ENGINEERS WITHOUT BORDERS AUSTRALIA (EWB

&

INTERNATIONAL DEVELOPMENT ENTERPRISES (iDE)

Final Report

ALL SEASONS UPGRADE PRODUCT

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1 BACKGROUND AND TECHNICAL CHALLENGE

The installation of a household pit latrine represents a critical step towards safely managed sanitation, increased public health and safety, and improved dignity and privacy. The pour-flush offset pit latrine is common to rural Cambodia. Pour-flush latrines prevent the wafting of odors from the pit into the latrine shelter, separate human contact from feces at the point of use, and can be set up to allow for immediate hand washing before leaving the toilet. All of these factors help encourage the use of latrines and improve public health through the reduction of fecal-oral disease transmission. The offset pit allows for easy emptying since the access point is outside of the toilet superstructure rather than below the toilet squat plate.

1.1 CAMBODIAN CONTEXT

Under normal operating conditions, open bottom latrine pits allow liquids in blackwater to infiltrate into the soil, leaving behind dense sludge. Ideally, the sludge is safely emptied, treated, and disposed of. In general, it is expected standard pits in Cambodia require emptying every 3-5 years. However, much of Cambodia's environment is not suitable for standard, infiltrating pit latrines, including areas with low infiltration rates due to impenetrable rock or high-clay soils as well as those with naturally high groundwater or seasonal flooding within the vast agricultural floodplains. Here, the liquid itself is unable to infiltrate into the soil, either due to low soil permeability or low hydraulic gradient. Therefore, latrine pits in these environments fill up at a faster rate than those in appropriate environments. Once full, the toilets are unable to flush and mitigation measures taken by households have often been observed to be unsafe.

At this point, some homeowners will install a second pit in series, which only extends the deadline of emptying both, rather than addressing the root problem. Other times, homeowners will manually empty the sludge by bucket or pump, often transporting and disposing of the sludge openly in the back of the property, without taking measures to protect personal or public health. In some cases, homeowners will open the tops of latrines during the rainy season to allow the pit to overflow and empty itself in a process called "flooding out." Another common practice is for homeowners to simply chisel a hole about a decimeter below the top of the pit, allowing blackwater to continually overflow onto the ground and into the environment. This practice essentially generates an open sewage stream into the commonly trodden ground, only transferring direct contact to fecal pathogens a few meters from the toilet itself. None of these common practices can be considered safely managed sanitation and although these methods concentrate fecal contamination at a household level, they are likely not much more effective than open defecation.

1.2 iDE-EWB INTERVENTION

As a leader in sanitation in Cambodia, iDE latrine sales have become more difficult as the bulk of the population in program activity areas has by now purchased their first latrine. Late adopters and laggards to household sanitation are often members of the hardest to reach populations. They are at risk for waterborne disease and increase the same risk to others around them, in many cases in challenging environments[1]. Additionally, the success of the market development has spurred ownership of latrines in areas where environmental conditions do not support latrine functionality, like high groundwater areas that inhibit the infiltration of liquid inside the pit into the surrounding area. Therefore, the development of interventions for sanitation in challenging environments is crucial to providing access to safely managed sanitation in Cambodia. However, since the market has already developed in the direction of latrine pits, it may be too late for many households to consider investing in a new, complete latrine product as an alternative in challenging environments. Therefore, an upgrade product for those latrines already installed is more likely to mitigate the problem and to be seen as valuable to consumers.

EWB has been working in Cambodia for over 10 years with a focus on technology development for hard-to-reach and difficult environments. In 2014 EWB established a stand-alone program dedicated to developing suitable technologies for those living in challenging environments in Cambodia.

Previously in 2017-2018, iDE and EWB collaborated on a latrine design called the 3-Chamber Pit (3C Pit). The design was an adaptation of a conventional pit latrine to reduce contamination of surface and groundwater in flooded and high groundwater areas. The project trialed 10 pit latrines and analyzed the sewage discharge quality and feedback from construction and use. These lessons learned have been integrated into the second iteration of this design as detailed in this report.

In keeping both organizations' focus on innovative technology and with iDE's market-based approach, the design iteration must be a scalable, affordable, and aspirational product that can be sustainably made available to customers in all wealth quintiles.

1.3 PURPOSE

Developing solutions for sanitation in challenging environments remains a critical hurdle towards reaching full and safely managed sanitation coverage in Cambodia. The iDE-EWB All Seasons Upgrade product represents the research and development of an intervention designed to mitigate public health risks associated with sanitation in challenging environments. The primary purposes of this design brief are to: provide a full technical understanding of the product for internal purposes; document assumptions and decisions throughout the product design process; and create source material for external communications if the product reaches a market-ready stage.

2 PROBLEM DEFINITION & IDEATION

2.1 MULTI-CRITERIA ASSESSMENT (LATE 2018)

After the prototyping and testing of the 3C Pit, an assessment was conducted to determine its viability for market deployment. The 3C Pit was compared against two other designs – the iDE

[1] A Challenging Environment refers to a rural location where it is either difficult to construct conventional latrines or where the use of conventional latrines is likely to contaminate the surrounding environment, particularly groundwater and surface-water resources. In Cambodia the most common challenging environments are seasonally flood prone areas, high groundwater locations, floating communities, coastal areas, seasonally water-scarce areas and hard ground. (Cambodian National Guiding Principles for Sanitation in Challenging Environments, July 2019)

Soak Pit and the iDE Bangladesh FilTo. The Soak Pit product concept was developed by iDE to increase infiltration into the soil but was never implemented. The FilTo was developed by iDE for high groundwater environments and was implemented in Bangladesh.

The weighted criteria included simplicity (40%), space requirement (5%), sustainability (30%), and functionality when flooded (25%), and a separate category was cost. Simplicity refers to the number of parts, installation time, amount of new equipment required, and other issues that might make the system difficult to implement on the market. Space requirements were broken down into 1 or 2 pit systems but were ranked low because rural homeowners tend to have sufficient land available for this type of infrastructure. Sustainability relates to general maintenance, including frequency and ease of pit emptying. Functionality compares the general viability of these products to protect the environment and to be operated (able to consistently flush) in flooded or high groundwater environments. Finally, the cost is a driving factor for all market-based products, since they must be affordable to the poorest groups in Cambodia. The three systems were evaluated with numerical values for each category by the assessment team and compared based on weighted values and cost.

The 3C Pit received the worst weighted score at the highest cost (3.3/10, $66.95), followed by the Soak Pit (4.72/10, $52.15), and then the FilTo (5.02/10, $37.16). None of the three systems would allow a toilet to flush in significantly high groundwater areas or minor flooding- a critical issue that the team decided would preclude a major consumer buying point and inhibit the product's market potential. A driving factor against the 3C Pit was simplicity, in which it scored 1/10. The prototyping phase showed that it was incredibly difficult to construct, required four unique molds, and significant training. During this process, critical consideration of market potential was discussed with the knowledge that most Cambodians, many of whom live in "challenging environments," have already purchased latrines. Therefore, the option to purchase an upgrade rather than the full-system product would likely offer the most market potential in the current context. It became apparent that design criteria must be revisited, and new options explored to develop a product that would address the needs of sanitation in challenging environments through a market-based solution.

2.2 DESIGN CRITERIA (JANUARY 2019)

Once it was deemed that the 3C Pit would likely not meet the sanitation needs of customers living in challenging environments, the redefinition of the problem and new ideation began.

The operational strategies for both EWB SCE and iDE were reviewed to ensure that this phase of product development would be in alignment with both partners' principles and aims. These goals are summarized as follows:

EWB SCE

- Communities living in challenging environments will be healthier and more resilient as a result of improved access to sanitation
- People in challenging environments will have access and use improved sanitation that does not contaminate the environment

- SCE- appropriate solutions will be mainstreamed in the WASH sector

iDE

- Market-based delivery approach to ensure the sustainability of sanitation solutions
- Demand: - Products are affordable, aspirational, and desirable, therefore, they can be sold for profit.
- Supply: Products can be procured, delivered, and installed cost-effectively and proficiently by local business owners, therefore supply chains will be sustainable.

Following the review of operational strategies, a stakeholder analysis was developed through the combined intuition of the partners' previous experience working with the targeted communities. This analysis focused on household, mason, and community needs, and went through the process of exploring needs, defining challenges, and developing design requirements for new technology. At each step, ideas were brainstormed and then categorically organized.

- Household needs
  - Maintenance
  - Health
  - Affordability
  - Function
  - Access
  - Technology
  - Awareness
- Mason/business needs
  - Business incentive
  - Marketing potential
  - Construction feasibility
  - Repair and maintenance ease
- Community needs
  - Commitment
  - Capacity
  - Pollution control
  - Technology

Next, challenges were defined for each household need category for high groundwater environments as there is a market potential for this product that could result in a net larger public health impact than a more expensive product that would be relevant in fewer areas.

The 3C Pit, FilTo, and Soak Pit designs were once again reviewed against the newly defined challenges. As the team refocused on the user's needs as critical for a market-viable product, a defining feature of the value proposition was decided to be that the system needed to function (i.e. flush) year-round. Managing this would reduce the household need to pierce or open their pits in the rainy season to release excess water. With this consideration established as paramount, all three design concepts were discarded as viable options due to the high likelihood that these designs would not be able to reliably flush in high groundwater contexts.

2.3 DESIGN CONCEPT DEVELOPMENT (FEBRUARY 2019)

The iDE-EWB team brainstormed types of technology that could address the high groundwater and seasonal flooding SCE challenge within the previously developed constraints, summarized below:

1. Functionality
    a. Containment of fecal matter to prevent groundwater contamination
    b. Ability to flush at all times, implying an outflow greater than or equal to the inflow
    c. Sufficient sludge storage capacity
2. Materials – available and easily transportable
3. Simplicity & Durability – ease of operation and maintenance
4. Affordability – comparable in price to an existing upgrade product iDE is selling, the Alternating Dual Pit which retails at ~ $50
5. Adaptable to existing pit latrines
6. Includes indicator for households to see remaining empty volume in the pit

Using sticky-notes to encourage thinking creatively, the team developed and expanded new ideas, before categorizing and refining them into a path forward. The general concern is how to discharge effluent (water) into the environment, after containment and treatment, at an acceptable level of risk to human and environmental health. This activity led to three general methods of solving the technical challenge:

The first strategy is to decrease the amount of water entering the latrine with the waste. However, dry toilets, including urine-diverting and composting toilets, are not popular in Cambodia. In this water-abundant context, there is a strong preference for pour-flush latrines with water traps to prevent the accumulation of odor and flies near the toilet pan and within the superstructure. Therefore, this course was quickly ruled out.

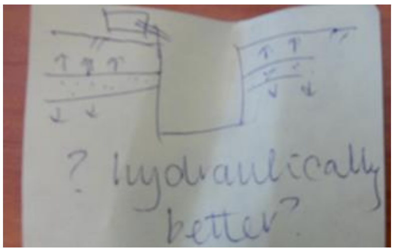
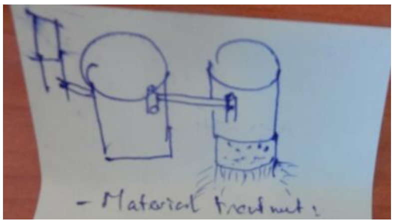
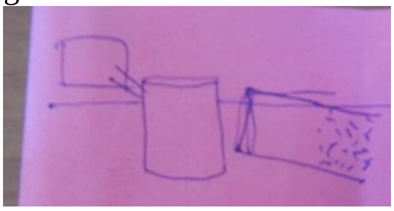
The second strategy is to prevent infiltration into the ground. If it is not feasible for latrine contents to drain quickly enough for toilet functionality, then it becomes necessary to develop a full containment, treatment, and disposal system above ground.

The third strategy is to increase infiltration rates into the ground. The guiding theory behind this strategy is that increased infiltration would significantly improve latrine functionality by allowing liquids to drain so that only sludge accumulates at a reasonable rate. The further technical challenge in this class of technology is to adjust latrine design to increase the infiltration area and separate effluent from immediate contact with shallow groundwater.

Summary of the design concepts developed in this process

Design No.	Design summary	Storage	Filtration	Infiltration	Elevation	Score
1	Increased surface area for discharge via pipes, gravel, sand			X		0.12

2	Soak pit with filtration material		X	X		0.15
3	Large pit and filtration pit	X	X			0.12
4	Raised pit above high groundwater level				X	0.11
5	Solar treatment					-0.05
6	Twin pit with different level seasonal pipes	X		X	X	0.14
7	Large latrine with bottom filtration	X	X		X	0.14
8	Above ground storage for the rainy season and filtration pit	X	X		X	0.13
9	Storage layered above filtration and soak pit discharge	X	X	X	X	0.17

<table>
<tr>
<td>1. Increase area of infiltrative surface
</td>
<td>2. Increase area of infiltrative surface and provide some filtration
</td>
<td>3. Underground system with increased distance between the discharge point and the groundwater
</td>
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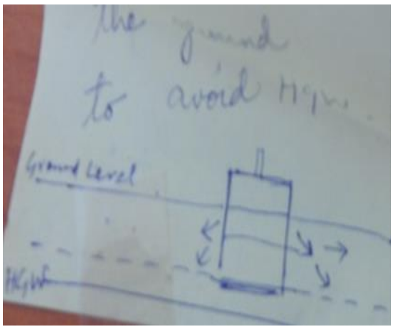
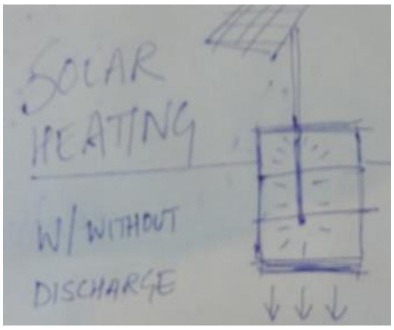
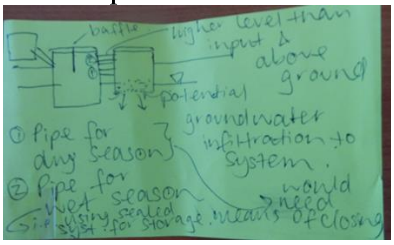
<tr>
<td>4. Partially above ground system with increased distance between the discharge point and the groundwater
</td>
<td>5. Solar heating to kill the bacteria
</td>
<td>6. 1st pit sealed, 2nd pit infiltration with filtration. Have alternating heights for transfer between the two pits between dry and wet season to increase groundwater storage capacity in the second pit before it backflows into the first pit
</td>
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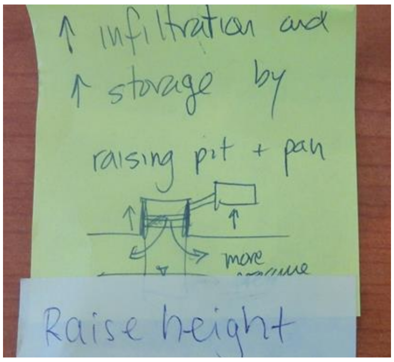
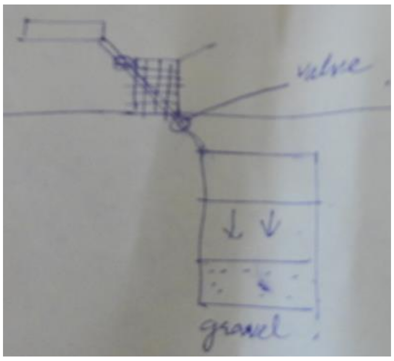
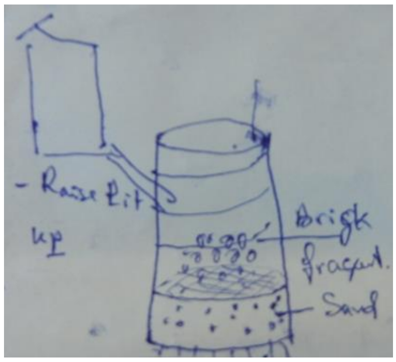
7. Four ring pit with brick and sand for filtration	**8**. Storage tank to capture flow during rainy season and discharge only in dry season	**9**. Raised system to prevent backflow and increase likelihood of infiltration
		

The first design (1) essentially explored various methods of pipe and material placement to increase surface area for infiltration of effluent into the subsurface but did not include any treatment methods. The filtration pit design (3) explored different placements and angles of filtration tanks to increase the surface area of filtered effluent into the soil. Further designs (4, 7, 8, 9) explored various methods of raising storage or latrine tanks, but these all require elevated latrine pans, which are highly atypical in this context. The variable level soak pit (6) requires a sealed latrine pit to ensure functionality throughout seasons, which is difficult to do as an upgrade product. The large latrine with bottom filtration (7) consists of a large latrine on top of a FilTo, combining filtration, elevation, and storage.

