International Journal of Disaster Risk Reduction 27 (2018) 512–523

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Evaluation of a smart toilet in an emergency camp

Fiona Zakaria[a,*], Josip Ćurko[b], Ahmed Muratbegovic[c], Hector A. Garcia[a], Christine Maria Hooijmans[a], Damir Brdjanovic[a,d]

[a] Department of Environmental Engineering and Water Technology, IHE Delft, Westvest 7, 2611 AX, Delft, Netherlands
[b] Faculty of Food Technology and Biotechnology, University of Zagreb, Pierottijeva 6, 10000 Zagreb, Croatia
[c] SYSTECH.ba, Franca Prešerna 22, 71000 Sarajevo, Bosnia and Herzegovina
[d] Faculty of Applied Sciences, Department of Biotechnology, Delft University of Technology, Building 58, Van der Maasweg 9, 2629 HZ, Delft, Netherlands

ARTICLE INFO

Keywords:
eSOS Smart Toilet
Operation
Usage
Field-test
Emergency

ABSTRACT

An experimental prototype of the eSOS (emergency Sanitation Operation System) Smart Toilet® was evaluated in an emergency settlement in the Philippines. The toilet was equipped with sensors and information communication technologies (ICT) for an efficient operation in an emergency setting. The field testing aimed at evaluating the toilet's service capacity related to the user frequency/intensity obtaining insight on the usage patterns in an actual post emergency situation. In addition, the novel features and functionality of the toilet were assessed. Operational performance of the toilet was assessed based on data collected from nearly 700 users within a 7-weeks period. The eSOS Smart Toilet has been properly operating during the evaluation period. A methodology to distinguish defecation and urination activities was developed based on determining discharges to faeces and urine tank. The toilet achieved up to 97% savings on water consumption compared to conventional toilets. The application of sensors and ICT features, combined with manually obtained data informed comprehensive usages data e.g. 62% of identified users were female users, 40% children, and 60% of the visits were for urination and 40% and for defecation. The accumulation of urine, faeces and grey water was measured to allow for a responsive maintenance resulting in optimized operation and increased interest to use the toilet. The field evaluation generated ideas for further improvements in terms of cost savings, services, and an overall vision for sustainability.

1. Introduction

People living in refugee camps are susceptible to displacement-associated diseases such as diarrhoea causing high morbidity and mortality rates [1–3]. Diarrheal diseases are transmitted predominantly through the faecal-oral route. Safe excreta handling, sufficient clean water supply, and proper hygiene practices are measures that need to be provided to intercept the transmission routes. Moreover, the sanitation provision at the emergency camps, being mostly on-site systems, needs to deal with the entire sanitation service chain including containment/collection (i.e. toilet/latrine facilities), conveyance (sewerage and desludging/transportation devices for non-sewered areas), treatment, and final disposal or reuse [4].

Servicing and maintaining onsite sanitation infrastructure is challenging, even for non-emergency situations, due to technical difficulties and under investments [5]. Digging toilet pits in an emergency camp can be difficult or practically impossible due to rocky soil and risk of flooding. Limited technical options suitable for the proper provision of sanitation under such challenging conditions call for innovations [6–8]. An example of such an innovation is the raised latrine using chemical or container toilets [6,9]. These raised latrines are usually waterless with different servicing and maintenance requirements compared to water-based toilets that use septic-tanks for storage of faecal sludge.

Several innovative container-based sanitation (CBS) toilets have been recently evaluated such as the MobiSan® and Uniloo® toilets [10–13]. These evaluations lead to a conclusion that more information on the usage pattern of these toilets is needed to make the required servicing frequency more effective and efficient, as the limited storage capacity of the containers demands a continued provision of emptying services. An improved operation and maintenance would likely lead to an increased number of users and revenues, and will reduce environmental, public health and social issues. Programs aiming at increasing sanitation coverage through the provision of latrines usually report on the number of facilities constructed; however, they fail to evaluate the usage and performance of the provided sanitation alternative with a proper accuracy and sensitivity [14,15]. Often, newly installed latrines

* Corresponding author.
E-mail address: fionazakaria@gmail.com (F. Zakaria).

https://doi.org/10.1016/j.ijdrr.2017.11.015
Received 25 July 2017; Received in revised form 21 November 2017; Accepted 22 November 2017
Available online 26 November 2017

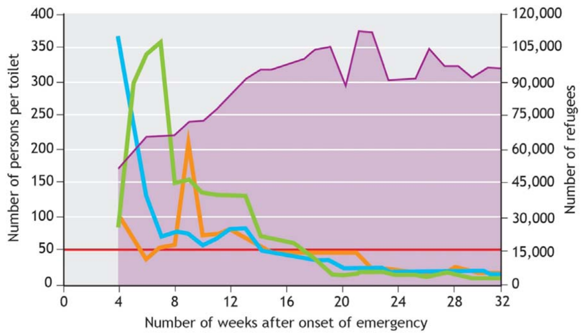

Fig. 1. Average number of persons per toilet for 90,000 South Sudanese refugees in Uganda at several camps - left abscissa in the figure. Adjumani camp (blue line); Arua camp (green line); and Kiryandongo camp (orange line). Violet shaded area shows the affected population fluctuation in all three camps – right abscissa in the figure. In total 6000 toilets were installed leading to 1:15 ratio i.e.15 persons per toilet (modified from Murray, 2015). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

are abandoned as soon as the storage tanks are filled up due to lack or absence of emptying service.

Fig. 1 shows an example of the sanitation provision in the context of an emergency where a single toilet was shared by more than 20 persons even after the occurrence of the acute phase of the emergency [16,17]. Also, the dynamics of the displaced community might affect the usage pattern in emergency camps.

The monitoring of the use and status of the toilets, if in place, has been so far carried out manually. Instead, an automatized monitoring system would provide direct and more detailed historical and actual information on the use and the filling state of the storage container(s), making the maintenance of the toilet and emptying of the container(s) more efficient also avoiding overloading of the container. In the context of an emergency, where many persons share a toilet, additional requirements such as accessibility, safety, and the provision of privacy is important [18].

A novel (emergency) sanitation concept that uses an advanced monitoring system, eSOS® (emergency Sanitation Operation System), was developed at IHE Delft (formerly UNESCO-IHE) Institute for Water Education [18]. The eSOS Smart Toilet®, with its associated software eSOS Monitor®, is the key component of the eSOS concept. The toilet addresses the particular needs for the sanitation provision in emergency contexts including features such as easiness to be transported to the desired location, made of durable materials, optimized maintenance requirements, and no need for excavation at the site. It is also provided with self-cleaning capabilities, hand-washing facilities outside the toilet, interchangeable squatting pan and sitting toilet (for universal use according to local preference), separate faeces and urine collection containers, locking system for safety and privacy, easy emptying provisions, and a measuring and monitoring information and communication technology (ICT). The provision of the ICT features allows to obtain detailed information to evaluate the performance of the toilet with confidence and deeper insight allowing both the maintenance requirements (e.g. servicing frequency) and the usage (e.g. frequency and intensity) of the toilet to be optimized.

An experimental prototype of the eSOS Smart Toilet was manufactured in the Netherlands and transported and tested by a typhoon-affected community located in a transitional settlement Abucay Bunkhouse in Tacloban City (Philippines).

The objectives of this research were as follows:

- Validation of functioning of the toilet's features and software performance and stability under challenging field conditions;
- Gaining information on the applicability of the toilet in a post emergency phase;
- Finding out the amount of waste materials produced by each user and number of usages in a given time period as a key input for sizing of emergency sanitation systems, designing the emptying and maintenance schedules, and sizing the treatment and disposal facilities;
- Assessment of whether the special (e.g. safety) features result in increased use by females and children.

