vietnam and Malawi. The experience with traditional Ecosan in rural Vietnam suggests that dry sanitation practices that apply Ecosan are effective at reducing fecal contamination in the surrounding water environment, thereby reducing the health risk from unavoidable accidental ingestion of contaminants. However, current sanitization processes involving the application of manure to agricultural products represent a significant health risk challenge. The experience with modern UDDTs in rural Vietnam suggests that they can be continuously used for defecation for long periods of time without intervention, while there remain major challenges to continuous use from physical damage to the UDDT structures. The proper management of fecal chambers can successfully control the offensive odors that are a source of wide concern. In rural Malawi, the introduction of modern UDDTs successfully fostered a demand for the use of feces by raising the perception of its value in agriculture and through an integration of the Ecosan project into an agricultural technology transfer program. Urine use, by contrast, did not gain a wide acceptance, suggesting that raising an awareness of the effects of urine on agriculture is a key challenge. Thus, although some challenges still need to be overcome, 3 cases of Ecosan showed bright potentials of the Ecosan approach from the 3 essential requirement.

Keywords: ecological sanitation, urine-diverting dry toilets, agriculture, health risk, Vietnam, Malawi

Introduction

Securing proper sanitation is vital to human health and dignity. Unfortunately, 2.3 billion people worldwide still lack access to basic sanitation services (WHO and UNICEF 2017). The United Nation's Sustainable Development Goals include water and sanitation targets of securing adequate sanitation for all by 2030[1)]. However, there are at present no ideal solutions to ensuring global sanitation.

Future sanitation solutions should also be compatible with solutions to the challenges of water shortage and food insecurity. This provides an opportunity for the implementation of sanitation approaches that utilize dry sanitation and the use of excreta with agriculture. Such approaches include ecological sanitation (Ecosan), which has been promoted for several decades (Esrey et al. 1998; Jonsson et al. 2004; Winblad and Simpson-Hébert

1) 70/1. Resolution adopted by the General Assembly on 25 September 2015, "Transforming our World: The 2030 Agenda on Sustainable Development", United Nations, 21 October 2015. https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf (Accessed July 4, 2019).

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2004; Werner et al. 2009). According to Winblad and Simpson-Hébert (2004), "[e]cological sanitation is based on three fundamental principles: preventing pollution rather than attempting to control it after we pollute; sanitizing the urine and the feces; and using the safe products for agricultural purposes." Ecosan is typically implemented through the use of urine-diverting dry toilets (UDDTs), which do not use water and separate nutrient-rich urine from physically harmful feces to enable the use of the separated urine and sanitized feces for agriculture.

Although many projects following the Ecosan approach have been implemented in developing countries, some have faced challenges in the initial acceptance of UDDT installation and in the continuous management of the UDDTs following installation (Drangert 2004; Jackson 2005; Uddin et al. 2014). Regardless of type, there are two essential toilet requirements: to provide a comfortable defecation space that can be continuously used (i.e., continuous defecation use); and to reduce health risk through toilet use (i.e., health risk reduction). Toilets using the Ecosan approach must meet these requirements and, unlike ordinary toilets such as water flush units or pit latrines, must be able to separate out human excreta for agriculture (i.e., excreta use). Typically, urine is used as liquid fertilizer while sanitized feces are used as manure for crops. Accordingly, a major challenge to the use of Ecosan is fecophobic attitudes reflecting a dislike of the use of excreta for agriculture.

This paper aimed to examine the challenges and potentials of Ecosan in terms of 3 essential requirements: continuous defecation use, health risk reduction, and excreta use. For this purpose, we re-examined 3 cases of Ecosan use in Vietnam and Malawi with which the authors were previously involved. The first case involves traditional Ecosan practices at a rural community in northern Vietnam in which traditional dry sanitation, including the use of UDDTs and the application of excreta to agriculture (Harada et al. 2016; Julian et al. 2018) was practiced. This case is used to discuss the health risk from fecal exposure through the long-term use of Ecosan. The second case involves the introduction by an NGO of UDDTs to a rural community in southern Vietnam in which excreta had not previously been used for agricultural (Harada et al. 2004a, b). This case is used to examine how the long-term use of modern UDDTs affects continuous defecation use. The final case involves the introduction of similarly designed UDDTs in rural Malawi by the same NGO, a project that was successfully scaled up (Harada et al. 2018). This case is compared with the preceding case in Vietnam to examine the use of excreta. Finally, the challenges and potentials of Ecosan are examined based on the experiences obtained from the 3 cases.

