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MCSP Bangladesh Water, Sanitation and Hygiene Study

Investigating the Effectiveness of Earthen Barriers to Mitigate the Leaching of Pathogens from Pit Latrines in Coastal Bangladesh

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Abbreviations

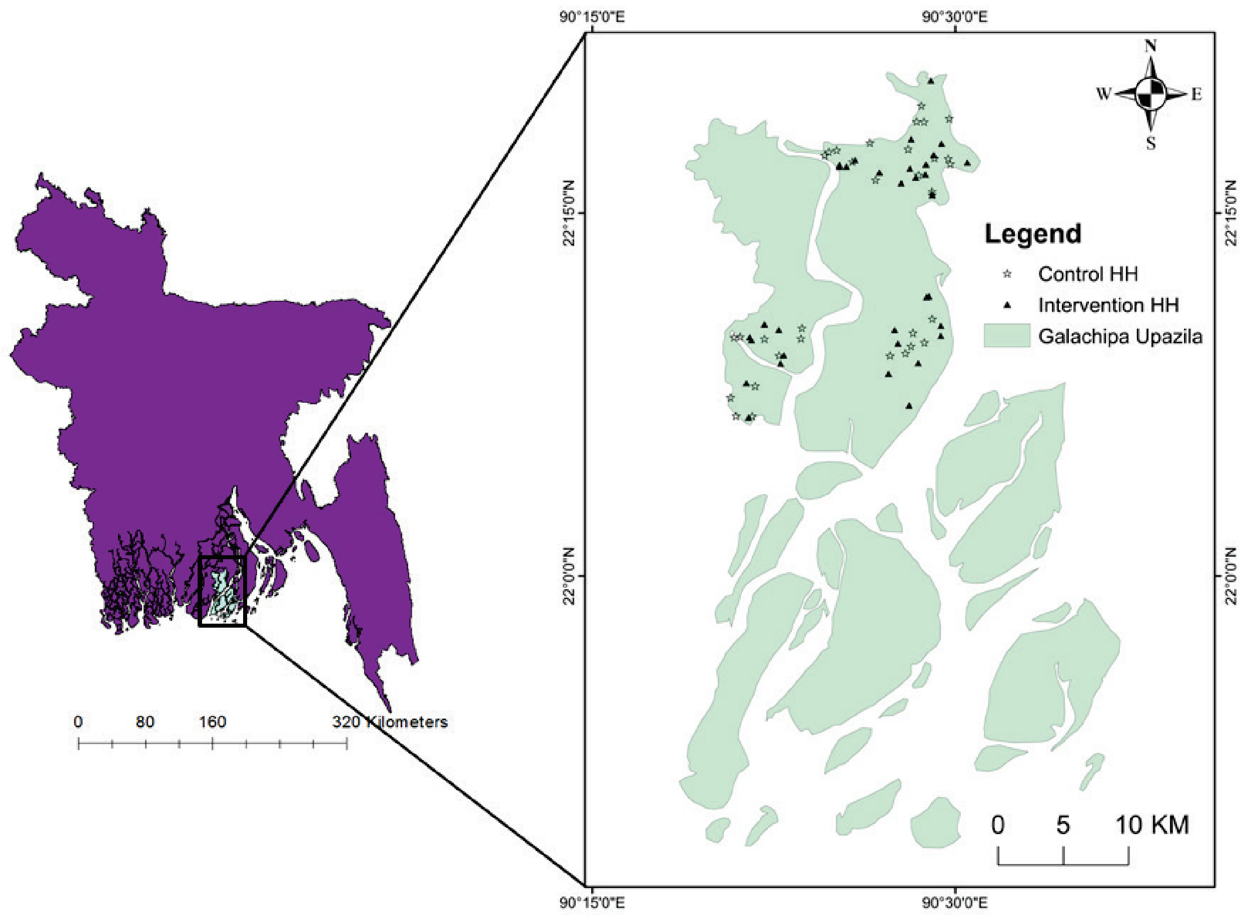
C/N	carbon-nitrogen
FRA	field research assistant
icddr,b	International Centre for Diarrhoeal Disease Research, Bangladesh
MPN	most probable number
PVC	polyvinyl chloride

Background

Improved sanitation is the primary barrier to prevent fecal contamination from entering the environment. Pit latrines are one of the most commonly used human excreta disposal systems in low-income countries due to their low cost and availability.[1] Globally, an estimated 1.8 billion people use pit latrines as the primary means of sanitation,[2] and construction of pit latrines is increasing as countries strive to meet the sanitation-related Sustainable Development Goal.[3] Pit latrines are the most common latrine technology in rural Bangladesh and are often installed in such a way that untreated effluent can directly contaminate surrounding aquifers.

The study team conducted a double-arm randomized controlled trial to determine the effectiveness of a 50 cm sand barrier around and below pit latrines to treat effluent and prevent pathogens from reaching the surrounding groundwater. The study took place in Galachipa Upazila (subdistrict) of Patuakhali district of Bangladesh (see Figure 1).

Figure 1. Study sites (HH=household)



[1] Cairncross S, Bartram J, Cumming O, Brocklehurt C. 2010. Hygiene, sanitation, and water: what needs to be done? *PLoS Med*. 7(11): e1000365. doi: 10.1371/journal.pmed.1000365.
[2] Graham JP, Polizzotto ML. 2013. Pit latrines and their impacts on groundwater quality: a systematic review. *Environ Health Perspect.* 121(5):521–30. doi: 10.1289/ehp.1206028.
[3] Jain N. 2011. *Getting Africa to Meet the Sanitation MDG: Lessons from Rwanda*. Washington, DC: Water and Sanitation Program

The static level of the groundwater table is variable in Galachipa depending on rainfall and tidal patterns. Data from the Bangladesh Water Development Board suggest that the groundwater in Galachipa typically is very shallow, under 2m deep, and fluctuates by 1 m between the dry and wet season (from a personal communication with the Bangladesh Water Development Board). A total 68 latrines were installed (34 with sand barrier and 34 without) using locally available sand that met the design criteria for intermittent sand filters recommended by the US Environmental Protection Agency (effective grain size 0.25–0.75 mm with a uniformity coefficient < 4.0). Four monitoring wells (6 m long) were constructed at each site, and monthly follow-up visit groundwater samples were collected and tested to enumerate *E. coli* and fecal coliforms using the IDEXX method.

