Alternative Sanitation in Protracted Emergencies: Final Report

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Final Report: Alternative Sanitation in Protracted Emergencies

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1 Executive Summary

Urine-diversion dry toilets (UDDTs) are a type of sanitation system designed for dry excreta management. In these above-ground systems, urine is diverted at the squat plate and feces is collected below in one or two (alternating) vaults. In the two vault system, one vault is in-use or 'active' at a time, while the other 'closed' vault stores and inactivates pathogens in the waste, primarily via desiccation, over a time period of six to 12-months. While these toilets are often described as an ecological sanitation or 'ecosan' system, excreta reuse is not necessarily a design goal for UDDTs. Instead, they are often used as an alternative, on-site sanitation option in areas where traditional below-ground options, such as pit latrines, are impractical due to difficult soil/ground conditions, flooding, or lack of space.

UDDTs have been in use in a variety of contexts for decades, however, with few exceptions they have only been implemented at a small scale. There is limited documentation of the use of UDDTs in humanitarian crises or refugee settings where they may have increasing relevance; of that available, there is a paucity of evidence with regard to the acceptability and performance of UDDTs in these contexts. Acceptability of these systems in the literature is mixed, and the information that is available has only been documented outside of the humanitarian context. Performance is primarily measured via the World Health Organization (WHO) guideline values for verification monitoring in treated feces for use in agriculture. While reuse may not always be a component of UDDT implementation, the WHO guideline value of <1 helminth (i.e., *Ascaris*) egg and <1000 *E. coli* per gram total solids is understood to be a conservative measure of performance.

In early 2012, Oxfam GB was the agency responsible for the provision of water, sanitation and hygiene (WASH) facilities in the Dollo Ado refugee camps in Ethiopia. Due to the soil conditions in the area, which made pit latrine construction difficult and expensive, Oxfam GB and the United Nations High Commissioner for Refugees (UNHCR) decided that it was appropriate to install UDDTs at a pilot-scale in one of the Dollo Ado camps (Hiloweyn). The program scaled up considerably over a period of three years, with management passing to Norwegian Refugee Council (NRC) in 2014. Because of the significant scale-up, the US Centers for Disease Control and Prevention (CDC) partnered with UNHCR, Oxfam GB and NRC to design an evaluation of the UDDT performance and acceptability in Hiloweyn Camp, Ethiopia. The evaluation aimed to collect information to improve the implementation and management of this large program, in addition to contributing to the evidence base for understanding the potential role of this alternative sanitation system in emergencies.

The evaluation started in May of 2014 and concluded in late 2016. The acceptability evaluation comprised two, cross-sectional surveys of UDDT users and non-users over a period of 18-months. The field-based performance evaluation included environmental sampling for key physico-chemical and microbial parameters. A baseline investigation was performed in 2014 and 2015, following which a longitudinal study was initiated over a period of 12-months where a sample of UDDTs were seeded with known quantities ('tea bags') of *Ascaris*; a small laboratory-based additive study was conducted in early 2017 to supplement field results of the performance evaluation. CDC designed and managed all aspects of the evaluations, UNHCR supervised and facilitated field work, and NRC provided logistical support and sampling teams for the performance evaluation.

The acceptability evaluation provided insight into the use, condition and perceptions of the UDDTs in Hiloweyn camp. Generally, adoption and current, consistent and correct use of the UDDTs was high. Notably, these indicators were high even after most UDDTs had been in use for several years. Additionally, the infrastructure condition and usability of the UDDTs did not deteriorate from baseline to endline. Similar to reported use, many of these indicators were actually higher at the time of the endline, indicating that the toilets are well maintained in this setting. These findings differ from the limited data available from acceptability evaluations of UDDT programs in the development context.

The acceptability results indicate successful efforts on the part of multiple implementing partners over time, in terms of user education, maintenance and upkeep of the units. Compared to other large UDDT programs in use in the development context, for example in South Africa, one major difference may be that oversight and active management of the UDDTs is higher in the humanitarian context. In other words, it's not possible to attribute satisfaction to the sanitation type, rather, sanitation satisfaction may be high because sanitation services are generally well managed in this setting. Our findings support this conclusion as we found that satisfaction and sanitation preference did not differ between those assigned to UDDTs and other forms of sanitation. Nonetheless, these findings demonstrate that UDDTs are effectively introduced and utilized in this context and this may have implications for other humanitarian and non-humanitarian settings.

The physico-chemical results of the performance evaluation indicated consistently hot, very dry, and moderately alkaline (i.e., elevated pH) conditions within closed UDDT vaults; these results are consistent with the hot, arid desert climate in Hiloweyn camp and represent conditions well-suited for a desiccation technology. Overall, the UDDTs sampled in Hiloweyn were successful in reducing both *E. coli* and viable *Ascaris* over the 12-month longitudinal study period. However, not all UDDTs met guideline levels for microorganisms after the storage period, in spite of the dry, alkaline environment, which has management implications for waste handling and emptying. The proportion of sampled UDDTs that met the WHO *E. coli* guideline increased steadily over the sampling period, with 95% meeting the guideline at 12-months; however, *E. coli* in excess of guideline value was still present in some UDDTs after 1.3 years of storage in the baseline investigation and after 1 year of storage in the longitudinal investigation. While *E. coli* might have been introduced during the study periods, it is more likely that *E. coli* was able to survival in very small amounts of waste that retained moisture.

The baseline data indicated low concentrations of naturally-occurring *Ascaris* ova in the vaults, suggesting that *Ascaris* carriage in the Hiloweyn population was low. We measured considerable $\log_{10}$ and percent reduction values of *Ascaris* in the tea bags over the study period. We were unable to determine if bags met WHO guideline value; however, it is likely that well-mixed UDDTs would contain a lower concentration of *Ascaris* ova than was seeded into the bags and therefore reductions could result in waste that meets the guideline value. Moreover, because the treated waste in Hiloweyn is not intended for agricultural use, the guidelines provided a conservative measure of performance. Our findings indicate that the UDDTs in Hiloweyn camp could be managed on a 12 month emptying cycle, as the program planned, with care to ensure appropriate precautions are taken to prevent exposure during waste handling and in a secondary storage site location. Finally, the laboratory additive study results indicated that addition of lime (at 2-5% by weight) at the time of emptying may result in additional microbial inactivation. These findings suggest an additional microbiological safety measure which could be explored if vault contents had to be emptied earlier than 12-months of in-vault storage; if appropriate safety precautions for handling lime can be ensured, this may have relevance in Hiloweyn or in other settings (e.g., where the climate is less than ideal).

This evaluation provided valuable insight into the acceptability and performance of a large UDDT program implemented in a humanitarian context in Ethiopia, several years into the program and after considerable scale-up in Hiloweyn camp, Dollo Ado. The evaluation was implemented over more than a two-year period, allowing documentation of real field conditions over time including stored waste characteristics, toilet infrastructure, and overall user experience. Given that the program was several years into scale-up and therefore may have had stronger management and oversight than other locations, it is recommended that additional evaluations are undertaken in 1) more temperate and humid environments, 2) different cultural settings, and 3) earlier in implementation phase in an emergency setting. This may assist with developing guidance around a range of appropriate settings and conditions for UDDT use in humanitarian contexts. A number of lessons learned were documented from this evaluation, which may assist implementers in Dollo Ado and elsewhere – both in humanitarian and non-humanitarian settings.

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2 INTRODUCTION

Urine-diversion dry toilets (UDDTs) are a type of sanitation system designed for dry excreta management. In these above-ground systems, urine is diverted at the squat plate and feces is collected in one or two (alternating) vaults under the squat plate. In the two vault system, one vault is in-use or 'active' at a time, while the other 'closed' vault stores the waste for sanitization, primarily via desiccation over a time period of six to 12-months (Rieck et al, 2012). After the storage period, the contents of the closed vault are emptied and it becomes the new active vault; the adjacent vault is then closed for storage. While these toilets are often described as an ecological sanitation or 'ecosan' system, excreta reuse is not necessarily a design goal for UDDTs. Instead, they are often used as an alternative, on-site sanitation option in areas where traditional below-ground options, such as pit latrines, are impractical due to difficult soil/ground conditions, flooding, or lack of space.

UDDTs have been in use in a variety of contexts for decades, however, with few exceptions they have only been implemented at a small scale (Uddin et al, 2013; WSP, 2005). There is little information regarding the use of UDDTs in humanitarian crises or refugee settings where they may have increasing relevance. Implementation of these systems on a small scale has been documented after emergencies in El Salvador (1998) and Afghanistan (1995) (Mwase, 2006). More recently, these technologies have been piloted in cyclone-affected regions of Bangladesh and the Philippines, in a refugee camp in Chad and at internally displaced person camps in Port au Prince, Haiti (Bastable & Lamb, 2012; Delepiere, 2011; Patinet, 2010). Despite documentation of implementation in these locations, little evidence exists as to the performance and acceptability of UDDTs in the humanitarian context.

In terms of acceptability of UDDTs, few evaluations have been published. Further, these evaluations have been completed in the development context, as opposed to the humanitarian context. Where evaluations have been completed, there have been mixed results in terms of acceptability (Roma, et al, 2013; Uddin, et al, 2012; Duncker & Matsebe, 2008). Most commonly, odor, maintenance issues and excreta handling have been cited as hurdles to acceptance and effective use of the toilets. Because of concerns that UDDTs would not be accepted by displaced or emergency affected populations they have rarely been implemented in these settings.

The specific environmental factors of UDDTs (temperature, moisture content, pH and storage time) needed to facilitate microbial inactivation are not well understood. While excreta reuse is often not a component of UDDT programs, the World Health Organization (WHO) guideline values for verification monitoring in treated feces for use in agriculture have been used as a conservative measure of performance of these systems (WHO, 2006). The WHO guideline values are <1 viable helminth (i.e., *Ascaris*) ovum and <1000 *E. coli* per gram total solids. In a recent technology review of UDDTs, the difficulty in reaching optimum conditions for microbial inactivation in-vault has been highlighted, in addition to the need to carefully consider handling and reuse (Rieck et al, 2012). Evaluations of UDDT performance in El Salvador, Panama, and South Africa showed that the necessary conditions were not achieved for inactivation of *Ascaris* eggs, after six to 12-months of storage (Mehl et al, 2011; Buckley et al, 2008; Moe et al, 2003). The use of additives (e.g., lime, ash, sawdust) to improve microbial inactivation has been piloted both in lab and field studies, with some promising results (Magri et al, 2013; Niwagaba et al, 2009; Austin and Cloete, 2008). However, optimization of these inputs under field conditions has not been achieved to-date.

2.1 UDDTs in Dollo Ado, Ethiopia

In early 2012, Oxfam GB was the agency responsible for the provision of water, sanitation and hygiene (WASH) facilities in the Dollo Ado refugee camps in Ethiopia. Due to the soil conditions in the area, which made pit latrine construction difficult and expensive, Oxfam GB and the United Nations High Commissioner for Refugees (UNHCR) decided that it was appropriate to install UDDTs at a pilot-scale in Hiloweyn, one of the Dollo Ado camps. Ninety, double-vault, single-family UDDT units were installed throughout 2012 and into early 2013. The design specifications of these units account for daily use by one household of 10-persons for six months.

Oxfam undertook a UDDT demand survey in September 2012, utilizing household questionnaires of users and neighbors as well as focus groups, in order to determine the preliminary acceptance of the technology. Over three-quarters of the units were in use at the time of the survey, with the primary reasons for non-use being that the unit was not fully constructed. Effective use of the units was also reported; almost all respondents reported adding ash after use and knew how to correctly use the UDDT. The perception of the UDDT was positive by both users and neighbors. However, uncertainty was expressed about the willingness to recycle the stored waste as a fertilizer (Oxfam, 2012). Additionally, it was identified that disabled persons and young children were unable to use the UDDTs effectively due to lack of mobility and understanding, respectively.

As a result of demand generated by promotional and mobilization activities, along with increased need as pit latrines filled, the pilot project was scaled up with an additional 49 single-family UDDTs (total: 139 units) and 630 shared-family UDDTs (two assigned households) installed during the second half of 2013 and the first half of 2014. Some design and maintenance modifications were implemented based on early feedback from the initial units. First, the vaults were lowered slightly below-grade to decrease the number of steps and increase ease of entry. Second, tools and training were provided to educate households to manually mix and level the stored waste in order to maximize the use period of each vault. In addition, cleaning kits were provided to aid in keeping the UDDTs clean. Finally, Oxfam advised households not to allow children under the age of 5 to use the UDDTs, as there was a consensus that they could not effectively use them.

After constructing a site for secondary storage of treated waste, Oxfam passed over management of WASH in Dollo Ado to another international NGO, Norwegian Refugee Council (NRC), in early 2014. During 2014, NRC constructed an additional 130 shared-family units. In 2015, a final 65 shared-family units were constructed. The total number, type and timing of the UDDT installation is illustrated in Appendix I.

2.2 UDDT Evaluation in Dollo Ado, Ethiopia

With significant scale-up of the implementation of UDDTs in Hiloweyn camp, the US Centers for Disease Control and Prevention (CDC) partnered with UNHCR, Oxfam GB, and NRC to evaluate UDDT acceptability and performance in Hiloweyn Camp, Ethiopia. The evaluation aimed to collect information to improve the implementation and management of this large program; specifically, to inform efforts to improve appropriate use of the toilets, as well as logistical aspects of the program such as UDDT emptying schedules and what to do with the treated waste. The evaluation started in May of 2014 and concluded in late 2016; a small laboratory-based additive study was conducted in early 2017 to supplement field results. CDC designed and managed all aspects of the evaluation. UNHCR supervised and facilitated field work and NRC provided logistical support and sampling teams for the performance evaluation.

The methodology, results and interpretation of each component of the evaluation are described separately herein this report – Section 3 describes the Acceptability Evaluation and Section 4 describes the Performance Evaluation. Overall implications and recommendations from the full evaluation are summarized in Section 5.

3 ACCEPTABILITY EVALUATION

3.1 Objectives and Design of the Evaluation:

The acceptability evaluation was designed for implementation over an 18-month period to document the overall acceptability and usability of the system in this setting. In addition to improving programming in Dollo Ado, the evaluation aimed to provide evidence to determine the suitability and role of UDDTs in this humanitarian context, and to determine if they can potentially be utilized in other refugee camps in Ethiopia.

The specific objectives for the evaluation were to:

1. Determine if adoption of UDDTs changes over time among individual users and households
2. Determine if UDDTS are consistently and correctly used and by whom
3. Determine if attitudes and preferences of UDDTs are more positive than for other forms of sanitation available (i.e. pit latrines) among users of single-family UDDTs, shared-family UDDTs and non-users
4. Determine the attitudes of waste reuse potential among users of single-family UDDTs, shared-family UDDTs and non-users
5. Determine the factors contributing to satisfaction with sanitation system among users and non-users of UDDTs

The evaluation included two, cross-sectional surveys of UDDT user and non-user households, which were conducted approximately 18-months apart in April 2015 (baseline) and October 2016 (endline).