1. Methodology

1.1. Case study A: Assessment of fecal exposure through traditional ecosan practices

Study area

The study area was located in northern Vietnam (Trai hamlet, Van Tu commune, Phu Xuyen district, Hanoi city; Figure 1). The area has a history of toilet use and the agricultural application of excreta (Pham et al. 2015; 2017). Farming is a major occupation and, in the past, most residents engaged in fishery in a nearby river to obtain supplemental income. As a result of recent industrialization and urbanization processes, however, the river has become seriously polluted and many people have stopped fishing. General information on the hamlet is given in Table 1.

As of 2010, 56% of the households in the study area employed dry toilets (Figure 2), which treat excreta using drying agents such as ash and dry soils. Following several months retention in a toilet chamber, the resulting fecal mixture is used for agriculture. Some dry toilets use urine diversion, while others do not. Households with higher economic status tended to use water flush toilets. Through urbanization and industrialization, a large amount of water has been available and house buildings have had modern structure. Accordingly, traditional dry toilets have been gradually replaced by conventional water-flush toilets.

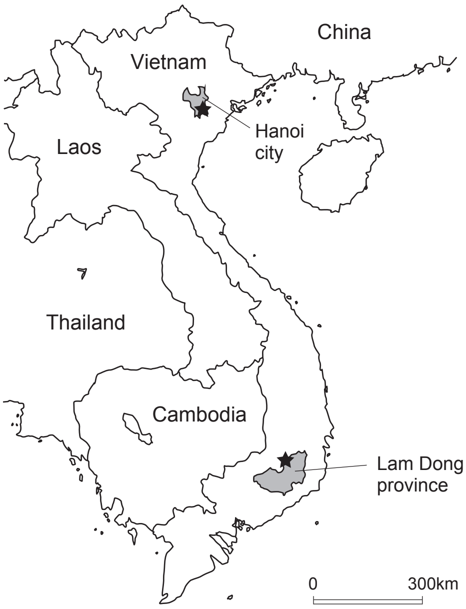

Figure 1. Project sites: Traditional use of human waste (Phu Xuyen district, Hanoi city); NICCO Ecosan project (Lam Ha district, Lam Dong province).

Table 1. Summary of target hamlet statistics. (Data as of 2010, modified from Pham et al. 2017)

Information	Unit	Data
Population	person	800
Household number	household	240
Total area	ha	56.1
Paddy field	ha	52.6
Household income	USD/month	98–147
Toilet type	-	-
Cistern flush toilet	%	19
Pour flush toilet	%	25
Dry toilet without urine diversion	%	44
Dry toilet with urine diversion	%	12

Figure 2. Urine diverting dry toilet at the Trai hamlet study site.
(Taken by the author)

Fecal contamination and fecal exposure assessment

Unsanitary conditions allow fecal matter to be emitted to the environment, causing contamination of the living and surrounding environment by fecal microorganisms and the potential exposure, via a number pathways, of humans to fecal pathogens through various fomites or media. Here, we discuss the impact of excreta use on human health in Trai hamlet, where people use dry feces from toilets for agriculture, based on the fecal contamination data and exposure trends in the hamlet uncovered by Harada et al. (2016) and Julian et al. (2018).

We first briefly explain the methodology used to construct and carry out the fecal contamination survey and calculate exposure. Fecal contamination was defined in terms of the concentration of *Escherichia coli* in traditional dry and water flush toilet users for 10 fomites (n = 5–34), including drinking and environmental water, eating utensils, soils, human manure, and environmental water. Fecal exposure for traditional dry toilet users was re-assessed through the eight pathways identified by Harada, et al. (2016): intentional intake of drinking water, unintentional intake of non-drinking water during bathing, irrigation activities, swimming and fishing, unintentional intake of soil during agricultural activities, and unintentional intake from dining equipment such as bowls and chopsticks. *E. coli* was used as the fecal contamination indicator bacteria, with exposure to *E. coli* calculated as follows:

$$Dose_{day} = \sum C_i \times F_{i,j} \times I_j \qquad (1)$$

where $Dose_{day}$ is the *E. coli* dose per day (CFU/day), C_i is the concentration of *E. coli* in medium i {CFU/(unit media amount)}, $F_{i,j}$ is the exposure factor, or unit intake amount of medium i during activity j {amount/(hour or count)}, and I_j is the intensity of activity j {(hour or count)/day}. The exposure factors and activity intensities used in the exposure calculations are listed in Table 2. Probability density functions (PDFs) defined based on survey results are listed in Table 3; using the PDFs, daily exposures to *E. coli* were stochastically estimated based on Monte Carlo simulations.

1.2. Case study B: Introduction of UDDTs in rural Vietnam

Study area

The project site was located at Dan Phuong commune, Lam Ha district, Lam Dong province in the central highlands of Vietnam (Figure 1), which has a tropical monsoon climate. A few households owned unsanitary simple pit latrine without slab, and most households had no toilet. People in the area had never experienced any use of human excreta for agriculture. In 2002, the total population at the project site was 491 across 84 households, of which 67 were ethnic minority families. Most of the households made a living from agriculture. Prior to the project, most of the population practiced open defecation and nearly 80% were infected with intestinal parasites (Kaku et al. 2004). The project site had hosted several community development projects sponsored by the Nippon International Cooperation for Community Development (NICCO), a Japanese NGO. At the request of the local residents, an Ecosan project was conducted by NICCO with the support of Kyoto University faculty (one of whom is an author of this paper) and the Nha Trang Pasteur Institute.

Project outline

Under the project, 85 UDDTs were introduced during 2012–2013. Eighty-four (one per household) of the UDDTs were introduced for household use and one was installed at a primary school for the use of the resident teachers. Outer and inner views of a UDDT are shown in Figure 3 and 4, respectively. The toilet design was based on UDDTs previously developed in Vietnam (Bui et al. 2001; Nha Trang Pasteur Institute VinaSanres Project

Table 2. Data used for calculation of daily exposure in the community where people use excreta for agriculture. (Modified from Harada et al. 2016)

Pathway	Media	Exposure factor	Activity intensity
Intentional intake of drinking and eating			
Eating	Raw vegetables	70.7 g-wet/day	-
Drinking	Boiled-and-stored rainwater	liter/day	-
Unintentional intake of water			
Bathing	Stored well water	0–21 ml/time	1 time/day
Irrigating activities	Irrigation water	0–11.2 ml/hour	8 hour/day
Swimming	Pond water	0–205 ml/hour	1–2 hour/day
Fishing	Pond water	0–11.2 ml/hour	8 hour/day
	River water	0–15.3 ml/hour	3 hour/day
Unintentional intake of soil			
Farming	Rice field soil	1–10 g/day	-
Unintentional intake during eating			
Using devices of eating	Bowl	All surface	3 time/day
	Chopsticks	All surface	3 time/day

Table 3. Probability density functions for drinking water consumption and *E. coli* concentration in each medium. (Modified from Harada et al. 2016)

Item	Distribution type	Parameter
Drinking water consumption (liter/day)	Lognormal	$\mu=1.15 \times 10^{0}$, $\sigma=5.60 \times 10^{-1}$
E. coli conc. in drinking water (CFU/100 ml)	Lognormal	$\mu=8.79 \times 10^{0}$, $\sigma=2.69 \times 10^{1}$
E. coli conc. in stored well water (CFU/100 ml)	Lognormal	$\mu=3.93 \times 10^{3}$, $\sigma=7.55 \times 10^{3}$
E. coli conc. in irrigation water (CFU/ml)	Lognormal	$\mu=9.10 \times 10^{2}$, $\sigma=5.03 \times 10^{3}$
E. coli conc. in pond water (CFU/ml)	Uniform	min.$=1.26 \times 10^{2}$, max$=4.67 \times 10^{3}$
E. coli conc. in river water (CFU/ml)	Lognormal	$\mu=1.78 \times 10^{3}$, $\sigma=2.55 \times 10^{3}$
E. coli conc. in rice field soil (CFU/g-dry soil)	Lognormal	$\mu=2.60 \times 10^{4}$, $\sigma=5.76 \times 10^{6}$
E. coli count on bowl surface (CFU/bowl)	Lognormal	$\mu=1.44 \times 10^{1}$, $\sigma=5.23 \times 10^{1}$
E. coli count on chopstick surface (CFU/pair)	Lognormal	$\mu=4.97 \times 10^{2}$, $\sigma=9.69 \times 10^{5}$