The International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) received a research grant from FHI360 under the WASHplus project. The study team monitored the pits for bacterial leaching into the groundwater for an initial 6 months, from December 2015 to May 2016. In total, there were 6 months of sample measurements, including baseline from December 2015 to May 2016. These measurements included testing of *E. coli* and fecal coliforms in surrounding groundwater collected through monitoring wells, depth of groundwater table, and depth of latrine pit contents. The team also received additional funding from the Swedish International Development Cooperation Agency to explore the effectiveness of the sand barrier under saturated soil conditions. The team conducted intermittent follow-ups during the 12th (December 2016), 15th (February 2017), 18th (June 2017), and 24th (December 2017) month of latrine installation. The findings enabled the study team to evaluate the effectiveness of sand barriers in reducing fecal pathogen leaching during different seasons of the year.

While pathogen leaching from pit latrines into surrounding aquifers is a concern, the study team was also interested in collecting data on the sustainability of pit latrines with the sand barriers considering programmatic aspects. The team wanted to answer the question "Does the sand barrier accelerate or slow down the process of pit fill-up?" There are a couple of factors that may accelerate pits filling up among latrines with a sand barrier compared to those without a barrier. The contents of pit latrines with a sand barrier undergo more aerobic decomposition, as the surrounding and bottom sand layer is more porous than soil.[4] Aerobic decomposition does not reduce sludge volume as anaerobic decomposition does. Therefore, the presence of a sand barrier may accelerate the pit-filling process. One of the important biological mechanisms that prevents pathogen leaching is the biomat formation on the surface of the effluent and sand barrier. Air in the sand barrier and nutrients from effluents favor bacterial growth and biomat formation. Often, the biomat layer becomes thick and may cause clogging of the system, leading to early system failure. Such system failure would be a threat to scale-up of sand barriers, even if it is effective in preventing pathogen leaching. Therefore, it was important to collect data on timing of pit fill-up for the intervention and control latrines.

Two types of decomposition of pit contents occur under normal circumstances: aerobic and anaerobic decomposition. Aerobic decomposition occurs close to the surface of the pit, where contents make contact with air. Anaerobic decomposition occurs in the remaining parts of the pit. Aerobic decomposition is faster than anaerobic decomposition and more efficiently kills pathogens as it generates more heat. During the decomposition process, pathogens, except helminths, die off; sludge volume decreases; and the chemical and biological properties of the sludge change. The study team hypothesizes that installing a sand barrier may favor more aerobic decomposition compared to a latrine without a sand barrier due to more air within the sand. In rural Bangladesh, filled pits are often emptied manually using buckets and ropes without safety precautions.[5] Often, pit contents are immediately emptied for latrine reuse and do not remain within the pit for several months for adequate decomposition due to space constraints. The untreated contents are dumped in waterways or on unused land, posing a great threat to water and soil contamination.[5] It is important to know whether installing a sand barrier may alter the decomposition processes of the pit contents. Ideally, high

[4] McEwen JB. 1998. *Treatment Process Selection for Particle Removal*. Denver, Colorado: American Water Works Association.
[5] Balasubramanya S, Evans B, Ahmed R, et al. 2016. Pump it up: making single-pit emptying safer in rural Bangladesh. *Journal of Water Sanitation and Hygiene for Development*. 6(3):456–54. doi: 10.2166/washdev.2016.049.

temperature is suggestive of aerobic decomposition, high pH is recommended for pathogen killing, and low moisture and high carbon-nitrogen (C/N) ratio are suggestive of more decomposition.[6]

The study team received a follow-up grant from the United States Agency for International Development and conducted two more follow-up measurements during June 2017 (18th month) and December 2017 (24th month). Similar to previous rounds, the team collected and tested groundwater samples for fecal indicator bacteria. The sludge samples from the study pits were tested for soil-transmitted helminth ova, pH, temperature, moisture percentage, and C/N ratio. Finally, the team compiled all follow-up results to illustrate the overall effectiveness of the sand enveloped latrines in coastal Bangladesh.

[6] Mehl J, Kaiser J, Hurtado D, Gibson DA, Izurieta R, Mihelcic JR. 2011. *J Water Health*. 9(1):187–99. doi: 10.2166/wh.2010.138.

Methods

Enrollment and Randomization

Sixty-eight eligible households were selected in Galachipa where WASHplus[7] subsidized latrine construction for extremely poor households identified as "hardcore poor[8]" on government social inventories. Many of these households had an existing unimproved latrine or shared pit latrines with neighbors. Eligibility criteria of the households were: four to 10 household members (to ensure standard loading rates in pit), space for new pit latrines to be constructed at least 5 m from existing unimproved latrines, and the land donated by the household for pit latrine construction was not adjacent to surface water bodies.

A statistician generated a unique household ID along with block randomization and prepared sealed envelopes coded for a latrine with a sand barrier and without a sand barrier. Block randomization was chosen to ensure equal number of latrines with and without a sand barrier among the geographically clustered households to minimize confounding from local geological factors and to ensure an equal number of latrines with and without a sand barrier in case construction crews had to stop installing latrines due to flooding and heavy rainfall during the wet season. The block number was written on top of the envelope, and the unique household ID and code for the study arm were placed inside the envelope to be chosen by the household head. The statistician shared the household randomization assignment with construction crews for installation of latrines as per the randomization schedule.