A multicriteria assessment was conducted on the nine designs, based on similar criteria to that of the soak pit, filto, and 3C pit assessment. These criteria included: contamination (16.7%), ability to flush (16.7%), contain fecal waste (16.7%), availability of materials (8.3%), constructability (8.3%), design simplicity (8.3%), and affordability (25%). The top options included the raised pit (9), soak pit (2), variable level soak pit (6), and storage tank (8). Solar treatment (5) was also strongly considered but eliminated because this technology is known to show better results in dry environments, and wet flush latrines make the large majority in Cambodia. The storage tank option (8) was eliminated because the basic volume estimate of 44L/day and 90 days of wet season storage would require 3.98 m^3, or the equivalent of 6 rings, which is unreasonable and expensive.

At this point, the team split up to focus on two different treatment systems. The iDE team focused on above-ground containment and treatment, while the EWB team focused on underground infiltration and urine-diverting dry toilets. After estimation of the cost of the two strategies by EWB, the iDE-EWB team decided that above-ground treatment or containment would not be affordable or feasible, and thus pursued the design of more traditional subsurface systems that improved infiltration into the ground. Variations of the soak pit (2) were expanded further. Considerations included baffling the first tank for settling and adding filtration, either inside, outside, or both, to the second tank for infiltration. The need for groundwater separation led to a shallow, simplified septic tank with gravity filtration, and became the starting point for the ASU. Based on the similarities with the previous 3C Pit, its prominent features were reviewed and used as a starting point for future work. These features are included below:

- >10 days HRT
- 50% of the capacity for settling
- 25% of capacity for up-flow filtration
- 0.5m^3 filter material (gravel)
- Effluent discharge ½ way up the pit (middle ring) through twelve 50mm holes
- 0.5 m radius of 25-40mm gravel outside pit at the discharge point

3 PRODUCT DEVELOPMENT (MARCH-MAY 2019)

3.1 OVERVIEW & THEORY

The All Seasons Upgrade (ASU) is a latrine upgrade product that attaches an upflow gravel filter pit and leach field to an existing latrine pit. The filter pit offers an additional treatment reactor for reducing BOD, turbidity, and pathogens, and prevents the leach field from clogging. The leach field is designed to greatly increase surface area for infiltration at a depth shallow enough to be above the groundwater table, but deep enough to prevent the upward flow of contamination to the surface.

3.2 DESIGN ASSUMPTIONS AND PARAMETERS

The following assumptions, based on a sample in the CSES 2017, were made as a starting point for product development.

- 4.4 individuals per household
- 2.5 toilet uses per person per day
- 4L water per flush
- 1m pit ring diameter × 0.5m height

These assumptions were used to develop the ASU design parameter for each pit:

Design Parameters	Units	Latrine	Filter
Inflow rate	L/d	44	44
Total volume	m^3	1.2	0.79
Active volume	m^3	0.98	0.67
Hydraulic residence time (empty)	d	22	15
Volume filter material	m^3	N/A	0.5
Filtration % of total active volume	%	N/A	0.3
The theoretical hydraulic residence time of filter material	d	N/A	11.3
Inlet distance from the top	mm	250	N/A
Outlet pipe distance from the top	mm	150	150

Finally, the area of the leach field was designed to discharge the 44 L/d effluent into the subsurface and was calculated via Darcy's Law for clay and fine sand.

3.3 PREFERRED CONCEPT DESIGN MEETING (10 APRIL 2019)

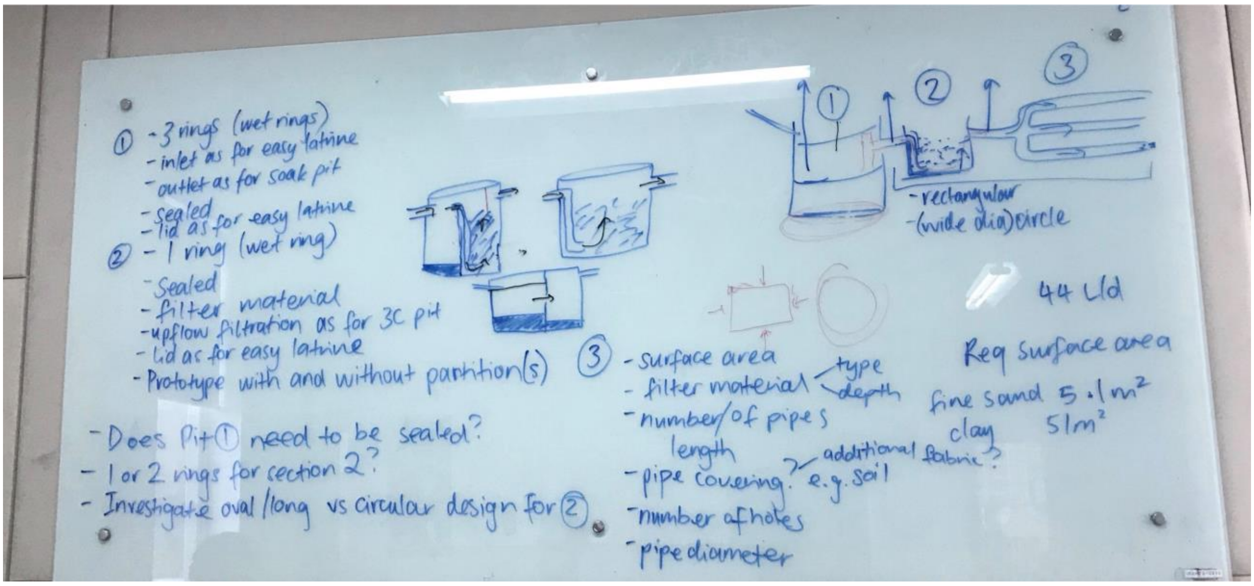


*Figure 1. **Primary Concept Design Specifications Note***

3.4 DESIGN SPECIFICATIONS MEETING (26 APRIL 2019)

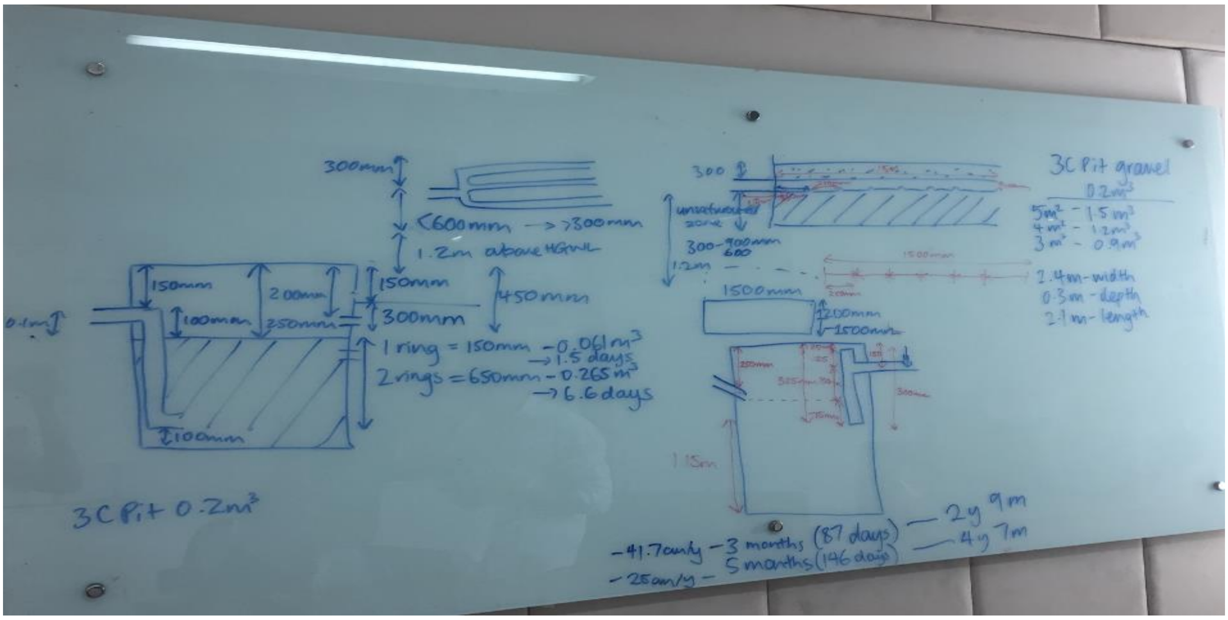


Figure 2*. **Final Concept Design Specification Note***

3.5 SMALL-SCALE PROTOTYPING (3 MAY 2019)

Three tests were conducted during small-scale prototyping to verify hydraulic assumptions and to adjust the leach field set up at low cost and effort.

The first test involved setting up a small-scale ASU prototype without the leach field to test flow through transfer pipes and the upflow filter. The latrine pit and filter pit were simulated by two 20L buckets and 20mm PVC pipes were used as transfer pipes. The influent pipe to the latrine pit included an elbow and a vertical section with a funnel for filling with water. There was no effluent pipe from the filter pit. The filter pit was filled with the same type of gravel to be used during construction. The latrine pit was filled with water until the effluent pipe level before the start of the test. Water was then added to the latrine influent pipe, and flow rates were observed through the upflow filter. This flow rate was deemed sufficient, verifying assumptions of system hydraulics, and the design was approved for further development.

Figure 3 ***. Small Scale Prototyping***

The second test assessed various combinations of leach field pipe diameters and hole and slit specifications, spacing, and number for flow conditions within the pipe. The goal was to find a combination of these factors that would allow fluid to reach all effluent points, but not reach the end of the pipe. Pipes were cut at design length with varying combinations of effluent points, and the far end was left open to assess if water would back up in the pipe. Both 80mm and 100mm diameter pipes were tested. An 80mm 45° elbow was available to place on the influent end of the 80mm pipe during testing to prevent backflow. However, a 100mm 45° elbow was not available, which made testing difficult. The pipe setups were subjected to varying flowrates from a hose tap, and flow rates were measured by 2L or 100mL bucket fill tests. Angles of the pipe from 0° to 4° were tested as well. Slits were found to be ineffective, as small blade width slits were not large enough to allow the flow of water, and the next available larger width allowed too much water to flow out at once. The most effective setup was deemed to be 16 holes, although the slowest flow rate tested was still 8 times higher than the estimated ASU flowrate.

The third test was a simple soil infiltration test, in which soil was packed into an approximately 40 L bin, and a 20cm pipe was buried 3cm deep. Water was poured into the pipe to assess the rate of infiltration. The first stage, completed in the morning infiltrated very quickly, but the second stage, completed in the afternoon, was much slower. This is thought to be either due to soil saturation or the drying and hardening of soil.

3.6 FULL-SCALE PROTOTYPING (9 MAY 2019)

Full-scale prototyping was conducted to further verify design assumptions relating to hydraulic conditions. Testing was guided by the following research questions and could be answered in small and full scale prototype note (See Appendix II, item 18):

1. Does the angle of the inlet pipe change the flow and/or Pit 1 level?
2. Does lowering the discharge point from Pit 2 change the rise in the water level in Pit 1?
3. What is the optimal discharge point (300mm or lower)?
4. Would perforations in the inlet pipe from Pit 1 to Pit 2 help to distribute and to lower the risk of clogging?
5. Would space around the end of the inlet pipe from Pit 1 to Pit 2 help to lower the risk of clogging?
6. Would a combination of holes and cuts in the leach pipe help to distribute the effluent to the end of the pipe?
7. What is the head loss throughout the system?
8. What size should holes in the leach pipe theoretically be to ensure the water is distributed to the end of the pipe?

Two sealed concrete ring pits were purchased, and PVC transfer pipes were installed using mortar and glue as per design specifications. The filter pit was filled with gravel to the bottom of the effluent pipe. Water was poured into the latrine pit influent pipe until it filled both pits. There was a visible reduction in turbulence between the latrine pit and the filter pit, and the system worked hydraulically as planned.

Figure 4. ***Full Scale Prototyping***

3.7 SEMI-FINAL CONCEPT DESIGN SPECIFICATIONS MEETING (10 MAY 2019)

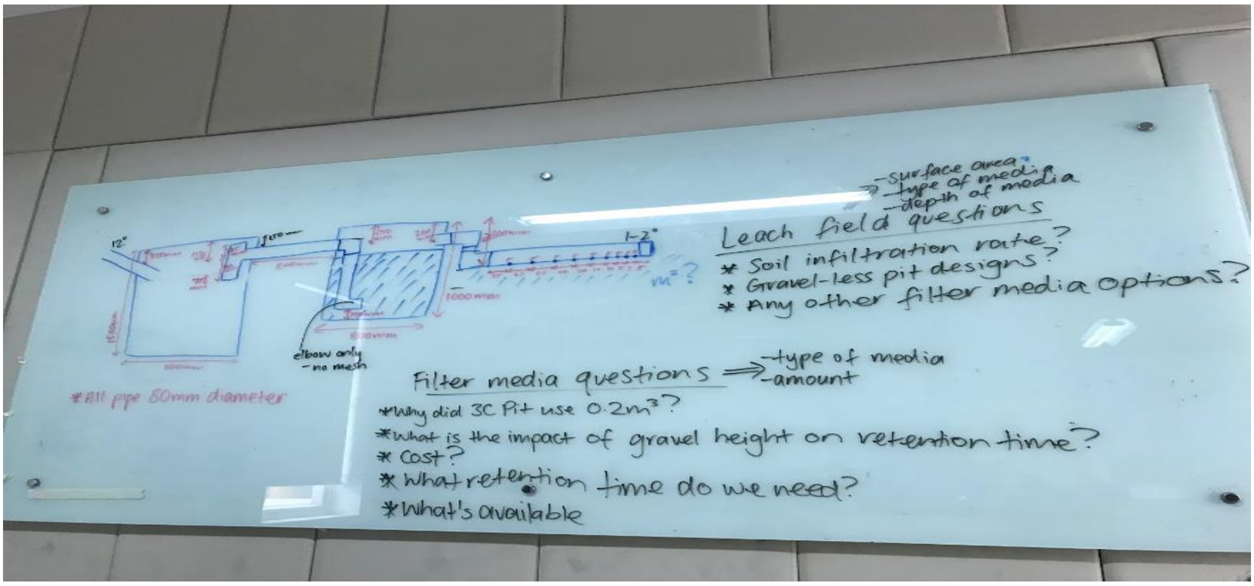


Figure 5. ***Semi-Final Design Specification Note***

3.8 SOIL ASSESSMENT (17 MAY 2019)

Soil testing was also part of small-scale prototyping. The test was carried out by pouring water into a 20 cm pipe that was buried 3 cm into the ground. The time for the infiltration of water to the soil was recorded at each 5 cm mark. Soil texture was determined using the technical brief on conducting soils evaluation for on-site wastewater system design (See Appendix II, item 8). Soil texture tests were carried out in each site before installing the treatment system to ensure that the selected households are in areas with clay or sandy soil.