Figure 3. UDDT outside views.
(Taken by the author)

Figure 4. Inner view of toilet.
(Taken by the author)

2002) and partly modified for the project. The UDDTs were constructed by local builders trained and supervised by NICCO; beneficiaries partly contributed the construction by providing labor.

The toilets employed a urine-diverting squatting pan with 2 covered and separated fecal chambers on each side. Urine deposited into a small hole between the chamber covers was piped to a urine container located behind the toilet building, while ash was mixed with feces deposited in the chambers for sanitization. The deposited feces were removed through small doors at the backside of the toilet following an appropriate retention period, which was determined to be at least 10 months based on an associated ascaris eggs inactivation experiment (Harada et al. 2006). After dilution, urine deposited in the container was used as liquid fertilizer for agriculture.

For the project structure, before conducting this Ecosan project, NICCO had conducted organic farming education activities in the same area, and later on started this Ecosan project together with the organic farming education activities. However, due to political reasons, NICCO faced a difficulty to continue the activities at the early timing of this Ecosan project. Finally, the organic farming education activities had been suspended and the Ecosan toilet project had been solely conducted.

Prior to construction of the toilets, orientation and lecture series were provided. Once use had begun, house-to-house instructions were provided to each household every 2 to 3 weeks for 4 months by a female local health worker who was also a beneficiary of the Ecosan project and a user of the UDDT. For further details on the project, refer to Harada et al. (2004a, b).

House-to-house survey on toilet management and user reactions

For our analysis, we used the monitoring results of UDDT operation from Harada, et al. (2004b) and Harada et al. (2009). During months 0–4 following installation, repeated house-to-house monitoring surveys were conducted. The surveys used true-or-false check sheets to assess 17 items related to toilet use and management conditions. From months 7–38, project members were barred from entering the village for political reasons, precluding any monitoring or intervention efforts during this period. Nearly 3 years later, at month 39, one of the authors was able to re-enter the village and conducted a post-intervention monitoring survey comprising structured interviews and observations on construction status, toilet management, and use.

1.3. Case study C: UDDT introduction project in rural Malawi

Study Area

Malawi is a landlocked country in southeast Africa that is separated from Tanzania and Mozambique by Lake Malawi, to which surface and ground water are collected from the west bank (Figure 5). Rural communities in the country face continued threat of famine as a result of poor infrastructure that hinders economic growth. Nevertheless, as of 2017, only 24.7% of Malawi's rural population did not have at least basic sanitation services (WHO and UNICEF 2019).

Project outline

Following their experience with the introduction of Ecosan in Vietnam, NICCO implemented a comprehensive rural development project starting in 2007 in 3 districts of Malawi (Nkhotakota, Dowa, and Lilongwe, shown in Figure 5). The UDDT design was based on that of the UDDTs introduced in Vietnam by NICCO, but with some modification. In total, 1,052 units were constructed across the 3 districts, including a number of public units (Figure 6). According to NICCO, there were a total of 26,100 beneficiaries. Most of them did not have any access to improved sanitation and had never experienced human excreta use for agriculture.

The UDDTs were constructed by local builders who were trained and supervised by NICCO, with beneficiaries

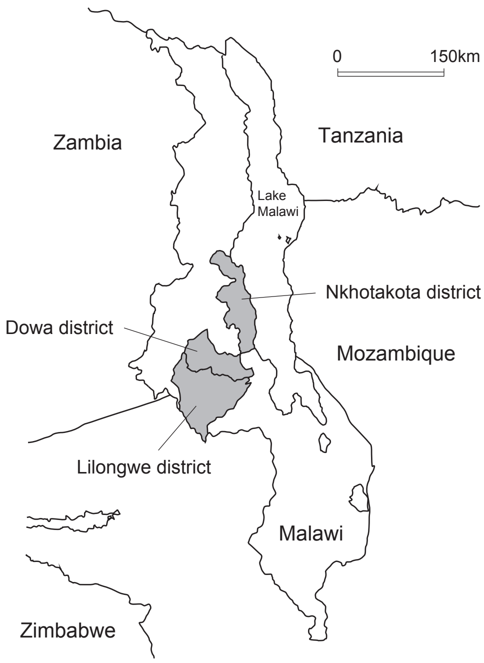

Figure 5. Location of Ecosan project in Malawi.