Latrine, Sand Barrier, and Monitoring Well Construction

The study team selected three local contractors to construct the latrines, sand barriers, and monitoring wells, and closely supervised their work to conform with specifications (see Supplemental Material 1). For all study latrines, contractors used five concrete liner rings for the pit (see Figure 2). The average cost of the latrines without sand barrier was approximately USD 100 (see Table 1), and incorporating the barrier increased the cost by an additional USD 25 (price of 10 cubic feet of sand and carrying cost).

[7] A multiyear project (2010–2016) funded through the US Agency for international Development's Bureau for Global Health and implemented by FHI 360 (lead implementer), CARE, and Winrock International to support healthy households and communities by creating and delivering interventions that lead to improvements in water, sanitation, and hygiene, and household air pollution. See https://www.fhi360.org/projects/washplus.

[8] Those who experience the deepest deprivations and are the least likely to be able to overcome their poverty and/or give their children childhoods that will allow them to escape from poverty (see http://research.brac.net/publications/hulme_matin_pdf.pdf).

Figure 2. Schematic longitudinal view of the intervention latrine

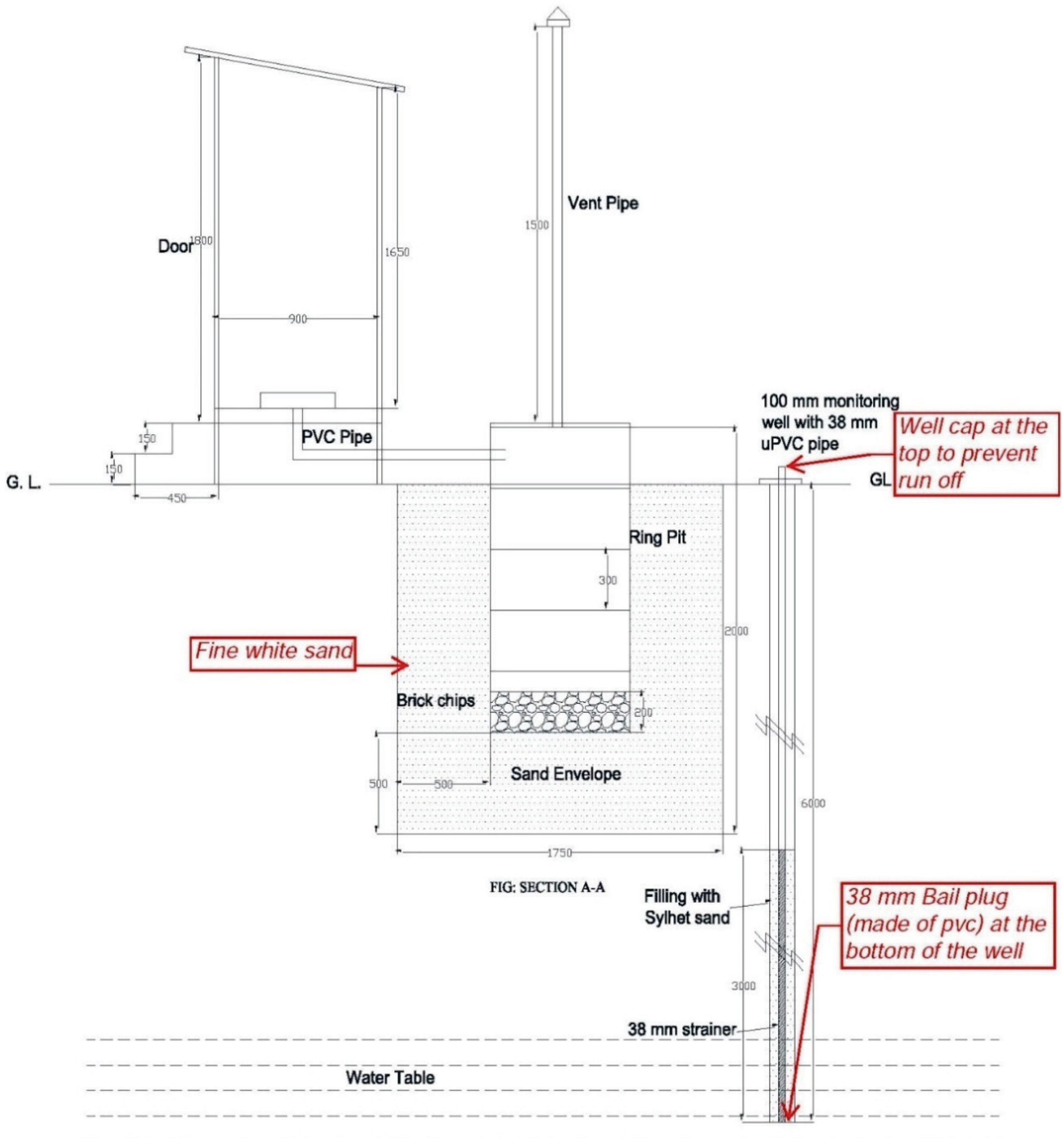


Table 1. Detailed latrine installation cost (without sand barrier)