2. Research approach, materials and methods

2.1. eSOS Smart Toilet Design

An experimental prototype of the eSOS Smart Toilet (further to be referred as test toilet) was developed. The toilet was designed as a urine diversion (semi-dry) toilet with provision of service water for hand washing, anal cleansing, and interior hygiene (Fig. 2). The urine diversion pedestal is shown in Fig. 3. The way this pedestal was designed and operated resulted in two separated waste streams, namely, the faecal sludge (mixture of faeces and anal cleansing water with occasional intrusion of smaller amount of urine), and the urine (mixture of urine and occasional intrusion of smaller amount of anal cleansing water). Another waste stream is the grey water (water from hand-washing and toilet's interior cleaning). Consequently, three collection/storage tanks (for grey water, urine, and faeces) were provided. Each tank was equipped with sensors (weight or water level sensors) to measure the amount of the tanks' content; the sensors send an alert signal when the tank is almost full, automatically shutting off the toilet and avoiding potential over-loading of the collection tanks.

2.2. Location and community

The Abucay Bunkhouse was a temporary settlement located in Tacloban City, the Philippines, for families who had lost their home during Typhoon Yolanda that hit Tacloban City in December 2013. At the time this research was carried out (from February to June 2015), 199 families (813 individuals) were living at the settlement. Shared sanitation facilities were provided in the camp consisting of two toilet blocks. Each toilet block was equipped with pour flush pedestal toilets and bathrooms. On average, three to four families were sharing one unit of toilets and bathrooms. The organization of the community was regulated by the municipality's social welfare office.

The test toilet was installed at a convenient and safe location at the Abucay Bunkhouse camp. After finishing the installation and preliminary functionality check, the test toilet was made available to the community 24 h a day, except when servicing/emptying and cleaning the toilet.

The toilet was introduced and its operation and use were explained to the community. The household representatives were asked about their willingness to use the toilet. One access key was provided for each participating household. Each access key was numbered and linked to the corresponding household. As many as 93 keys were distributed to 91 households.[1] The household members older than 7 years of age[2] were registered by obtaining their names, gender, age, and body weight with the approval of the corresponding family member(s). The body weight was used to link the electronic log data to the gender and age of the user.

The test toilet usage was observed for 49 consecutive days, from 13th March to 30th April of 2015. During that time, 662 valid[3] visits were registered. The toilet was cleaned daily with a customized cleaning procedure, including the use of a UV lamp for surface

[1] Two households which were given more than one access key (e.g. in case of too many people per household).

[2] Children younger than 7 years old appeared to need assistance to enter and use the toilet.

[3] Visits during which a full set of data was obtained (about 25% of the total number of visits).

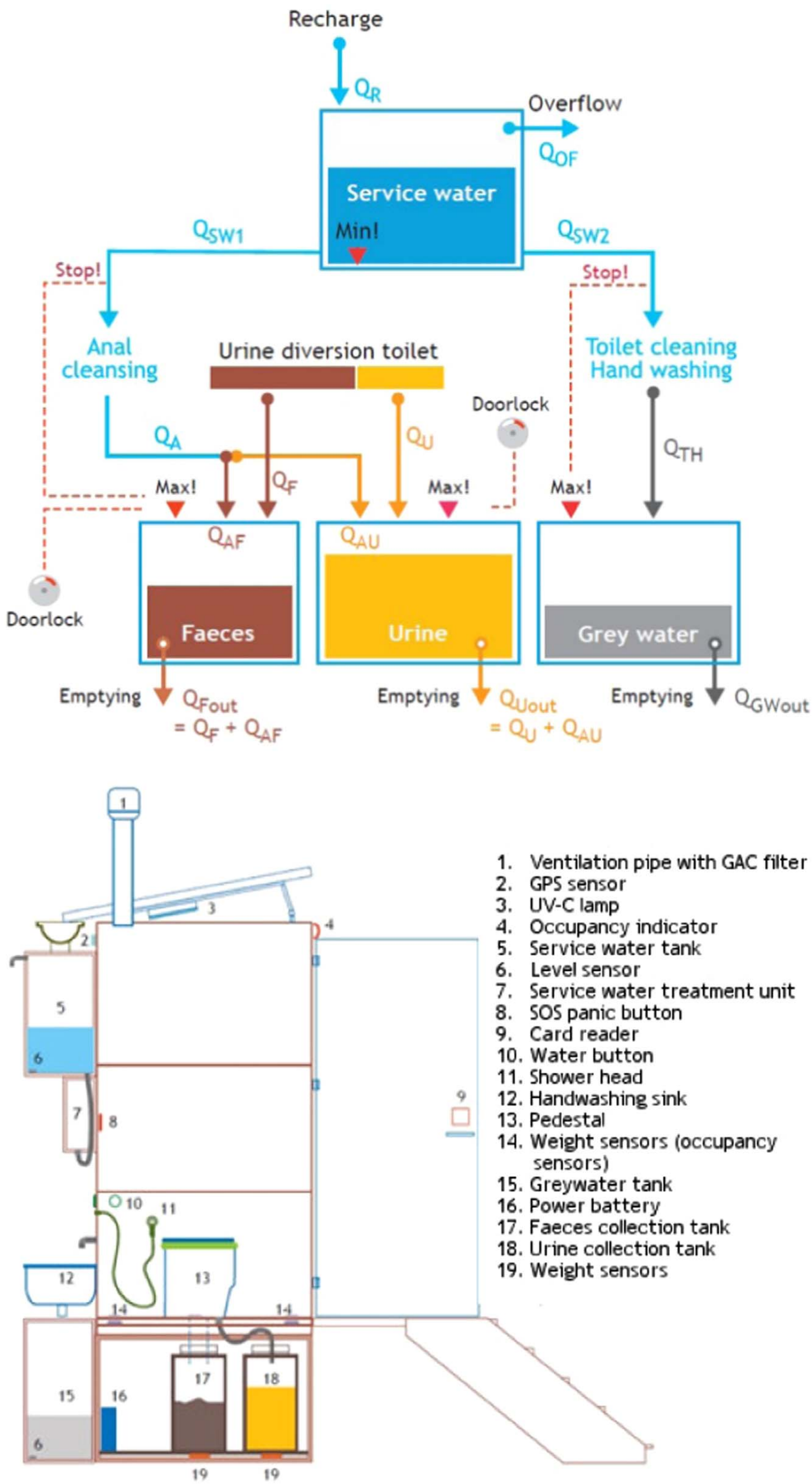

Fig. 2. Flow scheme of the test toilet (above), and its components (below).

disinfection [19]. The tanks were emptied before they are filled up completely.

2.3. Data collection and handling

The test toilet sensors and other electronic equipment were connected through GSM/internet with a server for data transfer, storage and handling. The data collected by the sensors were processed and displayed in real time or as historic data using a custom made software eSOS Monitor. The electronically gathered data are referred to as 'electronic logs' (EL). The software has built-in features which allow to remotely change, adjust, and control the operation of the toilet, and to assess the operational state of the toilet at any moment. In addition, some data were collected manually and registered in manually a log book located inside the test toilet ('manual logs' – ML). Collected data were used to develop a urination/defecation analysis (U/D A) method.

Fig. 3. Urine diversion pedestal of the test toilet (photo: F. Zakaria).

Table 1 gives an overview of the data collection schedule.

Distinguishing usage by urination or defecation was necessary to understand the user's needs and its implications for the toilet design. U/D A was carried out by observing the patterns of measured faeces amount (Q_{Fout}) (as in Fig. 2) and amount of urine (Q_{Uout}) discharged to the collection tanks. The U/D A was performed by processing the visit records from 662 individuals. The software calculated the amount of anal-cleansing water (Q_A) based on the amount of service water drawn inside toilet per each visit. Also, the total amount of material collected in the urine tank (Q_{Uout}) and in the faeces tank (Q_{Fout}) was recorded. The amount of urine (Q_U) and faeces (Q_F) collected during one visit was calculated by subtracting amount of the anal-cleansing water discharged to both tanks (Q_{AF} and Q_{AU}) from the total amount of material collected at both tanks (Q_{Uout}) and (Q_{Fout}).