*Figure 6****. Small Scale Soil Assessment Testing***

3.9 OVERVIEW OF FINAL DESIGN

- Dimensions

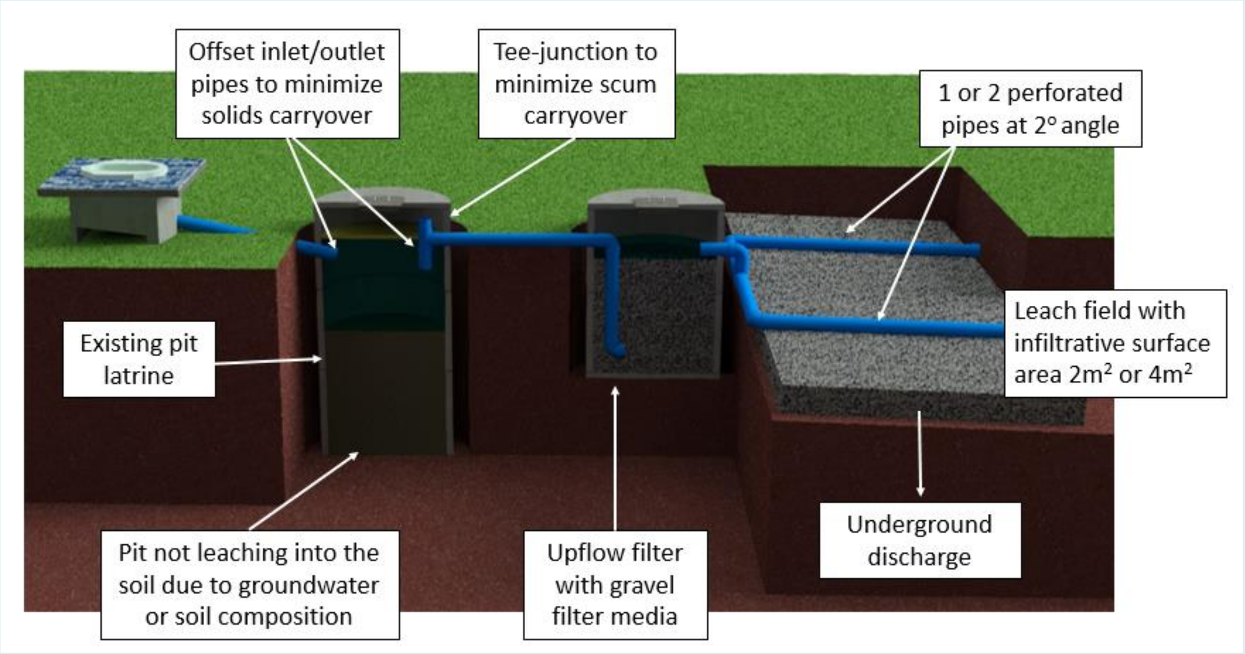


Figure 7. ***Section View of ASU Leach Field 4m^2***

Figure 8. ***Perspective view of ASU Leach Field 2m^2***

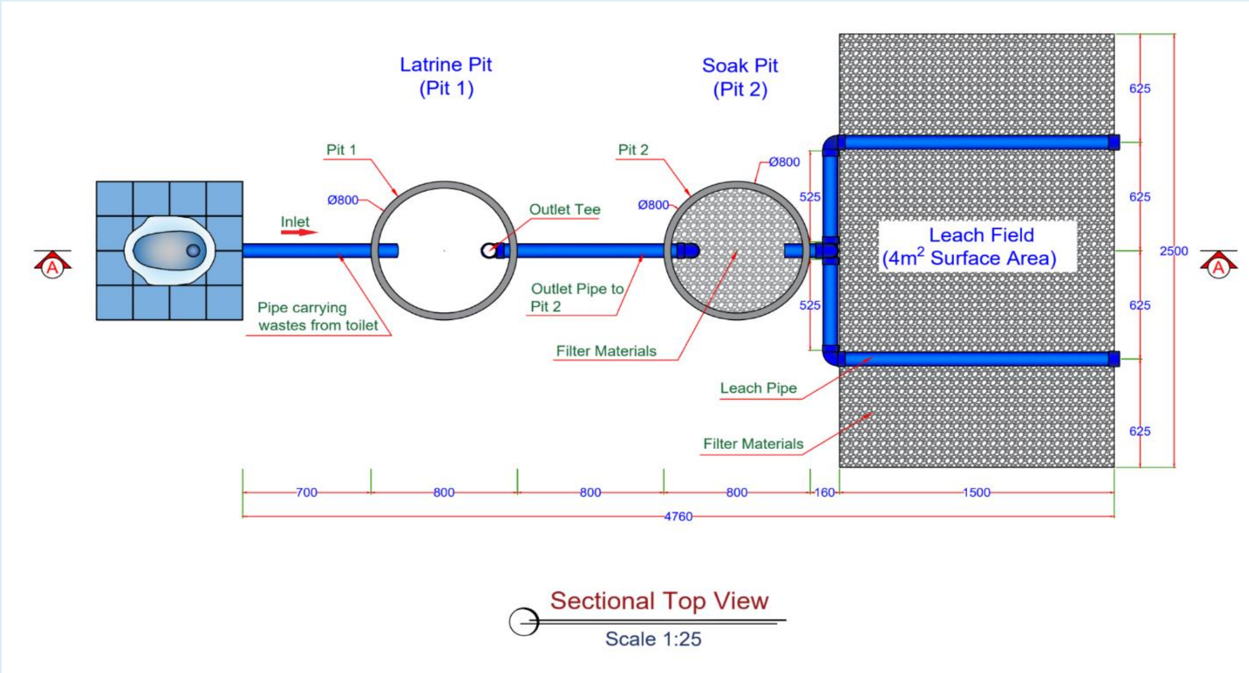


Figure 9. ***Sectional Top View of ASU Leach Field 4m^2***

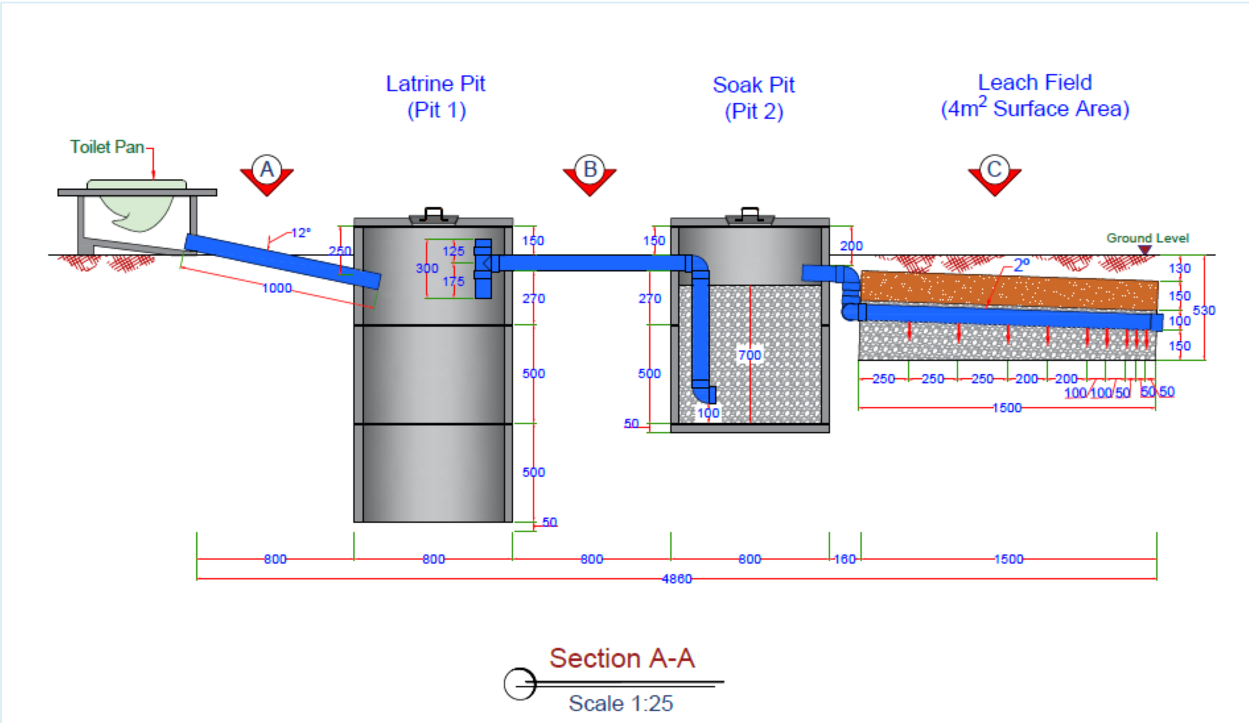


Figure 10. ***Section A-A View of ASU Leach Field 4m^2***

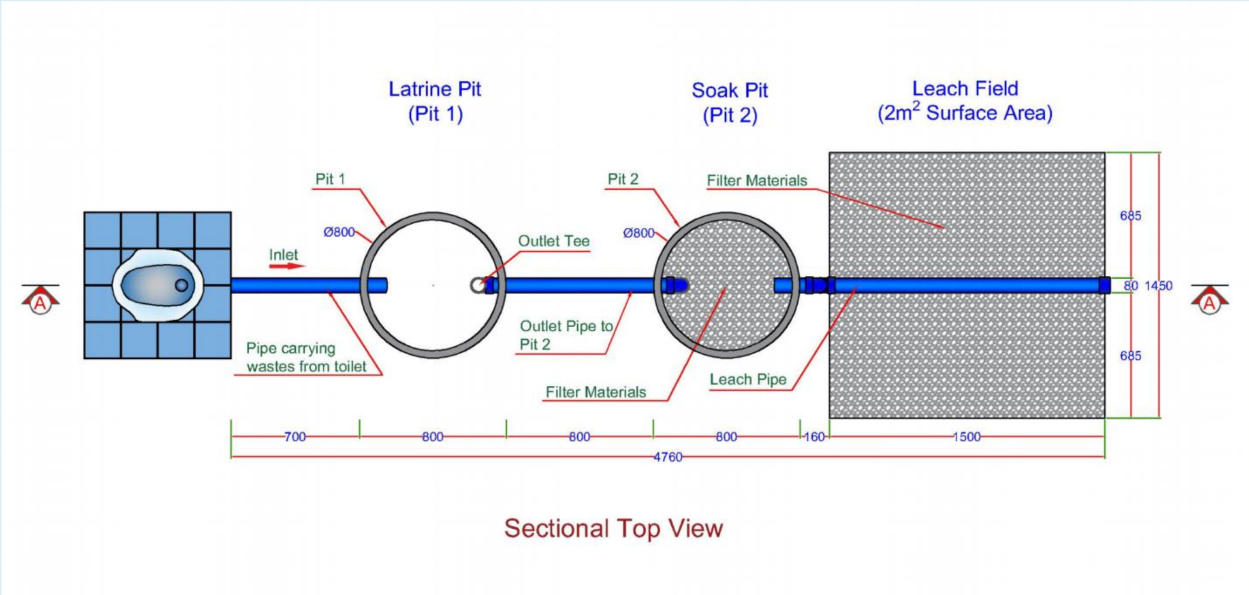


*Figure 11. **Sectional Top View of ASU Leach Field 2m²***

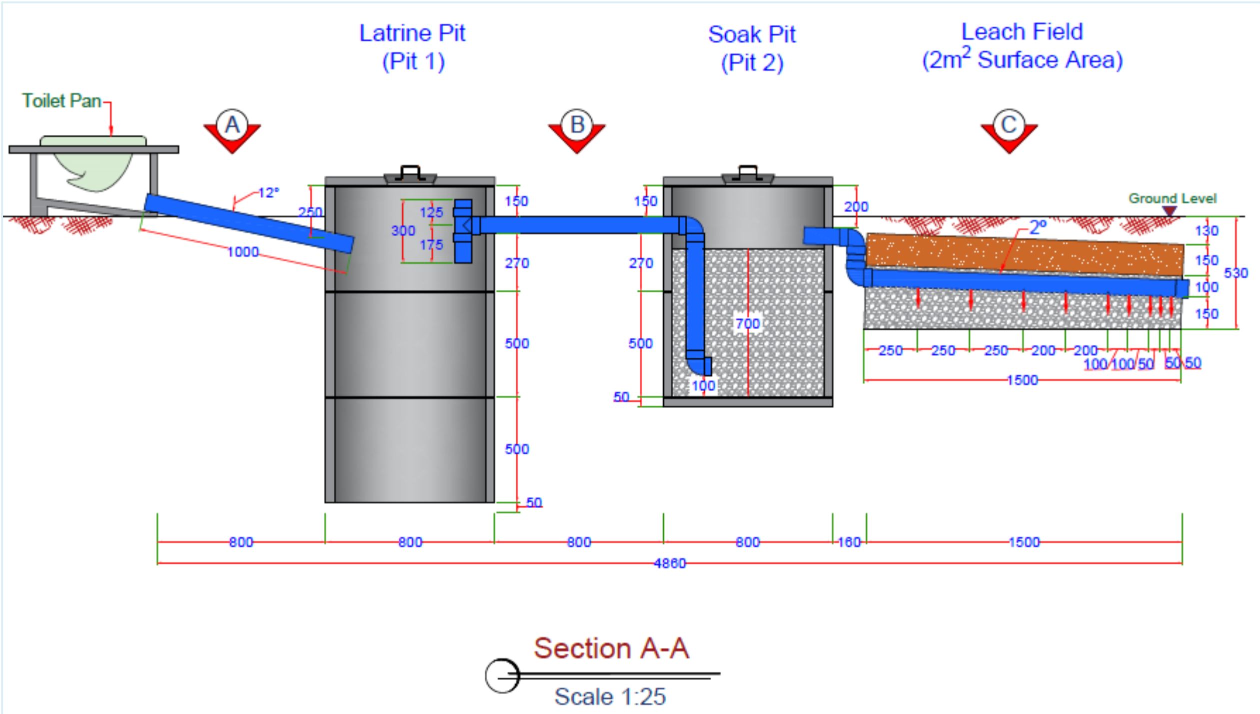


*Figure 12. **Section A-A View of ASU Leach Field 2m²***

- Materials
  The main materials used are wet concrete rings, PVC pipes, concrete ring cover, rice husk, gravel, and sand which are represented in the whole product drawing plan (See Appendix II, item 5).
- Product Cost
  The manufacturing cost for an 80 cm ring product is $31.97 and the 100 cm ring product is $40.47 (See detail in Appendix II, item 12).

4 FIELD TESTING

4.1 FIELD TESTING PLAN (MAY - JUNE 2019)

The high groundwater SCE context in Cambodia exists in both clayey and sandy environments, so the selection of field sites was made accordingly. Accordingly, (L1) Roka Leu Village, Khpob Commune, S'ang District was chosen for testing in a clayey environment and (L6) Tonloab Village, Toul Prech Commune, Ang Snoul District was chosen for testing in a sandy environment. According to the design calculations, the leach field size requirements are 4 m^2 for clay and 2 m^2 for sand. The decision was made to test five (5) prototypes according to design in each type of soil, as well as an additional five (5) 2 m^2 systems installed in clayey environments to assess the potential for cost savings using a smaller system. A goal of testing with two sealed latrine pits was also set but was not located in the field. Additionally, three control sites were selected for testing in each environment, although this number was subject to significant debate.

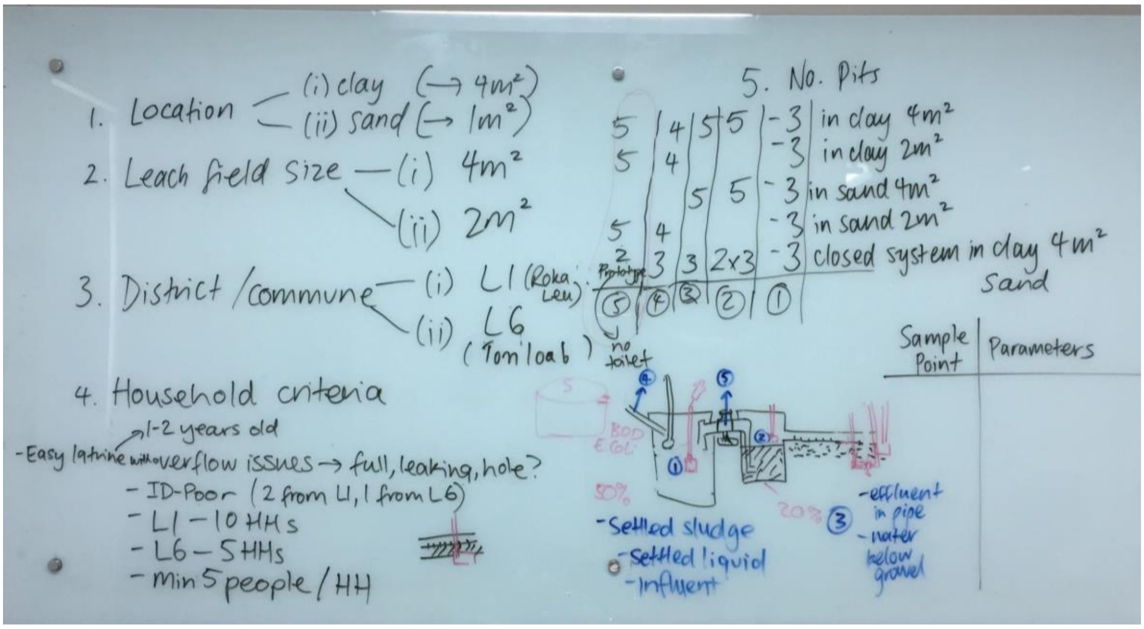


*Figure 13. **Number of Site Selecting Evaluation***

A client consent form was developed with a clearly articulated explanation for the households involved that this upgrade product is still in prototyping, and is not guaranteed to work effectively. This consent form was signed by all participating households before the commencement of ASU construction.

5 SHORTLISTING

The initial shortlisting of households was conducted by iDE staff based in Kandal Province. Households were selected based on the age of the pit, type of pit, and the number of users. A total of 15 households in S'ang and 10 in Ang Snoul were located by the Sanitation Business Advisors. During this stage of verification, about half the sites in S'ang and about one-third of the sites in Ang Snoul were deemed to be appropriate field-testing sites.

5.1 Site Selection

Since issues of seasonal high groundwater table and poor infiltration are difficult or time consuming to measure, a household questionnaire (See Appendix II, item 4) was written to determine appropriate field testing sites through symptoms of latrine functionality. Questions about details of pit construction and usage were used to determine if the pit experienced typical fill rates or abnormal fill rates associated with poor infiltration. Further questions assessed maintenance, including pit leakage, emptying, mitigation of overflows including emptying or pit piercing, and water content of wastewater during emptying or leakage events. Environmental questions were used to estimate groundwater table and seasonal flooding. Finally, the selection criteria assessed the feasibility of constructing an ASU at the site, which included sufficient flat land area, without nearby drinking water resources.

The project team spent a total of 14 days to finalize the selection of 15 sites for construction. However, several sites selected for construction or as controls did not meet criteria and had to be replaced with other sites during construction and baseline sampling phases. Some sites exhibited issues of ASU constructability, including insufficient available space, extreme slopes, and flooding. These issues would prevent the current design from working or would add significant barriers to construction, making this product unviable according to previously defined criteria. Another concern was surface soil integrity at sites where nearby animals, dense grass, garbage, or other coverage would either make it unsafe to sample or provide a significant risk of soil contamination from outside sources. Surface soil integrity is not a concern for ASU implementation but is for researching the system during prototyping.