Addressing Water, Sanitation, and Hygiene in Southwestern Bangladesh

Bill of Quantity

Latrine model: single offset pit latrine with sand envelopment

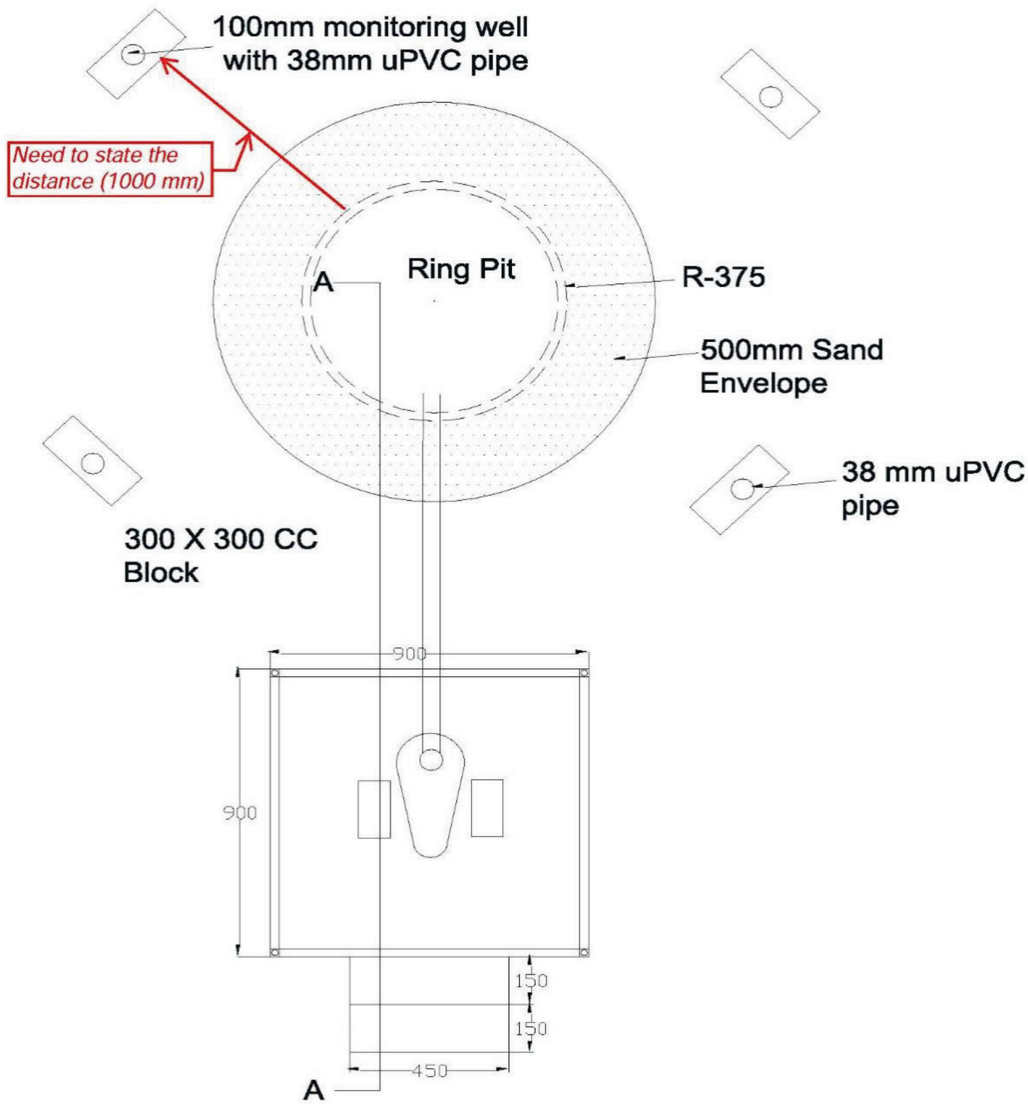
SN	Particulars	Specification	Unit	Quantity	Unit Rate (BDT)	Total cost (BDT)
1	Reinforced cement concrete ring	Supplying of locally available, best-quality 30-inch diameter reinforced cement concrete ring as per direction of project engineer	Numbers	5	270	1,350
2	Reinforced cement concrete slab with polyvinyl chloride pan	Supplying of locally available, best-quality 36-inch by 36-inch reinforced cement concrete slab with polyvinyl chloride pan as per direction of project engineer	Numbers	1	400	400
3	Reinforced cement concrete slab	Supplying of locally available, best-quality 36-inch diameter reinforced cement concrete slab as per direction of project engineer	Numbers	1	350	350
4	Local/filling sand	Supplying of local sand for sand envelopment of the ring	Cubic feet	70	8	560
5	Polyvinyl chloride pipe (vent pipe)	Supplying of locally available, best-quality 2-inch diameter polyvinyl chloride pipe as per direction of project engineer	Running feet	6	25	150
6	Polyvinyl chloride cowl	Supplying of locally available, best-quality 2-inch diameter polyvinyl chloride cowl as per direction of project engineer	Numbers	1	40	40
7	Wooden pillar/khuti	Supplying of locally available 3-by-2-inch wooden pillar/khuti (8 feet in length) as per direction of project engineer (including carrying cost)	Numbers	4	150	600
8	Wooden frame for door and roof	Supplying of locally available wooden frame as per direction of project engineer (including carrying cost)	Lump sum	1	700	700
9	Fittings and fixtures (4-inch diameter polyvinyl chloride pipe, hinges, galvanized iron wire, nut, bolt, etc.)	Supplying of locally available fittings and fixtures as per direction of project engineer	Lump sum	1	500	500

SN	Particulars	Specification	Unit	Quantity	Unit Rate (BDT)	Total cost (BDT)
10	Corrugated galvanized iron sheet for fencing, roof, and door	Supplying of locally available 0.12 mm corrugated galvanized iron sheets as per direction of project engineer	Bundle	0.75	3,400	2,550
11	Carrying cost	Materials carrying from market to individual household level	Lump sum	1	600	600
12	Signboard	Supplying of signboard according to the prescribed design of WASHplus	Numbers	1	400	400
Subtotal cost						8,200
Including 5.5% VAT						451
Total cost						8,651[9]
In word: Eight thousand six hundred and fifty-one taka						

The study team placed four monitoring wells at even intervals around the pit at a distance of 1m from the outside of the top ring (see Figure 3). All monitoring wells were 6 m deep—the top 3 m comprised a polyvinyl chloride (PVC) casing, and the bottom 3 m included a screen for accumulation of groundwater from the surrounding soil layers. The bottom end was sealed with a PVC cover to prevent turbidity of the well water.