3.2 Survey Methods

3.2.1 Survey and Sampling Design

The sample frame for the two surveys included all households registered with UDDTs and those registered with a single-family latrine as of the end of 2014. Units constructed during the evaluation period in 2015 were excluded from the sample frame (Phase 4; see Appendix I). The lists of registered households were updated in advance of each survey in March 2015 and September 2016. In order to meet the objectives specified above, a stratified sampling design was used to select households from each of four lists: 1) single-family UDDT households, 2) Phase 1 and 2 shared-family UDDTs user households, 3) Phase 3 shared-family UDDTs households, and 4) latrine user households. A sample size of 420 total households [105 households from each list] was determined based on the following parameters: limit of statistical significance (alpha) of 0.05 (95% confidence interval), power (1-beta) of 0.8, ability to detect a 20% difference between the hypothesized proportions for key indicators among the four groups (per table in Appendix II), and an anticipated response rate of 90%. Per the stratified design, we aimed to sample three-quarters (75%) of respondents from UDDT households and one-quarter (25%) from latrine user households. Additionally, among UDDT respondents only, we aimed to sample 2/3 (67%) from those who used a shared-family UDDT.

Simple random sampling was used to sample households from each list. Due to reports of population relocation from Hiloweyn to other camps in Dollo Ado, each list was oversampled (i.e. more than 105) and supervisors were instructed to continue until reaching the desired sample size (time permitting). Supervisors were instructed to have enumerators return to a household the next day if the targeted respondent was temporarily outside of the home, and replace with the subsequent household on the list if the household was abandoned or could not be located.

3.2.2 Supervision and Field Procedures

Before each survey, CDC conducted a 3-day training on survey and field methods, as well as electronic data collection, for enumerators (10), supervisors (3) and survey managers (2). During each training, the questionnaire was refined and translation/back-translation was completed from English-Somali (local dialect: May May). To test the survey tool and ensure clarity and accuracy, a one-day pilot was conducted in the field following the training. During the survey periods, CDC remotely supervised and did quality control and initial statistics on a daily basis. Data was collected electronically using the open data kit (ODK) application on CDC Foundation procured and password-protected Android devices (Samsung Galaxy Tab S). Data were stored locally at UNHCR on secure devices with FIPS 140-2 encryption and transferred daily via secure connection from UNHCR to CDC network.

In the field, informed verbal consent was obtained and a standardized questionnaire was administered to the female head of household (≥18-years old) at each selected household. If the female head was unavailable, the adult male was interviewed if he knew about sanitation practices within the home. The survey collected information on respondent and household demographics, sanitation knowledge and practices (past and present), sanitation preference, satisfaction as well as attitudes via a series of Likert type questions (5-point scale; strongly disagree to strongly agree). Based on the current primary sanitation type specified (i.e. latrine or UDDT), respondents were asked a series of sanitation type-specific questions.

For UDDT users, specific observations of the toilets were recorded in the survey by the enumerators to verify recent use, correct use and/or disuse and usability. Finally, attitudes towards potential reuse of the treated waste were measured among all households. No personally-identifiable information (PII) was collected.

3.2.3 Analytical Methods

Survey data were analyzed using SAS Version 9.3 (SAS Corporation, Cary, NC) by CDC staff in Atlanta, GA. Wald chi-square was used for univariate analysis and multivariable logistic regression modeling was also performed. For inclusion in the multivariable regression model, we screened selected variables with $p \leq 0.05$ as the cut-off by Wald chi-square. Manual backward elimination was performed on the included variables, with the final regression model generated when all variables had $p \leq 0.05$. Finally, two-way interactions were tested on the variables within the final model.

The protocol for the evaluation was subject to ethical review and oversight by the Institutional Review Board (IRB) of the US Centers for Disease Control and Prevention. The IRB board determined that the evaluation was a non-research public health program evaluation activity. Following this internal review at the CDC, the protocol was shared with the Administration for Refugee and Returnee Affairs (ARRA) for approval in Ethiopia prior to implementation.

3.3 Survey Results

A total of 397 and 414 household interviews were completed during the baseline and endline surveys, respectively. In total, 631 and 522 households were attempted at the baseline and endline, respectively; however these additional 234 and 108 selected households were attempted where the household (by name/ration card #) was either not located (i.e., unknown) or had relocated permanently out of the camp. There were no refusals at either time period when the selected household was located.

3.3.1 Demographics Of Respondents and Households

The major demographical characteristics of the respondents are summarized in Table 1. Certain variables were consistent between the two surveys or changed with respect to time as expected. These variables included proportion of female respondents, average age of respondent, average family size. The average length of time in the camp increased as expected with the time between surveys. These variables are highlighted in blue. However, there were key significant differences in other individual and family demographics between the two samples.

Table 1. Key Demographics of Survey Respondents and Households

Variable	Percent (95% CI)		p
	Baseline (n=397)	Endline (n=414)	
Respondent Characteristics			
Female respondent	86.9	87.7	0.68
Average age of respondent in years (range)	35.4* (18-91)	34.9* (18-90)	0.53
Ability to read	19.4 (15.5-23.3)	13.5 (10.2-16.8)	0.024
Completed some level of formal education	15.4 (11.8-18.9)	4.6 (2.6-6.6)	<0.0001
Previous occupations (in Somalia)			
Crop or vegetable farmer	91.4 (88.7-94.2)	61.8 (57.1-66.5)	<0.0001
Animal husbandry	61.5 (56.9-66.5)	46.1 (41.3-51.0)	<0.0001
Domestic cleaners or helpers	14.6 (11.1-18.1)	8.9 (6.2-11.7)	0.012
Household Characteristics			
Average family size (range)	6.42* (1-15)	6.64* (1-13)	0.1984
Average number of years in the camp (range)	3.75* (1-5)	5.11* (1-6)	<0.0001
Has one or more child < 5 years in HH	75.1 (70.8-79.3)	85.8 (82.4-89.1)	0.0001
Has one or more elderly person in HH	14.9 (11.3-18.4)	23.7 (19.6-27.8)	0.0015
Has one or more disabled person in HH	9.3 (6.4-12.2)	14.0 (10.7-17.4)	0.038
Previous primary sanitation (Somalia)			
Open Defecation	66.8 (62.1-71.4)	86.2 (82.9-89.6)	<0.0001
Pour-flush toilet	21.4 (17.4-25.5)	6.04 (3.7-8.3)	<0.0001
Pit latrine	5.5 (3.3-7.8)	3.4 (1.6-5.1)	0.95

*denotes a number, not a percent

The reported ability to read and education level were less than 20% in both surveys, however these variables were significantly higher in the baseline survey. In both surveys, farming and animal husbandry were the primary former occupations in Somalia prior to arriving in the camp; however a significantly higher proportion of respondents reported to have been domestic cleaners or helpers in the baseline survey. In terms of family composition, while the average family size was the same between surveys, there were significantly more families who reported having a child under 5, elderly or disabled family member in the home at the time of the endline survey.

The previous primary sanitation type used in Somalia was also significantly different between the two surveys. In the baseline survey, one-third of respondents reported using an improved sanitation type, with pour-flush toilets being the most commonly reported (21.4%; 95% CI 17.4-25.5). In contrast, fewer than ten-percent of respondents from the endline survey reported accessing an improved sanitation type; with a majority (86.2%; 95% CI 82.9-89.6) reporting to have had no sanitation system (i.e. defecated in the open) in Somalia. The proportion who shared their previous sanitation system with another family did not differ between the two surveys (p= 0.18), with 40.2% (n=132; 95% CI 31.7-48.6) and 29.9% (n=57; 95% CI 17.6-42.1) reported from the baseline and endline, respectively.

3.3.1.1 PAST AND CURRENT SANITATION IN HILOWEYN CAMP

Respondents were asked about all the types of sanitation used since arrival at Hiloweyn (Table 2).

Table 2. Sanitation systems used by respondents since arrival in Hiloweyn

	Percent (95% CI)	
Variable*	**Baseline (n=397)**	**Endline (n=414)**
Block latrine	82.9 (79.1-86.6)	78.3 (74.3-82.3)
UDDT	72.8 (68.4-77.2)	77.3 (73.2-81.4)
Private family latrine	43.1 (38.2-48.0)	50.7 (45.9-55.6)
Handicapped latrine	6.6 (4.1-9.0)	5.1 (3.0-7.2)

*multiple responses possible

A majority of respondents in each survey had used the block latrines[1] at some point since arrival in Hiloweyn, and 40-50% of respondents from each survey had also used one the private family latrines available in parts of Hiloweyn. The proportion of respondents who had used each type did not differ between the surveys.

Respondents were then asked to confirm their current primary sanitation type as well as other forms of sanitation they had used in the past week. Table 3 shows the current primary sanitation types reported by respondents.

Table 3. Primary sanitation system used by respondents at the time of the surveys in Hiloweyn

	Baseline (n=397)		**Endline (n=414)**	
Variable	**Frequency**	**Percent (95% CI)**	**Frequency**	**Percent (95% CI)**
Block latrine	41	10.3 (7.3-13.3)	19	4.6 (2.6-6.6)
Private family latrine	64	16.1 (12.5-19.8)	88	21.3 (17.3-25.2)
UDDT	**285**	**71.8 (67.3-76.2)**	**303**	**73.2 (68.9-77.5)**
Handicapped latrine	2	0.5 (0.0-1.2)	4	0.9 (0.0-1.9)
Other (unspecified)	5	1.2 (0.0-2.0)	0	0.0

There were 285 (71.8%) primary UDDT users in the baseline and 303 (73.2%) primary UDDT users in the endline survey. However, among these primary UDDT users, 88 respondents (30.9%) from the baseline and 38 respondents (12.5%) from the endline reported also using a latrine[2] in the past week; this proportion was significantly higher during the baseline than at the endline ($p<0.0001$). In both surveys, the majority of these respondents reported using a latrine every day. There were 107 primary latrine users in the baseline and 108[3] primary latrine users in the endline survey.

In the analysis that follows, we present the data from each survey according to these reported primary sanitation types, either as UDDT users or latrine users; any differences in variables detected between single-family and shared UDDTs are also reported.

3.3.2 PRIMARY UDDT USERS

Respondents who stated that they considered UDDTs to be their primary form of sanitation were asked a series of questions in order to determine practices (i.e., current, consistent and correct use), attitudes and level of satisfaction

[1] Block latrines have 4 stalls with each intended to be shared by 4-families (16-families total use each block)
[2] Type not specified in this question
[3] 111 expected from Table 3, however 3 respondents did not indicate that they used latrines when asked about all sanitation used in the past week so they were excluded from the analysis

with UDDTs, and sanitation preference. Basic information on use history and whether they shared the UDDT with another family was also collected.

3.3.2.1 UDDT Use History and Frequency

The proportion of respondents who reported sharing their UDDT with another household was significantly different between surveys (p<0.0001), with 51.8% (95% CI 46.2-57.5) reporting to share at the endline period compared to 68.1% (95% CI 62.6-73.5) at the baseline. The median number of families that the respondent household shared their UDDT with was 1 in both surveys; however the maximum number of other families that shared the UDDT was 7 in the baseline and 3 in the endline.

Respondents were asked about how long they have had the UDDT that they use (Table 4). The most common response at both survey time periods was between 1-2 years; however, the average length of time of use generally increased as expected between the two surveys.

Table 4. Length of time of use of UDDT among UDDT users

	Percent (95% CI)	
Variable	**Baseline (n=285)**	**Endline (n=303)**
Reported length of time of use		
3-5 years	13.0 (9.1-16.9)	34.7 (29.3-40.0)
1-2 years	49.1 (43.3-55.0)	59.4 (53.9-65.0)
6-11 months	21.1 (16.3-25.8)	2.0 (0.4-3.6)
3-5 months	14.0 (10.0-18.1)	1.3 (0.0-2.6)
<3 months	2.8 (0.9-4.7)	2.0 (0.4-3.6)

The majority of respondents from both surveys reported to have used the UDDT in the past 24 hours (current use) and reported to use the UDDT every day (consistent use) (Table 5). More than ninety-five percent of respondents from each survey said they had used the UDDT in the past 24 hours. The proportion who reported to use their UDDT consistently was *slightly* higher at the endline period (p=0.048).

Table 5. Current and consistent use of UDDT among UDDT users

	Percent (95% CI)		
Variable	**Baseline (n=285)**	**Endline (n=303)**	**p**
Reported current use (past 24 hours)	98.2 (96.7-99.8)	96.7 (94.7-98.7)	0.235
Reported consistent use (every day)	**88.8 (85.1-92.5)**	**93.4 (90.6-96.2)**	**0.048**

3.3.2.2 UDDT non-users among UDDT Households

At both survey time periods, majority of respondents reported that there were some family members who do not use the UDDT. This proportion increased significantly from the baseline to endline (p=0.012) from 64.9% (95% CI 59.3-70.5) to 74.6% (95% CI 69.7-79.5). In both surveys, an average of 2.3 persons per family did not use the UDDT. Over ninety-percent in both surveys reported that a child(s) under five did not use it, followed by a small number of elderly and disabled family members. There were no significant differences in non-user proportions between the two surveys nor between single-family and shared UDDT respondents. When asked the reasons why the children under five does not use the UDDT, the most common responses in both surveys were that they were unable to use them and afraid to use them, followed by not being allowed to use them. The most common response for why elderly and disabled family members could not use it was that they were unable to use them.

3.3.2.3 Knowledge of Correct Use

All respondents in both surveys said they add materials to the UDDTs after use, and all responded that they add ash when asked what type of material is added. In both surveys, over 98% produced their own ash by cooking in the home. Majority of respondents in both survey said they had enough ash to meet their needs for the UDDT; however this proportion was significantly higher at the endline ($p < 0.0001$), increasing from 81.2% (95% CI 76.6-85.8) to 96.4% (95% CI 94.2-98.5).

The knowledge of correct use of the additive was high across both survey time periods, with over 85% reporting correct use (addition 'After every use') in both surveys (Table 6). A significant increase in this proportion was observed from the baseline to endline ($p < 0.0001$), with almost all respondents reporting to add ash after every use at the endline survey.

Table 6. Frequency of additive use among UDDT users

	Percent (95% CI)	
Response Option	**Baseline (n=285)**	**Endline (n=303)**
After every use	85.3 (81.1-89.4)	97.0 (95.1-98.9)
Every day	8.4 (5.2-11.7)	3.0 (1.0-4.9)
A few times a week	6.3 (3.5-9.2)	0 (0)
Once a week or less	0 (0)	0 (0)
Do not know	0 (0)	0 (0)

Respondents were asked if someone in their family or another family cleans the UDDT (Table 7). The majority of respondents from both surveys said that someone was responsible for this task. The proportion who reported that someone was responsible for keeping the UDDT clean and that they had access to a cleaning kit was higher in the endline than the baseline survey (Table 7); both of these were significant at the $p<0.0001$ level.