Figure 6. Ecosan toilet constructed by the NICCO Malawi Ecosan project.
(Taken by the author)

partly contributing to the construction by collecting bricks and providing labor. Workshops were organized on how to use the UDDTs, maintain toilet cleanliness, and use collected feces and urine for agriculture. Ash was utilized to sanitize fecal matter and for washing hands with water following toilet use.

For the project structure, differently from NICCO's Ecosan toilet project in Vietnam, this Ecosan project in Malawi was conducted in integrated manner with other various community development activities; the details of which were described in the following results and discussion section. The Malawi Ecosan project itself comprised 3 sub-projects carried out over a total of eight phases from 2007 to 2014 and was of a much larger scale than the project in Vietnam. Although both projects employed similar UDDT designs, the project in Malawi had more success in scaling up and in establishing the use of fecal matter for agriculture. To ascertain the reason for the improved results, the Malawi project reports were analyzed from the perspective of project structures and NICCO personnel were interviewed.

Conditions of UDDTs after five years and beyond

Our data on the long-term conditions of the UDDTs installed by the NICCO Malawi Ecosan project were taken from Harada et al. (2018), in which 277 households were interviewed to determine their demographic conditions, the structural status of their UDDTs, the continuous use of urine and feces, and their perceptions of the effects of UDDT use on diarrhea reduction and of feces and urine on yield increase.

2. Results and Discussion

2.1. Health risk from using excreta for agriculture in rural Vietnam

Figure 7 shows a comparison of the *E. coli* concentration results in the living environment for traditional dry and

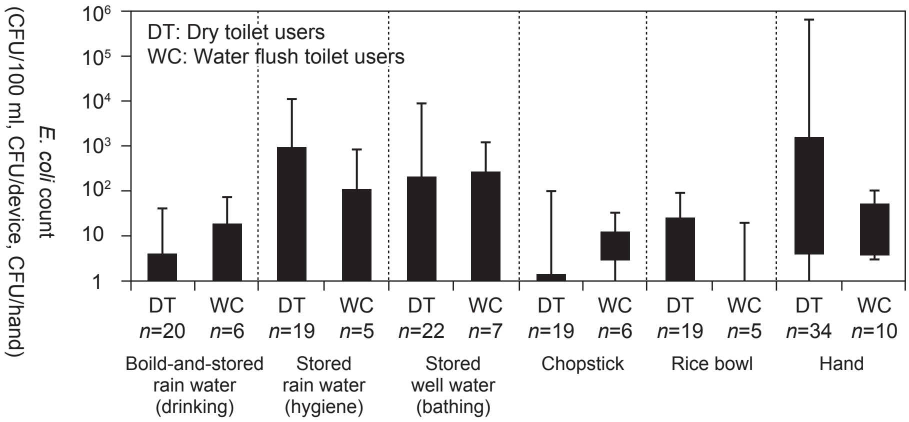

Figure 7. ***E. coli*** **concentrations in living environments and hands in Vietnam.**
Box plots indicate 1st and 3rd quantile ranges and whisker indicate the maximum and minimum values.