2.4. Data processing

Figs. 4 and 5 illustrate the observed different practices for urination and defecation, respectively, during the field testing as the result of U/D A. Assumptions were applied to distinguish between urination and defecation; defecation was assumed to produce a larger material flow requiring a relatively longer time and consuming more anal cleansing water. Defecation was likely to include sudden discharge of faeces to the faeces tank as opposite to a more continuous period(s) of urination

It was observed that defecation most likely include some urination. Fig. 5a shows that even without any usage of cleansing water, some discharge to the urine tank was observed which indicate urination activity. It is more prominent in Fig. 5b, where a steady discharge into the urine tank was observed right after a sudden large discharge into the faeces tank (at 00:17 mm:ss); this trend can be explained by an urination event right after the defecation.

After applying the assumptions and observations for defecations, urination was considered, as opposed to defecation, when the following conditions were observed: a dominant discharge into the urine tank, less or no water consumption for anal cleansing, a steady discharge flow within a short occupancy duration, and no sudden increase of weight in the faeces tank. Using this approach, it was possible to identify with sufficient confidence whether the user urinated or defecated; this information was needed to quantify the amount of urine and faeces, to quantify the amount of water consumption for anal cleansing, and to figure out the duration and timing of (combination of) these events.

It was confirmed by observations that the urine tank received only urine and water, except in very rare occasions when the stool fragments escaped the urine sieve. The faeces tank received all other waste materials: faeces, anal cleansing water, and toilet paper.

Each visit was categorized either as urination (producing urine only) or defecation (producing urine and faeces). Both urination and defecation practices also produced anal-cleansing water stream (Q_A, as described in Fig. 2), which can be either discharged into the urine or faeces tank.

U/D A results provided information about the mechanism of stream separation at urine diversion pedestal making it possible to relate the urine and faeces flow to each tank (urine and faeces tanks) based on activities (urination or defecation). The average of these flows is presented in Table 2. Usages without use of cleansing water were separated to check the differences between urine and faecal sludge flows.

3. Results

3.1. Operation of test toilet during the field testing

Fig. 6 shows the number of visits per day, as well as the amount of urine and faeces collected in the storage tanks during the evaluated period until a tank emptying event took place.

At the beginning of the evaluation, the test toilet received a large number of first-time visitors. This number of visits decreased in the following days because of pungent urine smell observed in the toilet cubicle indicating malfunctioning of the urine odour trap. Therefore, starting on *day 6,* the urine tank was emptied each day to minimise the bad smell, although the amount of urine did not reach the 25 L maximum emptying threshold. A subsequent steady increase of the toilet usage to approximately 10 visits per day was observed until *day 19*. A second drop in the number of visits to the toilet was noticed during the Easter holidays (*day 22–24*). Shortly after, and for a period of approximately two weeks, the number of visits increased up to an average of 20 visits per day. The third drop on *day 37* was caused by the malfunctioning of the occupancy sensor; the night-time visits on that day were not recorded. Therefore, for the calculation of average users after *day 24*, the data from *day 37* was excluded. Further on, until the end of the evaluation period, the observed average number of visits reached

Table 1
List of selected parameters of interest for field testing.

Parameter	Indicator	Data
Faeces tank emptying time and frequency	Dates of emptying, # of emptying events per week.	EL
Urine tank emptying time and frequency	Dates of emptying, # of emptying events per week.	EL
Cumulative usage	# visits per day	EL
Day-time and night-time usage	# visits at day and night per day (24 h)	EL
Male and female visitors	# visits by males and females per day	EL + mL
Adult and child visitors	# visits by adults and children per day	EL + mL
Defecation and/or urination	# visitors defecating and/or urinating per day	EL + mL + U/D A
Duration of occupancy by males and females	minutes	EL
Duration of defecation and urination	minutes	EL + U/D A
Amount of urine produced by male and female visitors per visit	mL (measured as g, 1 mL = 1 g) per visit and cumulative amount	EL + U/D A
Amount of faeces produced by male and female visitors per visit	g per visit and cumulative amount	EL + U/D A
Wash-water usage by male and female visitors, for urination and/or defecation, and by adult and child visitors.	mL (measured as g, 1 mL = 1 g) per visit and cumulative amount	EL + U/D A

EL: Electronic Logs; ML: Manual Logs; U/D A: urination/defecation analysis.

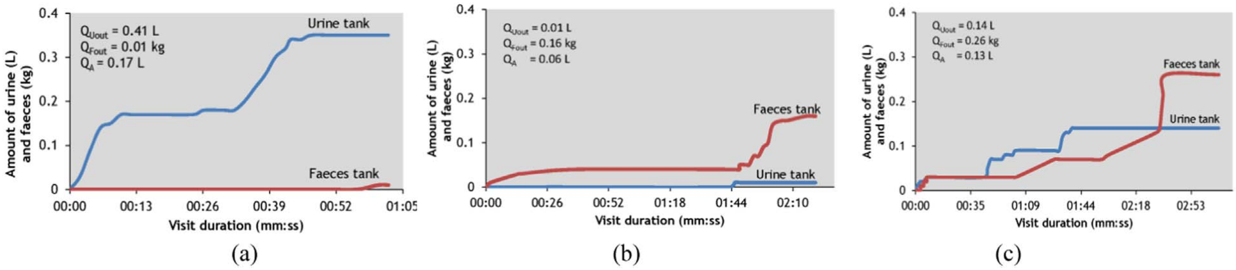

Fig. 4. Examples of individual practice in case of urination: (a) urination to urine tank only; (b) urination to faeces tank; (c) steady flow to urine tank with occasional discharge to faeces tank, with some cleansing water flowed to faeces tank at the end of the visit.

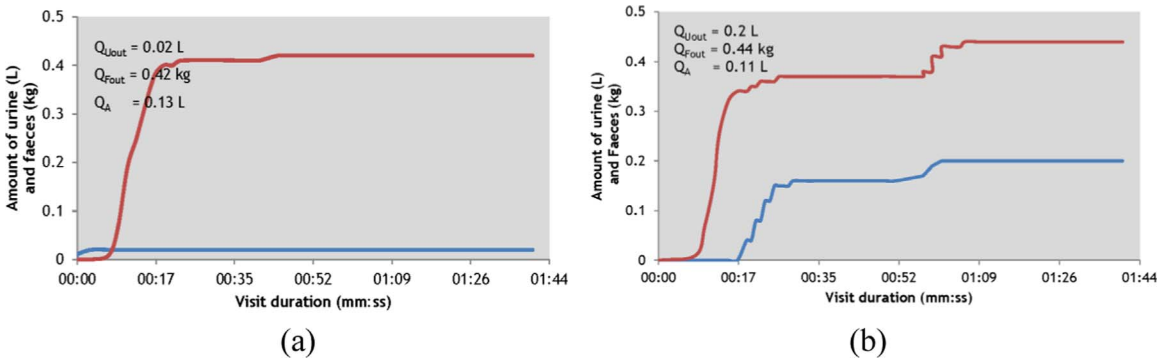

Fig. 5. Examples of individual practice in case of defecation; (a) practice with minor discharge of urine to urine tank; (b) practice with considerable discharge of urine to urine tank.

19 visits per day.

The faeces tank was emptied every 3–5 days, while the urine tank had to be emptied every day. When the toilet usage increased, the emptying frequency for the faeces tank became every 2 days on average (after *day 26*). In total, the faeces and urine tanks were emptied 19 and 43 times, respectively, during the evaluated period.

3.2. Quantification of waste streams

The average amount of urine excreted by a male and female visitor were 170 ± 134 mL[4] and 178 ± 130 mL, respectively. No distinction was made between adult and child visitors. Subsequently, the amount of generated faecal sludge was calculated, revealing an average amount of faeces excreted per visit by male and female visitor of 356 ± 250 g and 350 ± 240 g, respectively.

The recorded water consumption per visitor was also calculated in relation to gender, age (adult or child), and activity (urination or defecation). Males and females used on average approximately the same volume of water of 0.27 and 0.29 L respectively; comparatively, more water was used when defecating (0.44 L) than when urinating (0.17 L). Children used on average 0.31 L of water, which is nearly 30% more than adults (0.24 L). The average water consumption varied between 120 mL and 500 mL per visit. Further aggregated water consumptions to male/female per activity and adult/child per activity are presented in Figs. 7 and 8 respectively.