Table 7. Reported cleaning practices among UDDT users

	Percent (95% CI)		
Variable	**Baseline (n=285)**	**Endline (n=303)**	**p**
Someone is responsible for cleaning the UDDT	90.5 (87.1-93.9)	100.0	<0.0001
There is a cleaning kit available	60.4 (54.6-66.1)	77.2 (72.5-82.0)	<0.0001

3.3.2.4 Observed UDDT Condition

Interviewers obtained consent to view the UDDT after each interview in order to observe correct and recent use and usability (Table 8 and 9). **The indicators that stayed the same or improved at the endline are shown in blue, and those that declined are shown in pink.** There were six indicators of correct use observed (Table 8). The presence of 1) an ash bucket and 2) ash in the bucket was lower at the time of the endline than the baseline, however over ninety-percent of UDDTs were observed to have an ash bucket in both surveys. Ash observed in the bucket decreased from 81.4% (95% CI 76.9-86.0) to 67.0% (95% CI 61.7-72.3) of UDDTs at the endline period.

Table 8. Observed correct use indicators of UDDTs

	Percent (95% CI)		
Variable	**Baseline (n=285)**	**Endline (n=303)**	**p**
Presence of ash bucket	97.9 (96.2-99.6)	91.1 (87.9-94.3)	0.0003
Ash in the bucket	81.4 (76.9-86.0)	67.0 (61.7-72.3)	<.0001
Covers down on squat plate	60.4 (54.6-66.1)	65.0 (59.6-70.4)	0.2422
No foreign objects in vaults	91.2 (87.9-94.5	80.5 (76.0-85.0)	0.0002
No foreign objects in urine pipe	77.2 (72.3-82.1)	88.4 (84.8-92.1)	0.0003
No wet waste in active vault	58.6 (52.8-64.3)	73.3 (68.2-78.3)	0.0002

Four other features indicating correct use were observed; these included 3) whether both covers were down on the squat pan, absence of foreign objects in 4) either vault or 5) the urine pipe, and 6) absence of wet waste (indicating urine or water addition) to the active vault (Table 8). There were significant differences between the baseline and endline survey for three of four variables; with a reduction in correct use for one indicator, while the other three improved or stayed the same.

Among the six indicators of correct use, the only significant difference noted between single-family and shared UDDTs was that there was a slightly higher proportion of shared UDDTs with an ash bucket present in the UDDT (p=0.005).

An indicator of recent use, measured by the presence of fresh waste in the active vault, decreased significantly from 63.5% (95% CI 57.9-69.1) in the baseline to 50.2% (95% CI 44.5-55.8) in the endline survey (p=0.0009). No difference was observed between single-family and shared UDDTs.

Usability was measured by six observations related to both structural features (3 observations) and cleanliness (3 observations). These indicators are summarized below for all UDDTs (Table 9).

Table 9. Observed usability issues of UDDTs

	Percent (95% CI)		
	Baseline (n=285)	**Endline (n=303)**	**p**
Cracks in masonry (slab or walls)	19.6 (15.0-24.3)	9.2 (6.0-12.5)	0.0003
Doors (entrance or vaults) broken/damaged	22.1 (17.2-27.0)	12.5 (8.8-16.3)	0.002
Urine pipe clogged or broken	15.8 (11.5-20.0)	10.2 (6.8-13.7)	0.045
Flies inside UDDT	28.1 (22.8-33.3)	17.8 (13.5-22.2)	0.003
Visible waste on floor of UDDT	30.5 (25.2-35.9)	38.6 (33.1-44.1)	0.042
Strong odor inside UDDT	26.3 (21.2-31.5)	16.8 (12.6-21.1)	0.005

Improvements in these usability issues from the baseline to the endline period are shown in blue. With the exception of waste on the floor of the UDDT, which increased slightly with approximately one-third of observed UDDTs in the endline, all the indicators improved significantly. Nonetheless, there were structural issues identified in approximately ten percent of the UDDTs at the endline period, and cleanliness issues identified in approximately 16-38% of UDDTs.

Of the six usability indicators, there were significant differences noted between shared and single-family UDDTs for two of the variables. Broken or damaged doors were observed on a higher proportion of shared UDDTs (p=0.013) and a strong odor inside the UDDT was observed on a higher proportion of shared UDDTs (p=0.013). There was also a marginally significant difference between single-family and shared UDDTs for having clogged or broken urine pipe and presence of flies (p=0.07 and p=0.08, respectively); these proportions were also higher in shared UDDTs.

3.3.3 Primary Latrine Users

Primary latrine users were also asked questions regarding consistent and correct use of latrines. Respondents were asked about frequency of use, as well as if they had used it in the past 24 hours. Almost all respondents stated they use the latrine every day and had used it in the past 24 hours, and there was no difference observed between the baseline and endline surveys (Table 10).

Table 10. Current and consistent use and proportion sharing with another family among latrine users

	Percent (95% CI)		
Variable	**Baseline (n=107)**	**Endline (n=108)**	**p**
Reported current use (past 24 hours)	98.1 (95.5-100)	99.1 (97.2-100)	0.555
Reported consistent use (every day)	94.4 (90.0-98.8)	93.5 (88.8-98.2)	0.788
Share latrine with another family	**32.7 (23.7-41.7)**	**18.5 (11.1-26.0)**	**0.011**

The proportion who reported to share their latrine with another family was significantly lower at the endline period (p=0.011), with one-third of respondents reporting to share their latrine with another family at baseline and approximately eighteen-percent at endline. Of those who shared (n=31 in baseline and n=20 in endline), the mean number of other families who used the facility was 2.2 (range 1-7) at baseline and 1.4 (range 1-3) at endline (p=0.01). Notably, the proportion who used a block latrine as their primary sanitation type was significantly higher at the baseline survey time period (p<0.0001) (Table 3).

When asked if all family members use the latrines, a significantly higher proportion of respondents from the endline said they did not (p=0.0104); half of respondents said they did not (51.4%, 95% CI 41.8-61.0) in the baseline compared to 68.5% (95% CI 59.6-77.4) at the endline. Similar to the UDDT results, the vast majority of these families reported that a child(s) under five years of age did not use the latrine; over ninety-percent in both surveys. The two most common reasons for young children not using was that they are afraid to use or unable to use the latrines. Elderly (60+ years) and disabled family members as non-users were also mentioned by a handful of respondents.

3.3.4 Sanitation Attitudes and Preference

3.3.4.1 UDDT Users

Respondents using UDDTs as their primary form of sanitation were asked about how satisfied they were with the UDDT they use; five response options were provided and the respondent was asked to pick the one that most closely represented their level of satisfaction (Table 11). Satisfaction levels were significantly higher during the endline (p<0.0001) with 97.0% (95% CI 95.1-98.9) of respondents stated either that they were mostly or very satisfied with their UDDT in the endline, compared to 62.8% (95% CI 57.2-68.4) in the baseline. Overall, the single-family UDDT users had a significantly higher proportion than the shared UDDT users that were mostly or very satisfied (p<0.0001), with 88.9% (95% CI 84.9-93.0) of single-family UDDT users reporting satisfaction, compared to 75.2% (95% CI 70.7-79.7) of shared UDDT users. However, when stratified by survey period, a significant difference in satisfaction level between single-family and shared UDDT users was only detected during the baseline period.

Table 11. Current satisfaction level for primary UDDT users

	Percent (95% CI)	
Response Option	**Baseline (n=285)**	**Endline (n=303)**
Very dissatisfied	7.7 (4.6-10.8)	1.0 (0.0-2.1)
Mostly dissatisfied	17.2 (12.8-21.6)	1.3 (0.0-2.6)
Neutral / No opinion	12.3 (8.5-16.1)	0.7 (0.0-1.6)
Mostly satisfied	**42.8 (37.0-48.6)**	**13.5 (9.7-17.4)**
Very satisfied	**20.0 (15.3-24.7)**	**83.5 (79.3-87.7)**

Sanitation preference varied between survey time periods and UDDT groups (Table 12). At both survey time periods, the majority of UDDT users listed a UDDT as their preferred sanitation type. However, the proportion was significantly higher at the endline survey (p<.0001), with 93.0% (95% CI 90.2-95.9) at endline and 82.4% (95% CI 77.9-86.9) at baseline. Similarly, the proportion of UDDT users who said they would prefer a latrine decreased from baseline to endline, with 17.6% (95% CI 13.1-22.1) at baseline compared to 6.9 (95% CI 4.1-9.8) at endline.

There were also differences noted among UDDT groups in each survey time period, with a higher proportion of single-family than shared-family UDDT users preferring their own type in both surveys (Table 12). Between the two surveys, the reported preference among the single-family UDDT users did not differ; however, there was a shift in reported preferences among those who shared their UDDT between the baseline and endline time period. For shared UDDT users, a higher proportion said they would prefer a UDDT (for their own family) and a lower proportion said they would prefer a latrine (for their own family) at the endline time period (Table 12).

Table 12. Sanitation preference for single-family and shared-family primary UDDT users

	Baseline (n=285) Percent (95% CI)		**Endline (n=303) Percent (95% CI)**	
Sanitation Preference Response Option	**Single-family UDDT**	**Shared UDDT**	**Single-family UDDT**	**Shared UDDT**
Single-family pit latrine	10.1 (3.7-16.5)	17.5 (12.1-22.9)	6.9 (2.7-11.0)	7.0 (3.0-11.0)
Shared pit latrine	0	3.1 (0.6-5.5)	0	0
Single-family UDDT	84.3 (76.6-92.0)	50.0 (42.9-57.1)	91.1 (86.4-95.8)	69.4 (62.1-76.7)
Shared UDDT	4.5 (0.1-8.9)	29.4 (22.9-35.9)	1.4 (0.0-3.3)	23.6 (16.8-30.3)
Do not know/ No preference	1.1 (0.0-3.4)	0	1.0 (0.7-2.0)	0

Finally, general perceptions of usability of UDDTs as a sanitation system were also significantly different between the surveys ($p<0.0001$), with 72.6% (95% CI 67.4-77.0) of respondents at the baseline period stating that the UDDTs were not usable by some people in the camp (based on their construction) compared to 34.0 (95% CI 28.6-39.4) at the endline.

3.3.4.2 Latrine Users

Respondents using latrines as their primary form of sanitation were also asked about how satisfied they were with the latrine(s) they use; five response options were provided and the respondent was asked to pick the one that most closely represented their level of satisfaction. Approximately two-thirds of respondents (66.4%; 95% CI 57.3-75.5) stated either that they were mostly or very satisfied during the baseline, compared to 88.9% (95% CI 82.9-94.9) at the endline (Table 13). At either survey time period, this proportion was not significantly different than the UDDT respondents ($p=0.28$). Similar to reported UDDT satisfaction level, there was a significant difference between the baseline and endline, with satisfaction higher at the endline ($p<0.0001$).

Table 13. Current satisfaction level for primary latrine users

	Percent (95% CI)	
Response Option	**Baseline (n=285)**	**Endline (n=303)**
Very dissatisfied	7.5 (2.4-12.5)	3.7 (0.1-7.3)
Mostly dissatisfied	15.9 (8.8-22.9)	3.7 (0.1-7.3)
Neutral / No opinion	10.3 (4.4-16.1)	3.7 (0.1-7.3)
Mostly satisfied	**50.5 (40.8-60.1)**	**34.3 (25.2-43.4)**
Very satisfied	**15.9 (8.8-22.9)**	**54.6 (45.1-64.2)**

Among the latrine users, the proportion of those users of single-family latrines who were mostly or very satisfied was significantly higher than users of block latrines (p=0.04) at the baseline; with 73.4% of single-family latrine users stating satisfaction versus 56.1% of block latrine users. There was no difference detected based on type of latrine at the endline survey.

In both surveys, the proportion who preferred a latrine was almost the same as the proportion who said they were satisfied; however, most of these respondents indicated they would prefer one that was for their own family (i.e. not shared) (Table 14).

Table 14. Sanitation preference for primary latrine users

	Percent (95% CI)	
Response Option	**Baseline (n=285)**	**Endline (n=303)**
Single-family pit latrine	54.2 (44.6-63.8)	79.6 (71.9-87.4)
Shared pit latrine	15.9 (8.8-22.9)	5.6 (1.2-10.0)
Single-family UDDT	29.0 (20.2-37.7)	14.8 (8.0-21.6)
Shared UDDT	0.93 (0.0-2.8)	0
Do not know/ No preference	0	0

Thirty-two respondents (29.9%) stated that they would prefer to use a UDDT at the baseline, compared to 14.8% at endline; however, at both time periods most of these respondents had not actually used one before. Among all primary latrine users, 4.7% (n=5; 95% CI 0.6-8.7) at the baseline and 23.1% (n=25; 95% CI 15.1-31.2) reported that they used a UDDT before. Among these respondents, 80.0% and 20.0% at the baseline and endline, respectively, said that a UDDT would be their preferred form of sanitation in Hilowen.

3.3.4.3 Perceptions of Reuse Among All Respondents

All respondents were asked if they thought that the UDDT creates a waste product that could be beneficial for agriculture (i.e. reuse). Among UDDT respondents, there was no difference between the two surveys, with 62.8% (95% CI 45.7-66.7) and 59.9% (95% CI 54.4-65.5) responding positively regarding the potential for reuse of end product at the baseline and endline, respectively. Similarly, among latrine users, there was no difference in responses between the surveys; with 36.4% (95% CI 27.2-45.7) and 38.0 (95% CI 28.7-47.3) at the baseline and endline, respectively, responding 'yes' to the question. Unsurprisingly, at both survey time periods, the proportion of UDDT users who thought that the waste could be reused was significantly higher than the latrine users ($p<0.0001$).

3.3.5 Factors Contributing to Acceptability of Sanitation Type

In order to determine factors that were associated with level of satisfaction with respondents' current sanitation, all the data from both surveys were combined, with a variable created to differentiate from which survey the respondent corresponded (i.e. baseline or endline). With the full dataset, multivariable logistic regression models were constructed; one for all respondents and one for UDDT users only. The level of satisfaction was redefined as unsatisfied or undecided (combining very, mostly dissatisfied and neutral) and satisfied (combining mostly and very satisfied) for the models. Selected variables were tested individually for association with satisfaction level, and those that were found to have significant association were put into the multivariable models.

3.3.5.1 AMONG ALL RESPONDENTS

The selected variables included respondent and household characteristics (demographic variables) as well as previous (before arriving at the camp) and current sanitation type, and whether the current type was shared (Appendix III). Of the variables tested, formal education, having a child < 5 years of age in the home, length of time in the camp, previous sanitation type, and sharing their current sanitation system with other families were significant by univariate analyses; these were therefore included in the model.