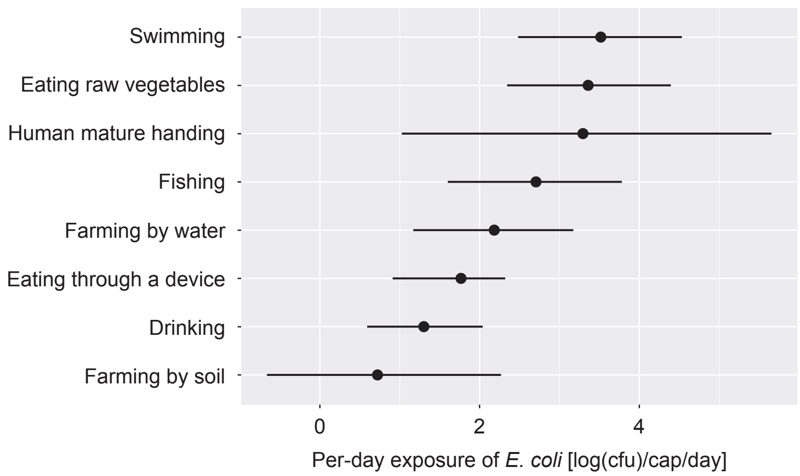

Figure 8. Daily exposure pathways to ***E. coli*** **in a community using excreta.**
The figure shows 75-percentile ranges and median values.

water flush toilet users. The living environments of both user types were heavily contaminated and posed potential health risks from fecal pathogens. No significant difference in contamination could be found between the 2 user types, indicating that the use of traditional dry toilets did not significantly affect fecal contamination in the highly contaminated living environment.

The exposure patterns in the daily life of the Vietnamese community that uses excreta are shown in Figure 8. Three major pathways of fecal exposures are swimming (12.5th percentile–median–87.5th percentile: 2.48–3.52–4.53 log[CFU]/cap/day), eating raw vegetables (2.34–3.36–4.39), and human manure handling (1.01–3.30–5.65). These high daily exposures can be respectively attributed to the accidental ingestion of strongly contaminated pond/river water, the consumption of contaminated raw vegetables, and the accidental ingestion of contaminated human manure.

It is notable that the exposures from the pond and river water have the largest pathways, indicating the importance of avoiding the discharge of fecal matter to local water bodies. In the area, 56% of households used dry feces and liquid urine for agriculture, while the other 44% discharged excreta using water-flushed toilets with very limited

Table 4. Continuity of use of UDDTs with and without serious damage.
(Modified from Harada et al. 2009)

Status of toilet construction	Toilet in use		Toilet not in use	
	%	*n*	%	*n*
All toilets	65.8	50	34.2	26
Toilet not seriously damaged	*83.6*	*46*	*16.4*	*9*
Toilet seriously damaged	*19.0*	*4*	*81.0*	*17*

Note: Four toilets used by families that left the village are excluded.

Table 5. Proportion of toilets with properly operating fecal chambers.

Check item	Months 0–4	Month 39
	% of UDDTs in use	% of UDDTs in use
Offensive fecal smell inside toilet rooms	1.3	14.0
Maggots inside fecal chambers	0	12.0
Many flies (> 10) inside fecal chambers	0	0.0

or no treatment.

Unlike water-flushed toilet systems, which pollute the water environment through the dumping of sanitary wastewater, traditional dry toilets do not directly pollute the water environment because they produce no sanitary wastewater beyond urine. However, improperly used dry toilets are associated with exposure through the contamination of raw vegetables and the handling of human manure. Contamination of human manure (7.17×10–1.27×10^4–2.53×10^6 CFU/g-wet) as a result of the improper sanitization of human feces in traditional dry toilets is a direct exposure pathway and a major source of raw vegetable contamination.

Thus, improper sanitization of their fecal products can increase the health risk associated with exposure to unsanitary fecal products (i.e., manure) and foods grown with the manure while traditional dry toilets do not discharge fecal wastewater and can be effective at reducing the health risk from exposure to nearby water bodies. Feces extracted from dry toilets can be properly sanitized theoretically; this is, however, not always achieved throughout long-term use. The experience with traditional Ecosan practices in Vietnam suggests that long-term sustainability of sanitization performance is a potential challenge.

2.2 UDDTs introduced in rural Vietnam: continuous defecation use

At month 39 following the installation of the UDDTs, 65.8% of the units remained in continuous use (Table 4). Of the toilets that had not been seriously damaged, more than 80% were still in use. Given the 3-year non-intervention period, these proportions can be considered to be high and an indicator of the suitability of UDDTs for continuous defecation use. However, long-term physical damage, primarily from the strong highland winds, remained a major challenge to continuous use.