3.3. Usage patterns

The information gathered both by the sensors and manually allowed the disaggregation of the data into defined categories to elucidate the toilet usage patterns. Fig. 9 illustrates the toilet occupancy during day time (06:00 to 18:00 h) and night time (18:00 to 06:00 h). During the evaluated period, the average number of day- and night-time visits

[4] The sensor measures the weight of urine. Using the urine density of 1 g/mL, the results were then reported in mL.

Table 2
Flow division between urine and faeces tank depending on the practice in the toilet.

No		Urination (%)		Defecation (%)	
		Urine tank (%)	Faeces tank (%)	Urine tank (%)	Faeces tank (%)
1	All usages (n = 394; 259, respectively)[a]	52	48	26	74
2	Usages with cleansing water (n = 252; 225)	48	52	27	73
3	Usages without cleansing water (n = 142; 34)	61	39	17	83

[a] n = urinate; defecate.

were 8.2 and 5.3, respectively, with a maximum of 21 day-time visits (on *day 27*) and 10 night-time visits (on *day 48*).

Subsequently, an analysis was conducted across other categories i.e. gender, age, and urination and defecation activities. It was found out that more females than males visited the toilet, and more adults did than children. The results are summarised in Table 3.

When looking at the time a user spent on the toilet it was observed that women on average occupied the toilet a bit longer (3.8 mins on average) compared to men (3.4 mins on average). The occupational time varied from 7 s to a maximum of 20 min.

The individual time a user spent on the toilet was related to the activity (urination or defecation, including urination) as presented in Fig. 10. The time needed for a urinating visit was on average 2.9 ± 2.5 min, while the time needed for a combined defecating and urinating visit was on average 4.7 ± 3.5 min; which is approximately 50% longer.

Further analysis of the data showed that the usage duration classified per males urinating, males defecating, female urinating, and female defecating was 2.7, 4.1, 3.1, and 5.1 mins, respectively.

Out of the total reported day-time usage, only 34% corresponded to male usage, 53% to female usage, and 13% corresponded to

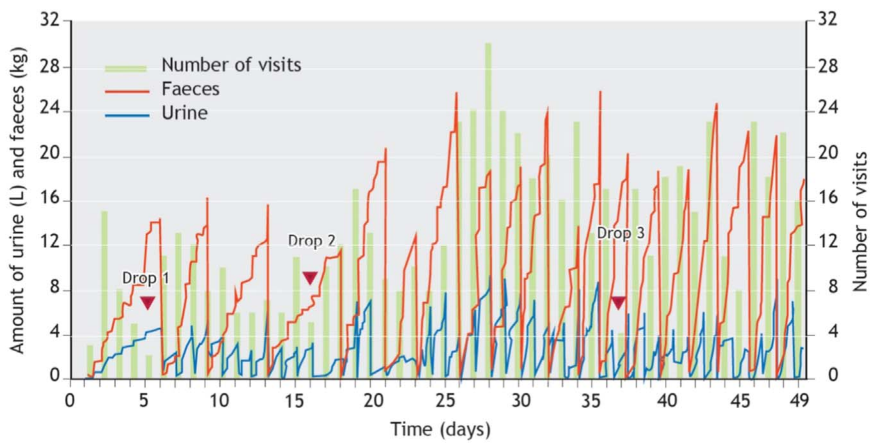

Fig. 6. Number of visits to test toilet (green bar) and cumulative amount of urine (blue line) and faeces (red line) recorded during the evaluation period. Drop 1, 2 and 3 indicate the time a sudden decrease in number of visits occurred. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

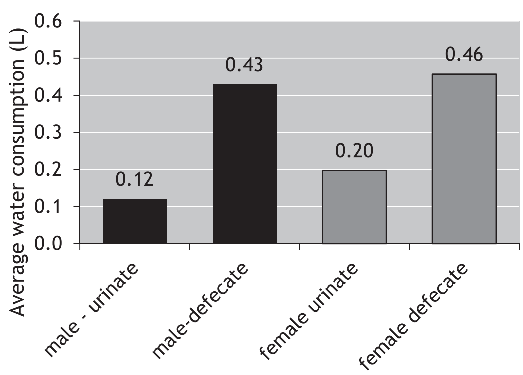

Fig. 7. Average service water consumption by male and female users per activity (urination and defecation).

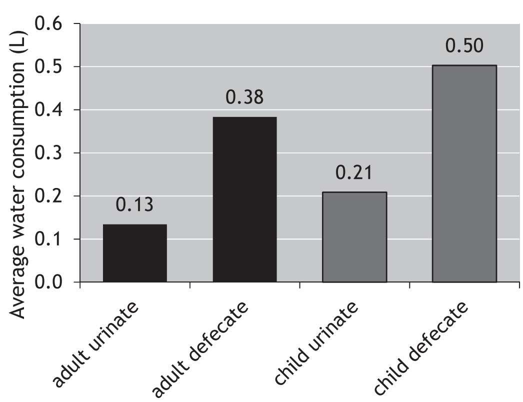

Fig. 8. Average service water consumption by adult and child users per activity (urination and defecation).

Table 3
Disaggregated toilet usage data into gender, age and activities categories.

Parameters	Average daily visits	% of total users	% of total users (excluding unidentified users[a])
Male	4.4	33	38
Female	7.3	54	62
Unidentified[a]	1.8	13	
Adult (≧ 18 years old)	7.0	52	60
Child (< 18 years old)	4.7	35	40
Unidentified	1.8	13	
Urination	8.3	60	
Defecation	5.1	40	

[a] Some visits did not match entry at the manual log, thus toilet user for that particular visit could not be identified.

unidentified or unregistered users. These figures are similar to the ones obtained for the night-time usage. Out of the total reported day-time usage, 58% corresponded to urination, while 42% for defecation. From the night-time usage observations more urination episodes were observed (64%), while only 36% was identified for defecation. Table 4 summarises these results.

The cross-category analysis generated additional insights, such as the increased usage for urination at night (58% day-time to 64% night-time). Men used the toilet equally for urination and defecation (50% urination, 50% defecation), while women used it more for urination (63% urination, 37% defecation). A consistent proportion was observed for women urinating and defecating during the day and night time (64% urinating and 36% defecating). Men changed their behaviour, where more men (55%) using the toilet to defecate during the day time, but at night, more men (60%) urinating. Unidentified users are mostly those who visited the toilet for urination (67%).

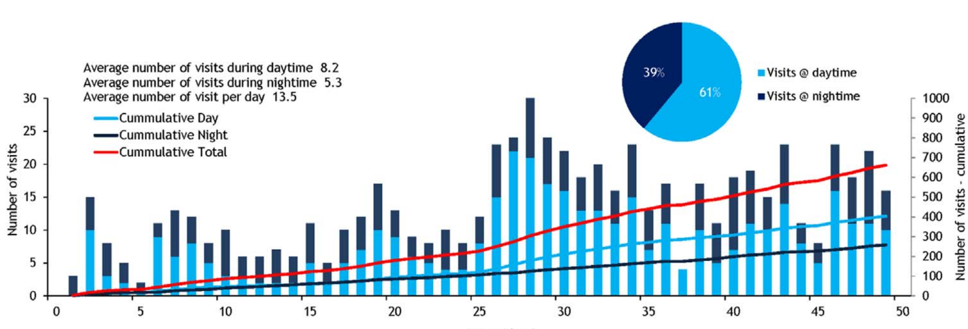

Fig. 9. Test toilet occupancy during day and night hours.