Among all respondents, the final model showed that four factors remained significantly associated with satisfaction of current sanitation system (Table 15). Respondents who did *not* have any formal education, had *not* used a pour-flush toilet previously (before coming to the camp), had been in the camp for longer, and did *not* share their current sanitation system were more satisfied. Type of current sanitation (latrine vs. UDDT) was not significant. Length of time in the camp was the most highly associated variable with satisfaction level of sanitation system.

Table 15. Multivariable model of factors associated with higher satisfaction with current sanitation among all respondents

Variable	**Odds Ratio**	**95% Wald Confidence Limits**	**Wald X^2**	**p**
Has some education (ref) vs none	2.057	1.20-3.52	6.95	0.0083
Previous sanitation type in Somalia				
Previously used pit latrine vs pour-flush (ref)	2.532	1.20-5.34	5.95	0.0147
Previously used field vs pour-flush (ref)	2.050	1.27-3.30	8.74	0.0031
Years in the camp (Increase in satisfaction per year)	1.893	1.58-2.27	46.4	<0.0001
Shared (ref) vs not	1.729	1.18-2.53	7.98	0.0047

For the variables that were significant in the final model, the previously used sanitation type variable and currently shared sanitation variable was the only significant two way interaction. In other words, these variables were related to each other in terms of association with satisfaction level; therefore the model was re-run with the each related variable fixed. For those households who said they had no sanitation system (i.e. field) and those who had used a pit latrine in Somalia, no significant association was found between sharing their current sanitation system and satisfaction level (p=0.0718 and p=0.3001, respectively). For those households who had accessed a pour-flush toilet in Somalia, the level of satisfaction was significantly greater for those who did not share their current sanitation system (p=0.0015).

3.3.5.2 AMONG UDDT RESPONDENTS

The selected variables for the UDDT user model included respondent and household characteristics (demographic variables) as well as previous and current sanitation type, sharing with another family and UDDT condition (Appendix III). Of the variables tested, formal education, length of time in the camp, previous sanitation type, length of time using UDDT, sharing their UDDT with other families, and level of cleanliness (i.e. none of three lack of cleanliness issues observed) of the UDDT were significant by univariate analyses; these were therefore included in the model.

Among UDDT respondents, the final model showed that five factors remained significantly associated with satisfaction (Table 16). Not having any formal education was the only variable that did not remain significantly associated with satisfaction in the final model. Similar to the all model, those had not used a pour-flush toilet previously (before coming to the camp), had been in the camp for longer and did not share their UDDT were more satisfied. Of the UDDT-specific variables, respondents who had used their UDDT for longer and had a cleaner

UDDT and were more satisfied. The most significant associations with a higher level of satisfaction were related to length of time in the camp and the cleanliness of the UDDT.

Table 16. Multivariable model of factors associated with higher satisfaction of current sanitation among UDDT respondents

Variable	Odds Ratio	95% Wald Confidence Limits	Wald X^2	p
Previous sanitation type in Somalia				
Previously used pit latrine vs pour-flush (ref)	4.158	1.366-12.657	6.29	0.0121
Previously used field vs pour-flush (ref)	2.411	1.334-4.36	8.48	0.0036
Years in the camp (Increase in satisfaction per year)	2.261	1.695-3.014	30.877	<0.0001
Shared (ref) vs not	1.762	1.031-3.011	4.28	0.0385
Time of use of UDDT (increase in satisfaction per year)	1.713	1.207-2.433	9.0576	0.0026
Clean (ref) vs unclean	2.819	1.724-4.609	17.07	<0.0001

There were two, two-way interactions between the previous sanitation type variable and both cleanliness and length of time of use of UDDT variables; therefore the model was re-run with previous sanitation type fixed. For those who had no access to a sanitation system (i.e. field) in Somalia, cleanliness remained significantly associated with satisfaction level (p-0.0071) however time of use of UDDT did not. Neither cleanliness nor length of time using UDDT were significantly associated with satisfaction for those who previously accessed a pit latrine. Finally, for those who had used pour-flush toilets in Somalia, both cleanliness (p=0.0005) and length of time of use of the UDDT (p=0.0044) were significantly associated with satisfaction level.

3.4 Discussion

The two cross-sectional surveys collected information approximately 18-months apart related to sanitation practices, preferences and satisfaction level among UDDT users and non-users in Hiloweyn camp. Among both survey samples, the respondents were predominantly female and of reproductive age. The average family size was approximately six persons and there was at least one child under 5 years of age in the home for three-quarters or more of respondents. Only a small proportion of respondents had received any formal education, and over two-thirds had not accessed any form of sanitation (i.e. practiced open defecation) before coming to the camp. Of those who had used a sanitation system before coming, the most common type was a pour-flush toilet followed by an improved pit latrine (i.e. with a slab). Approximately 30-40% of these were shared facilities.

Despite some similarities, there were marked differences in the demographics of the respondents and their households between the two surveys. Significant differences in terms of ability to read, education level, previous professions and previous sanitation type indicate that we may have sampled more respondents of urban origin and/or higher socioeconomic status (in Somalia) during the baseline time period. There were no identified reasons for this variation between the surveys, and the reported length of time in the camp did not indicate that we sampled a new population at the endline. Therefore, it is possible that the different sampling periods reflected seasonal and/or temporal movement into and out of the camp for work or otherwise among those of different demographics/origin.

Adoption of UDDTs was high at both surveys, with almost all households who had been assigned a UDDT reporting to currently and consistently use them. There was a slight increase in reported consistent use (i.e. every day) among UDDT users from the baseline to endline survey, and a lower proportion of UDDT users who reported to also use latrines. Current and consistent use was also high among latrine users, and did not differ between surveys.

While adoption was high among UDDT respondents, there were household members at both survey time periods who did not use the units and also indications that some households may have abandoned (i.e. disused) the UDDTs over time. The proportion and type of non-user household members did not differ between the surveys; most non-users were children under 5 years, though some elderly and disabled family members were also reported as non-users. The primary reason for non-use was that these groups were unable to use them. These results are consistent with the previous assessment undertaken by Oxfam after the first single-family UDDTs were installed. A similar proportion of latrine users also reported non-use by children under 5 suggesting this is an issue for both latrines and UDDTs in Hiloweyn. In terms of indicators of disuse by households, the surveys indicated that the proportion who shared their UDDT was significantly lower at the endline period. While the reason for disuse is unknown, this may indicate that certain families had decided to use another sanitation type. Relatedly, a small percentage of respondents (5.3%) at the endline period reported that they had used the UDDT for less than a year, which, because units had all been constructed prior to the baseline, indicates that they may have taken over the unit from another family.

Correct use, in terms of reported additive use and cleaning practices, was also high at both surveys. All respondents reported to use ash, and majority of respondents reporting to add ash to the UDDT after each use (i.e. correct practice). The proportion reporting this correct practice increased significantly from baseline to endline. Reported cleaning practices increased marginally and access to a cleaning kit also increased significantly from baseline to endline.

The observed conditions of the UDDTs quantified several other indicators of correct use, as well as confirming reported practices. While almost all of the observed UDDTs had an ash bucket at both surveys, there was a slight reduction in observed ash in the bucket at the time of the endline. Nonetheless, ash was still available in two-thirds of the UDDTs at the time of the spot visit at the endline survey, when most UDDTs had been operational for several years. A majority of the UDDT vaults were free of foreign objects and more than half had squat pan covers down to prevent flies from entering. These correct use indicators also improved or stayed the same between the surveys. However, a small proportion of UDDTs did have foreign objects in the urine pipe and signs of liquid addition to the vaults, which indicates that there may still be some work to do to improve correct use.

Of the six observed usability issues, including structural faults and lack of cleanliness indicators, all but one decreased from the baseline to endline; in other words, the condition of the UDDTs generally improved from baseline to endline. However, up to one-third of UDDTs still had one or more issue identified at the time of the endline, which may negatively affect satisfaction and use among users in Hiloweyn camp. Among all respondents, there were some differences noted in condition of the UDDT between shared and single-family users. Unsurprisingly, there were fewer usability issues identified when only one family was using the UDDT.

Satisfaction increased significantly among all respondents and sanitation types from the baseline to endline time period. At the endline survey, the vast majority of both UDDT and latrine users reported that they were mostly or very satisfied with their sanitation system. Users of single-family units (both latrine and UDDT) were more satisfied than those who used shared units, however this difference was only detected at the baseline time period. The trends of increased satisfaction were the same between UDDT and latrine users, and at each survey, there was no detectable difference between reported satisfaction for UDDT users and latrine users (UDDT non-users). In other words, the acceptability of UDDTs among UDDT users did not appear to be higher or lower than the level of acceptability of latrines among latrine users (i.e. UDDT non-users).

Sanitation preference differed between survey time periods and UDDT groups. Consistent with reported satisfaction, the preference for UDDT as their sanitation system in Hiloweyn increased from baseline to endline. At both time periods, a higher percentage of single-family UDDT users preferred their system than those who shared with one or more families. Notably, significantly fewer of the shared UDDT users said they would prefer a latrine at the endline survey; with significantly more indicating that they would simply prefer a UDDT for their own family.

Attitudes towards reuse did not differ between the surveys and were higher than during the Oxfam assessment, with more than half of UDDT respondents indicating they think the treated waste product could be beneficial for agricultural application. Unsurprisingly, the attitudes of non-users were significantly lower towards this potential use of treated waste.

There were a number of factors associated with a higher level of satisfaction (i.e. acceptability) with current sanitation. Among all respondents, those who had received formal education and had access to a pour-flush toilet in Somalia were less satisfied than those without; these two variables may be related to socioeconomic status or a more urban environment back in Somalia. However, independent of those two variables, those who had spent longer in the camp were more satisfied, which indicates that satisfaction level can potentially increase with time. In other words, regardless of previous experience, it may simply take time to become accustomed to the sanitation type available in the camp. Among those who had previously used a pour-flush toilet, not sharing their current sanitation type was also associated with higher satisfaction. Notably, for those who had used a pit latrine or didn't have access to a sanitation system (i.e. openly defecated) prior to arrival in Hiloweyn camp, sharing their sanitation system was not significantly associated with satisfaction level.

Among UDDT respondents specifically, five factors were found to be associated with satisfaction level. Those who had previously accessed a pour-flush toilet, shared their UDDT, had some indication of uncleanliness in their UDDT and had been in Hiloweyn (and also used their UDDT) for fewer years were less satisfied than others. In particular, cleanliness was a major driver of satisfaction across all UDDT users and was the most significant association with satisfaction, along with length of time in the camp. Similar to the model among all respondents, there were marked differences in the factors associated with satisfaction based on the type of previous sanitation system used in Somalia. For those that didn't have access to a sanitation system in Somalia, the length of time of use of the UDDT was not associated with satisfaction level; whereas for those who had used pour-flush toilets, the length of time of use of the UDDT significantly impacted their satisfaction level. In other words, for this group, the model indicated that satisfaction with the UDDT may increase over time, as they become accustomed to it. Sharing the UDDT was only marginally associated (inversely) with satisfaction level; indicating that this may not be one of the major barriers to UDDT acceptability in Hiloweyn camp, regardless of small differences observed during the surveys. It appears that cleanliness matters the most, in addition to time of use (particularly for those who had previously used a pour-flush toilet prior to arrival in the camp).

3.5 Limitations

This evaluation is subject to several important limitations. First, because staff from CDC were not allowed to travel to Hiloweyn during either survey, all training was conducted off-site and CDC supervision was remote. However, UNHCR and ARRA staff helped supervise activities on the ground, and we hired extra supervisors (4 total) for the ten data collectors to address this limitation. Next, population movements and potentially inaccurate lists of UDDT and latrine users meant that many selected respondents could not be located and were therefore replaced. It's not known if these respondents were different than those who were found. Next, longer recall periods may be inaccurate in terms of length of time in the camp and length of time of use of the UDDT. Finally, we interviewed one person per household, usually the female head of that household. We did not attempt to determine the satisfaction levels among other family members such as adult men, school aged children or younger children. We assumed that the respondents reported satisfaction likely represents that of the household as a whole, however we do not know if this was indeed the case.

4 PERFORMANCE EVALUATION

4.1 Objectives of the Evaluation

The overall objectives of the environmental testing were to:

- Determine the performance of the UDDTs, in terms of microbial inactivation, in order to provide guidance on their use in this setting
- Document the environmental factors influencing the performance of the UDDTs (i.e., temperature, pH, moisture content, and storage time) for microbial inactivation.

4.2 Methods

4.2.1 Parameter Selection

Performance of UDDTs was assessed using the following World Health Organization (WHO) guidelines **for the safe use of excreta for agricultural use** (WHO 2006): <1000 *E. coli* and <1 viable *Ascaris* ovum (i.e., egg) per gram total solids. *E. coli* are bacteria that are common in feces of humans and other warm-blooded animals, and can be used as an indicator of pathogen inactivation and bacterial regrowth in treated waste. *Ascaris* spp. are helminthes whose ova are both heat- and desiccation-resistant and are therefore used to provide a conservative measure of treatment efficacy.

Temperature, moisture content and pH are physico-chemical parameters which have been found to influence microbial inactivation in the literature. Elevated temperature, elevated pH, and decreased moisture content (or increased total solids) have been shown to be associated with increased microbiological inactivation. Additionally, moisture content measurement also enables normalization of weight units so that data can be compare to WHO guidelines, which are reported on a dry weight basis.

4.2.2 Baseline Study Design

The environmental evaluation comprised two baseline investigations, in July 2014 and March 2015, in order to determine the level of microbiological inactivation and to characterize existing waste in selected single-family UDDTs in terms of the selected parameters. Samples from the closed vaults of the original 90 single-family UDDTs were targeted between the two investigations. In July, both active vaults and vaults that had been closed for 8 months were sampled; in March, only vaults that had been closed for 13 months were sampled. The number of units sampled was based on time and logistical constraints, as there was only one day available for sampling during each site visit, based on the need to start laboratory analysis within 1-2 days after collection; samples were transported to the lab immediately after collection. Therefore, field teams were instructed to sample as many vaults as possible from various locations throughout the camp. A convenience sample strategy was used, with the teams instructed to purposively select units where the closed vault was more than half full of waste and, in July, to also sample 2-3 active vaults over the sampling day.

4.2.3 Longitudinal ("Seeded") Study Design

To specifically assess *Ascaris* ova inactivation over time, a "seeded study" of 20 shared-family UDDTs (from the original 630 units) was implemented over a 1-year time period starting in August 2015 (Figure 1). Manually adding (or "seeding") a large number of ova within nylon mesh bags into UDDTs enabled measurement of a wide range of reduction in ova viability over time. In addition, nylon waste bags containing only waste were used to measure physico-chemical properties of waste. Bags were embedded in stored fecal sludge piles in UDDTs in September (t=0), and then removed in March 2016 (t=6 months), June 2016 (t=9 months) and September 2016 (t=12-months) for analysis.