Upon selection of a site for use in the study, the surface soil composition was determined by observation and hand texturing technique as per a technical brief published by USAID, PSI, PATH, and WSUP (See Appendix II, item 8). This simple technique consists of rolling, squeezing, and otherwise manipulating a wetted palm-sized soil sample to assess its basic soil type. This information was used to plan a 1- or 2-pipe ASU system at each site. The specific soil type at the bottom of each leach field was later confirmed during the construction stage through a laboratory soil particle size analysis.

5.2 Construction Process & Complications

The first construction site (#8) was located on extremely dense clay and took significantly longer to dig than previously estimated. Although this environment is a prime example of the type of challenging environment that ASU seeks to address, it must be noted that manual digging in this soil type of environment is extremely time and energy-consuming in comparison to sandy sites. Pricing for additional labor may be required so as not to disincentivize construction at these types of sites.

The location of the filter pit and leach field in the ASU system was designed for flat ground. However, completely flat ground is quite rare in the study areas, which complicated the determination of feature depth. This could be improved by marking depth to the existing latrine pit with recommended solutions on how to manage construction at sites with sloping ground surfaces. Additionally, digging the leach field and installing pipes at a two percent grade was difficult and complicated to describe to the LBOs and laborers. This section of construction was completed by the iDE-EWB team with smartphone level apps that provide angle in degrees. Installation guides should be updated with absolute numbers to ease the pipe placement process.

Furthermore, the design of the multi-joint pipe system requires leveling to grade on several different planes. This makes installation particularly difficult because pipe angles must be adjusted and forcefully pushed together and glued, while the mortar is freshly placed between the filter pit and the leach field pipe. In many cases, there are likely leaks at this joint because of the installation process. The leach field pipes should be glued before mortaring to the filter pit, and any sections that can be completed before lowering into the pit should be done on a flat surface.

The quality of building materials, primarily concrete and mortar, caused significant concern during field testing. Several of the filter pits broke during transportation; they were repaired using mortar mixed on-site. Evident cracks along the sides, completely crumbled bottoms, and chips were visible. Additionally, it took minimal effort to chisel or hammer holes into the concrete. The mortar used to fix the broken pits and to seal lids and pipes was also very watery when mixed. An example of poor-quality materials was the PVC access ports for sampling, which were attached to the latrine pit and filter pit lids with mortar. When attempting to remove the access port caps for baseline sampling, the mortar gave way before the PVC pipe caps at several sites.

The design of the ASU requires a completely sealed filter pit and suggests a completely sealed latrine pit for newly constructed sites. Sealed pits allow for proper containment and prevent untreated wastewater from entering the subsurface. In this study, none of the latrine pits were completely sealed, and the construction of the filter pits was deemed inadequate to prevent leakage due to poor construction timing and material quality.

6 MONITORING & EVALUATION (JUNE 2019 – SEPTEMBER 2020)

The purpose of laboratory testing on the ASU systems is to determine levels of treatment and safety of its use. For this study, laboratory tests are divided into three categories: operating parameters, microbiological testing, and chemical testing.

6.1 LABORATORY TESTING – OPERATING PARAMETERS

The operating parameters considered for testing included total suspended solids (TSS), volatile suspended solids (VSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD). TSS, a measure of the particulate matter within a sample, was chosen over VSS, which only measures the organic content of particulate matter because all particulate matter can clog filters and facilitate the growth of microorganisms in the water. BOD, a proxy for the amount of biodegradable organic material, was chosen over COD, which also includes oxidizable non-organic material, as only the former is of interest in regards to treatment goals. Testing for both BOD and COD was considered because the ratio of the two can characterize the biodegradability of its contents. However, this information was not deemed worthwhile given the additional cost it would add.

6.2 LABORATORY TESTING – MICROBIOLOGICAL

Microbial testing is used to understand the treatment and to assess the level of safety in both the effluent and the surrounding environment. Three microbial tests were considered for this study: total coliforms, fecal coliforms, *Escherichia coli* (*E. coli*), and *Enterococcus*. Enterococcus testing was not available at the selected laboratory. The most specific of the coliform tests is *E. coli*, which is a species-specific test that includes pathogenic and non-pathogenic strains. It is widely accepted as an effective indicator of human fecal contamination. However, the magnitude of *E. coli* concentrations in small-scale complex environments such as latrine pits and their surroundings is highly variable. This issue was experienced by the iDE-EWB team while testing previous designs, which made it difficult to distinguish seasonal trends in treatment. Additionally, *E. coli* is not particularly resilient in the unsaturated zone of the soil, which could generate false negatives for fecal contamination in soil testing.

Broader and alternative tests were explored in hopes of producing lower variability in results. The total coliforms test would likely achieve low variability since it is a very broad test for many kinds of bacteria, many from the fecal origin. However, it is not an ideal indicator because it includes many types of microbes naturally found in the environment, and not necessarily related to human waste. A good balance between the *E. coli* and total coliforms test is the fecal coliform test, also known as thermotolerant coliforms. This test is thought to be broad enough to reduce variability, while still maintaining a high degree of certainty that results are related to contamination from latrines.

An additional microbial water quality indicator unrelated to the coliforms is *Enterococci*[2]. Testing for *Enterococci* is gaining popularity as a test for human fecal contamination as its presence correlates well to fecal contamination and exhibits low variability due to its high resistance in the environment[3].

Monitoring of additional pathogens such as helminths, Pseudomonas, Giardia, and Salmonella was considered, as the iDE-EWB team recognizes the high likelihood of their presence and threat to human and environmental health. Although the team recognizes the value of adding this information to the body of knowledge regarding sanitation in challenging environments, the limited M&E budget and lack of targeted treatment for these pathogens led these tests to be deemed beyond the scope of this study.

6.3 SOIL INFILTRATION RATE & SOIL GRAIN SIZE DISTRIBUTION ANALYSIS

Hydraulic conductivity is the rate at which water can travel through a block of soil with a given force. In natural systems, the source of this force is either downward from gravity or in any direction due to pressure exerted from water outside that parcel of soil. Hydraulic conductivity increases with soil water content[4] until its maximum rate at soil saturation.

[2] https://www.ncbi.nlm.nih.gov/pubmed/17416563
[3] https://onlinelibrary.wiley.com/doi/abs/10.2175/106143004X141807
[4] https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/CSES/CSES-141/CSES-141-PDF.pdf

Note that the infiltration rate, rather than hydraulic conductivity, is the rate at which water travels downward through the soil. The infiltration rate is a function of hydraulic conductivity rates (from dry to saturated) and the hydraulic gradient. The infiltration rate is highest when the soil is saturated from above, either by rain or pooled effluent, and reaches zero when saturated from below, either by a raised water table or flooding. (Additional resources[5,6,7,8])

During the construction phase, a sample of soil from the bottom of the dug leach field pit was collected for a grain size distribution analysis. In this test, the soil is dried and sieved to determine the proportion of various particle sizes within the sample. This information is used to characterize soil type and can be used to estimate the maximum (saturated) hydraulic conductivity rate of the soil at each site.

However, the input parameters to calculate the hydraulic gradient might be available at some sites during certain times of the year. The hydraulic gradient can be calculated knowing the water elevations in the leach field (standpipe) and the surrounding groundwater (monitoring well), and the distance between the two.

6.4 SAMPLING POINT SELECTION - LIQUIDS

Laboratory testing was conducted on two media in this study. The first medium, liquid as wastewater, is used to assess the constructed ASU systems based on treatment goals. The testing points considered for liquid sampling included the toilet flush water, latrine pit, filter pit, leach field, and surrounding groundwater.

The latrine influence was considered as the first point of testing. However, the process of selecting for and collecting a sample of flush water would be infeasible. Without the construction of a catch basin before the latrine, the team would have to arrive at each site and request an individual to use the toilet. Regardless of the collection method, any such sample would be highly variable as the chemical and biological composition of waste changes between people at varying levels of health and sickness and varies naturally between days. Additionally, the dilution factor from varying amounts of flush water would make a small sample size meaningless. Therefore, sampling at this stage was abandoned, and the first sampling point in the system was moved to the latrine pit.

The latrine pit is assumed to be comprised of three distinct layers. At the top rests a thick (approximately 1-10 cm) scum layer which consists of "floaters", paper, plastic, and menstrual hygiene products. Below the scum layer is the liquid wastewater, which in the targeted environments has a significantly higher water content due to infiltration into the pit or lack of infiltration out of the pit. The water content decreases and the density increases into the sludge layer. This boundary is assumed to be a gradual transition rather than an actual layer as the scum layer is characterized. These assumptions are developed from intuition and visual observation during several emptying events within this context.

5 https://slideplayer.com/slide/4142508/
6 https://slideplayer.com/slide/4628654/
7 http://www.soilmanagementindia.com/soil-water/characteristics-of-soil-moisture-soil-water-relationship-soil-science/4530
8 http://www.fao.org/3/T0231E/t0231e05.htm

Given these assumptions of reactor composition and knowledge of pit construction, it is also assumed that a plug of influent undergoes an almost immediate treatment stage as it enters the pit. The “floaters” rise quickly to the surface scum layer, the “sinkers” drop town into the transitional sludge layer away from the effluent point, and the low-density wastewater remains in the upper liquid zone. Since these plugs of waste are fairly regular and forceful, it is assumed that the liquid zone remains continuously mixed, and thus the composition of the effluent is the same as the composition of the upper liquid zone.

Due to the complexities of collecting influent before this first treatment step, this study is forced to set influent concentrations as waste exiting the pit latrine. On one hand, this results in a more conservative treatment efficiency of the toilet-latrine-ASU system, which is lower than the true nature of the system. However, in comparison to the alternative, the ASU does not alter the treatment or hydraulic functions of the latrine pit, but rather collects the fluid that would be exiting pierced pits for additional treatment stages. Therefore, effluent at this stage represents a true baseline for comparison, as any treatment that occurs in a pit latrine should not be attributed to the ASU. This assessment also removes the need for a control set of additional latrines, which would further complicate the study due to the high variability of microbial communities between latrines in small sample sizes. All major tests (BOD, TSS, TTC) are conducted at this stage, but minor tests (nitrate, alkalinity, pH) are not deemed useful, as the ASU is not designed to treat any of those parameters, and they are only intended to explore additional treatment stages post-filtration.

A small PVC access port was installed above the T-Junction to collect samples close to the discharge point and to avoid the scum layer. An alternative sampling location for the same sample would have been within the pipe connecting the latrine pit to the filter pit, although this was dismissed primarily due to complexities in construction. Additionally, concerns regarding potential treatment between the T-Junction and entrance to the filter media may exist since the wastewater likely changes from anoxic in the well-mixed liquid zone of the latrine to aerobic in the horizontal pipe which has significant air contact and ultimately to anoxic and anaerobic within the vertical pipe. Any of these potential treatment stages would be unintended benefits of the ASU, and thus would be recorded in samples from the top of the filter pit.

With the discharge point of the latrine pit set as the ASU influent, the discharge point of the filter pit is regarded as the next appropriate sampling location to assess treatment within that reactor. The filter pit was designed hydraulically for a layer of fluid to exist above the filtration media and below the discharge pipe at all times after it primes.

This region is assumed to be uniform in composition, as the treatment occurs in the highly tortuous fluid dynamics within the upflow filtration media. Once the fluid reaches the open space at the top, flow exhibits extremely low resistance and mixes thoroughly as it flows towards the discharge pipe.

Figure 14. ***Liquid Wastewater Sampling at Household #16***

The final stage of treatment is in the leach field, which also serves as the point of infiltration into the soil. Standpipes for collecting samples were installed into the prototypes with the bottom of the pipe open at the bottom of the gravel layer, with slits up to the top of the gravel layer. This gives an understanding of the standing water level within the gravel layer but prevents shortcutting of effluent from the gravel layer down into deeper levels of the soil. Although it would be greatly preferable to have access to sufficient samples at the leach field throughout the year as it is the final point of effluent discharge into the environment, it was deemed not worth sacrificing functionality. When possible, wastewater samples were collected at this site for all major tests (BOD, TSS, and TTC). Alkalinity will not be tested, since it is highly unlikely to change significantly within the leach field and is not predicted to have a significant impact on the environment.

6.5 LIQUID WASTEWATER SAMPLING METHODOLOGY

1) Wastewater is taken from inside the pit using a syringe,1.5 L bottles are used.

2) One sample is filled at a time.

3) Samplers use gloves and masks.

4) The samples are kept inside ice buckets; samples are directly put into the ice bucket.

5) Alcohol is rubbed in the outside of the sample bottle before putting in the ice bucket

6) Samples are usually taken from sites in the morning and then taken in the lab in the afternoon.

7) Samples are taken in hot weather

8) One syringe is used in three bottles, or sometimes 2 syringes in 6 bottles, randomization of samples is carried out before sending it to two labs.

9) During transportation, samples are shaken as the road conditions are not great, an apparatus was created to limit the shaking of the sample bottle during transportation.

6.6 SAMPLING POINT SELECTION - SOIL

The purpose of testing the second media, soil, is to better quantify the risk of exposure to fecal pathogens between sites with and without the ASU systems. For this reason, only testing for TTC was to be conducted. The testing protocol was adapted from the United States Environmental Protection Agency standard operating procedure for soil contaminant exposure[9], with sample depth between 2 cm and 8 cm. Composite sampling is used to mitigate the naturally high variation of microbial activity in the shallow subsurface between locations in close proximity. Three individual samples were composited at each sampling location for every site.

Surrounding the latrine pit, samples were collected at a radius of 35 cm greater than the radius of the pit (75 cm radius for 80 cm diameter pits and 85 cm for 1.0 m pits). This distance away from the pit is thought to be great enough to avoid misleadingly high testing results from minimal leakage from the pit while being close enough to assess significant leakage. These individual samples are to be collected in equal angles apart from the pit center, with one point chosen in the direction of any evident waste outflow or simply the steepest downhill gradient in absence of an outflow. This protocol standardizes a selection process for a radially uniform soil composite while also targeting the most likely source of contamination. The purpose of this protocol is that a composite of three locations will provide smoother results than would one individual sample, but will still be extremely high if at one point contains fecal contamination.

The second location for sampling is in the area of the leach field for the treatment sites and in the location that would be selected for the construction of the leach field for the control sites. The first two sampling points are located at 0.5 m and 2 m away from the edge of the filter pit in the direction of the leach field. The third point is located 0.65 cm perpendicularly away from the midpoint of the former two points (1.25 m from the filter pit) towards the lower side of the pit for single-pipe systems and 1.25m away for double pipe systems. Although some slight variation of leach field location and size exists between sites, these locations generally mark the edges of the pit, where contamination is most likely to travel upward in case of system failure.

The location of third point soil sampling is 0.65cm perpendicularly away from the midpoint of the former two points (1.25 m from the filter pit) towards the lower side of the pit for a single pipe system and 0.85cm away for the two-pipe system.

The size and locations of proposed leach fields at control sites were selected according to the same criteria as the treatment sites. These criteria are stringent enough to provide very few reasonable options for location and in many cases only one. Regardless, the locations of the proposed leach fields for the control sites have been recorded to ensure that subsequent sampling would occur at the same locations.

6.7 FREQUENCY & DURATION

A field testing duration of one year was chosen to monitor seasonal variation on the ASU system. A high testing frequency reduces longitudinal variability in results and improves understanding of trends against time and seasonality. These benefits are offset by budgeting and staffing

[9] [US EPA Soil Testing]

constraints, including laboratory testing, sampling equipment, and resources for field visits. The team agreed upon a frequency of six (6) sampling visits in addition to a baseline after construction through intuition developed from previous work. The results from the iDE-EWB 3C Pit trial were largely inconclusive as treatment trends could not be identified from only four (4) sampling visits, thus setting the minimum bound for sampling frequency. The maximum bound of sampling frequency was set by the overall sampling budget, and the estimated time and resources required for a full sampling run. Available resources limited the maximum frequency to approximately once per two months or six (6) sampling visits over a year.

6.8 DUPLICATES

Unexpected outliers in the laboratory results from the 3C Pit study and variation between two laboratories led to concerns about laboratory reliability and informed the need for budgeting duplicates to test for quality. Based on this learning, for the ASU duplicate samples for all tests at one site were provided for laboratory testing. Besides, some samples were provided to an additional laboratory to evaluate laboratory precision for alternatives. For sampling round 4, two sets of replicates were sent to two laboratories and for sampling round 5, three sets of duplicates were analyzed at three laboratories in Phnom Penh.

Controls were put into place for maintaining the integrity of samples through sterilizing equipment, protecting equipment and samples during transportation, and preventing cross-contamination during sampling through a standard operating procedure for sampling[10]. However, the complex nature of collecting samples in rural areas at a significant distance from the office of operations without a proper laboratory environment or sampling tools leaves a considerable risk of contamination during collection.