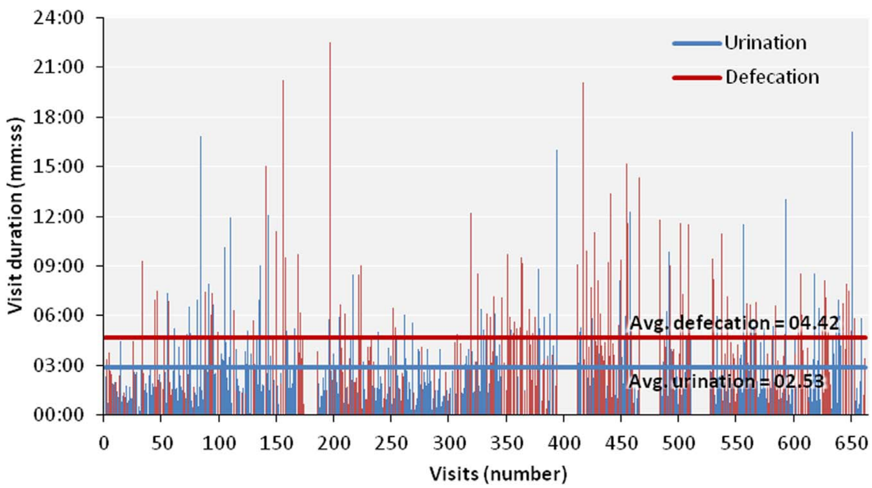

Fig. 10. Duration of occupancy of the test toilet for visitors who only urinate, or defecate and urinate.

Table 4
Summary of cross category analysis (%).

Category	Day	Night	Male	Female	Non-registered m/f	Adult	Child	Non-registered a/c	Urinate	Defecate
Day	NA	NA	34	53	13	52	35	13	58	42
Night	NA	NA	30	56	14	52	34	14	64	36
Male	64	36	NA	NA	NA	62	38	NA	50	50
Female	60	40	NA	NA	NA	58	42	NA	63	37
Non-registered m/f	59	41	NA	NA	NA	NA	NA	NA	67	33
Adult	61	39	40	60	NA	NA	NA	NA	57	43
Child	62	38	35	65	NA	NA	NA	NA	61	39
Non-registered a/c	59	41	NA	NA	NA	NA	NA	NA	67	33
Urinate	58	42	28	58	15	49	36	15	NA	NA
Defecate	64	36	40	49	11	55	34	11	NA	NA
Day-time men									45	55
Day-time women									64	36
Night-time men									60	40
Night-time women									64	36

4. Discussion

From the overall operational perspective, the test toilet and the associated software functioned properly providing a large amount of novel and reliable data. All the smart components of the toilet functioned as planned. Some issues were found after a few days of usage such as a malfunctioning urine odour trap at the UD (urine diversion) pedestal. A few other issues developed later, e.g. the occupancy sensor (person's weight sensor) gradually lost sensitivity due to moisture and infestation of insects.

The results of the field testing are considered valid to the chosen study location, time period, and testing conditions. A user acceptance evaluation was also performed in this period [20]. As the present study only involved one experimental version of the toilet located in the vicinity of other earlier built standard toilets, the application in a different setting, for example a scaled-up field testing with more units of test toilet and no other toilets, are present, may yield different results. Moreover, different results may also be observed when separate male and female toilets, or a separate male urinal inside or outside the toilet are applied. These aspects deserve further research in the future.

4.1. Service capacity assessment

During the field testing, the test toilet received up to 30 visits per day. Because each visit in most cases was by a different person, it can be safely assumed that the toilet was used by up to 30 persons a day. According to SPHERE [21] and UNHCR standards,[5] this usage corresponds to a transitional phase between short and long term phases commonly observed at emergency settings

The maximum serving capacity for the experimental toilet unit evaluated in this research was calculated. A maximum stay duration of 5.4 mins for urination and 8.2 mins for defecation was considered; in addition, a daily urination to defecation ratio of 60/40 was considered. Within a 24 h period taking into account 8-h of inactive and maintenance period, the toilet would have been capable of serving approximately 105 urinating visits and 45 defecating visits; that is, a total of 150 visits per day. In case of not considering urination and defecation details into account, and using an overall average visit duration of 3.6 mins, a total of 265 visits per day can be estimated to be possible. Assuming that a person visits the toilet twice a day, 265 visits equate to approximately 130 users.

Based on this calculation, and considering the reality in the field where an emergency toilet may need to serve over 100 displaced persons per day at the beginning of a crisis (Fig. 1), the test toilet has the potential for being also used in the acute emergency phase.

In addition, the load accumulation rate for the faeces and urine tank can be calculated to find a suitable urine/faeces volumetric ratio for sizing the volume of the urine and faeces collection tanks considering a simultaneous emptying of both tanks. The calculations are presented in Table 5. Different usage/operation modes are included in this evaluation considering the actual usage (as in this research), waterless usage, and non-urine-diverting interfaces (that is, the use of only one tank with

[5] Sphere and UNHCR standard for latrine provision lined that one latrine should be provided to every 50 persons in the short-term emergency and every 20 persons in the long term emergency phase.

Table 5
Calculation of tank volume ratio and corresponding retention time.

No		Calculation formula/source	Actual				Waterless usage				Combined tank with cleansing water	
			Urination		Defecation		Urination		Defecation		Urination	Defecation
			Urine tank	Faeces tank	Urine tank	Faeces tank	Urine tank	Faeces tank	Urine tank	Faeces tank	Combi tank	Combi tank
[1]	Load per visit incl. anal cleansing water (average, kg)	Obtained data	0.35		0.91		0.15		0.58		0.35	0.91
[2]	Flow (average, %)	Obtained data	52	48	26	74	61	39	17	83	100	100
[3]	Urinate-defecate visitors ratio	Obtained data	0.6		0.4		0.6		0.4		0.6	0.4
[4]	Tank capacity (L)	Actual	80	80	80	80	80	80	80	80	160	
[5]	# of visits daily	Assumption	20				20				20	
[6]	Load per visit per tank (kg)	[1] × [2]	0.18	0.17	0.23	0.67	0.09	0.06	0.10	0.48	0.35	0.91
[7]	Mass volume (kg/L)	Estimated values	1	1	1.25	1.25	1	1	1.4	1.4	1	1.25
[8]	Daily load volume to tank (L)	[6] × [5] × [3] /[7]	2.16	1.99	1.49	4.32	1.10	0.70	0.58	2.75	4.15	5.80
[9]	Retention capacity of urine tank (d)	[4]/Σ[8] urine tank	22				48				16	
[10]	Retention capacity – faeces tank (d)	[4]/Σ[8] faeces tank	13				23					
[11]	Volume ratio	[9]/[9]; [9]/[10]	1	1.7	1	1.7	1	2.1	1	2.1	N/A	
[12]	Simulated volume using [11] (L)	Correlated tank ratio to result in total volume of app. 160 L[a]	60	102	60	102	50	105	50	105	N/A	
[13]	Control retention capacity - urine tank (d)		16				30				N/A	
[14]	Control retention capacity (faeces tank)-days		16				30				N/A	

[a] Current tanks volume is 80 L each to make up to total 160 L. This volume also represents the available space at the tank chamber – thus it is used as the basis for calculation.

mixed urine and faecal sludge). This approach was considered useful for application in locations under different situations i.e. where users do not use water for anal cleansing or where there are non-urine diverting toilet interface provisions. The integration of sensors and ICT into the toilet provided information for determining the flows of urine and faeces into the urine and faeces tanks. The flow percentage to each tank in Table 5 Row 2 was obtained from Table 2. The exact mass of urine and faeces discharged into each tank was calculated and presented in Table 5 Row 6. Tanks flow data from usages without cleansing water was used to project waterless usage, i.e. the case of dry toilets. Such tank flow data was averaged to be included for the tank volume ratio calculation. The application of a mixed tank (i.e. where there is only one tank for faeces and urine collection) was also projected using all tank flow data and same calculation process. This approach is useful for application in locations under different situations i.e. where users do not clean with water or a non-urine diverting toilet interface.

Assuming 20 visits to the toilet per day, the daily load of each tank was calculated and converted to volume. The retention time, which is related to the emptying frequency, was obtained by dividing the designed tank volumes by the daily produced volume (Table 5 Rows 9 and 10). Finally, the urine/faeces tank ratio was obtained (Table 5 Row 11). The calculations suggested that for the current usage situation (using anal cleansing water), the urine/faeces tank volume ratio should be 1–1.7; however, for the case of waterless usage, the tank ratio should be 1–2.1. The volumes of each tank were recalculated considering that both tanks have the same retention capacity; therefore, both tanks can be emptied at the same time (calculations presented in Table 5 Rows 12–14).