4.2.4 Supervision and Field Procedures

Following a two-day training led by CDC staff in Arba Minch, NRC staff conducted all field sampling for both the Baseline and Longitudinal studies. UNHCR provided on-site supervision and logistical support for sample transport. The detailed Standardized Operating Procedures (SOPs) for field sampling, sample packaging and shipment can be provided upon request to the authors.

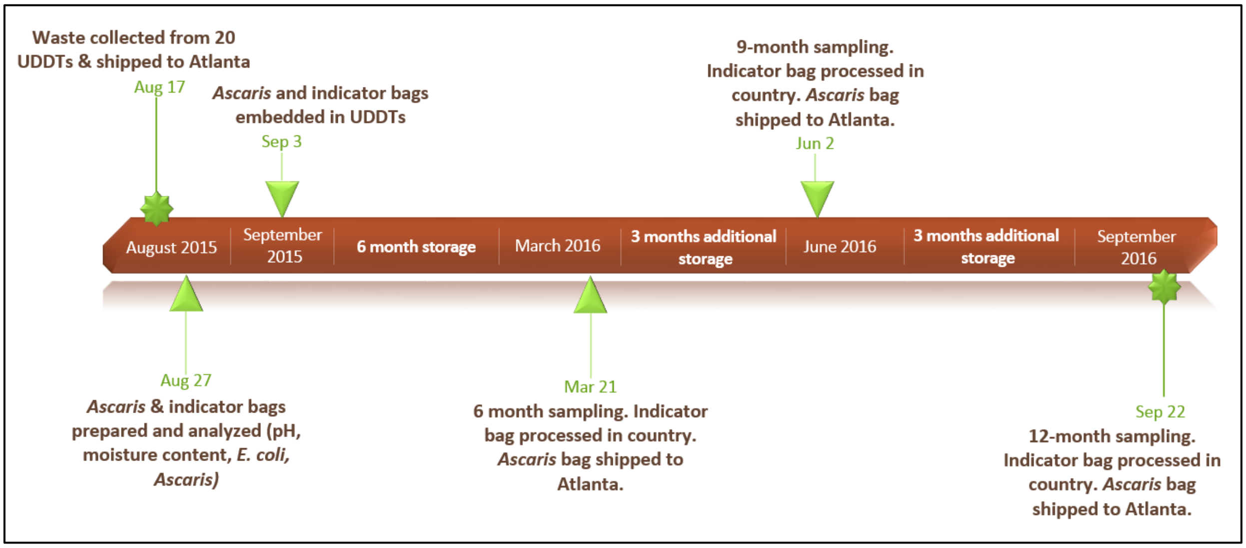

Figure 1. Sampling and processing timeline for 20 shared-family UDDTs

4.2.5 Laboratory Preparation: Longitudinal Study

Waste extracted from the 20 UDDTs in August 2015 was prepared for the ”seeded study” in the laboratory by CDC staff in Atlanta, GA using a technique in which a large number of purchased, viable *Ascaris* ova are manually added to a small volume of waste within nylon mesh bags (Jensen 2009). The small pore size (20 micron) of this nylon mesh confined the ova, but also allowed ova to be exposed to the same environmental conditions as the surrounding waste.

On August 26, four “*Ascaris* bags” each containing approximately 15,400 viable *Ascaris suum* ova (Excelsior Sentinel, Inc; Trumansburg, NY) in 3 g of UDDT waste and four “indicator bags” each containing 60 g of unaltered UDDT waste were prepared in the laboratory for each of the 20 UDDTs. One of each bag type was immediately analyzed at CDC to characterize initial, or 0 month, conditions. The remaining three bags were shipped on ice to Hiloweyn camp to be embedded in UDDTs for up to 1 year.

4.2.6 Field Sampling: Longitudinal Study

OnSeptember 3, 2015, three *Ascaris* bags and three indicator bags were embedded by field teams into the respective UDDT from which waste was retrieved (Figure 2).

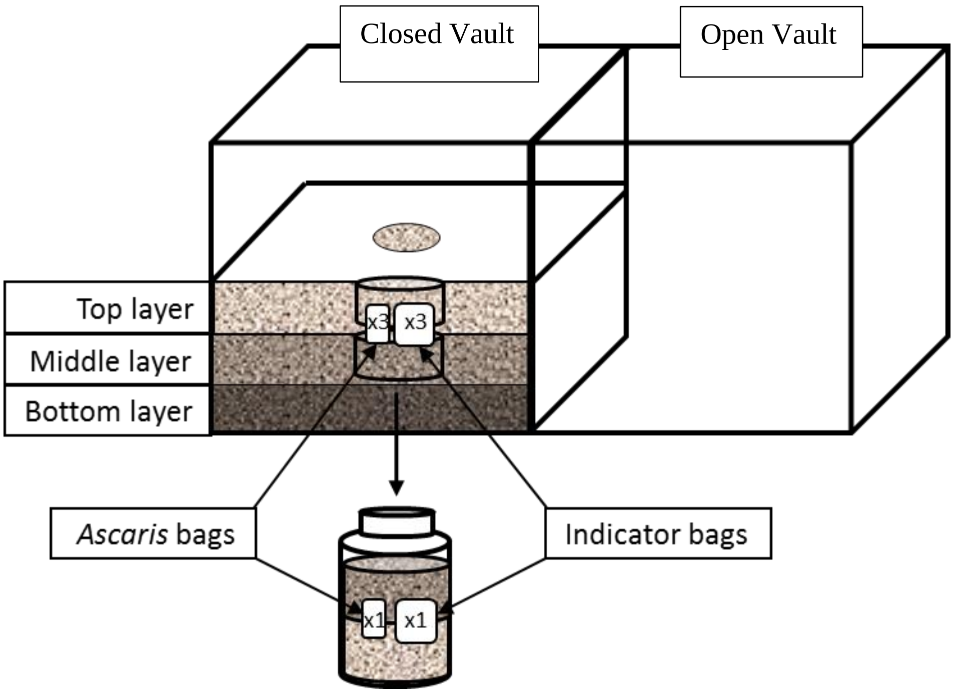

Figure 2. Diagram of sampling location within UDDT and the transfer to a 1 L bottle prior to processing

At each sampling interval (6, 9, and 12 months), one *Ascaris* bag and one indicator bag were removed from each of the 20 study UDDTs and placed in 1 L bottles; additional waste from the respective UDDT was added to each bottle to surround the bags. Bottles were then placed in cool boxes containing ice packs andshipped to a laboratory in Ethiopia. There, indicator bags were processed for pH, *E. coli*, and moisture content. The *Ascaris* bags remained in bottles with waste and were shipped to CDC-Atlanta and processed for *Ascaris* viability. Early experiments were conducted to assess the effect of shipment conditions (i.e., within a cooler with ice packs to maintain 4 °C) on *Ascaris* viability. Results indicated that viability did not appreciably vary over a 13-day time period under these conditions (data not shown).

Temperature of waste in top, middle, and bottom layers within each UDDT were measured at 0 months and at 6, 9, and 12 months of storage. Additionally, for the first 6 months of the study, a temperature logger was inserted in the top, middle and bottom layers of two UDDTs in order to determine diurnal variation in temperature.

4.2.7 Analytical Methods

CDC staff performed all laboratory analyses, with assistance from Arba Minch University students (Baseline Study) and Ethiopian Public Health Institute staff (Longitudinal Study) for moisture content, pH, and *E. coli* analyses.

4.2.7.1 Percent Moisture Content

EPA Method 1684 (US EPA 2001; slightly modified) was used to determine percent total solids. Briefly, a known quantity of mixed biosolids was initially weighed, heated in an oven at 103-105 °C for at least 12 hours, then reweighed and compared to the original measurement to determine percent solids in the collected sample. The following equation was used to determine the percent moisture content:

$$Percent\ Moisture\ Content = 100\% - Percent\ Total\ Solids$$

4.2.7.2 pH

EPA Method 9045D (US EPA 2004) was used to determine pH of samples. Briefly, known quantities of mixed biosolids and distilled water were stirred on a magnetic stir plate for at least 5 minutes. Solids in the suspension were allowed to settle for at least 15 minutes before pH was measured using a calibrated pH probe.

4.2.7.3 E. coli Quantification

Samples were analyzed for *E. coli* as follows: a 25 g mixed sample was added to 200 mL sterile elution buffer and shaken by hand for 5 minutes. Solids in the suspension were allowed to settle for at least 5 minutes. The supernatant was diluted in sterile elution buffer then analyzed using the quantitative IDEXX® Colilert®-18 (IDEXX Laboratories; Westbrook, Maine) methodology, according to manufacturer's instructions. A positive control and a negative control were analyzed following analysis of all samples. Wells with a yellow color change (indicating the presence of total coliforms) and wells with a yellow color change plus fluorescence under 365 nm long-wave UV light (indicating the presence of *E. coli*) were enumerated. A most probable number (MPN) table was used to determine the MPN of *E. coli* present; back-calculation was used to determine *E. coli* MPN/g total solids for each sample.

4.2.7.4 *Ascaris* Viability Testing

In the Baseline Study, the Bowman (2003) flotation method was used at CDC to separate *Ascaris* ova from heavier particles in the biosolids. This method allows a larger quantity of sample to be analyzed, therefore concentrating ova that may be present in lower numbers. It also removes most particulates from the matrix, resulting in a "cleaner" sample that is easier to analyze by microscopy. The flotation procedure is followed incubation at 28 °C for a minimum of 28 days. Samples are then concentrated and transferred to a glass microscope slide and examined under 100X magnification in order to visualize both viable (containing larvae) and nonviable ova (no visible larvae). Additionally, a quantitative polymerase chain reaction (qPCR) method was used to detect *Ascaris* nucleic acids (i.e., DNA) in the material recovered from the flotation procedure.

In the Longitudinal Study, a filtration and flotation procedure (based on Roepstorff and Nansen, 1998; Vadlejch, J. et al., 2011) was used to separate *Ascaris* ova from heavier particles in the 3 g of waste within each bag. The resulting suspension of ova in a known volume of flotation solution was then transferred into Petri dishes, covered with plastic paraffin film, and incubated at 28 °C for a minimum of 28 days. A subset of the incubated solution was then transferred to a Sedgewick Rafter counting slide and examined under 100X magnification in order to enumerate viable and nonviable ova. Counts were used to calculate viability $\log_{10}$ and percent reduction values.

4.3 Results

4.3.1 Baseline Study

In the Baseline Study, physico-chemical and microbiological data were collected for 4 active vaults (July 2014) and 21 closed vaults (6 vaults were closed for 8 months [July 2014] and 15 vaults were closed for 1.3 years [March 2015]). In the active vaults, average temperature (top layer only) was 31 °C; average pH was 8.9; and average percent moisture content was 12%. In the vaults closed for 8 months, average temperature (top, middle, and bottom layers) was 32.8 °C; average pH was 9.0; and average moisture content was 1%. In the vaults closed for 1.3 years, average temperature (top, middle, and bottom layers) was 34.1 °C; average pH was 8.6; and average moisture content was 3%.

E. coli concentration was not measured in the active vaults or the vaults closed for 8 months. In the vaults closed for 1.3 years, samples from 7 vaults met the WHO *E. coli* guideline of <1000 *E. coli*/g total solids and samples from 3 vaults exceeded this value (range 2200 - >98000 *E. coli*/g total solids); data are not available for the 5 additional vaults. Therefore, 70% of the samples tested met the WHO *E. coli* guideline after 1.3 years of storage.

At the July 2014 time point, no *Ascaris* ova (viable or non-viable) were detected by microscopy in samples from active vaults or from vaults closed for 8 months; however, *Ascaris* DNA was detected in a sample from 1 of these closed vaults. At the March 2015 time point, very low numbers (<1 per g total solids) of *Ascaris* ova were detected by microscopy in samples from 8 of the 15 vaults that had been closed for 1.3 years, however none of these ova were viable. From these vaults, *Ascaris* DNA was detected in samples from 2 vaults, both of which were also positive by microscopy. The presence of *Ascaris* DNA confirms that *Ascaris* had been present at one time; it does not provide information on viability or on concentration of ova in waste.

The original study plan was developed to utilize existing viable *Ascaris* ova in vaults to measure inactivation over storage time. However, these extremely low levels of *Ascaris* (viable or non-viable) in Hiloweyn vaults prevented use of this approach to assess efficacy of inactivation over time.

4.3.2 Longitudinal Study

4.3.2.1 Physico-chemical parameters

Temperature, moisture content and pH results are summarized in Table 1 for 20 shared-family UDDTs. Temperature readings were taken at the time of sample collection, between 8:30 am and 2:40 pm. At 0 months (September 2015), the average temperature readings in the top, middle, and bottom layers were 32 °C, 33 °C, and 32 °C, respectively. At 6 months (March 2016), the average temperature readings were 36 °C, 36 °C, and 36 °C, respectively. At 9 months (June 2016), the average temperature readings were 34 °C, 34 °C, and 35 °C, respectively. At 12 months (September 2016), the average temperature readings were 32 °C, 32 °C, and 32 °C, respectively. Therefore, the average annual temperature range in these closed vaults was 4°C. The temperature logger data indicated that the average diurnal variation within a 24-hour period was 1.6 °C (range: 1.1°C to 2.1°C). Therefore, there was minimal temperature change in the closed vaults over a typical 24 hour day.

Samples from the closed vaults were relatively dry throughout the study. The average percent moisture content was 9% at 0 months, 3% at 6 months, 4% at 9 months, and 3% at 12 months. Similarly, the pH did not change appreciably over the study period. The average pH was 9.0 at 0 months, 9.1 at 6 months, 9.1 at 9 months, and 9.1 at 12 months.