The high levels of suitability of the project UDDTs for continuous defecation use was potentially associated with good fecal chamber condition. The by-condition breakdown in Table 5 reveals that only a small proportion of UDDTs had offensive smells, maggots, and/or more than 10 flies in the fecal chambers. While fecal smell had been a particularly strong concern prior to installation, the proportion of UDDTs reported to have a bad smell was only 14%. These results indicate that the fecal chambers retained a satisfactory interior status even after the 3-year no-intervention period. The results in Figure 9 focus on the relation between smell and chamber condition, revealing that smell was significantly reduced in chambers that were in good condition. This suggests

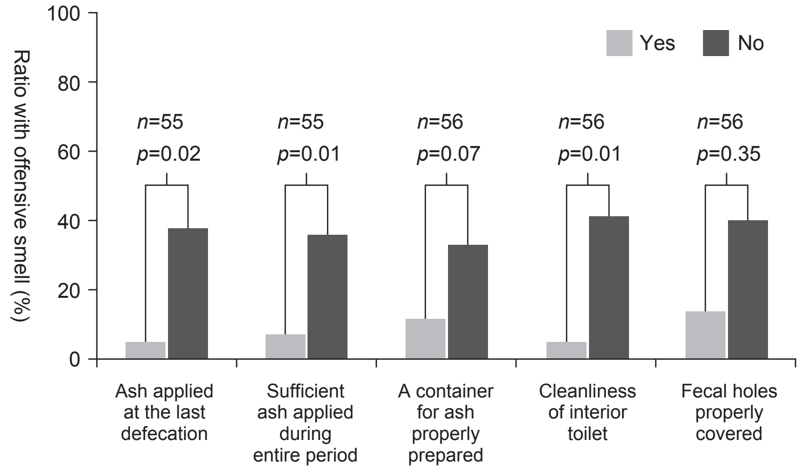

Figure 9. Proportion of toilets with offensive fecal smell by conditions.
Significant differences were tested using the Mann-Whitney U-test.
(Adopted from Harada et al. 2009)

Table 6. Improper use of feces and urine at month 39.

Check item	% of UDDTs in use
Fecal matter never used for agriculture	58.8
Urine not used for agriculture	65.4

that, through proper fecal chamber management, an acceptable defecation enclosure without offensive smell can be successfully provided to users.

A potential reason for the long-term sustainability of proper UDDT operation was the continuous house-by-house instruction on toilet management provided by a local health worker whose family also owned the UDDT. According to our interview of this worker, she irregularly administered instruction up to month 39, although her activities during months 6–39 could not be confirmed by the authors. As reported in Harada et al. (2004b), a typical improper practice during the project involved the incorrect use of ash in the fecal chamber; however, this was corrected during the continuous instruction provided during months 0–5. This continuous effort to train people to properly use the fecal chambers possibly kept the sanitization process running smoothly, resulting in reduced smell and more comfortable defecation rooms.

The agricultural use of feces and urine results recorded at month 39 are summarized in Table 6. Of the households who adopted the use of UDDTs, 58.8% had never used collected feces for agriculture over the course of the project, while 65.4% were not currently using the urine. Thus, the UDDTs were generally accepted for continuous defecation use, whereas the majority of UDDT users did not utilize the feces and/or urine, and the adoption of such measures remained a major unresolved challenge of the project.

2.3 UDDTs introduced in rural Malawi: continuous feces use for agriculture

Table 7 summarizes the operational conditions of the UDDTs in the Malawi Ecosan project, which had been installed 5–9 years prior to the survey. Eighty percent of the 277 household UDDTs were still in use, with the primary reason for ceasing use identified as physical damage to toilets as a result of heavy rains and/or strong winds. Similarly to the case in Vietnam, physical damage to the UDDT structure was a major challenge to continuous use.

Table 7. Proportion of toilet, feces, and urine use (n = 277).
(Data from Harada et al. (2018)

	n (%)
Toilet use	221 (80%)
Feces used	216 (78%)
Urine used	79 (29%)

Table 8. Eight components of integrated community development plan in NICCO Malawi project. (NICCO 2015)

Eight components	Activities
Ecological sanitation	UDDT introduction
Reforestation	Moringa and Jatropha planted; 5,520 fruit trees planted; useful trees introduced; improved oven stoves introduced
Agricultural technology transfer	Organic farming; permaculture; distribution of local seeds; use of feces and urine
Human resource development	Fostering of local leaders; development of project, agriculture, women's, and health committees; workshop for local people
Infectious disease control	Malaria control; HIV prevention; infectious diseases control
Water supply	Construction of wells; workshop for village level operation and maintenance
Maternal and child health	Education activities for maternal and child health; introduction of bicycle ambulance
Income creation	Product development using local agricultural product