[9] USD conversion rate = 82 BDT, so the total cost for latrines without sand barrier was USD 105.50.

Figure 3: Schematic cross-sectional view of the intervention latrine



The top of the monitoring well was encased with a 1 foot by 1 foot concrete pad and capped to firmly secure the well in place and prevent any surface water runoff from leaking (see Supplemental Material 1). For the latrines with a sand barrier, the contractors constructed a 50 cm sand barrier using locally available sand. The study team randomly selected two sand barrier latrines from each of the four unions[10] and collected the sand samples used for sand barrier for sieve analysis at University of Dhaka's Department of Geology laboratory to determine the textural composition of the sand barrier. The team employed community health promoters to ensure hygienic and regular use of the study latrines. The baseline water samples were collected before the latrines were in use.

[10] Union refers to geographical administrative unit in each subdistrict of Bangladesh

A: Empty pit during construction phase, B: Pit with concrete ring during construction phase, C: Constructed pit with four monitoring well

Sample Transport, Process, and Analysis

Upon collection, water samples were immediately poured into sterile Whirl-Pak® bags and transported on ice in an insulated cool box (temperature maintained at 35.6°F to 46.4°F) to a field laboratory for processing. The study team established a field laboratory to process samples within 6 hours of collection. Samples were processed to enumerate the most probable number (MPN) of the fecal indicator bacteria *E. coli* and fecal coliforms using IDEXX Colilert®-18/Quanti-Tray® following a standard methodology (International Organization for Standardization standard 9308-2:2012, US Environmental Protection Agency-approved Standard Methods for Examination of Water and Wastewater). One lab blank was run each day of sample testing. Field blanks were collected once per week per sample collector.

The study team used a 2 m long stainless steel T-shaped scoop for collecting four separate fecal sludge samples 200g each. The collection scoop was inserted through the top layers up to 1 m deep and was pushed toward the pit wall so the sludge entered through the open end. The closed end of the scoop had multiple small holes to discard the excess fluid. The collected samples were placed in an airtight Whirl-Pak bag and transported to the Patuakhali Science and Technology University's Agricultural Chemistry Department laboratory in a cool box maintaining 2–8°C. To estimate the C/N ratio, the organic carbon were determined by wet combustion (Walkley-Black method) technique,[11] and total nitrogen was estimated using the Kjeldahl

[11] Mylavarapu R. 2014. Walkley-Black. In: Crouse KK, Hardy DH, Heckendorn S, et al. 2014. *Soil Test Methods from the Southeastern United States*. Clemson, South Carolina: Clemson University.

method.[12] Moisture content and pH analyses of the sludge samples were carried out using Standard Methods for the Examination of Water and Wastewater.[13] The temperature of the latrine sludge was measured onsite using a compost thermometer from REOTEMP. A sludge sample aliquot was sent to the icddr,b laboratory to microscopically quantify the soil-transmitted helminth eggs. To determine the pit-emptying practices, a small survey was administered during the 18- and 24-month follow-ups.

Data Analysis

The study team replaced the *E. coli* and fecal coliform MPN values with 0.5 (half the of the lower detection limit) where no contamination was detected and then converted the counts into log10MPN for analysis. The team used multilevel mixed effect linear models using two random effects to address clustering at latrine and monitoring well levels to determine the difference in mean log10MPN counts between water samples from intervention (with sand barrier) and control (no sand barrier) latrines.

The team fitted generalized linear model with Poisson family to estimate the average number of helminths in pit contents at different follow-up points since the data distribution was highly skewed. The standard errors were adjusted by the over dispersion and clustering effect to estimate the differences between intervention and control latrines at different times. In case of normally distributed data, generalized linear models with Gaussian family were also applied. The team also investigated effect modification of the impact of the sand barrier on water quality by including an interaction term with season (dry versus wet) in the regression models. Follow-up visits conducted between May and November were considered as wet season visits.[14]
All analysis was conducted in Stata (version13).

[12] Jones, JB. 1991. *Kjeldahl Method for Nitrogen Determination*. Athens, Georgia: MicroMacro Publishing.
[13] Rice EW, Baird RB, Eaton AD, Clesceri LA, eds. 2012. *Standard Methods for the Examination of Water and Wastewater*. 22nd ed. Denver, Colorado: American Water Works Association.
[14] Qureshi AS, Ahmed ZU, Krupnik TJ. 2014. *Groundwater Management in Bangladesh: An Analysis of Problems and Opportunities*. Dhaka, Bangladesh: International Maize and Wheat Improvement Center.