The usage of a waterless toilet reduced the load volume, as well as changed the flow segregation percentage to each tank. With almost the same volume, the emptying frequency for waterless usage could be once every 30 days, compared to 16 days for the usage with cleansing water.

4.2. Usage pattern analysis

The automatized monitoring system allowed collection of usage information to justify the effectiveness of the toilet provision in the community. The automatized monitoring system combined with manual log data was able to inform about gender and age group of the toilet users, as well as to provide details of the stay duration, and timing of the visit. There were more usages during the day than during the night. However, the fact that 39% of the usages took place at night suggests that the night-time related toilet features such as lighting and smart lock system functioned properly during the night. This positive result is also supported considering that 40% of female users visited the toilet at night and so did 38% of child users.

When segregating the usage by males and females, the results showed that the test toilet was used more by females than males (despite there were about equal proportion of males to females in the bunkhouse). This is an extremely encouraging observation; that is, the test toilet support access to more women, contradicting concerns that communal sanitation facilities often poorly serve the less privileged including women for example the case of urban slums [22,20].

The male population at the camp did not necessarily need the privacy features of the toilet to urinate as it was observed that they were urinating in the open. In addition, adult males hesitated to change their urinating habit and be seated to urinate (as required by the toilet users guidance) since they are accustomed to urinate standing [20]. However, the data indicated that there were males who used the toilet to urinate, and that they usually do it during night (60% night-time male users urinated, compared to only 45% day-time male users that urinated). This might be because they feel more secured urinating in the toilet at night-time. It can be concluded that the provision of a male urinal would not likely be effective at this study location, unless the urinal is in well-protected structure and well-lit at night.

Out of the entire identified usages, 60% were by adults and 40% were by children. An adult is defined as a user of 18 years of age or older. The toilet was regulated to be used by users older than or equal to 7 years old. Thus, despite this restriction, still having 40% of child users implies that the toilet was appealing to children.

It was observed that 60% of usages were for urination and 40% were for defecation. Considering that a person normally urinates 5–8 times a day [23–25], and defecates 1–2 times a day [26], the number of defecation visits was relatively high. This may be attributed by the availability of other alternatives to urinate e.g. males that urinated in the open and other toilets. Also, most users did not stay at the bunkhouse all day.

On average females spent 3.8 min in the toilet, and males 3.4 min. The type of activity (urination or defecation) had more effect on the toilet occupancy time than gender. On average, users spent 2.9 mins to urinate and 4.7 mins to defecate. Nevertheless, although the difference between males and females was not significant, when the gender category was split up into urination or defecation, a more prominent difference was observed. Females appear to take nearly half a minute longer to urinate, and a minute longer to defecate than males. The time people spend in a toilet depends on many factors such as user's habitual routines, health condition, and many more, which might not be related to the toilet's functionalities.

Insignificant differences between males and females were also observed for the average generated amount of combined urine and faeces per toilet visit. Male users generated on average 170 mL of urine and 360 g of faecal sludge per person per toilet visit, while female users generated on average 180 mL urine and 350 g faecal sludge. Calculating the daily urine production per person that ranges between 600 – 2600 mL and average urination frequency of 6 times per day [26], then a person excretes between 100 and 430 mL urine every time. This study reports urine excretion at the lower side of that range; this may be attributed to less water consumption, hotter climate (people transpire more), or a combination of these factors. When comparing faeces production results obtained in this research with a compilation of wet faeces amounts reported by Franceys et al. [27], the results fit into the suggested range of 209 – 520 g per person per day, assuming that the test toilet users defecate once a day.

The results were reported after removing some abnormal usage data such as a case where an extremely high faecal sludge volume was discharged within a short period of usage (e.g. 3 kg by a 12-year old boy who weighted 36 kg). Assuming on the fact that people keep a pot in their house for emergency-use, for children or for elderly during night, some users might have used the toilet to discharge their night soil, but this could not be confirmed.

Assuming that a person urinates twice and defecates once a day, using the same toilet, then this study shows that a person produces on average 360 g faecal sludge a day without anal-cleansing water. This result is within range with studies characterizing faecal sludge mass [26,27]. Norris [28] showed an average sludge build-up rate of 0.07-L/persons/day for VIP latrines and 0.08 L/persons/day for septic tank systems, much lower than the findings of this study. However, this sludge build-up rate resulted from a combination of processes such as consolidation at the bottom of the pit or tank, leaching of soluble substances, and evaporation [27].

The SPHERE standard recommends the use of a female to male ratio of 3:1 to calculate the required number of toilet cubicles. The findings of this research suggest a-3:2 ratio, considering that the proportion of toilet usage was 60% females and 40% males, and that the duration of females and males is not significantly different.

Women used only a bit more water i.e. 0.29 L per visit compared to 0.27 L per visit for men. The amount of water consumed depended more on the type of activity (urination or defecation). On average, users spend almost three-times the amount of water when they defecate (0.43 L) compared to when they urinate (0.17 L). Comparison of the difference between adults and children revealed that children users tend to spend more water (0.31 L) compared to the amount that the adults used (0.24 L). Nevertheless, the overall water consumption of the test toilet has proven that it uses significantly less water compared to the traditional pour flush toilets in use at the testing site. This is attributed to the combination of the mechanism (non-flushing) and the smart features (i.e. water button – solenoid valve) that limits and thus reduces the water use. It was observed that people used on average 1.2 L of water to wash after urinating, and 1.9 L after defecating in their conventional toilet [29]. These figures exclude an average of 4.4 L of water used for flushing the pour-flush pedestal. It can be concluded that the test toilet reduced the water consumption from 77% saving without considering flushing water, to 97% saving when considering flushing water. Considering that the water was scarce at the evaluated location, the water-saving feature of the toilet was a valuable contribution for the community.

4.3. O&M and monitoring

Choosing a container based sanitation system has an inevitable consequence of frequent tank emptying relevant to usages; therefore higher maintenance cost. In the case of test toilet which is categorized as a container based sanitation, the sensors integrated with the online monitoring system allowed for a responsive maintenance. This resulted in an optimized tank emptying frequency and continuous use of the toilet throughout the evaluated period, except during the daily cleaning time. The faeces tank was emptied when it was at its maximum holding capacity (25 kg), and the emptying frequency was adjusted for the toilet usage (once per 3–5 days at the beginning, once per 1–2 days later). Without the monitoring system, fixed periodical emptying would have been applied, and this would have caused either lack of emptying efficiency or missing collections; thus, loss of toilet service capacity.[6]

A simulation applying a fixed periodical emptying of once every 1-, 2-, 3-, 4-, and 5-days was made to support this argument. The simulation compares the fixed periodical emptying activities to the emptying frequency observed at the toilet field testing; that is, using the same duration of 7 weeks, same amount of faecal sludge generation (faeces, wash-water and incidental urine), and same daily visits. The analysis was conducted under steady state (same number of visitors generating steady daily faecal sludge of 5.2 kg) and dynamic state (fluctuating number of visitors and faecal sludge loads as experienced in the field testing). When the cumulative faecal sludge production reached 25 kg, the toilet was made closed from visitors resulting in loss of users for that day. The loss of service capacity and the number of emptying/maintenance performed for each simulated emptying period were calculated. Results are as presented in Table 6.

When simulating a fixed periodical emptying frequency of once every 4 days in comparison with the actual toilet usage, the faeces tank would have been emptied 12 times during the study period, instead of 18 times in practice, reducing approximately 33% the maintenance cost dedicated for emptying (as shown on the second row on Table 6). When simulated under dynamic state, this action would cause the loss of service capacity of 35% of the total toilet visits. Subsequently, a once every 3 days emptying frequency, which was the closest to the actual operation at the field, reduced the maintenance costs with 11% (as shown on the second row on Table 6). Still a 22% of service capacity on a dynamic scenario would have been lost. However, increasing the emptying frequency of once every 2 days would need 24 times of maintenance (6 times more than the evaluated test operation), a 33% increase on the maintenance costs and still causing a loss of about 4% on service capacity. When simulated under steady state, no loss of service capacity is experienced until the emptying frequency is set to once every 5 days, in which there would be approximately 18% loss.