Table 1. Temperature, moisture content, and pH in 20 shared-family UDDTs at 0 months and after storage for 6, 9 and 12 months

	Temperature (°C)												**Moisture Content (%)**				**pH**			
UDDT ID	**0 months**			**6 mo**			**9 mo**			**12 mo**			**0 mo**	**6 mo**	**9 mo**	**12 mo**	**0 mo**	**6 mo**	**9 mo**	**12 mo**
	Top	**Mid**	**Bottom**	**Top**	**Mid**	**Bottom**	**Top**	**Mid**	**Bottom**	**Top**	**Mid**	**Bottom**								
L1	31	33	33	36	36	36	33	34	34	30	30	30	10	2	3	2	8.6	9.2	9.1	9.1
L2	33	33	34	41	39	39	33	33	33	32	33	33	6	1	2	2	10.3	10.6	10.3	10.4
L3	32	33	33	36	36	36	33	33	33	30	32	32	6	2	8	2	9.3	9.7	9.8	9.9
L4	34	34	35	36	37	37	34	35	35	33	33	33	4	1	3	2	9.2	9.6	9.5	9.5
L5	34	34	33	39	38	38	34	34	34	32	33	33	5	1	2	9	10.6	10.9	10.2	8.9
L6	31	32	32	32	33	33	33	34	34	33	33	33	12	10	11	2	8.6	8.7	9.1	10.7
L7	34	34	34	38	38	38	33	34	34	32	32	33	9	2	4	4	8.2	8.7	8.8	8.8
L8	33	32	33	35	36	36	33	33	33	33	33	33	3	1	10	2	10.0	10.5	9.8	9.5
L9	34	34	33	36	37	37	33	34	33	33	33	33	6	2	3	4	8.4	8.8	8.8	8.8
L10	33	33	33	36	37	37	33	34	34	32	33	33	5	1	2	2	8.8	8.9	8.9	9.7
L11	31	33	29	37	37	37	34	35	36	31	32	32	15	2	3	2	8.2	8.0	7.7	8.1
L12	33	30	26	37	37	36	34	35	36	31	32	32	20	3	2	2	8.0	8.2	8.4	8.4
L13	31	32	34	38	37	37	36	37	37	32	33	33	9	2	3	2	10.1	10.6	10.4	10.3
L14	32	31	31	37	37	37	35	36	37	32	33	33	4	1	3	2	9.5	9.4	9.7	9.8
L15	31	32	33	ND	ND	ND	34	35	36	31	32	32	6	ND	ND	7	9.2	ND	ND	8.4
L16	30	31	31	35	35	35	33	34	35	29	31	31	9	5	ND	11	8.4	8.1	ND	8.4
L17	34	32	32	38	38	38	33	34	35	31	32	32	9	1	2	2	9.0	9.9	10	9.3
L18	32	32	31	34	34	34	33	33	34	33	34	34	12	9	13	2	8.2	7.3	7.4	8.2
L19	33	34	34	35	35	35	32	33	34	31	32	33	9	3	2	2	8.7	7.9	7.9	7.8
L20	33	32	32	35	35	35	34	35	35	30	31	31	14	1	5	4	8.4	7.6	8.3	8.4
Average	**32**	**33**	**32**	**36**	**36**	**36**	**34**	**34**	**35**	**32**	**32**	**32**	**9**	**8**	**4**	**3**	**9.0**	**9.1**	**9.1**	**9.1**

ND: no data

4.3.2.2 MICROBIAL PARAMETERS

4.3.2.2.1 *E. COLI* ANALYSIS

At 0 months, samples from 30% (n=6) of UDDTs met the WHO *E. coli* guideline of <1000 *E. coli*/g total solids. At 6 months, samples from 74% (n=14) UDDTs met this guideline. At 9 months, samples from 89% (n=16) UDDTs met this guideline. At 12 months, samples from 95% (n=19) UDDTs met this guideline (Table 2).

Table 2. *E. coli* concentrations in 20 shared-family UDDTs at Time 0 and after storage for 6, 9 and 12 months

	***E. coli* (MPN/g total solids)**			
UDDT ID	**0 mo**	**6 mo**	**9 mo**	**12 mo**
L1	**$<1\cdot10^{2}$**	**$<9.2\cdot10^{1}$**	**$<9.2\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L2	**$<9.6\cdot10^{1}$**	**$<9.1\cdot10^{1}$**	**$<9.2\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L3	**$<9.6\cdot10^{1}$**	**$<9.2\cdot10^{1}$**	**$9.8\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L4	$8.9\cdot10^{6}$	**$<9.1\cdot10^{1}$**	**$2.8\cdot10^{2}$**	**$<9.4\cdot10^{1}$**
L5	$<1.3\cdot10^{5}$	**$<9.1\cdot10^{1}$**	**$<9.1\cdot10^{1}$**	**$<9.9\cdot10^{1}$**
L6	$1.1\cdot10^{6}$	**$<1.0\cdot10^{2}$**	**$1.0\cdot10^{2}$**	**$<9.2\cdot10^{1}$**
L7	$5.6\cdot10^{3}$	$6.6\cdot10^{3}$	**$<9.3\cdot10^{1}$**	**$<9.4\cdot10^{1}$**
L8	$1.2\cdot10^{6}$	**$<9.1\cdot10^{1}$**	**$<1.0\cdot10^{2}$**	**$<9.2\cdot10^{1}$**
L9	$4.1\cdot10^{7}$	**$<9.2\cdot10^{1}$**	**$<9.3\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L10	$1.1\cdot10^{7}$	$4.0\cdot10^{3}$	**$<9.1\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L11	$3.3\cdot10^{6}$	**$1.0\cdot10^{3}$**	**$<9.3\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L12	$2.2\cdot10^{6}$	$8.9\cdot10^{3}$	**$<9.2\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L13	**$<9.8\cdot10^{1}$**	**$<9.2\cdot10^{1}$**	**$<9.3\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L14	**$<9.4\cdot10^{1}$**	**$<9.1\cdot10^{1}$**	**$<9.3\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L15	$5.0\cdot10^{3}$	ND	ND	**$1.9\cdot10^{2}$**
L16	$1.9\cdot10^{5}$	$5.2\cdot10^{4}$	ND	$>2.5\cdot10^{5}$
L17	$3.8\cdot10^{4}$	**$<9.1\cdot10^{1}$**	**$<9.2\cdot10^{1}$**	**$<9.2\cdot10^{1}$**
L18	$1.3\cdot10^{4}$	$9.1\cdot10^{4}$	$2.9\cdot10^{3}$	**$<9.2\cdot10^{1}$**
L19	**$<9.9\cdot10^{1}$**	**$9.2\cdot10^{1}$**	**$<9.2\cdot10^{1}$**	**$9.2\cdot10^{1}$**
L20	$1.3\cdot10^{8}$	**$<9.1\cdot10^{1}$**	$1.3\cdot10^{4}$	**$<9.3\cdot10^{1}$**
No. (%) UDDTs that met WHO guidance (<1000 *E. coli* / g total solids)	**6 (30)**	**14 (74)**	**16 (89)**	**19 (95)**

MPN: Most Probable Number

ND: no data; see Limitations section

Notes:

1) Shaded cell indicates sample met WHO *E. coli* guideline value of <1000 *E. coli*/g total solids

2) Numbers may vary slightly due to differences in denominators

4.3.2.2.2 *ASCARIS* VIABILITY

At 6, 9 and 12 months of storage, there was a >2.8 $\log_{10}$ (>99.8%) reduction, >2.7 $\log_{10}$ (>99.7%) reduction, and >2.8 $\log_{10}$ (>99.8%) reduction, respectively, in *Ascaris* viability, as compared with *Ascaris* viability at Time 0 (Table 3). Log reduction values (versus concentrations of ova per g total solids) are reported due to methodological constraints. Although large numbers of ova were seeded into bags, much lower numbers of ova, even those that were non-viable, were observed after incubation, likely due to decomposition over storage time. In addition, it was time- and resource-prohibitive to analyze the entire 3 g of waste from each of the 20 bags. Due to these two factors (low concentrations and low volumes analyzed), the detection limit of the assay was limited to 8 ova/g (6 and 12 month assays) or 16 ova/g (9 month assay).

Table 3. Average no. of viable Ascaris ova / g and $\log_{10}$ reduction values (LRV) (%) of *Ascaris* in 20 shared UDDTs after storage for 6, 9, and 12 months

Treatment Time	**Average no. of viable *Ascaris* ova / g**	**Average LRV (%) of viable *Ascaris***
0 mo	5133	---
6 mo	<8	>2.8 (>99.8%)
9 mo	<16	>2.7 (>99.8%)
12 mo	<8	>2.8 (>99.8%)

LRV: $\log_{10}$ reduction value

Note: "<" value indicates that the lower detection value of the test method was met; these samples may or may not have met WHO guidelines of <1 viable ova/g

4.4 DISCUSSION

The goals of these studies were to 1) determine the performance of the UDDTs, in terms of microbial inactivation, in order to provide guidance on their use in Hiloweyn camp; and 2) document the environmental factors influencing the performance of the UDDTs (i.e., temperature, pH, moisture content, and storage time) for microbial inactivation.

The physico-chemical parameters of stored UDDT waste measured in these studies indicate that conditions within closed UDDT vaults in Hiloweyn camp were consistently warm, very dry, and moderately alkaline (i.e., elevated pH). Temperature of waste in shared-family UDDTs in the Longitudinal Study followed a moderate annual seasonal pattern, with lowest average temperatures at 0 and 12 months (September) and highest average temperatures at 6 months (March). Percent moisture content of the waste seeded at baseline was 9% and decreased to 3% over the course of the 12-month study period; for reference, the average moisture content of fresh human feces is 75% (Rose et al, 2015). The moisture content of waste sampled in our evaluation was considerably lower than that of stored waste in similar UDDT studies; for example, a study in Panama reported moisture content of waste ranging from 29% to 67% after six to 10 months of closed storage (Mehl et al., 2011). The low moisture content observed in Hiloweyn was likely due to arid conditions and the amount of time waste had been stored prior to seeding (~1.5 years). The average pH of human feces is neutral and ranges from 6.6 to 7.0 (Dinoto et al., 2006). In our study, over the 12-month time period, the pH of the waste material remained relatively constant at pH 9. This elevated pH is possibly due to the addition of ash after each defecation. Overall, these conditions are as expected in a warm, arid desert climate, and result in an inhospitable environment for many microorganisms including *E. coli* and *Ascaris* ova.

Overall, UDDTs were successful in reducing both *E. coli* and viable *Ascaris* over the 12-month Longitudinal Study period. However, *E. coli* was still present in 3 of 10 UDDTs after 1.3 years of storage in the Baseline Study and 1 of 20 after 1 year of storage in the Longitudinal Study. As the closed vaults are not completely sealed, there is a possibility that *E. coli* could have been introduced during the study periods (e.g., by rodents), although this is not likely. It is more likely that *E. coli* was able to survival in very small amounts of waste that retained moisture within the vaults. Other studies have shown *E. coli* is able to survival in soils containing animal feces for up to 231 days (at 21 ˚C and 7% moisture content) (Jiang 2002) and that *E. coli* from animal feces initially can grow in soils (Lau 2001). In addition, while no viable *Ascaris* ova were detected after any of the treatment times, nor during the Baseline Study, the amount of sample analyzed and the overall low sample size in the study does not mean that viable *Ascaris* ova were completely absent. Were we able to sample larger volumes of waste, or a larger number of samples, we may have detected viable *Ascaris* ova.

At the start of the Longitudinal Study (0 months), shortly after vaults were closed, samples from most (70%) of the 20 UDDTs studied did not meet the WHO guideline value of <1000 *E. coli*/g total solids. *E. coli* is abundant in human waste, often in concentrations as high as 10^9/g, so these findings are as expected. By six months, samples from three-quarters of UDDTs met WHO guidelines, and by 12 months, samples from all but one UDDT (95%) contained <1000 *E. coli*/g total solids. While temperature likely did not play a role in these reductions (i.e., *E. coli* thrives in similar temperatures found within the human gut), these results are not surprising because of the dry, alkaline environment of the waste. As described above, the *E. coli* that were able to survive during the 12-month study were likely embedded in small particles of waste bound by moisture and protected from environmental conditions. However, as waste continued to dry out, *E. coli* concentrations decreased.

The Baseline Study results indicated very low concentrations of naturally-occurring *Ascaris* ova in stored fecal sludge. The fact that no viable ova were detected in the active vaults, which would likely have the highest chance of containing viable ova, suggests that *Ascaris* carriage in the Hiloweyn population was low. Due to these low concentrations, we elected to seed a large number of viable *Ascaris* ova in existing waste (~5100/g total solids) to maximize our ability to measure inactivation over time. While methodological constraints, which led to limitations with the assay's lower detection limit, prohibit asserting that this seeded waste met WHO guidelines (i.e., <1 viable ova/g total solids) after up to one-year of treatment, a >99.7% reduction in viability of *Ascaris* ova is very promising. In a drug efficacy study in Bangladesh, the mean *Ascaris* ova concentration in stools of infected children was 1778 ova/g (Hall and Nahar, 1994); a 99.7% reduction of this concentration would result in approximately 5 ova/g. However, UDDTs will contain stools of both infected and non-infected persons, along with other additives such as ash. In well-mixed UDDT waste, we would expect a vastly lower overall starting concentration of *Ascaris* and a >99.7% reduction in viability would very likely result in waste that meets WHO guidelines. However, it is important to note that in practice, UDDTs may not be well mixed. Therefore, there may be small pockets within the waste pile where *Ascaris* may find suitable conditions to survive (as was indicated by *E. coli* data from the present study). Proper use and maintenance of UDDTs, including regular mixing of waste, is important to maximize treatment efficacy.

4.5 LIMITATIONS

Baseline Study

- Due to complications during collection and transport of the specimens collected in July 2014, the results are limited for this sampling investigation. Testing could not be completed for *E. coli* due to the length of time it took to transport the samples to Atlanta.
- The study's low sample size, as well as the small volume of sample that was analyzed, prohibit definitive assurance that conditions in the vaults produced waste that met the WHO guideline value of <1 viable *Ascaris* ova/g total solids.

Longitudinal Study

- In nearly all 6, 9, and 12 month samples, very few or no viable ova were present in the amount of sample analyzed by microscopy; this is likely due to natural decay of ova over time while in dry conditions. The effectiveness of the method is based on the amount of sample analyzed. For example, if no viable ova were present in 0.125 g of waste, then <1 ova per the 0.125 g, or <8 ova/g, is what is reported. In these experiments, we chose to analyze an amount of waste that was practical for counting all slides within 1-2 work days, so that incubation times were consistent across all samples. Analysis of a larger amount of sample might have allowed us to report if treatment times achieved the WHO guideline value (<1 viable ova/g total solids). Please note that *Ascaris* bags were seeded with a high concentration of viable ova (~5100 ova/g) in order to detect large reductions in viable ova. These concentrations are not likely to be present in well-mixed UDDT waste, therefore not meeting the WHO guideline value does not mean that treatment was ineffective.
- At each time point, an *Ascaris* and/or an indicator bag was not collected for a small subset of UDDTs because it was unable to be located within UDDTs.
- Due to inconsistent electricity throughout the incubation time period at the 6-month time point, *E. coli* analysis for each UDDT was repeated the following day using waste material in which indicator and *Ascaris* bags were embedded for shipment.

4.6 Additional Controlled Laboratory Study

A supplemental laboratory-based study was undertaken in early 2017 to provide further guidance to the UDDT program in Hiloweyn camp in terms of additional actions (i.e. secondary treatment) that could be taken as needed to assist with safety aspects of UDDT waste handling and emptying schedules.

4.6.1 Objective of the Laboratory Study

The specific objective of the study was to evaluate the effects of increased pH, as the most readily controllable environmental condition, on *Ascaris* ova and *E. coli* inactivation in dry UDDT waste.