Feces from 78% of the total installed UDDTs (98% of the UDDTs in use) were used for agriculture, while urine from only 29% of all UDDTs (36% of the UDDTs in use) was used. This proportion of UDDTs with fecal use in Malawi was significantly higher than that in the Vietnam study (41.2%) although the people in Malawi had never experienced human excreta use for agriculture. According to Harada et al. (2018), 98% of the UDDT users reported yield increases from using feces for agriculture, while only 44% reported increases from the use of urine; these figures reflect the respective proportions of feces and urine use. These indicate that regardless the cultural background of human excreta use for agriculture, human excreta can be utilized if people perceived its value to agriculture.

Although the use of feces is understood to be beneficial for agriculture, there are in fact much higher proportions of nutrients such as nitrogen, phosphorus, and potassium in urine (Matsui et al. 2001). Urine use, therefore, should be prioritized more than feces from an agricultural nutrient perspective and used more widely to effectively increase the yield of agricultural production. Nevertheless, the proper use of Ecosan urine remained as an unresolved challenge to the project. In fact, the agricultural value of urine was explained to the local population according to our interviews to NICCO personnel. One of possible reasons for the great difference between the use of urine and feces is their knowledge and/or previous experiences to use animal manure. The use of animal manure was widely recognized by local people in the area, which might positively affected the continuous use of feces, whereas the use of animal urine separately collected from feces was not recognized, which lead to a greater psychological barrier to use human urine than feces. It appears that its successful continued use would require some change of their perception concerning its value.

Next to the perception on the value of feces, another possible reason of the remarkably different ratios of feces use in Malawi and Vietnam was how these 2 Ecosan projects were structured. Whereas the Ecosan project in Vietnam was solely conducted, the Ecosan project in Malawi was a part of 8 integrated community development activity components, as summarized in Table 8. In this integrated structure, the Ecosan approach was not introduced as a standalone practice but was instead directly connected to an agriculture technology transfer effort to promote effective use of human waste for agriculture. Demonstration farms were used to instruct how urine and feces could be used for agriculture, enabling the participants to recognize the effect of using human waste on agriculture. This integrated educational environment likely contributed to the above-mentioned high perception of the agricultural value of feces and spurred a high ratio of continuous use. In addition, other agriculture, health, and human resource components were also indirectly associated with Ecosan. By integrating Ecosan in this manner, a demand for agricultural use of feces was successfully created.

Conclusion

In this paper, we examined the challenges to and potentials for Ecosan based on 3 cases in Vietnam and Malawi from the viewpoint of 3 essential requirements: health risk reduction, continuous defecation use, and excreta use. The experience with traditional dry toilets in rural Vietnam suggested that dry sanitation including Ecosan practices is effective at reducing the fecal contamination of the surrounding water environment, thereby limiting the health risk from unavoidable accidental ingestion of water. However, the long-term sustainability of sanitization performance of the toilets and the health risk reduction from manure handling and agricultural product application remained as challenges. The experience with the introduction of modern UDDTs in rural Vietnam indicated that the UDDTs could be continuously used for long-term defecation use even without intervention, with physical damage to the UDDT structure constituting the primary challenge to continuous use. In this case, proper management of the fecal chamber proved successful at controlling offensive fecal smells. The experience with the introduction of modern UDDTs to rural Malawi demonstrated that, even without cultural background of human excreta use, a high demand for feces use could be successfully created through association with a perception of the value of feces in agriculture and by integrating the Ecosan project into an agricultural technology transfer program. Urine use, by contrast, was not accepted widely and changing the perception of the usefulness of urine in agriculture was suggested as a key challenge that should be overcome. Thus, although some challenges still remain, 3 cases of Ecosan showed bright potentials of the Ecosan approach in terms of the 3 aspects: health risk reduction, continuous defecation use, and excreta use. Further academic studies and/or practical experience will be required to overcome the identified challenges and forward the successful scaling up of Ecosan.

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