High variability between duplicates implies that there may not be significant evidence to mark its source, but low variability suggests that both sampling and laboratory cross-contamination were below an acceptable level.

7 RESULT AND ANALYSIS

The analysis of the data collected from the one-year field testing of the ASU systems focused on: (1) Testing the treatment effectiveness of the ASU system to meet standard levels of safe disposal into the environment; (2) Understanding the contextual appropriateness of the ASU product.

BOD, TSS, and E.coli sampling, soil quality sampling, and field observations were used to evaluate the effectiveness of the ASU system at reducing pathogens while qualitative user survey questions were used to understand the household behaviors, customer satisfaction, and overall functionality of the ASU system.

7.1 LABORATOY TESTING REFERENCE

The Research and Innovation Center **(RIC)** lab in Phnom Penh was selected for analysis of all the data from sampling. The methods described in the labs are presented in the table below.

[10] Sampling SOP

Parameters	Method
Total Suspended Solids (TSS)	Gravimetry method: membrane filtration
Biochemical Oxygen Method (BOD) 5	Manometric method
Fecal Coliform (E-Coli)	MPN Method
Laboratory Testing Results	

7.2 Laboratory Result

Liquid wastewater and soil samples were collected from 14 households for 6 rounds every two months for a one-year period to monitor and evaluate the ASU treatment pit system. For each round, the team attempted to collect liquid samples from point A (latrine pit), point B (filter pit), and point C (leach field) while soil samplings were collected from point D (soil surrounding latrine pit) and point E (soil surrounding leach field). Originally samples were supposed to be collected from 15 households, however household #12 was quickly removed as a testing site for the ASU as the latrine pit turned out to be empty and the location did not meet design criteria.

Samples at point A were collected for all households and for all rounds. However, sampling at point B and C was rarely possible as there wasn't enough liquid to collect a complete lab sample. The results at point A for BOD, TSS, and E. coli parameters were compared with baseline concentrations (collected shortly after ASU pit installation) as well as the typical low and high untreated wastewater concentration range[11].

The soil quality around the latrine pit (point D) and leach field (point E) was tested by the number of fecal coliform (FC) in soil. The results were compared to baseline FC content, the high and low FC range in raw wastewater[12], and safe FC content in soil[13]. In addition, soil samples at point D and E were collected at 5 households. These households acted as the control group to be able to compare soil quality at households with and without the ASU system. However, the comparison of soil samples to the control group was excluded from this report as it was very difficult to consider various outside factors that might have affected the results.

Laboratory results for all liquid and soil samples are summarized in Appendix III, item 1 and 2.

7.2.1 General Finding

7.2.1.1 (BOD)

Figure 15 shows the BOD concentrations from the latrine pit (point A) in all 14 households for all 6 sampling rounds. Overall, all households showed some fluctuation in BOD concentrations between round 2 and round 6. The general trend shows that BOD is lower than the baseline and

[11] Wastewater characteristics, treatment and disposal. IWA, 2007.
[12] Wastewater engineering: treatment and reuse, 4th edition. Metcalf & Eddy Inc, 2003.
[13] Guidelines for environmental management: biosolids land application. EPA Victoria, April 2004

typical range of untreated wastewater. Since BOD concentrations were typically lower than the baseline value, the results speculate that the ASU system could have a positive effect in reducing BOD levels in the latrine pits. Moreover, this graph allows us to estimate the range of field BOD concentrations (35.87mg/L to 470mg/L) in latrine pits in rural Cambodia which can be used for future design applications. A liquid sample at point A was not possible to collect in round 3 for household #4 as solid fecal sludge content in the pit at the time interfered with the collection process.

For round 1, there are 9 households with BOD higher than typical untreated wastewater range while other 5 households (HH #3, #13, #14, #15, and #16) are lower. It is interesting to note that those 5 identified households own a twin-pit latrine system.

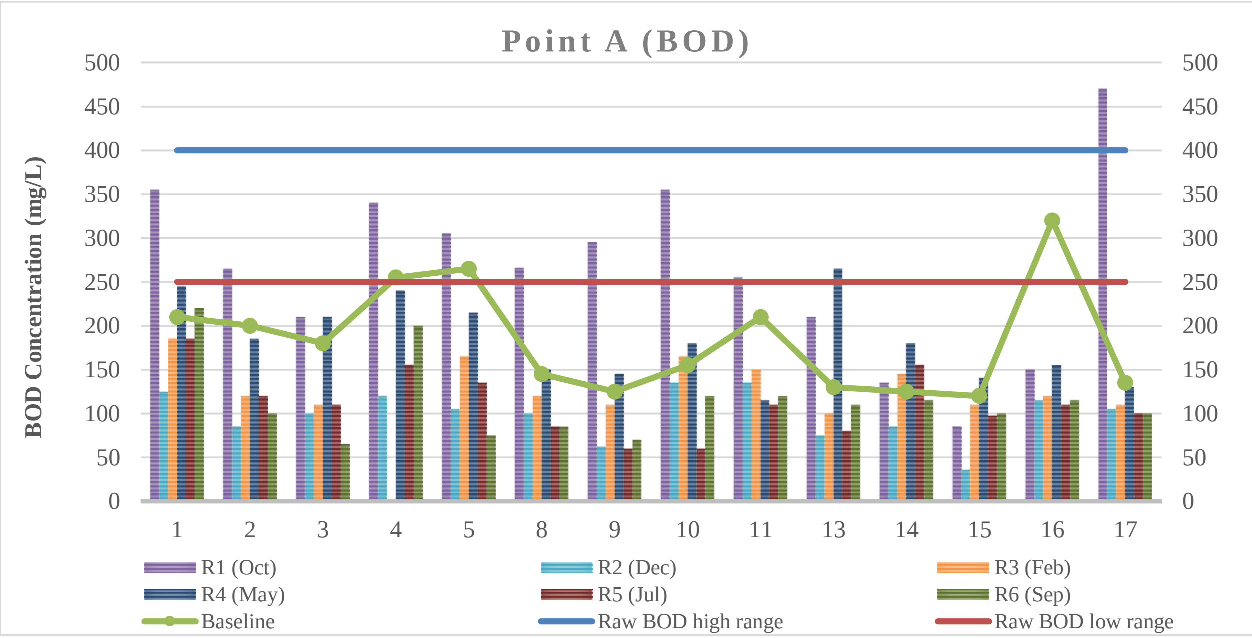


Figure 15. ***BOD Concentration in Latrine Pit (Point A) Compared to Baseline with Typical Low and High BOD Concentration Range***

7.2.1.2 <u>(TSS)</u>

Figure 16 shows the TSS concentrations from the latrine pit (point A) in all 14 households for all 6 sampling rounds. TSS baseline concentrations were much lower than the typical TSS range in untreated wastewater, except for HH #2, HH #4 and HH #5.

Overall, the majority of households showed TSS concentrations lower than the typical range. The exception was HH #11 showing very high concentrations which is due to very high content of sludge in the latrine pit observed in the field. TSS concentrations fluctuate throughout all rounds which could be connected to having various thicknesses of sludge layer at the bottom of the latrine pit or different methods used when collecting the sample with a syringe tube. Moreover, this graph allows us to estimate the range of field TSS concentrations (20mg/L to 880mg/L) in latrine pits in rural Cambodia which can be used for future design applications.

2 outliers were found in the results (round 5 of HH #5 and round 4 of HH #11) and removed from the graph due to the presence of extremely high concentrations of TSS (9900 mg/L and 13000 mg/L, respectively). These outliers are likely caused by lab testing error. Also, no liquid wastewater samples were collected at round 3 for HH #4 due to sludge and scum layers in the latrine pit.

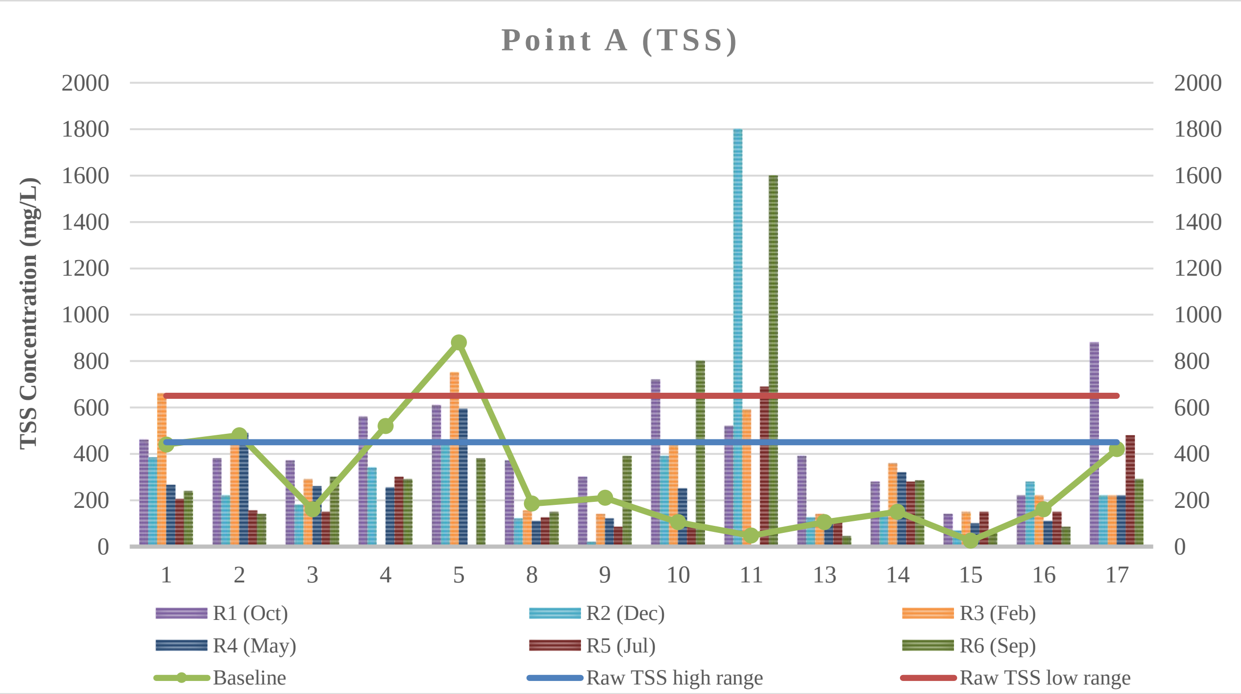


Figure 16. ***TSS Concentration in Latrine Pit Compared to Baseline with Typical Low and High TSS Concentration Range***

7.2.1.3 E. COLI

Figure 17 shows the E. coli concentrations from the latrine pit (point A) in all 14 households for all 6 sampling rounds. The baseline E. coli concentrations (min value of 1.1×10^{4}CFU/100mL and max value of 2.8×108CFU/100mL) in the liquid wastewater at point A were generally around the same range of typical concentrations in untreated wastewater. In comparison, with the ASU system, the E. coli concentrations collected in the field at all 14 households (5.6×10^{6} and 3.8×10^{3}CFU/100mL) were lower than the baseline and the typical raw wastewater concentrations range. This could be explained by the fact that the ASU system installation increased the length and volume of fecal waste containment system allowing for higher retention time and flow of pathogens. In general, since E. coli concentrations were typically lower than the baseline value, the results speculate that the ASU system could have a positive effect in reducing E. coli levels in the latrine pits.

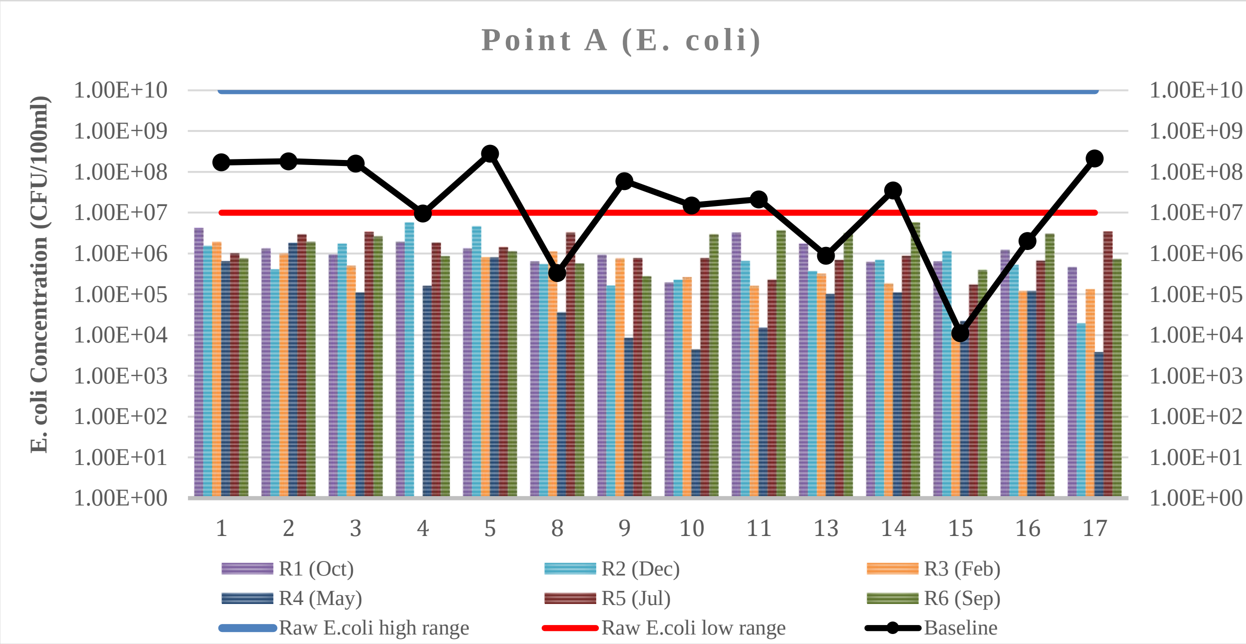


*Figure 17. **E. coli concentration in Latrine Pit (Point A) Compared to Baseline with Typical Low and High E. coli Concentration Range***

7.2.1.4 Soil Sampling at Point D

Figure 18 shows the faecal coliform (FC) content in the soil around the latrine pit (Point D). Overall, the majority of soil samples show FC concentrations lower than the raw wastewater range and baseline. Also, the FC content in the soil in some rounds is below the safe standard. This indicates that the ASU system has some capacity to reduce FC contamination in the soil around the pit latrine which is mainly attributed to the lack of raw wastewater overflow from the latrine pit. HH #14, #15 & #16 illustrate that noticeable decreasing trend of FC content in the soil.

The FC concentration in HH #1 is slightly greater than the baseline likely because the 1st existing pit in the twin-pit system was not sealed well and sometimes it overflowed to the soil around it. As for HH #11 in round 1, the bar chart is significantly higher than baseline likely due to soil contamination around the latrine pit from wastewater leakage from the latrine pit and the household throwing baby diapers and animal droppings around the ASU system. In fact, the user of HH #11 had pierced their pit to discharge wastewater to the environment but after the 2nd round until the final round of soil sampling, the result shows that the number of FC decreases due to the house owner following the designed suggestion to seal the pit ring.