Results

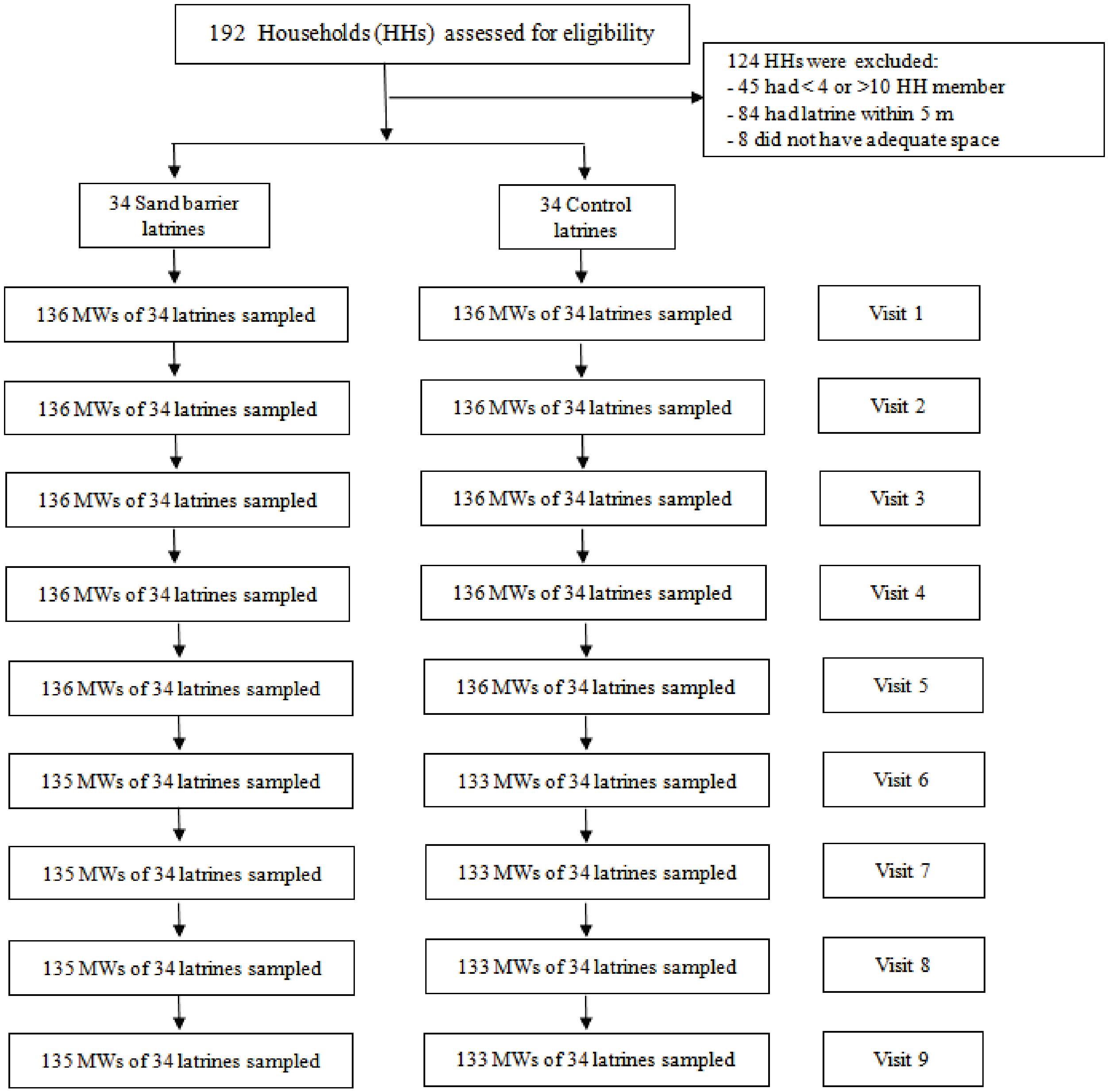
Preintervention Characteristics of Latrines and Trial Profile

Table 2 presents preintervention characteristics of the study population. The mean numbers of people living in the intervention and control households were 5.24 versus 5.18. Seventy-six percent of the intervention households had an existing latrine, compared to 79% among control households. The median nearest distance between the study latrine and an existing latrine was 17.5 m both for intervention and control households. Fifty percent of intervention household and 56% control households had a surface water source within 10 m of the study latrines. The number of water samples collected in each follow-up visit is shown in Figure 4. Four monitoring wells were damaged, and the study team was unable to collect water samples from them in the last four visits.

Table 2. Preintervention characteristics of the intervention and control latrine households

Characteristics	Study Latrines	
	Intervention	Control
Number of people living in compound, mean (SD)	14.32 (12.33)	12.76 (10.00)
Number of people living in household, mean (SD)	5.24 (1.74)	5.18 (1.57)
Number of latrine user, median (interquartile range)	5 (4–6)	5 (4–6)
Proportion of households with an existing latrine, n/N (%)	26/34 (76)	27/34 (79)
Distance from nearest latrine to study latrine in meter, median (interquartile range)	17.5 (10–20)	17.5 (10–25)
Household feces disposal, n/N (%)		
Existing pit latrine	22/34 (65)	18/34 (53)
Surface water	9/34 (26)	13/34 (38)
Open place	3/34 (9)	2/34 (6)
Presence of surface water within 10 m of study latrine, n/N (%)	17/34 (50)	19/34 (56)
Primary source of drinking water of households, n/N (%)		
Deep tube well	22/34 (65)	26/34 (76)
Shallow tube well	11/34 (33)	8/34 (24)