This simulation demonstrates that a fixed emptying period would not result in optimum toilet maintenance for operation in an area where the toilet usage highly fluctuates, and that the monitoring system optimizes the maintenance efficiency at minimum maintenance expenses and service capacity loss.

Table 6
Simulation of applications of different fixed periodical emptying compared to the emptying practice during the field-testing period ("This study", which ranged between once every 2–3 days).

Emptying frequency (d)							
		1	**2**	**This study**	**3**	**4**	**5**
Number of emptying events		48	24	18	16	12	9
Emptying efficiency vs. test toilet's emptying		−167%	−33%	N/A	11%	33%	50%
Loss of service capacity	Dynamic	0%	4%	N/A	22%	35%	39%
	Steady	0%	0%	N/A	0%	0%	18%

A case of a fixed emptying schedule was demonstrated for the usage of the Freshloo Toilet by Sanergy in Kenya with daily collections [10]. There was no report of missing collection in this case for the frequent collection schedule; however, the system would benefit from an optimized collection system using the responsive maintenance scenario. Particularly, considering that Sanergy operates in an up-scaled system (170 toilets with 8000 usages a day); in addition, the collected faecal sludge is used to either produce fertilizer or biogas. An optimum collection frequency would result in an optimized operation reducing the expenses and increasing the production of faecal sludge by-products.

Pilot testing of CBS in Haiti were conducted on a weekly collection period. Occasional missing collections[7] were reported representing 0.5% of total faecal sludge removed by household service over the study period [13]. Despite the small proportion that accidentally was released into the environment, it may represent dire risks should the event take place in an epidemic prone area, as it is frequently the case in most emergency settlements. On this work conducted at the Philippines, the toilet was locked using the software whenever the tanks reached its full capacity threshold. Nevertheless, the application of the toilet with its smart monitoring system has not been evaluated in an up-scaled application. Thus, a 100% safe faecal sludge removal, although promising, cannot be concluded at this phase.

The field testing of the toilet did not include the treatment of the collected faecal sludge and urine. The collected faecal sludge and urine was discharged to a communal septic tank near the pre-existing shared toilet block. The faecal sludge and urine were characterized to determine their physical-chemical composition. The results showed similar properties as observed on fresh faecal sludge and fresh urine. Further study is required to determine suitable treatment option for such discharges. Previous reports trialling a portable dry toilet in emergency suggest possibility of composting with fertilizer as end product as treatment and reuse or disposal option [30], as well as potential of urine utilization as fertilizer [31]. References on treatment option for much more watery faecal sludge coming from a community that wash after toilet with water, is scarce. There are variety of treatment options under developments, including the microwave-based technology that was recently tested with fresh faecal sludge, septic sludge and waste activated sludge [32].

5. Conclusions and recommendations

The following general conclusions can be drawn: (a) the eSOS Smart Toilet features and its accompanying eSOS Monitor software was

[6] Loss of service capacity implies to the loss of potential visitors that might have used the service of the toilet.

[7] The CBS team operates by having weekly collection to each household subscribing to the CBS system services. The household users however have the access to remove the containment tank by themselves.

proven to work effectively during the field testing, (b) the ICT functionality allowed for continuous monitoring and remote adjustable operation of the toilet, (c) the smartness of the toilet was found useful to gain new insights in the design requirements of the toilet related to the frequency/intensity of use, usage patterns of the toilet in a real-life situation, requirements for improved O&M, and for continuous monitoring of the toilet, and (d) the experimental toilet is currently considered to be at technology readiness level 5 (TRL 5).[8]

With regards to design requirements the following applies: (a) the toilet was evaluated by the occupancy of maximum 30 persons per day in a long term emergency phase. It was calculated that the toilet could serve more than 200 visits a day; thus, the toilet can also be applied in the short term/immediate emergency phase, and (b) urine to faeces tank volume ratio was calculated to be 1.0:1.7 for usage with anal-cleansing water, and 1.0:2.1 for waterless usage considering a simultaneous urine and faeces tank emptying.

The most prominent outcomes related to usage patterns can be summarised as: (a) the eSOS Smart Toilet field testing generated data in detail that has never been obtained before, such as usage patterns by day-night time, by gender, by age group, by activity (i.e. it was possible to develop a methodology for automatic identification of urination and defecation), toilet occupancy time, faecal sludge and urine production per visit, and water consumption per visit, (b) the toilet was predominantly used during the daytime (61%), by adult users (60%), by female users (62%), and mostly for urinating (60%), (c) male users tend to use the toilet to urinate at dark hours (60% of total male visits were at night), (d) male and females are not different with regards to the time spent in the toilet, amount of urine and faecal sludge produced, and water consumption, and (e) differences in stay duration in toilet and water consumption depend on the type of activities i.e. urination or defecation.

The most important finding related to the O&M practices as follows: (a) knowledge on the O&M under real usage allowed the performance of a proper evaluation aiming at achieving improvements in terms of cost savings, better services, and a vision for sustainability, (b) the eSOS Smart Toilet saves up to 97% of water compared to a conventional pour flush toilet, and (c) application of the toilet's sensor and monitoring system allowed for a responsive maintenance. Application of such a responsive maintenance resulted in an optimum toilet usage efficiency by a minimum loss of users.

Based on the findings, some recommendations are presented as follows: (a) to continue with the prototype development to reach TRL 7 and ultimately TRL 9 using the feedback gained from the field testing and to test it for endurance and functionalities, (b) to develop a modular set-up (which has not been developed for the experimental prototype) and different types of eSOS Smart Toilet adjustable to socio-cultural requirements (urine diversion / non-urine diversion user interface, pedestal / squatting pans, anal wash water / waterless, etc.), (c) to develop the eSOS Smart Toilet configurator (to allow for different custom-made configurations), and (d) to develop the eSOS Business Model Software (to calculate economic and financial feasibility to different eSOS applications globally).

Acknowledgement

This work is funded under the project ‘Stimulating local innovation on sanitation for the urban poor in sub-Saharan Africa and South-East Asia’ financed by Bill and Melinda Gates Foundation (OPP1029019) and the field research was funded by Asian Development Bank (ADB) through its scheme titled ‘Knowledge and Innovation Support for ADB's Water Financing Program’ (RET 6498). The field research would not have been possible without assistance and support of Samaritan Purse Philippines and the community of Abucay Bunkhouse, Tacloban City, Philippines.

[8] Using European Comission (EC)’s definition, TRL 5 is defined as technology where it has undertaken technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies); TRL 7 – system prototype demonstration in operational environment and TRL 9 – actual system proven in operational environment.(competitive manufacturing in the case of key enabling technologies; or in space) [33].