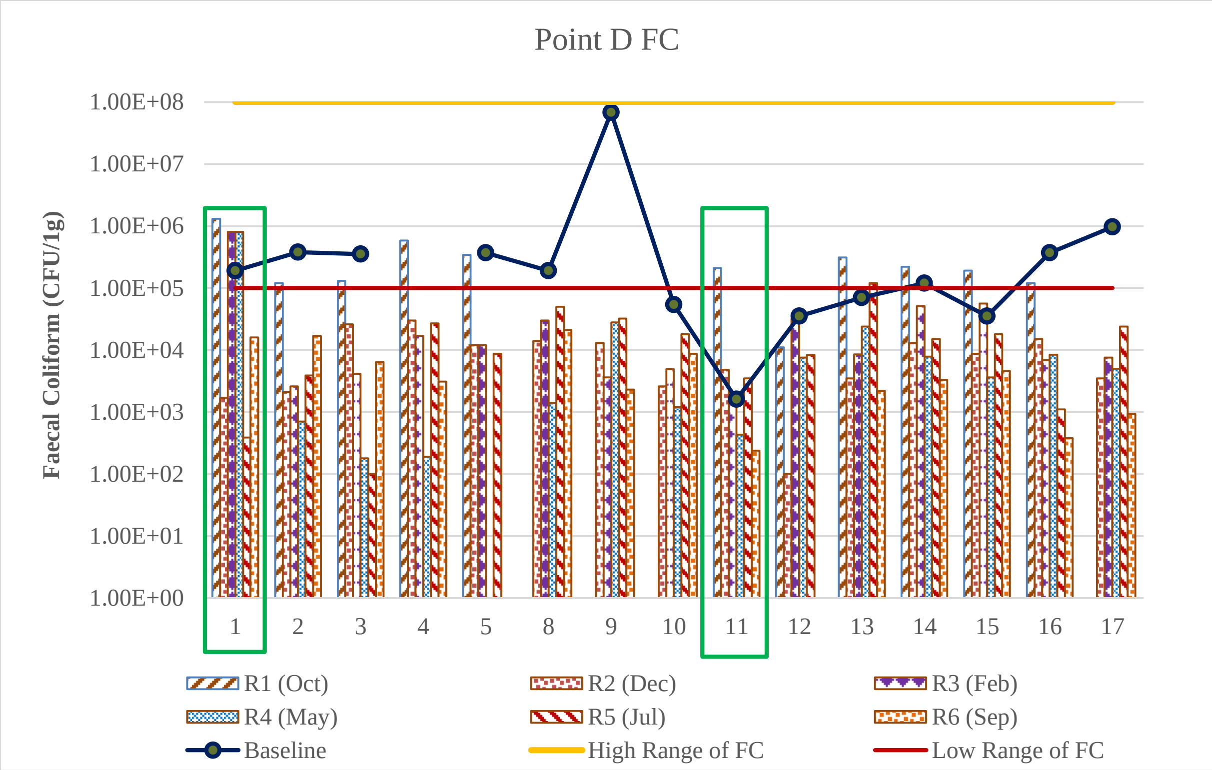


Figure 18. ***Faecal Coliform Concentration of Soil Around Latrine Pit (Point D) in All Round Compared to Baseline with Typical Low and High Concentration Range***

7.2.1.5 SOIL SAMPLING POINT E

Figure 19 shows the faecal coliform (FC) content in the soil around the leach field (Point E). The FC content in the soil at point E is mostly below the baseline and FC typical raw wastewater range. Also, the FC content in the soil in some rounds is below the safe standard, especially by round 6. This indicates that the treated effluent from the ASU system does not worsen local soil quality and can even improve the soil quality to safer levels. A few expectations arise, in round 1 of HH #4 & #5, the FC content is higher than the baseline which is likely due to pre-contamination of the soil from latrine pit wastewater overflow before ASU installation. However, the soil quality seems to have gradually improved after round 2. For HH #5, rounds 5 and 6 are missing as the household had built a chicken shelter above the ASU system preventing soil samples at point E to be collected.

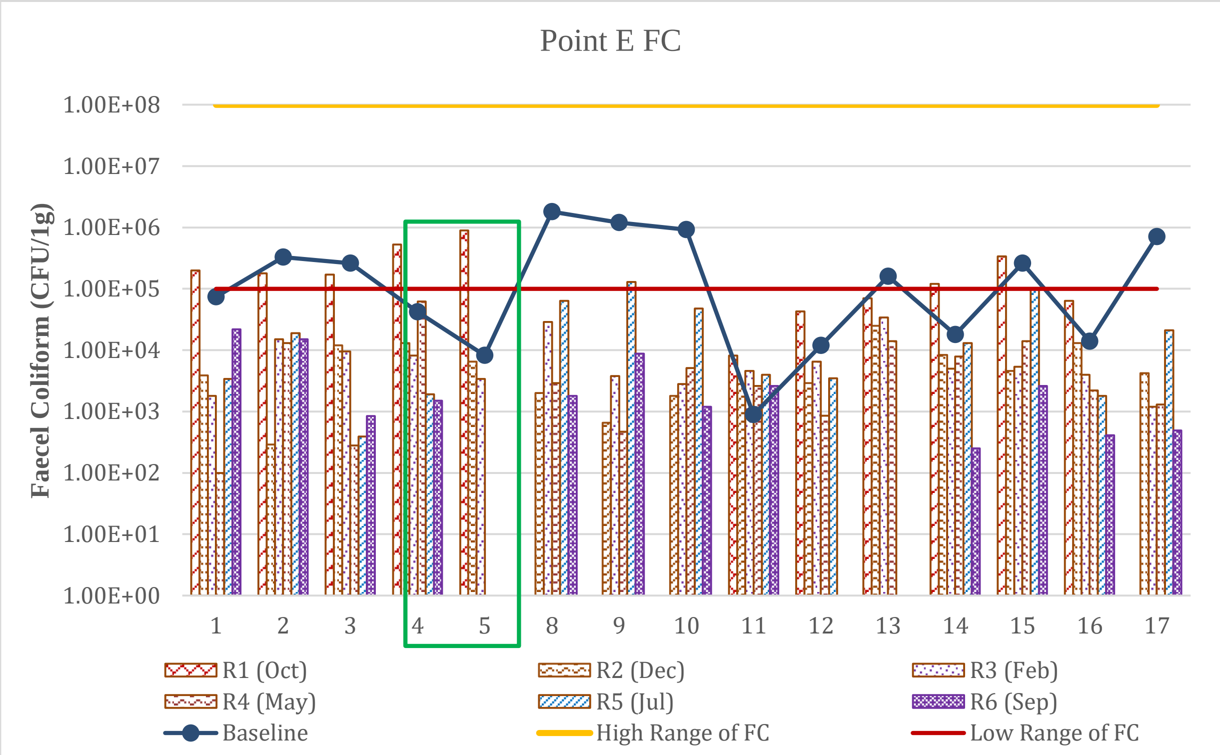


Figure 19. ***Faecal Coliform Concentration of Soil Around Leach Field (Point E) in All Round Compared to Baseline with Typical Low and High Concentration Range***

7.2.2 THE REMOVAL EFFICIENCY OF BOD, TSS AND E. COLI IN ASU SYSTEM

Out of all the households, sampling at point A, B, and C for all rounds was only possible at household #8. Household #8 happens to be the first construction site selected which likely means that the installation was up to design standards. Also, household #8 is located in a dense clay environment meeting the low infiltration design criteria. Therefore, household #8 was selected to evaluate the effectiveness of ASU system at pathogen removal by comparing the results from the field to the Cambodian wastewater effluent standards for BODs, TSS and E. coli[14].

7.2.2.1 BOD

Figure 20 shows a general decreasing trend of BOD concentrations at point A, B, and C over time following the ASU system installation. By round 2, BOD concentrations dropped significantly and reached low enough concentrations at point B and C to meet the effluent standard. Although there seems to be some fluctuation in the BOD concentrations over time, the overall decreasing trend hints the ASU system could reach even lower concentrations if the system was tested for a longer time. This graph illustrates that the ASU system reduces BOD concentrations at point A, B, and C over time. It is interesting to note that BOD concentration in the latrine pit gradually improved over time almost reaching safe effluent levels by round 5.

Figure 21 plots the average BOD concentration of point A, B and C to evaluate the treatment efficiency at each step of the ASU system. There is a slight increase in the average BOD concentrations between point A and B followed by a significant drop from point B to C. The first

[14] Cambodian sub-decree wastewater standard disposal to environment, MoE 1999.

treatment step from A to B was not effective in removing BOD. However, the second and final treatment step from B to C (24% removal) shows a significant improvement in effluent quality, almost meeting effluent standards. Overall, the average BOD concentration was reduced by 35% from point A to C.

Figure 20 and 21 demonstrate that the ASU system can effectively reduce BOD concentrations to meet safe effluent standards allowing safe discharge into the open environment and reducing public health impacts.

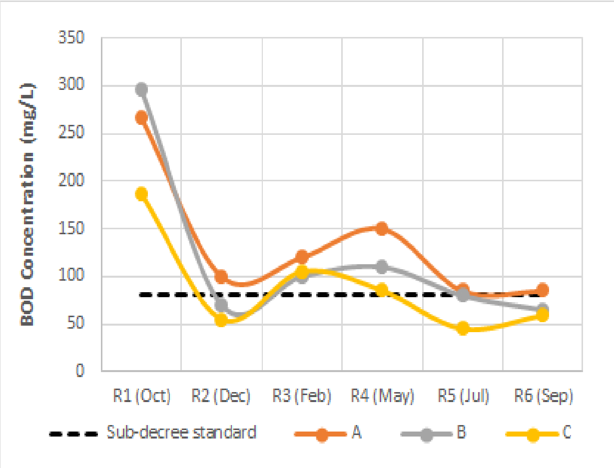


Figure 20. ***BOD Concentration from Point A, B and C at household #8 compared with Cambodian sub-decree standard***

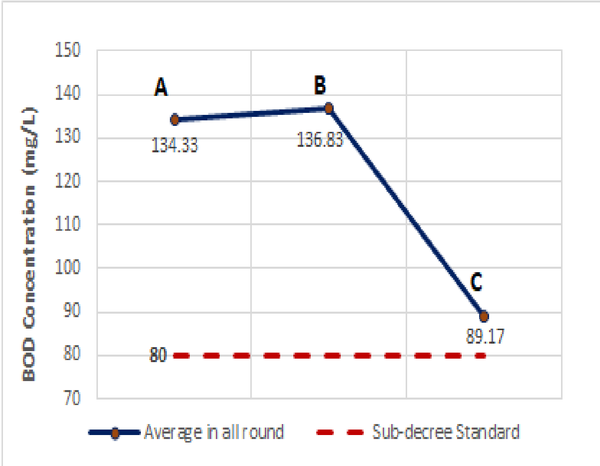


Figure 21. ***Average BOD Concentration from Point A, B and C at household #8 compared Cambodian Sub-Decree Standard***

7.2.2.2 <u>TSS</u>

Figure 22 shows a general decreasing trend of TSS concentrations at point A, B, and C over time following the ASU system installation. By round 2, TSS concentrations dropped significantly and reached low enough concentrations at point B and C to meet the effluent standard. The level of TSS in each point fell slightly from round 2 to round 4 compared to round 1, and then remained level through the following sub-decree standard in round 5 and 6. Noticeably, outliers of TSS at point B in round 5 and 6 were removed from this graph. These outliers are likely due to a sampling error or laboratory testing error. This graph illustrates that the ASU system reduces TSS concentrations at point A, B, and C over time. It is interesting to note that TSS concentration in the latrine pit reached the safe effluent levels by round 2.

Figure 23 plots the average TSS concentration of point A, B and C to evaluate the treatment efficiency at each step of the ASU system. The results show that point B has higher TSS content than point A on average. Overall, the TSS content decreased from point A to point C however the TSS concentrations in the effluent does not meet the standard. The ASU treatment system was then not highly effective at reducing TSS. TSS concentrations higher than standard could often mean higher concentration in bacteria, nutrients, pesticides, and/or metals in the effluent.

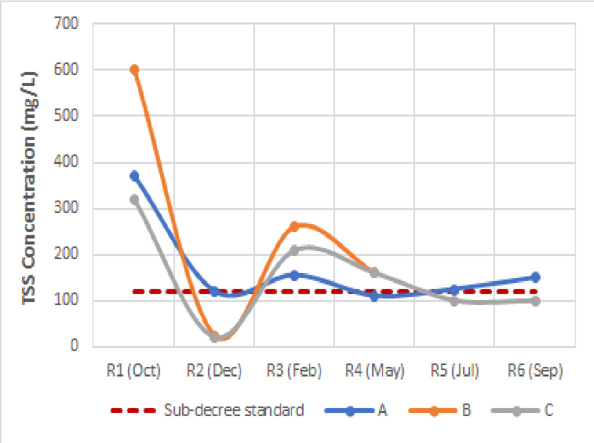


Figure 22. ***TSS Concentration from Point A, B and C at household #8 compared Cambodian Sub-Decree Standard***

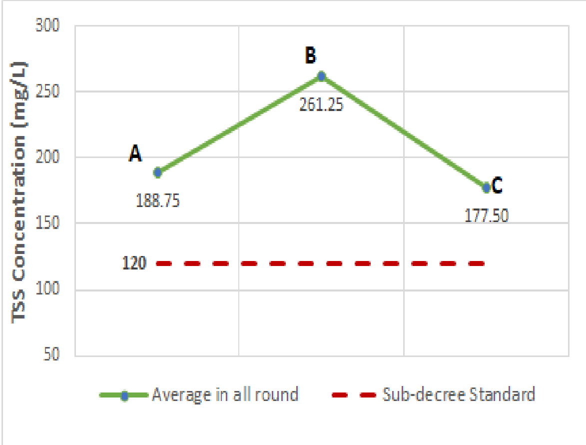


*Figure 23****. Average TSS Concentration from Point A, B and C at household #8 compared with Cambodian sub-decree standard***

7.2.2.3 E. COLI

Figure 24 shows that the E. coli concentrations fluctuated for all round and at all points A, B, and C. For household #8, it is important to note that the latrine pit and ASU system were often covered by solid waste including diapers. Interestingly, the E. coli in round 4 significantly dropped due to the environment around the latrine pit and ASU system was dry which commonly it was muddy and had stagnant water on the pit. Overall, this graph does not show any trend that proves high treatment efficiency. Point C met the safe effluent standards in round 2 and 4 which indicates that the ASU system does provide treatment capacity to remove pathogens. E.coli removal in the ASU treatment system could be attributable to anaerobic conditions in the latrine pit after it was sealed and/or the low pore size filtration media in the gravel pit and leach field. The concentration of E. coli in the latrine pit is also usually connected to the ratio of fecal sludge to liquid wastewater inside the pit. More data is required to make stronger conclusions in this case.

Figure 25 shows that the % removal in E. coli between sample point A and point B is 58% while the % removal of sample point A and C is 69%. The results show that concentration of E. coli steadily decreases from the latrine pit to the leach field. However, the average E coli concentration in the ASU effluent (point C) does not reach the required 2012 MoE standards (5000 CFU/100ml). Overall, this indicates that the ASU system does have a E. coli removal capacity and shows a higher safety in discharge in comparison to raw liquid wastewater directly from the pit latrine.

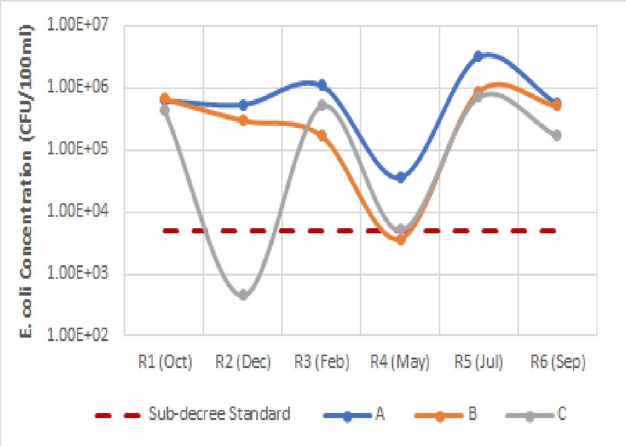


Figure 24 ***E. coli Concentration from Point A, B and C at household #8 compared with Cambodian sub-decree standard***

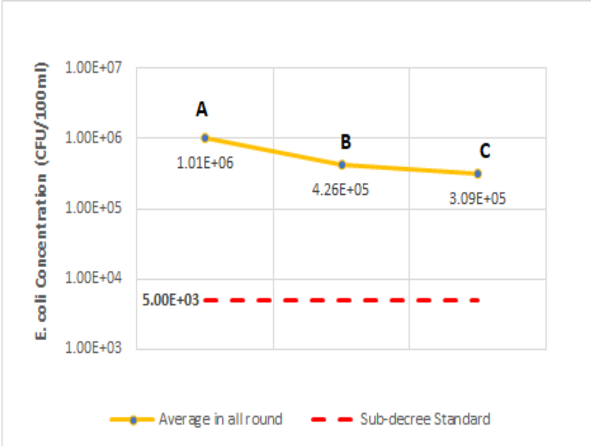


Figure 25 ***Average E. coli Concentration from Point A, B and C at household #8 compared Cambodian Sub-Decree Standard***

7.3 HOUSEHOLD SURVEY RESULTS

A field observations survey was conducted at all households for all rounds to collect support information from the field including the pit gauge level and the groundwater level. A user survey was conducted at all households for only round 2 and round 6 to collect information on product functionality, user satisfaction, and product marketability.

7.3.1 GROUND WATER LEVEL AND SOIL COMPOSITION, IMPORTANT PARAMETERS TO ASU'S APPROPRIATENESS

Figure 26 plots the average distance between the ground level and the groundwater (GW) table, the pit latrine height based on the number of rings, and the clay content in the soil which is related to the infiltration rate into the ground from the bottom of the pit. Similarly, **Figure 27** attempts to connect groundwater level, soil composition, and number of samples at filter pit to understand local infiltration.

Only 4 households (1, 3, 8, and 9) had groundwater levels that were higher than the latrine pit bottom. GW levels that are higher than the latrine pit bottom result in soil saturation and no/low infiltration from the bottom of the latrine pit, which is one of the main design criteria's for the ASU product efficacy. It was possible to collect liquid wastewater samples at households 8 and 9 but it wasn't possible for households 1 and 3. Households 8 and 9 have high clay content, while households 1 and 3's soil composition is mainly porous (sand, low clay/silt) which could have caused higher infiltration rate. Faulty installation at the latrine pit (leakage between the rings) or gravel pit (did not wait for cement to dry and seal the bottom) could also cause higher infiltration rates.