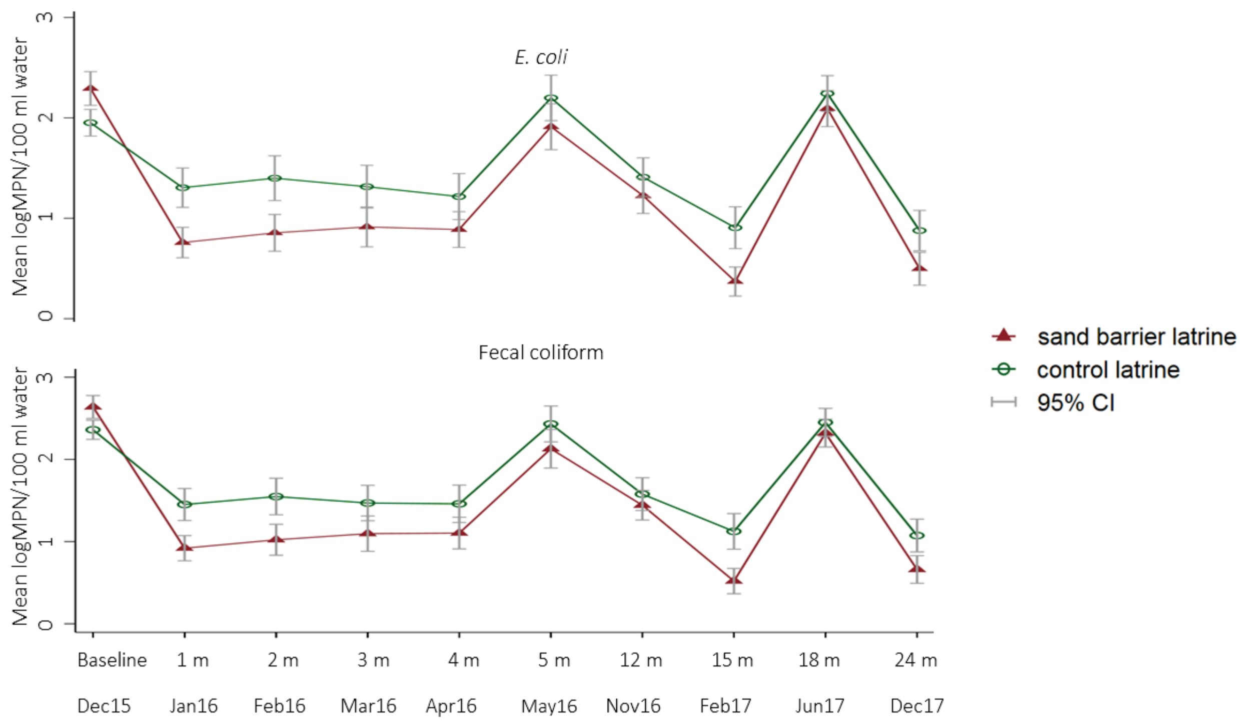
Figure 4. Trial profile and sample collection during each visit



Monitoring Well Fecal Contamination

The latrines were in use after the baseline water sampling was done. The baseline mean log10MPN *E. coli* from intervention and control latrine monitoring wells was 2.3 and 2.0, respectively; the baseline mean log10MPN fecal coliforms was 2.6 and 2.4, respectively (see Figure 5).Thereafter, mean log10MPN *E. coli* and fecal coliforms counts of monitoring well water samples from intervention latrines were consistently lower than *E. coli* and fecal coliforms counts from monitoring wells of control latrines (see Figure 5).

Figure 5. Temporal trend in mean log10MPN fecal coliforms and *E. coli* across the intervention and control latrines during all visits



Compared to control latrine monitoring well water samples, those from intervention latrines had 0.38 (95% CI: 0.16, 0.59; p = 0.001) mean log10MPN reduction in *E. coli* and 0.38 (95% CI: 0.14, 0.62; p = 0.002) mean log10MPN reduction in fecal coliforms/100 ml water, translating to a 27% reduction in *E. coli* and 24% reduction in fecal coliforms in shallow aquifers by the sand barrier.

Helminth Ova in Pit Latrine Sludge

Among soil-transmitted helminth eggs, nonlarvated Ascaris mean count/dry gram was 1,220 (95% CI: 144, 2,295) higher in the intervention pits than the controls; larvated Ascaris was 38 (95% CI: -236,313) mean count/dry gram higher in the intervention sludge samples, though the difference was not statistically significant. The study team detected 122 (95% CI: -13, 257) mean count/dry gram higher nonlarvated Trichuris in the sand barrier latrine pit samples. The larvated Trichuris count was -1 (95% CI: -22, 19) mean count/dry g lower in the sand barrier latrines compared to samples from latrines without sand barrier. Both nonlarvated and larvated Trichuris counts declined by more than 50% at the 24-month follow-up compared to the 18-month measurement (see Table 3).

Table 3. Mean helminth egg counts per dry gram of latrine sludge samples during 18- and 24-month follow-up

Mean log10 helminth count/ wet gram sludge	Follow-up	Mean		Mean difference	95% CI
		Intervention	Control		
Nonlarvated Ascaris lumbricoides	18th month (June 17)	2,451	1,184	1,267	-32, 2,566
	24th month (December 17)	2,988	1,815	1,173	-566, 2,912
	Combined	2,719	1,499	1,220	144, 2,295
Larvated Ascaris lumbricoides	18th month (June 17)	404	194	210	-34, 454
	24th month (December 17)	519	652	-133	-632, 365
	Combined	462	423	38	-236, 313
Nonlarvated Trichuris trichiura	18th month (June 17)	555	339	216	-41, 474
	24th month (December 17)	135	108	27	-60, 114
	Combined	345	223	122	-13, 257
Larvated Trichuris trichiura	18th month (June 17)	56	55	1	-36, 38
	24th month (December 17)	19	23	-4	-19, 12
	Combined	37	39	-1	-22, 19

pH, Moisture Content, Temperature and Carbon-Nitrogen Ratio of the Latrine Sludge

Intervention and control latrines had the same average pH (7.44 versus. 7.44), temperature (97.42°F versus 97.44°F), and percentage of moisture (71.91% versus 71.36%). However, control pits had significantly higher mean C/N ratio (mean difference: 9.16, 95% CI: 0.15, 18.18), particularly during the 24-month follow-up (mean difference: 17.98, 95% CI: 1.23, 34.73) (see Table 4).