References

[1] M.A. Connolly, M. Gayer, M.J. Ryan, P. Salama, P. Spiegel, D.L. Heymann, Communicable diseases in complex emergencies: impact and challenges, Lancet 364 (2004) 1974–1983, http://dx.doi.org/10.1016/S0140-6736(04)17481-3.
[2] S.C. Waring, B.J. Brown, The threat of communicable diseases following natural disasters: a public health response, Disaster Manag. Response 3 (2005) 41–47, http://dx.doi.org/10.1016/j.dmr.2005.02.003.
[3] I.K. Kouadio, S. Aljunid, T. Kamigaki, K. Hammad, H. Oshitani, Infectious diseases following natural disasters: prevention and control measures, Expert Rev. Anti. Infect. Ther. 10 (2012) 95–104, http://dx.doi.org/10.1586/eri.11.155.
[4] F. Zakaria, H.A. Garcia, C.M. Hooijmans, D. Brdjanovic, Decision support system for the provision of emergency sanitation, Sci. Total Environ. (2015) 512–513, http://dx.doi.org/10.1016/j.scitotenv.2015.01.051.
[5] J. Parkinson, M. Quader, The challenge of servicing on-site sanitation in dense urban areas: experiences from a pilot project in Dhaka, Waterlines 27 (2008) 149–163, http://dx.doi.org/10.3362/1756-3488.2008.017.
[6] A. Bastable, J. Lamb, Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas, Waterlines 31 (2012) 67–82, http://dx.doi.org/10.3362/1756-3488.2012.007.
[7] J. Brown, S. Cavill, O. Cumming, A. Jeandron, Water, sanitation, and hygiene in emergencies: summary review and recommendations for further research, Waterlines 31 (2012) 11–29, http://dx.doi.org/10.3362/1756-3488.2012.004.
[8] A. Johannessen, J. Patinet, W. Carter, J. Lamb, Sustainable sanitation for emergencies and reconstruction situations - Factsheet of Working Group 8. 〈http://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/797〉.
[9] G. Morshed, A. Sobhan, The search for appropriate latrine solutions for flood-prone areas of Bangladesh, Waterlines 29 (2010) 236–245, http://dx.doi.org/10.3362/1756-3488.2010.024.
[10] D. Auerbach, Sustainable Sanitation Provision in Urban Slums–The Sanergy Case Study, in: Evan A. Thomas (Ed.), Broken Pumps and Promises, Springer, Cham, Switzerland, 2016, pp. 211–216.
[11] A. Naranjo, D. Castellano, H. Kraaijvanger, B. Meulman, A. Mels, G. Zeeman, The MobiSan approach: informal settlements of Cape Town, South Africa, Water Sci. Technol. 61 (2010) 3078–3090, http://dx.doi.org/10.2166/wst.2010.225.
[12] K. Russel, S. Tilmans, S. Kramer, R. Sklar, D. Tillias, J. Davis, User perceptions of and willingness to pay for household container-based sanitation services: experience from Cap Haitien, Haiti, Environ. Urban. 27 (2015) 525–540, http://dx.doi.org/10.1177/0956247815596522.
[13] S. Tilmans, K. Russel, R. Sklar, L. Page, S. Kramer, J. Davis, Container-based sanitation: assessing costs and effectiveness of excreta management in Cap Haitien, Haiti, Environ. Urban. 27 (2015) 89–104, http://dx.doi.org/10.1177/0956247815572746.
[14] V. Nayak, M. LuckoseA mobile based system for monitoring usage of household latrines and hygiene practices in Madhya Pradesh, India, in: Water, Sanit. Hyg. Serv. beyond 2015 Improv. Access Sustain, Proceedings of the 38th WEDC International Conference, Loughborough, UK, 2015.
[15] K. O'Reilly, E. Louis, E. Thomas, A. Sinha, Combining sensor monitoring and ethnography to evaluate household latrine usage in rural India, J. Water, Sanit. Hyg. Dev. 5 (2015) 426, http://dx.doi.org/10.2166/washdev.2015.155.
[16] A.A. Cronin, D. Shrestha, N. Cornier, F. Abdalla, N. Ezard, C. Aramburu, A review of water and sanitation provision in refugee camps in association with selected health and nutrition indicators - The need for integrated service provision, J. Water Health 6 (2008) 1–13 http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed8&NEWS=N&AN=2008107582.
[17] B. Murray, Average number of persons per toilet for 90,000 South Sudanese refugees in Uganda in camps of Adjumani, Arua and Kiryandongo, Presentation Slides in WASH in Emergencies Training by UNICEF-UNHCR at IHE Delft, Netherlands, 2015.
[18] D. Brdjanovic, F. Zakaria, P.M. Mawioo, H.A. Garcia, C.M. Hooijmans, J. Ćurko, Y.P. Thye, T. Setiadi, Practical paper eSOS– emergency sanitation operation system, J. Water Sanit. Hyg. Dev. 5 (2015), http://dx.doi.org/10.2166/washdev.2014.098.
[19] F. Zakaria, B. Harelimana, J. Ćurko, J. van de Vossenberg, H.A. Garcia, C.M. Hooijmans, D. Brdjanovic, Effectiveness of UV-C light irradiation on disinfection of an eSOS® smart toilet evaluated in a temporary settlement in the Philippines, Int. J. Environ. Health Res. 26 (2016), http://dx.doi.org/10.1080/09603123.2016.1217313.
[20] F. Zakaria, Y.P. Thye, C.M. Hooijmans, A.D. Spiegel, D. Brdjanovic, User acceptance of an eSOS smart toilet in a temporary settlement in the Phillippines, Water Pract. Technol. 12 (4) (2017) (in press).
[21] H. Charter, D. Response, The Sphere Project. doi:ISBN 978-1-908176-00-4, 2011.
[22] A. Biran, M.W. Jenkins, P. Dabrase, I. Bhagwat, Patterns and determinants of communal latrine usage in urban poverty pockets in Bhopal, India, Trop. Med. Int. Heal. 16 (2011) 854–862, http://dx.doi.org/10.1111/j.1365-3156.2011.02764.x.
[23] N.L. Schouw, S. Danteravanich, H. Mosbaek, J.C. Tjell, Composition of human excreta — a case study from Southern Thailand, Sci. Total Environ. 286 (2002)

155–166, http://dx.doi.org/10.1016/S0048-9697(01)00973-1.
[24] A.M. Bael, H. Lax, H. Hirche, E. Gäbel, P. Winkler, A.L. Hellström, R. Van Zon, E. Janhsen, S. Güntek, C. Renson, J.D. Van Gool, Self-reported urinary incontinence, voiding frequency, voided volume and pad-test results: variables in a prospective study in children, BJU Int. 100 (2007) 651–656, http://dx.doi.org/10.1111/j.1464-410X.2007.06933.x.
[25] B.A. Clare, R.S. Conroy, K. Spelman, The diuretic effect in human subjects of an extract of Taraxacum officinale folium over a single day, J. Altern. Complement. Med. 15 (2009) 929–934, http://dx.doi.org/10.1089/acm.2008.0152.
[26] C. Rose, A. Parker, B. Jefferson, E. Cartmell, The characterization of feces and urine: a review of the literature to inform advanced treatment technology, Crit. Rev. Environ. Sci. Technol. 45 (2015) 1827–1879, http://dx.doi.org/10.1080/10643389.2014.1000761.
[27] R. Franceys, J. Pickford, R. Reed, A Guide to the Development of On-Site Sanitation, WHO, 1992, p. 229, http://dx.doi.org/10.1002/ppul.1950120122.
[28] G. Norris, Sludge build-up in septic tanks, biological digesters, and pit latrines in South Africa, Pretoria, South Africa. ⟨http://www.wrc.org.za/Knowledge⟩ Hub Documents/Research Reports/544-1-00.pdf.
[29] Y.P. Thye, A framework to improve the product development process to achieve more effective sanitation response during emergencies, Institut Teknologi Bandung, Indonesia, 2016.
[30] Y. Kim, S. Hashemi, M. Han, T. Kim, H.-G. Sohn, The Waterless Portable Private Toilet: an Innovative Sanitation Solution in Disaster Zones, Disaster Med. Public Health Prep. 10 (2016) 281–285, http://dx.doi.org/10.1017/dmp.2015.166.
[31] S. Hashemi, M. Han, T. Kim, Optimization of fertilization characteristics of urine by addition of Nitrosomonas europaea bio-seed, J. Sci. Food Agric. (2016) 4416–4422, http://dx.doi.org/10.1002/jsfa.7652.
[32] P.M. Mawioo, C.M. Hooijmans, H.A. Garcia, D. Brdjanovic, Microwave treatment of faecal sludge from intensively used toilets in the slums of Nairobi, Kenya, J. Environ. Manag. 184 (2016) 575–584, http://dx.doi.org/10.1016/j.jenvman.2016.10.019.
[33] European Commission, Technology readiness levels (TRL), Horiz. 2020 – Work Program. 2014–2015 Gen. Annex. Extr. from Part 19 - Comm. Decis. C 4995, 2015.