Interestingly, it was possible to collect liquid wastewater samples at households (4, 10, 13, and 16) even when the GW level was low and the soil composition did not have a significant clay content. As GW levels fluctuate continuously in rural Cambodia, the ASU system at these households must have been working intermittently. Also, household 14 shows GW levels that are very close to the bottom of the latrine pit and high clay content but a sample at point B was only possible in round 6. This could mean that soil composition is less connected to ASU functionality in comparison to GW level. The combination of the two characteristics however does guarantee ASU's designed functionality (e.g. household 8 and 9).

Standpipes for collecting samples were installed into the prototypes with the bottom of the pipe open at the bottom of the gravel layer, with slits up to the top of the gravel layer. This gives an understanding of the standing water level within the gravel layer but prevents shortcutting of effluent from the gravel layer down into deeper levels of the soil. In non-heavy clay environments, the quick infiltration of the effluent into the soil in the leach field is thought to be the main reason for not being able to collect liquid samples at point C.

The next two cases studies below are example that add some complexity to why collection at point C was not possible:

- Household 11 and 16. Both households showed low GW levels, yet samples were only possible to collect at household 16. Household 11 has a higher clay composition in comparison to household 16. In household 16, 5 people used the toilet twice daily while 6 people used the toilet three times daily in household 11. The reasons behind why samples were collected at household 16 and not at household 11 are therefore unclear.

- Household 14: Even though the groundwater levels recorded were high, the clay content in the soil was high, and the pit was full (see figure 27), sample collection was not possible at point C for all rounds.

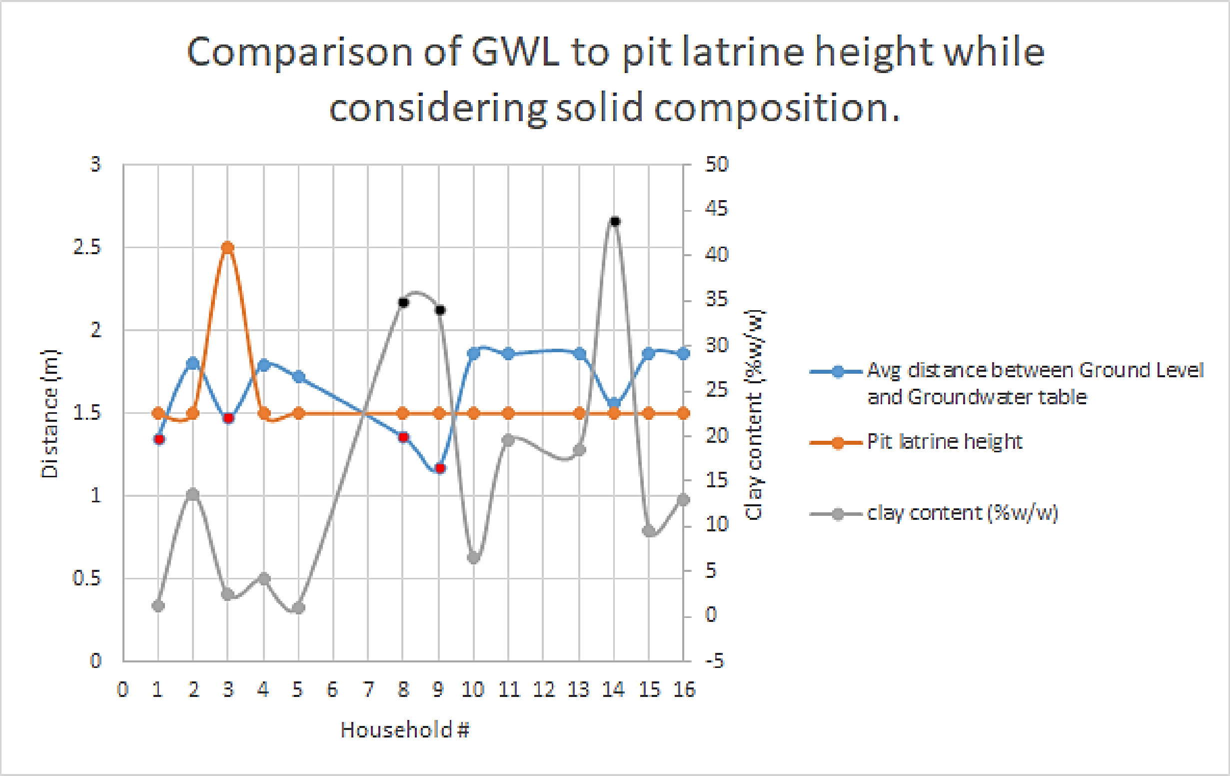


*Figure 26. **The plotting graph of average distance between the ground level and groundwater table (GW).***

HH #	Avg distance from Ground Level to GW table	Pit latrine depth(m) / Filter Pit depth(m)	GW level is lower than pit latrine bottom? (i.e. soil infiltration is possible)	At least 3 liquid samples were collected at filter pit (point B)	clay content (%w/w)	Notes
1	1.346	1.5	No/Low Infiltration	No	1.25	No/low infiltration at point A but since soil composition below leach field is mainly sand samples at point C were not collected. As for point B, the issue could be liquid seeping out due to cracks or holes at the bottom and sides of the filter pit caused by improper waiting time for cement to dry during installation.
2	1.8	1.5	Yes	No	13.5	
3	1.48	2.5	No/Low Infiltration	No	2.5	No/low infiltration at point A but since soil composition below leach field is mainly sand samples at point C were not collected. As for point B, the issue could be liquid seeping out due to cracks or holes at the bottom and sides of the filter pit caused by improper waiting time for cement to dry during installation.
4	1.796	1.5	Yes	Yes	4.1	With low clay/silt soil composition and GW levels lower than pit latrine, it is unclear why sampling was possible in this case.
5	1.722	1.5	Yes	No	1.1	
8	1.362	1.5	No/Low Infiltration	Yes	35	Challenging environment model household showing low infiltration due to both HGW and clay composition.
9	1.174	1.5	No/Low Infiltration	Yes	34	
10	1.86	1.5	Yes	Yes	6.55	HH10 has less clay and silt soil content than HHs 11,13,14,15,16.
11	1.86	1.5	Yes	No	19.5	HH11 has a similar soil composition to HH 13.
13	1.86	1.5	Yes	Yes	18.5	HH13 has high amounts of clay that are predicted to cause low infiltration. Very similar composition to HH 11.
14	1.562	1.5	Yes	No	44	HH14 shows the highest amount of clay yet no sampling was possible. The soil composition at point A and/or B could be much more sandy allowing infiltration. However, this case is intriguing.
15	1.86	1.5	Yes	No	9.6	
16	1.86	1.5	Yes	Yes	13	HH 16 has higher amounts of clay that could result in low infiltration. It has less clay content than HH 11.
17	1.86	1.5	Yes	No	4.9	

Figure 27. ***Comparison of groundwater level to pit latrine height while considering soil composition***

7.3.2 PIT GAUGE (LEVEL OF WASTEWATER IN LATRINE PIT - POINT A)

Measurement of the inner and outer pit gauge were completed during field observations. However, only households 15 and 16 had continuous recording for at least 4 rounds. By round 6, many households (HH 1, 2, 3, 8, 9, 11, 13, and 17) had a broken pit gauge.

Figure 28 plots the height of the liquid wastewater in the latrine pits of households 15 and 16 and compares that to the maximum height of liquid that can be reached in the latrine pits in a 3 ring pit. The ASU system does not truly operate unless the maximum wastewater liquid level is reached (pit is full). Both households happen to be twin-pit systems with the pit gauge on the second pit in series.

Only 2 household members were continuously using the toilet in household 15 and the liquid wastewater level measured in the latrine pit was almost constant throughout all rounds. No samples were collected at point B or C for any round at household 15. Since the pit latrine was rarely full, then the ASU system seems to have barely been used throughout the 1-year testing period. Infiltration rates at the pit latrine are thought to be almost equal to the toilet flush usage in this case.

Household 16 on the other hand had samples collected at point B and C in rounds 5 and 6. Results from the field however report that the liquid wastewater height in the pit latrine fluctuated overtime without reaching the maximum. Therefore, there is some infiltration from the latrine pit but it is likely to be less than the flushing volume coming in. Also, since samples were collected, the wastewater liquid level must have reached the maximum level at times. It is interesting to note that the samples were only collected in round 5 and 6 in the leach field which is the start of the rainy season.

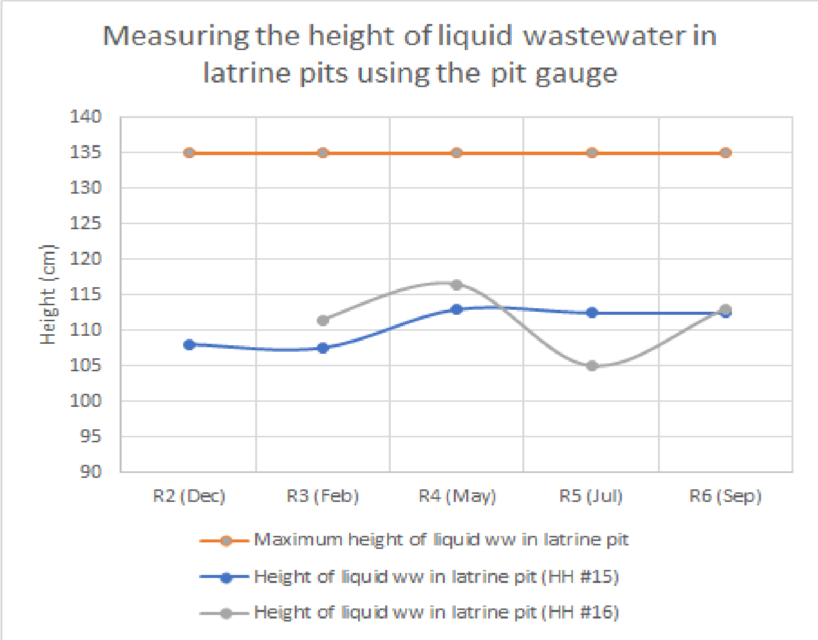


Figure 28. ***Measuring the height of liquid wastewater in latrine pits using the pit gauge***

7.3.3 <u>Comparison of user responses before and after ASU installation</u>

Prior to the ASU installation and according to the users' responses, overflow, bad smell, and hard to flush were recorded as the most common events occuring when the pit gets full as shown in **Figure 29 (a)**. The results revealed that the frequency of such undesirable events decreased drastically once the ASU system was installed. Based on the users' responses, the ASU product eliminated bad smell, reduced overflow, and improved ease in flushing.

In particular, difficulty in flushing was identified as the most common concern among the rural households. **Figure 29** (**b**) showed that the number of households that experienced difficulty in flushing decreased and that the ease in flushing increased after ASU installation. After the ASU was installed, 12 households experienced ease in flushing and no household experienced difficulty flushing. Therefore, the ASU product seems to have improved the overall user experience and toilet functionality. However, reports of not having issues with latrine functionality (i.e. lack of difficulty in flushing) cannot be completely attributable to the ASU system alone because (1) it was difficult to assess with certainty if and when the ASU system was working as pit gauges in the field were commonly broken and sample collection at point B and C were very inconsistent, and (2) during installation a depth of 1 ring (0.5 m) was emptied from the latrine pits.

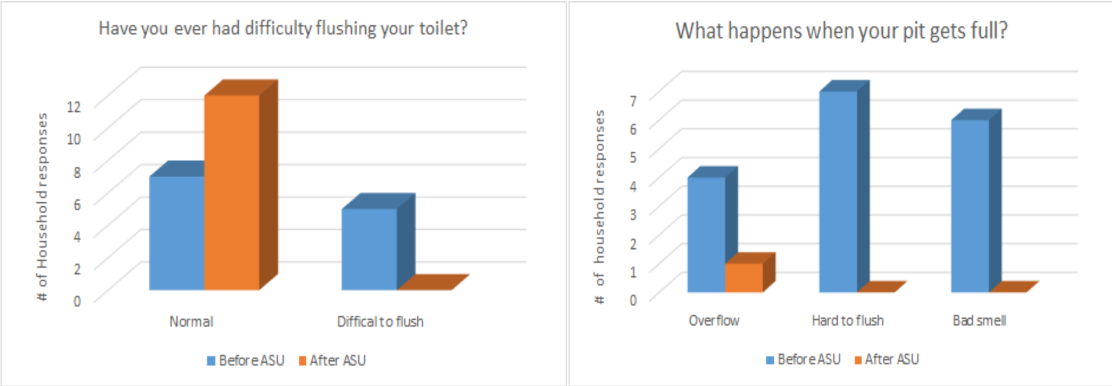


Figure 29. ***(a) key problems when the pit gets full; (b) experience of difficulty to flush the latrine.***

Figure 30 shows the identified advantage and disadvantage of the ASU system by the users. The majority of responses mentioned that ASU benefits in increased pit capacity (thus reducing the frequency of pit emptying), easier flushing, and eliminating bad smell. Other less commonly identified advantages are pit gauge monitoring and environmental protection. Some of the disadvantages identified were bad smell coming from the pit gauge, disliking the standpipes used for monitoring, and the need for a large space to install the product. However, only one response in each concern mentioned those main disadvantages and standpipes would not be part of the product in the future. Overall, more households identified advantages than disadvantages. Therefore, the ASU system seems to have been an effective product in solving some of the common latrine issues that households were facing in rural areas.

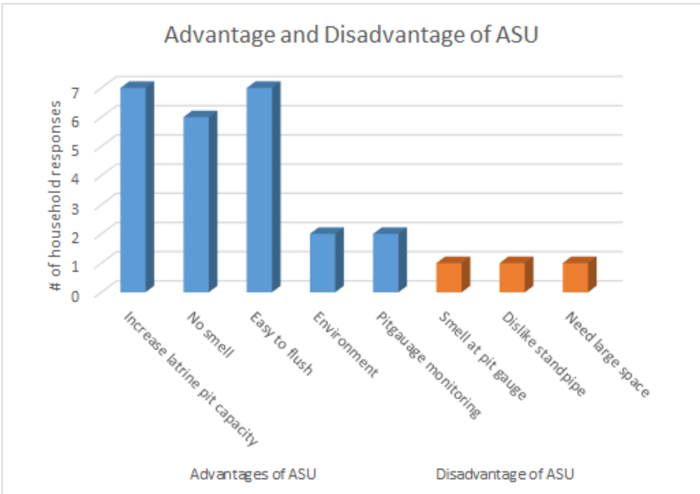


Figure 30. ***The advantage of disadvantage of ASU from user experience***

7.3.4 <u>General Findings from User Survey</u>

Product satisfaction: The households who had the ASU system were overall satisfied or very satisfied with the product, only one household was neutral about it. The responses however could have some bias, as the question was asked by iDE, the organization that installed the product.

Pit emptying: There were 2 households who emptied their pits during the one-year period of the ASU testing experiment. The reasons behind why pit emptying occurred after ASU installation were related to behavior change issues:

- Household 11 emptied the latrine pit as they were expecting a lot of visitors to attend their households and did not want to take the risk of the pit latrine filling up.
- Household 1 had a twin pit latrine installed in an area which experienced flooding during the rainy season. The ASU system failed (bad smell and difficulty flushing) because the lid of the first latrine pit in the system was opened by the households allowing the flood water to quickly seep into the system. The household in response emptied the pit by opening the pit lid, an unsafe disposal.

Concerns Around ASU: All households seem to want to continue using the ASU product even after the one year testing period is completed. However, 3 households had concerns that their latrine pit will fill up in the future even with the ASU system.

Flush Water Volume: The average volume of water used to flush toilets in the field was 3.8L per flush, slightly below the 4.4L per flush design assumption.

Flooding: We cannot evaluate how the ASU functions in significantly flooded conditions as only 1 of the households in the sample experienced such an event.

Other notes: With a limited sample size and only a few household responses, the findings hint that latrine pits tend to become full in the rainy season instead of the dry season and that high groundwater affects a localized area such as a small neighborhood rather than isolated cases.
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7.3.5 ASU MARKETABILITY

Only a few neighbors had opinions on the ASU product. Those opinions were: (1) Interested in ASU if it was affordable and worked properly; (2) Don't know enough information to have an opinion about it; (3) Not interested as neighbor hadn't heard of it; (4) It seemed expensive; (5) prefer having latrine pits with many rings. Overall, the majority of households said they would recommend the ASU product to their neighbors.

The willingness to pay ranged between $30 to $200 and was at an average of $78.

All households had not seen anything similar to the ASU system before. This could be a challenge for the initial scalability of the product.

7.4 SUMMARY OF RESULTS & ANALYSIS

The lab testing of liquid wastewater at point A did not provide much insights on the overall effectiveness of the ASU system. However, BOD, TSS, and E. coli concentrations were typically lower than the baseline concentrations and recommended concentrations of raw wastewater, and so the ASU system did have a positive effect in reducing those parameters in the latrine pit.