4.6.2 Background and Rationale

Optimization of environmental conditions (i.e., moisture content, pH, and temperature) of waste can improve pathogen inactivation, thus decreasing storage time required to ensure safe and hygienic disposal of human waste. Previous studies have shown that addition of some materials ("additives"), such as lime, ash, or sawdust, to fecal waste can increase the rate of inactivation of microbes, including *Ascaris* and *E. coli*, primarily through increasing pH and/or desiccation (Magri et al, 2013; Austin and Cloete, 2008; Brewster et al., 2003; Eriksen et al., 1995).

UDDT users in Hiloweyn camp were instructed to add one "cup-full" (~150 g) of ash following each defecation to further desiccate waste. Based on the extremely low moisture content and slightly elevated pH (~9-10) of waste measured during the Longitudinal Study, ash appears to have been effectively utilized by UDDT users. However, ash is primarily used as a desiccant and may not elevate pH to values associated with increased microbial inactivation (i.e., pH > 12) due to a wide range in basicity (i.e., pH 9.0-13.5) (Etiegni and Campbell, 1991). Hydrated-lime ($Ca(OH)_2$) and quick-lime (CaO), on the other hand, are commonly used for the alkaline treatment of waste, due to well-documented efficacy in inactivating *Ascaris* ova in wastewater and sewage sludge (Pecson et al, 2007). However, the concentration of lime required to achieve the recommended pH level for microbial inactivation in dry UDDT waste is unknown.

Therefore, we conducted a controlled laboratory study to evaluate the effects of increased pH via hydrated lime addition on *Ascaris* ova and *E. coli* inactivation in dry UDDT waste. The study was designed to simulate field conditions for secondary treatment of waste inside the UDDT vault at the point of vault closure. UDDT waste collected from the Longitudinal Study was treated with various concentrations of hydrated lime then seeded with

Ascaris ova and *E. coli*. *Ascaris* viability and *E. coli* inactivation were monitored over a 3-month study period. Moisture content and temperature of the waste were adjusted to mimic those inside UDDT vaults in Hiloweyn camp during the time of the Longitudinal Study.

4.6.3 METHODS

4.6.3.1 PREPARATION AND SAMPLING

UDDT waste collected from Hiloweyn during the Longitudinal Study was shipped and stored at 4 °C in the Atlanta laboratories prior to the controlled study. Waste was moistened to the highest moisture content observed (~20%) in UDDTs at Baseline (0 months) in the Longitudinal Study. Waste was then transferred into nine 1-L polypropylene bottles and commercially available hydrated lime (Bonide; Oriskany, NY) was added to achieve 0.5%, 2%, and 5% (w/w) concentrations in triplicate bottles. Three additional bottles containing UDDT waste without the addition of lime were included to observe inactivation of *Ascaris* and *E. coli* in the absence of lime.

Ten "*Ascaris*" bags each containing approximately 18,500 viable *Ascaris* ova were layered into waste in each bottle, with each *Ascaris* bag completely surrounded by waste (Figure 3). Due to difficulties in evenly distributing seeded *E. coli* in bottles of UDDT waste, 1-g aliquots of waste from each bottle were transferred into each of two 2-mL microcentrifuge tubes containing 10^8 *E. coli* colony forming units (CFU). Moisture content, pH, *E. coli* concentration, and *Ascaris* viability were assayed immediately after seeding microbes, as described below, to characterize Time 0 conditions.

All bottles and microcentrifuge tubes were sealed and placed in an environmental chamber at 34 °C.

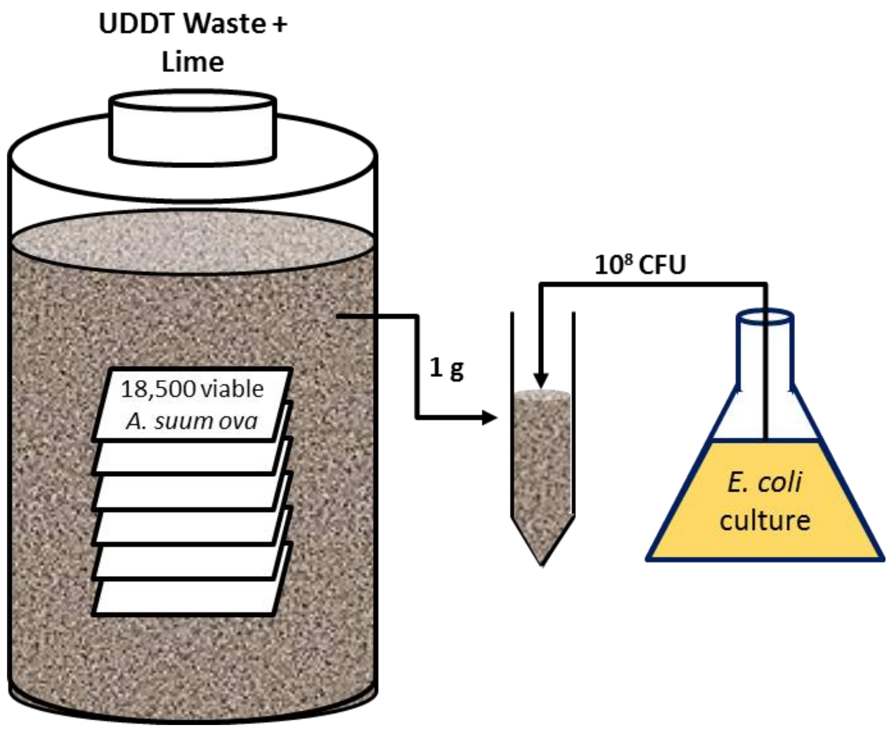

Figure 3. UDDT waste treated with 0.5%, 2%, or 5% (w/w) hydrated lime and seeded with *Ascaris* ova and *E. coli*

Moisture content and pH of waste surrounding *Ascaris* bags were analyzed after 1, 2, 3, 4, 6, 8, and 12 weeks at 34 °C. UDDT waste inside microcentrifuge tubes were analyzed for *E. coli* concentration after 12 weeks of storage time. One *Ascaris* bag was removed from each bottle and viability of ova was assessed after 1, 2, 3, 4, 6, 8, and 12 weeks at 34 °C.

4.6.3.2 Analytical Methods

The analytical methods used for the physico-chemical parameters are the same as previously described in Section 3.2.7.

4.6.3.2.1 *E. coli* Quantification

Samples were analyzed for *E. coli* as follows: the 1 g sample inside the microcentrifuge tube was added to 4 mL of sterile elution buffer (0.1% peptone water with 0.05% Tween 80) and shaken by hand for 5 minutes. Solids in the suspension were allowed to settle for at least 5 minutes. An aliquot of the supernatant, or liquid layer containing eluted microbes, was diluted tenfold in sterile phosphate buffered saline (PBS), then analyzed by membrane filtration methodology. A positive control (ATCC 11775 *E. coli* in sterile PBS) and a negative control (sterile PBS only) were analyzed following analysis of all samples. Colonies that were blue in color (*E. coli*) were enumerated after 20-24 hours of incubation at 35 °C. Concentration of *E. coli* was expressed in colony forming units (CFU) per unit volume of sample; back-calculation was used to determine *E. coli* CFU/g total solids for each sample.

4.6.3.2.2 *Ascaris* Viability Testing

Ascaris bags were removed from bottles and washed with sterile deionized water to remove residual waste on outside of bag. *Ascaris* bags were aseptically cut open then transferred into glass Petri dishes containing 10 mL incubation solution (0.5% formalin). An additional 10 mL of incubation solution was added, directing the stream on the *Ascaris* bag to elute ova from the bag surface. *Ascaris* bags were left in Petri dishes and lightly covered with plastic paraffin film. Samples incubated at 28 °C for a minimum of 28 days. A subset of the incubated solution was then transferred to a Sedgewick-Rafter counting slide and examined under 100X magnification in order to enumerate viable (containing larvae) and non-viable (no visible larvae) ova. Counts were used to calculate viability $\log_{10}$ and percent reduction values.

4.6.4 Results

4.6.4.1 Physico-chemical parameters

The average pH of the control samples ranged from 8.3 to 8.8 over 12 weeks of storage (Table 4). Average pH of 0.5% lime treatment was initially elevated (>12) at baseline, but pH values decreased to pH ~8 by week 1. Average pH of 2% lime treatment remained elevated (>12) for 4 weeks of storage time, then decreased to pH ~8 by week 8. Average pH of 5% lime treatment remained elevated (>12) for the duration of the 12 week study period and ranged from 12.5 to 12.8.

Moisture content remained stable throughout the study period for all treatments. Average moisture content of controls ranged from 19 to 21%; average moisture content of 0.5% lime treatment ranged from 19 to 22%; average moisture content of 2% lime treatment ranged from 19 to 20%; and average moisture content of 5% lime treatment ranged from 18 to 19%.

Table 4. Average pH and moisture content in untreated (control) and treated (0.5%, 2%, and 5% lime [w/w]) UDDT waste at 34 °C for 12 weeks

	Control		**0.5% lime**		**2% lime**		**5% lime**	
Storage Time (weeks)	**pH**	**Moisture Content (%)**	**pH**	**Moisture Content (%)**	**pH**	**Moisture Content (%)**	**pH**	**Moisture Content (%)**
0	8.8	21	12.1	22	12.7	19	12.8	18
1	8.3	19	8.9	19	12.6	19	12.7	19
2	8.4	20	8.5	20	12.6	19	12.7	19
3	8.4	19	8.4	20	12.5	19	12.8	19
4	8.6	20	8.3	20	12.5	19	12.7	18
6	8.5	20	8.3	20	11.1	19	12.6	18
8	8.5	21	8.3	20	8.6	20	12.5	19
12	8.3	19	8.2	19	8.8	19	12.7	18

ppm: parts per million, or mg/L

4.6.4.2 MICROBIAL PARAMETERS

4.6.4.2.1 *E. COLI* ANALYSIS

Immediately after seeding ~$1.6 \cdot 10^8$ CFU *E. coli* into waste (t=0 weeks), the 0.5%, 2%, and 5% lime treatments met the WHO guideline of <1000 *E. coli*/g total solids. After 12 weeks of storage, all treatments (including control) met this guideline (Table 5).

Table 5. *E. coli* concentrations in control and treated (0.5%, 2%, and 5% lime [w/w]) UDDT waste at time of treatment (t=0 weeks) and after 12 weeks at 34 °C

	***E. coli* / g total solids**	
Treatment	**t = 0 weeks**	**t = 12 weeks**
Control	$1.7 \cdot 10^8$	**7.4**
0.5% lime	**45.9**	**5.9**
2% lime	**<4.4**	**<4.4**
5% lime	**<4.4**	**< 4.4**

Notes:
1) "<" value indicates lower detection limit was met
2) Shaded cell indicates sample met WHO E. coli guideline value of <1000 E. coli/g total solids

4.6.4.2.2 *ASCARIS* VIABILITY

In the samples treated with 2% and 5% lime, there was an immediate >2.7 $\log_{10}$ (>99.8%) reduction in *Ascaris* viability after one week and no viable was detected at subsequent time periods (Table 6). Notably, in the control samples, *Ascaris* viability also reduced significantly over the study period and no *Ascaris* was detected after 4 weeks. *Ascaris* viability in the 0.5% lime concentration followed a similar trend to the control samples.

Table 6. Average log_{10} (%) reduction values (LRV) of *Ascaris* ova in control and treated (0.5%, 2%, and 5% lime) UDDT waste at 34 °C for 12 weeks

	Average LRV (%) of viable *Ascaris*			
Treatment Time (weeks)	**Control**	**0.5% lime**	**2% lime**	**5% lime**
1	0.7 (77.6%)	0.5 (70.4%)	>2.7 (>99.8%)	>2.9 (>99.9%)
2	0.9 (84.0%)	0.8 (84.0%)	>2.8 (>99.8%)	>2.9 (>99.9%)
3	1.4 (96.3%)	1.7 (97.9%)	>2.9 (>99.9%)	>2.9 (>99.9%)
4	2.7 (99.8%)	>2.9 (>99.9%)	>2.9 (>99.9%)	>2.9 (>99.9%
6	>2.4 (>99.6%)	>2.4 (>99.6%)	>2.4 (>99.6%)	>2.4 (>99.6%)
8	>2.9 (>99.9%)	>2.9 (>99.9%)	>2.9 (>99.9%)	>2.9 (>99.9%)
12	>2.9 (>99.9%)	>2.9 (>99.9%)	>2.9 (>99.9%)	>3.0 (>99.9%)

Note: 18,740 viable *Ascaris* ova seeded into control and 0.5% bags; 18,720 viable *Ascaris* ova seeded into 2% and 5% bags.

4.6.5 Discussion

The results of the laboratory study demonstrate that the addition of hydrated lime increases the rate of inactivation for both *Ascaris* and *E. coli* in Hiloweyn UDDT waste, thus suggesting that lime addition may provide an additional level of microbiological safety for vault emptying as well as potentially allowing decreased storage time, if needed. Hydrated lime addition at both 2% and 5% (by weight) resulted in a substantial decrease in *Ascaris* viability (>99.8%) after one week at 34 °C as compared to the control and 0.5% lime conditions. At a lower dose of lime (0.5%), *Ascaris* viability reductions were similar to those measured in control waste up through three weeks; however, both achieved ≥99.8% reduction by one month. *E. coli* was rapidly reduced at all lime concentrations tested. No *E. coli* was detected immediately following exposure to waste containing both 2% and 5% lime. At the 0.5% lime condition, initial *E. coli* inactivation in waste resulted in an immediate 7 log_{10} reduction in bacteria and additional slight reduction continued to occur up to 12 weeks at 34 °C.

The "control" waste results for our laboratory study reinforce previous findings that the Hiloweyn waste conditions may be inhospitable to microorganisms, as *Ascaris* ova inactivation was observed rapidly over a period of weeks without any supplemental lime addition and *E. coli* also met WHO guideline values after 12 weeks. These findings support those of the Longitudinal Study suggesting that the extremely dry environment in Hiloweyn is likely a major factor contributing to microbial inactivation.

4.6.6 Limitations

- To improve ova recoveries and decrease laboratory processing time, *Ascaris* ova were seeded into bags that did not contain UDDT waste, thus results could not be reported according to WHO guideline value (viable ova / g total solids).
- Due to improper seal on petri dish, formalin evaporated out of petri dish incubating a 2% lime sample at week 8 and a 5% lime sample at week 12. For these, only two of three replicates were used to calculate average *Ascaris* ova counts.

5 Conclusions, Recommendations and Lessons Learned

This evaluation provided valuable insight into the acceptability and performance of a large UDDT program implemented in a humanitarian context in Ethiopia, several years into the program and after considerable scale-up in Hiloweyn camp, Dollo Ado. The evaluation was implemented over more than a two-year period, allowing documentation of real field conditions over time including stored waste characteristics, toilet infrastructure, and overall user experience.