Since sampling at point A, B, and C for all rounds was only possible at household #8, the lab results from household #8 were the ones used to evaluate the treatment effectiveness of the ASU system. The ASU treatment system was most effective at reducing BOD concentrations, allowing safer discharge into the open environment, limiting dense growth of unwanted plant life in nearby water bodies (i.e. eutrophication), and reducing local public health impacts. The ASU treatment system was able to reduce TSS content but not effectively, the effluent could still contain higher than standard concentrations in bacteria, nutrients, chemicals, and/or metals in the effluent. The ASU treatment system was the least effective in E. coli removal however it showed some capacity to reduce E. coli between point A and C. It is difficult to make general conclusions based on household #8 alone, however the data does prove that the ASU system can reduce BOD, TSS, and E. coli concentrations making it a safer choice than discharging raw wastewater from pit piercing or pit overflow.

Based on the soil testing results, the ASU system showed some capacity in reducing the fecal coliform content in the soil. Reaching safer levels of fecal coliform in the soil is assumed to be mainly caused by the end of direct raw wastewater discharge from the latrine pit and safe effluent disposal in the leach field.

The lack of samples at point B and C prompted investigation from the research team. High clay content in the soil and/or groundwater levels that are higher than the latrine pit bottom are the main design criteria for ASU's operation. These two factors translate into low infiltration rates, resulting in latrine pits that are likely to fill quickly. The combination of these two criteria appears to guarantee an appropriate context for the ASU's designed functionality. This was shown by the ability to collect wastewater samples from multiple points in household 8 and 9. However the exception of household 14 indicates that other factors may affect the functionality of the ASU system. Since the ASU system does not truly operate unless the maximum wastewater liquid level is reached in the latrine pit (latrine pit is full), infiltration rates at most households are thought to be higher than expected. With fluctuations in groundwater levels and/or increased toilet usage, the ASU system at these households works intermittently throughout the year.

According to the households' users, the ASU product was able to effectively reduce latrine pit overflow occurrences and improve ease of flushing. However, this success cannot be only attributed to the ASU system as (a) the impact of emptying one ring of the latrine pit during installation was not take into consideration, and (b) it is unclear how often the ASU system was actually functioning as the pit gauges were often broken and sampling at the filter pit and leach field was rare. Nevertheless, the overall results show that the ASU product provided continuous functionality of the toilet throughout the one-year testing period despite seasonal changes. This also demonstrates that ASU can significantly increase the pit capacity and reduce the latrine pit emptying frequency. Users claimed more product advantages than disadvantages, were satisfied by the product, and would likely recommend it to their neighbors. However, there was a common concern regarding the latrine pit filling up again in the future. The users were willing to pay between 20-200 $, on average $78.

8 RECOMMENDATIONS

Treatment Effectiveness

- The fact that very few effluent samples at the leach field were collected (13 samples of 84 total collection attempts) is most likely due to the standpipe installation with the bottom of the pipe open at the bottom of the gravel layer of the leach field. This limited the possibility for a rigorous data set and analysis to evaluate the treatment of fecal matter in the ASU effluent to prevent groundwater contamination.
    - To further investigate the effectiveness of ASU in meeting E. coli, BOD, and TSS standard effluent concentrations, it is recommended to think of alternative ways for collecting samples at the filter pit and leach field without interfering with the ASU system functionality.
    - Lab results from household #8 did indicate that the ASU system can reduce BOD, TSS, and E. coli concentrations making it a safer choice than discharging raw wastewater from pit piercing or pit overflow. Therefore, another approach would be to consider the ASU system as a harm reduction technology that has the potential to reduce groundwater contamination but more importantly prevent households from pit piercing and overflowing their latrines limiting their exposure to raw wastewater.
- Since E. coli concentrations in ASU effluent do not seem to meet the standards, it is recommended to re-assess the use of gravel as the filtration media for primary and secondary treatment in the ASU system.
- Assessing the impact of the ASU system in comparison to the Easy latrine on groundwater contamination in HGW environments is very difficult and not feasible. It is recommended that this metric is not used to assess the benefits of the ASU system in HGW areas.
- Since high groundwater levels can create anaerobic conditions that limit leaching of liquids into the soil and reduce the effectiveness of pathogen removal, in the next design iteration it is recommended to focus on increasing the system’s capacity for aerobic treatment within the top unsaturated layer of the soil in HGW areas.

Functionality

- For this pilot test, even though almost all households reported not having issues with latrine functionality (i.e. lack of difficulty in flushing), that could not be completely attributable to the ASU system alone.
    - It was difficult to assess with certainty if and when the ASU system was working as pit gauges in the field were commonly broken and sample collection at point B and C were very inconsistent. To assess ASU's functionality (i.e. water traveling from latrine pit to gravel pit and discharging into the leach field), it is recommended to observe a combination of characteristics simultaneously: A full latrine pit (maximum pit gauge indication), liquid level surpassing the gravel layer at the gravel pit as it is sealed pit (i.e. possibility to collect a sample at point B), and households being able to flush their toilet normally (data from household survey).
    - Emptying a depth of 1 ring (0.5 m) from the latrine pits during installation of ASU was not taken into account on how it could affect latrine functionality. It is recommended to observe what was emptied in latrine pits. Two scenarios should be considered: (1) if the volume emptied was only liquid then the improved functionality of the toilet can be attributed to the ASU system alone; (2) if the volume emptied had some or was mostly solid fecal matter then the improved functionality of the toilet cannot be attributed to the ASU system alone.
    - For areas where groundwater levels were lower than the bottom of the pit for most of the year and the soil permeability wasn't too low (i.e. mostly sandy environment), the infiltration rates at the bottom and side of the pit might have been much larger than we assumed resulting in very intermittent flow into the ASU system.
- One of the most beneficial characteristics of the ASU system is that in theory it should drastically decrease the pit emptying and/or pit piercing frequency in environments of low infiltration (i.e. HGW and/or low soil permeability), leading to an extended use of the pit latrine without any functionality issues. However, those characteristics were not well tested in this pilot.
    - For environments characterized by low soil infiltration, it is recommended to attempt to estimate the extended storage capacity of a latrine pit connected to an ASU system in comparison to an Easy latrine. In HGW or low soil permeability environments, the latrine pit capacity in an Easy latrine would be dependent on the liquid level in the pit while the latrine pit capacity in an ASU system would be dependent on the solid fecal sludge layer. For example, using fecal sludge loading rate assumptions, one can estimate how many years it might take for a latrine pit connected to an ASU system to become full with solid fecal sludge.
    - It is also recommended to think of simpler solutions than the ASU product to increase liquid infiltration into the local environment in pit latrines as long as the distance to the nearest drinking water source is more than 2m away in dry

environments and more than 15 m away in saturated environments. For example, add larger gaps between latrine pit rings to allow increased water seepage into the soil and increased soil treatment surface area around the pit.

- A field testing duration of one year was chosen to monitor seasonal variation on the ASU system. A high testing frequency reduces longitudinal variability in results and improves understanding of trends against time and seasonality. However, due to the limitation of sampling collection and survey questionnaire, the pilot study was not able to test the impact of seasonal variation on the ASU system. For this to be accomplished, more planning is required before another round of testing.
- It was not possible to calculate the hydraulic gradient during the pilot study as it was dependent on knowing the water elevations in the leach field (standpipe) and the surrounding groundwater (monitoring well), and the distance between the two. The main challenge was that we were rarely able to observe the water elevation in the leach field standpipe. In order to calculate hydraulic gradient, more planning is required before another round of testing.

Appropriateness

- The appropriateness of the ASU system for HGW challenging environments was not well tested as the households selected did not all seem to meet these criteria. Several sites selected for construction or as controls did not meet criteria and had to be replaced with other sites during construction and baseline sampling phases. Household criteria for this pilot included: issues in latrine functionality (i.e. pit filling up too quickly, latrine overflow/leak, pierced pit), slow soil infiltration rate due to high groundwater (i.e. above bottom of latrine pit) and/or low permeability soil (i.e. clay content at the bottom of latrine pit), and a spacious generally flat area to allow the construction of ASU.
    - If the ASU system or any other SCE technology were to be assessed further, it is recommended that household selection criteria be stricter as the criteria are crucial for the understanding the product's appropriateness, functionality, and effectiveness.
    - A challenging but very useful next step would be to determine how to more simply evaluate qualitatively if a household is living in a slow soil infiltration area (i.e. HGW or clay environment) causing the latrine pit to fill up with water too quickly. Moving forward, it is recommended to continuously collect data related to latrine functionality (filling up too quickly, constant difficulty in flushing, pit overflow, pit piercing, etc.).
    - Flood's impact on ASU was also not tested in this pilot study. It is recommended to further understand from literature the impact of flood on latrine pits and leach fields to predict some of the issues that the ASU product might face in HGW areas that also experience flooding events.
    - Despite not having proof of HGW table, for households that evidently live in high clay soil content environments and experienced issues with their latrine constantly

filling up, it is advised to consider the ASU product or a similar product with a leach field option to increase surface infiltration.

Feasibility of installation, operation, and maintenance

- Installation
    - It is recommended to find ways to reduce the installation cost of the ASU product. For example, simplifying the design and/or construction process. The material and installation cost for ASU is on average: $80-90 for a single pipe or $115-130 for two pipes. Households' willingness to pay spread between $30 and $200 with an average of $78.
    - One of the most common issues for ASU installation is households not having enough space or not wanting so much space from their land taken up by a sanitation system. This limitation must be accounted for moving forward. Regardless of having one or two-pipe set up in the leach field, the area required for the leach field was still considered quite large.
    - At least one ring depth of the existing latrine pit had to be emptied in order to install the ASU system. Emptying caused challenges during the installation process as laborers had to dig extra holes for sludge and/or carry fecal sludge across the property. This limitation must be taken into consideration as emptying might be very challenging in some cases.
    - The ASU system installation was labor intensive. On average it required 3 laborers working for 4 hours to complete the installation. Additional laborers might be preferred for a quicker installation.
    - Clay environments created significant delays to ASU installation increasing labor hours and cost. However, ASU's functionality seems to be more appropriate in clay environments posing a dilemma for meeting household criteria and reducing cost.
    - It is recommended to investigate the accessibility of rice husks to LBOs. It might not be feasible for a LBO to buy this material if it is too far from their property. Also, rice husks stock is available only after harvesting seasons which might be different for some provinces.
    - Improved transportation arrangements should be investigated, such as placing the rings on top of the rice husks, may help protect the concrete while driving long distances over bumpy roads. Also, the large quantity of gravel needed for construction posed a challenge for transportation and labor installation (i.e. carrying gravel from truck to construction site).
    - It was difficult to enforce laborers to wait enough time (more than 15 minutes) for the concrete and mortar to dry before adding the gravel into the filter pit. This might have caused breaks in the seal causing liquid to seep out from the filter pit and not reaching the leach field. Further discussion is required to evaluate the

consequences of not properly sealing the filter pit on the functionality of the ASU system.

- It was difficult to enforce laborers to clean the gravel before adding it into the fiter pit and leach field. Therefore, understanding from literature the importance of cleaning gravel on treatment efficiency would be beneficial.
- The laborers had difficulty measuring the slope of the leach field during installation. Therefore, a level tool is recommended to provide ease and accuracy in creating the correct slope for the pipes in the leach field.
- Account for some increase in installation cost due to one or all of the following reasons: (1) the volume of one ring of the pit latrine is expected to be emptied prior to installation; (2) in clay environment, a larger time is spent excavating; (3) more planning around transporting and gathering materials for construction might be required; (4) delays in excavation due to water seepage from recent rainfall or HGW; (5) slope constructability of the leach field was observed to be a challenging task for most laborers.

- <u>Operation</u>
  - Overall, the operation of the ASU product at the household level was as simple as an easy latrine. Maintaining this simplicity in operation moving forward is ideal.
  - Ensure that all latrine pits's lids, single and twin pits, are sealed to avoid large quantities of water seeping into the system during flooding. For pit lids that had been opened before and haven't been re-sealed (e.g. twin pit in HH#1), large quantities of flood or rain water could seep into the ASU system halting its operation.
  - One household (HH#4-round 2) had an issue with the ASU's operation as there was no flow detected from the latrine pit to leach field. As a result, the filter pit was opened and the pressure was released and regulated allowing the latrine pit wastewater to start flowing. It is still not completely clear why this particular household had issues with the liquid flow in the system but a ventilation pipe could solve any future issue related to that.
  - Consider putting a mesh on the t-junction entering the filter pit as scum had blocked the pipe for HH#3.
- According to the design calculations, the leach field size requirements are 4 m^2 for clay and 2 m^2 for sand. The pilot study selected households living in environments with different types of soil to assess the potential for cost savings using a smaller system. However, the results from the pilot study were not enough to test or prove the cost effectiveness of one pipe in comparison to two pipes. More information should have been collected to compare the one-pipe and two-pipe systems.

- <u>Maintenance</u>
    - Maintenance was not tested or taken much into account in this pilot test. The more complicated the design, the harder it is to problem solve when there is an issue. Therefore, it is crucial to have ideas of what could go wrong in the ASU system, how to diagnose those issues when the time comes, and if and how these issues can be resolved to ensure the ASU continues to operate correctly. For example, is clogging of the pipe in the leach field inevitable? if so, how can that be detected easily? how costly would it be to unclog the pipe?
    - It is recommended to investigate how to improve the durability of pit gauges as they would be a key tool in assessing and monitoring the operation of the ASU system. The ball at the bottom of the pit gauge seems to be the one failing most commonly. ASU only operates when the liquid level in the latrine pit reaches the maximum capacity of the pit which can be indicated by the pit gauge.
    - For future maintenance problem solving, the pit gauge design should be considered to have a function for measuring both liquid and sludge level in the pit latrine. For the ASU system and any other iDE sanitation products, assessing when and if the latrine pit is full of water or solid fecal sludge would allow the household to make a well informed decision (e.g. wait for water level to recede, empty pit, install a new latrine pit).

Behavior change

- Ensure that households are well aware about pit gauge functionality especially within the ASU system. Conventionally, having a "full" pit latrine or a pit gauge indicating a red color means that the toilet will stop flushing or functioning properly as designed. On the contrary, only when the pit latrine is full and the pit gauge is indicating red does the ASU system start working as designed. Households might get confused thinking that a full latrine is indicative that the ASU system is in fact not working.
- Some households built local animal shelters and/or added new soil on top of the ASU system during the pilot duration which interfered with soil sampling. Also, as the ASU system does take up a large area, it is predicted that households might want to use up that space by building something on top of it. This behavior should be taken into consideration as it makes it much harder to access the ASU product in case maintenance is required.
- When considering marketability and initial scalability of the product, it should be taken into consideration that all households during the pilot reported not seeing any products similar to the ASU in their lifetime.

Testing & Sampling Learnings

- Quality checks of laboratories are recommended using duplicates and triplicate samples so that the data can be trusted. In order to compare the lab reliability, the household selection for duplicate samples should be the household which has high concentration of BOD/TSS/E.coli to minimise the testing error from laboratory.
- During the sampling process, steps must be taken to make sure that samples are intact and well preserved before reaching the lab. This can be carried out by filling the samples bottles at the same time, maintaining the temperature by placing the samples in the icebox, and keeping the samples in a sterilized environment during transportation.
- Measuring pH, DO (dissolved oxygen), and temperature could be helpful parameters to interpret the changes in concentrations of BOD and E. coli. Assuming it would be cheap and easy to do, it is advised to record pH, DO, and temperature in the field using in-situ instruments when taking samples.
- The testing method, testing standard, volume of sample, sampling bottle, and sample preservation might need to be reviewed to ensure that is the most consistent sample collection process.
- Sampling methods of E. coli or other sensitive parameters should be improved to ensure that samples are not contaminated or destroyed by sunlight or any activities due to the sampling process taking time about 30-45min per one liquid bottle.
- The sampling bottle’s cap should be protected by covering with parafilm to ensure that it is not leaking during transportation.

9 APPENDIX I – OVERVIEW OF SITES

1. Map of ASU Study Area
2. Overview of Site 1 to site 20 in S'ang and Angk Snuol districts

10 APPENDIX II – ADDITIONAL RESOURCES

3. All Seasons Upgrade Construction Guidance Folder
4. Sampling Operation Procedure
5. Product Drawing Plan Folder
6. Household Selection Criteria Sheet
7. Household Selection Information
8. Technical Brief of Soils Evaluation for On-Site Wastewater System Design
9. Sampling Form
10. Sampling Round Preparation Checklist
11. Household Questionnaire Survey
12. All Seasons Upgrade Cost Calculation
13. Meeting Minutes
14. Design Criteria
15. Concept Design Specification
16. Consideration for Design of Leach Field Component
17. The preferred option for underground discharge
18. Small and Full scale prototype note
19. Small scale prototyping - Photos and videos
20. Full-scale prototyping - Testing Procedures
21. Full-scale prototyping - Photos and video
22. ASU Project Budget

11 APPENDIX III - LABORATORY RESULTS

1. Results from Laboratory for all Liquid and Soil Samples
2. All Graph Results Analysis