5.1 Acceptability Evaluation

This evaluation provided insight into the current acceptability and usability of the UDDTs in Hiloweyn camp, several years into the program and after considerable scale-up. Generally, adoption and current, consistent and correct use of the UDDTs was high. Notably, these indicators were high even after most UDDTs had been in use for several years. Additionally, the infrastructure condition and usability of the UDDTs did not deteriorate from baseline to endline. Similar to reported use, many of these indicators were actually higher at the time of the baseline, indicating that the toilets are well maintained. These findings differ from the limited data available from acceptability evaluations of UDDT programs in the development context.

The results of the acceptability evaluation indicate successful efforts on the part of multiple implementing partners over time, in terms of user education, maintenance and upkeep of the units. Compared to other large UDDT programs in use in the development context, for example in South Africa, one major difference may be that oversight and active management of the UDDTs is higher in the humanitarian context. In other words, it's not possible to attribute satisfaction to the sanitation type, rather, sanitation satisfaction may be high because sanitation services are generally well managed in this setting. Our findings support this conclusion as we found that satisfaction and sanitation preference did not differ between those assigned to UDDTs and other forms of sanitation. Nonetheless, these findings demonstrate that UDDTs are effectively introduced and utilized in this context and this may have implications for other humanitarian and non-humanitarian settings.

5.1.1 Recommendations for Improving Acceptability and Usability

There were small issues identified in terms of correct use and usability of some of the UDDTs, which it is recommended to address to ensure continued use and high satisfaction levels in Hiloweyn camp. Correct use practices should be reinforced on a periodic basis to minimize any user error; particularly, those practices which impact cleanliness should be emphasized, given that cleanliness is an important component impacting satisfaction. Finally, it may be possible to explore adaptations to enable children under 5 years, elderly and disabled persons to effectively use the UDDTs. Given the breadth of experience and familiarity with the UDDTs in Hiloweyn at this point, it may be an opportune time to explore these and additional improvements to the design.

It is also recommended that acceptability evaluations are conducted in other settings, to 1) examine the impact of socioeconomic and cultural factors on acceptability and 2) further inform effective programmatic strategies to improve acceptability and effective use of this toilet design.

5.2 Performance Evaluation

The field-based studies provided a unique opportunity to test the performance of UDDTs in a hot, extremely dry environment, likely representing an ideal location for a desiccation technology. Overall, UDDTs were successful in reducing both *E. coli* and viable *Ascaris* over a 12-month storage period. Of the vaults sampled, temperature in stored waste remained over 30 °C, with small annual and diurnal variation, and the conditions were moderately alkaline, likely due to ash addition. The percent moisture content measured in stored waste in Dollo Ado is lower than has been reported in the literature to-date, and, of the environmental parameters tested, was the condition that was the most inhospitable to microorganism survival. Nonetheless, not all UDDTs met guideline levels for fecal microorganisms after the storage period, in spite of these dry conditions, which has management implications for waste handling and emptying.

It is important to note that the WHO Guidelines quoted in this study are based on monitoring treated feces for use in agriculture. Therefore, these are conservative guidelines for the Hiloweyn setting because treated waste in Hiloweyn is not intended for agricultural use. Based on our results, the UDDTs in Hiloweyn camp should be able to be managed on a 12-month emptying cycle. However, care should be made to ensure appropriate precautions during waste handling and in secondary storage site location, as outlined in the recommendations below.

The laboratory-based study provided additional insight for pH modification as another factor which could potentially improve UDDT performance in this setting. Our results indicated that the addition of lime at 2-5% to the stored waste could be a promising method for increasing microbial inactivation. Therefore, if it was necessary to empty the UDDT after a period of less than 12 months, vaults could be treated with lime at the time of emptying; either in-vault or at the secondary storage location. Calcium hydroxide (lime) is an irritant and contact with skin and eyes should be avoided. Those who handle lime should be trained on proper handling and storage procedures as indicated on Material Safety and Data Sheets provided by manufacturers.

5.2.1 Recommendations for Handling and Disposal of UDDT Waste

In addition to 12-months of storage within closed vaults, the following are recommendations for handling and disposal of waste in order to move it to the secondary waste disposal site. The National Institute for Occupational Safety and Health (NIOSH) at the CDC and the US Environmental Protection Agency (EPA) have provided the following guidance on safe handling practices to minimize the potential risk to workers exposed to Class B biosolids[4] (https://www.cdc.gov/niosh/docs/2002-149/):

1. Appropriate personal protective equipment (PPE) should be provided for all workers likely to have exposure to waste. The choices of PPE include goggles, splash-proof face shields, respirators, liquid-repellent coveralls, and gloves.
2. Keep wounds covered with clean, dry bandages.
3. Change into clean work clothing on a daily basis and reserve footgear for use at worksite or during waste transport.
4. Wash hands thoroughly with soap and water after contact with waste; before you eat, drink, or smoke; and before and after using the toilet. Hand-washing stations with clean water and mild soap should be readily available whenever contact with waste occurs.
5. Avoid touching face, mouth, eyes, nose, genitalia, or open sores and cuts while working with waste
6. Eat in designated areas away from waste-handling activities.
7. Do not smoke or chew tobacco or gum while working with waste.
8. Remove excess waste from footgear prior to entering a vehicle or a building.
9. Do not wear work clothes home or outside the work environment.
10. Thoroughly, but gently, flush eyes with water if waste contact eyes.

[4] Class B biosolids are defined by US EPA as treated waste that still contains detectible levels of pathogens. There are buffer requirements, public access, and crop harvesting restrictions for virtually all forms of Class B biosolids.

11. Periodic training on standard hygiene practices for waste workers should be conducted by qualified safety and health professionals.
12. Workers should be trained to report potentially work-related illnesses or symptoms to the appropriate supervisory or health care staff.
13. Ensure that all employees are up-to-date on tetanus-diphtheria immunizations, since employees are at risk of soil-contaminated injuries. Current CDC recommendations do not support hepatitis A vaccination for waste workers.

The following recommendations are also made for the distance secondary waste disposal sites should be from features such as dwellings, roads, and water sources, which may help with planning for these sites at Hiloweyn Camp:

Setbacks for Application of Waste to Land (US EPA, 2013)

Feature	**Setback**
Occupied Dwelling	60 meters
All Wells	30 meters
Surface Water	30 meters
Public Roads	15 meters
Property Lines of Publicly Accessible Sites (e.g., Churches, Schools, etc.)	60 meters

5.2.2 Recommendations for Additional Study

Given the hot, arid environment of this evaluation, the UDDT program in Dollo Ado may represent the upper limit in terms of UDDT performance. Furthermore, given that the program was several years into scale-up and therefore may have had stronger management and oversight than other locations, it is recommended that additional evaluations are undertaken in both 1) more temperate and humid environments and 2) earlier in implementation phase in an emergency setting. This may assist with developing guidance around appropriate settings and conditions for UDDT use in humanitarian contexts.

Additionally, while the limited results of the laboratory study are promising, field testing is required to determine the feasibility and effectiveness of lime addition for elevating fecal sludge pH. For example, the laboratory setting allowed for thorough mixing of hydrated lime and UDDT waste, which might not be easily achievable in the field. Further, field studies comparing UDDTs with and without the addition of lime are warranted to better understand the impact on microbial inactivation in a real-world scenario, where waste conditions may vary. Finally, additional laboratory studies assessing the effect of moisture content on microbial inactivation are also recommended, as they will allow better understanding of the effects of lime addition under a wider range of environmental conditions.

5.3 Overall Lessons Learned

A number of findings of this evaluation could be used to assist UDDT implementers in Dollo Ado and elsewhere working in the humanitarian context. These lessons learned include:

Acceptability:

- The type of sanitation system that a targeted user is familiar with may affect acceptability of UDDTs, and strategies for increasing acceptability and adoption may need to be tailored to particular demographic groups. In Hiloweyn, the UDDT was more acceptable after a lesser time of use for those who had not had any sanitation system previously (compared to those who had used a pour-flush toilet). Conducting specific knowledge, attitudes and practices (KAP) surveys or other sanitation-specific surveys to understand previous practices and potential barriers may assist with targeted implementation strategies.

- Regardless of demographics and previous sanitation experience, cleanliness of the UDDT matters (significantly in our evaluation). Programming decisions to allocate sufficient resources to educational sessions on the UDDTs could be a strategy to improve effective use and acceptability. These sessions should emphasize consistent cleaning and correct use practices *early* in the introduction of the units. If appropriate, specific cleaning tools and/or cleaning staff may be a useful addition to programming during the introduction and scale-up phase.
- Time of use significantly impacts satisfaction level of UDDTs, meaning that it takes time for users to become accustomed to this new type of sanitation system. While this may be more marked for specific populations, this reinforces/indicates that UDDTs may be more appropriate in a protracted/stable emergency setting as opposed to a sanitation system utilized during the early phases of an emergency.

Performance:

- UDDTs perform well in hot, dry climates, which create inhospitable conditions for microbial survival. These systems may have capability to meet WHO guidelines for agricultural reuse after 12 months of storage in settings with conditions similar to those found in Dollo Ado.
- Promoting conditions which desiccate stored waste (e.g. additive use) and performing secondary treatment in the form of elevating pH ($\geq$12) may help improve UDDT performance in some settings. However, secondary treatment that elevates pH may render the waste unsuitable for agricultural application. Further, cost and safety requirements should be considered carefully to determine feasibility of the use of lime additives.
- Not all of the UDDTs sampled in Dollo Ado met WHO guidelines for agricultural reuse after 12 months of in-vault storage. This suggests a need to better understand the performance of these systems in less arid settings, both in terms of the need for safe handling during emptying and in terms of the potential use of this technology as an ‘ecosan’ option where waste is reused without additional treatment.
- This technology can provide an effective, sustainable option for excreta management in settings where traditional sanitation options are not feasible. Prerequisites may include the ability to install permanent infrastructure, sufficient land space for secondary waste storage and/or treatment and disposal, strong management and oversight such that proper use of the UDDTs is maximized (e.g., to prevent liquid from entering the waste vault) and safe handling and disposal can be assured to minimize public health risk.

6 References

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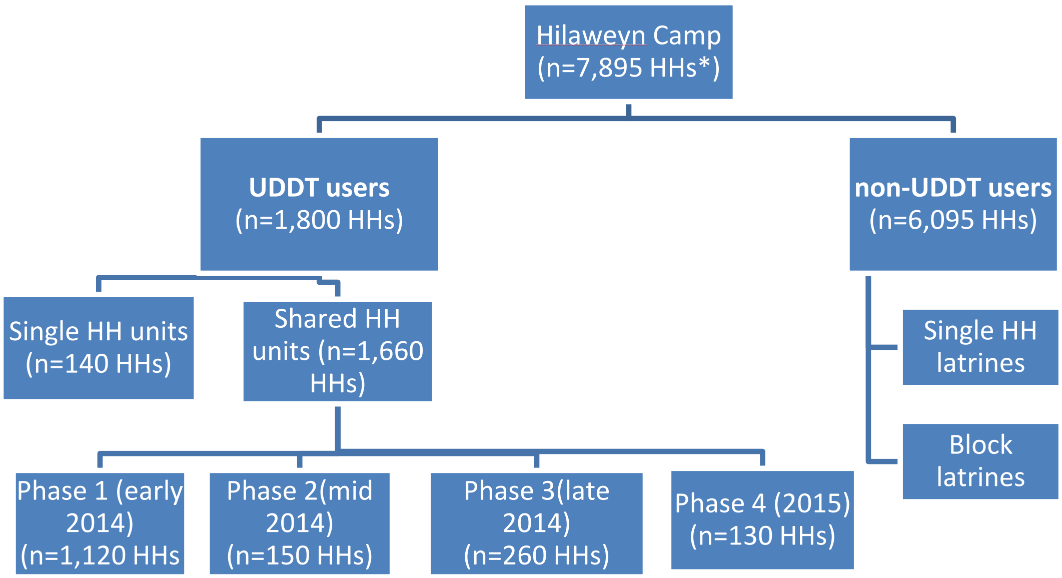
7 APPENDIX I



- **Single-family UDDTs (140 units / 140 families)**
  - Earliest installation in January 2012, latest in April 2013
    - In use for a range of 3.5– 4.8 years (as of October 2016)
  - First vault closed of original 89 units on 27 Nov, 2013 (almost 3 years from endline)
  -
- **Shared-family UDDTs – 1st set (560 units / 1,120 families)**
  - Installed in late 2013/early 2014
    - In use for a range of 2.75 – 3 years (as of October 2016)
  - Most still using the first vault, some have switched to the second vault
  -
- **Shared-family UDDTs – 2nd set (75 units / 150 families)**
  - Installed in early/mid 2014
    - In use for ~2.5 years
  - All still using the first vault
  -
- **Shared-family UDDTs- 3rd set – NRC (130 units / 260 families)**
  - Installed in late 2014
    - In use for ~2 years
    -
- **Shared-family UDDTs – 4th set – NRC (65 units / 130 families)**
  - Installed throughout 2015

8 APPENDIX II

Variables of Interest	**New shared UDDT users**	**Original shared UDDT users**	**Required sample size**
Overall satisfaction with/ acceptability of sanitation type	60%	80%	82
	Not-shared UDDT users	**Shared UDDT users**	**Required sample size**
Overall satisfaction with sanitation type	90%	70%	63
	UDDT users	**non-UDDT users**	**Required sample size**
Overall satisfaction with sanitation type	75%	55%	89
Positive perception towards value of reuse	*70%*	*50%*	*94*

9 Appendix III

Univariate tests for association using cumulative odds for all respondents (n=811)

Variable	**contrast**	**p**
Age of respondent		0.3909
Ability to read (0=no vs 1 yes)	0 vs 1	0.8095
Received formal education (0=no vs 1 yes)	0 vs 1	<.0001
Has a child < 5 years in the home (1=yes vs 0=no)	1 vs 0	0.0040
Time in Hiloweyn camp		<.0001
HH size		0.5457
Previous sanitation type		
1= no sanitation system/field	1 v 3	<.0001
2= pit latrine	2 v 3	0.0015
3= pour flush toilet		
Current sanitation type		
latrine vs uddt	1 vs 0	0.2377
Shares current sanitation (1=yes vs 0=no)	1 vs 0	0.0011

Univariate analyses for association using cumulative odds for UDDT respondents (n=588)

Variable	**contrast**	**p**
Age of respondent		0.4321
Ability to read (0=no vs 1 yes)	0 vs 1	0.6042
Received formal education (0=no vs 1 yes)	0 vs 1	0.0003
Has a child < 5 years in the home (1=yes vs 0=no)	1 vs 0	0.0558
Time in Hiloweyn camp		<.0001
HH size		0.4649
Previous sanitation type		
1= no sanitation system/field	1 v 3	<.0001
2= pit latrine	2 v 3	0.0005
3= pour flush toilet		
Shares UDDT (1=yes vs 0=no)	1 vs 0	<.0001
Length of time using UDDT		<.0001
Clean Index		<.0001