Table 4. Average pH, temperature, percentage of moisture content, and carbon/nitrogen ratio of latrine sludge samples during 18- and 24-month follow-up

	Follow-up	Mean		Mean difference	95% CI
		Intervention	Control		
pH	18th month (June 17)	7.41	7.41	0.00	-0.07, 0.07
	24th month (December 17)	7.47	7.48	0.01	-0.17, 0.19
	Combined	7.44	7.44	0.00	-0.09, 0.10
Temperature (°F)	18th month (June 17)	97.96	97.99	0.03	-0.12, 0.18
	24th month (December 17)	96.88	96.96	0.08	-0.08, 0.25
	Combined	97.42	97.48	0.06	-0.05, 0.17
% Moisture content	18th month (June 17)	73.34	71.47	-1.87	-8.27, 4.52
	24th month (December 17)	70.49	71.26	0.77	-6.12, 7.66

	Follow-up	Mean		Mean difference	95% CI
		Intervention	Control		
	Combined	71.91	71.36	-0.55	-5.63, 4.53
C/N ratio	18th month (June 17)	15.17	15.52	0.35	-4.61, 5.31
	24th month (December 17)	11.77	29.75	17.98	1.23, 34.73
	Combined	13.47	22.64	9.16	0.15, 18.18

Pit-Emptying Practices

One latrine pit in the intervention arm was emptied before the 12-month (November 16) follow-up. Of the intervention latrines, nine (n1=34) were emptied versus three (n2=34) of the control pits, which were emptied during the study period (24 months). Few latrines were emptied (three interventions and one control pit) more than once, and the average fill-up time was 4 months in the intervention arm and 7 months for the control pits. None of the households in intervention or control arm used any protective measure when emptying the pits, and all pits were emptied manually using a bucket and shovel. Only two households buried the sludge to prevent recontamination (see Table 5).

Table 5. Pit-emptying practices

	Study Arm	
	Intervention	Control
Pit emptied, n/N (%)	9/34 (27)	3/34 (6)
Multiple times emptied, n/N (%)	3/34 (9)	1/34 (3)
Average pit fill-up duration (months)	4	7
Pit emptied manually, n/N (%)	9/34 (27)	3/34 (6)
No protective measure, n/N (%)	9/34 (27)	3/34 (6)
Sludge disposed, n/N (%)		
River/canal/pond/ditches	8/34 (24)	3/34 (12)
Buried	2/34 (12)	-
Untreated sludge disposal, n/N (%)	12/34 (35)	5/34 (15)

Discussion and Conclusion

The study team found that a sand barrier under and around latrine pits significantly reduced leaching of *E. coli* and fecal coliforms into the surrounding shallow groundwater. These results have important public health implications for fecal contamination of shallow aquifers from pit latrine contents in similar settings where onsite sanitation is prevalent and water tables are high. Incorporating the sand barrier into the existing latrine design in coastal Bangladesh and other similar settings may reduce fecal contamination of the shallow aquifer water that is often used for drinking and other household activities.

The team found a high concentration of fecal indicator bacteria in baseline water samples from shallow aquifers, but their concentration decreased sharply in the first follow-up. The use of surface water from nearby ponds during installation of monitoring wells may explain the high fecal indicator bacteria in baseline water samples. Pond water in Bangladesh has substantially higher levels of fecal contamination than shallow aquifer water.[15] The difference in mean log10MPN *E. coli* and fecal coliform counts between intervention and control groups were the highest during the early follow-up rounds but decreased during successive follow-up rounds, which is suggestive of higher efficacy of the sand barrier during the early phase. The fecal leaching increased during the following monsoon, when soil became saturated.

Larvated and nonlarvated helminth ova counts were higher in the intervention pits than the controls. This indicates enveloping latrine pits with a sand layer helped to contain helminth eggs within the intervention pits. Helminths are typically larger than bacterial pathogens and thus were more likely to be retained with the use of an effective filtration method. However, it is also evident that the sand barrier may be delaying the die-off process, since more helminth eggs remained viable. The average C/N ratio of the control pits was significantly higher than intervention pits and was within the preferable range (25–35) for rapid decomposition. As a result, the study team assumed that control pits went through more rapid decomposition and thus had fewer viable helminth ova, yet more helminths may have slipped through the soil layers to the surrounding soil and water.

Sand barriers showed another drawback, since more sand barrier latrines filled up within the study period than the controls. The sand barriers reduced leaching, which led to increased sludge content, resulting in quick filling up of the pits. Pit-emptying practices were poor, since most of the pits were emptied manually without using any protective measure and the sludge was disposed of in rivers, canals, and ditches, or in an open space.

This study has several strengths and important limitations. Among the strengths are the block randomization of latrine construction, which likely reduced small-scale geological variability between intervention and control latrines. The follow-up rounds that covered a 2-year period captured data on both dry and wet seasons that enabled better understanding of the effect of the sand barrier in different seasons. Installation of four monitoring wells around each latrine helped to capture microbiological contamination of shallow aquifers due to groundwater flow in all directions and increased the study power. Since the study team was blinded to intervention status and relied on objectively measured water quality data as the outcome, the team believes that it had minimum bias in its results.

Since shallow groundwater is the main water supply in many rural areas of South and Southeast Asia where pit latrines are also the primary method of sanitation, a modest reduction of leaching from pit latrines may likely provide a benefit. The recently emerged Sustainable Development Goals unify sanitation and safe water supply under a common goal, so promoting pit latrines with a sand barrier may be a pragmatic approach to achieve both goals compared to promoting pit latrines without a sand barrier.

[15] Knappett PS, Escamilla V, Layton A, et al. 2011. Impact of population and latrines on fecal contamination of ponds in rural Bangladesh. *Sci Total Environ*. 409(17):3174–82. doi: 10.1016/j.scitotenv.2011.04.043.

Supplemental Material 1: Methods for Pit Latrine and Monitoring Well Installation

WASHplus selected 68 sites to study the effectiveness of sand envelopment on mitigating groundwater pollution from pour-flush pit latrines in Golachipa, Bangladesh. The superstructure for all 68 latrines will be installed following the current WASHplus design furnished by WaterAid. The characteristics of offset pits will be modified slightly from the current design to include a 50 cm sand barrier in the experimental latrines and no sand barrier in the control group.

This document describes the construction process that vendors contracted by the local nongovernmental organization South Asia Partnership-Bangladesh, in coordination with icddr,b staff, will follow to construct the latrine pits used in the study.

General Procedures

- icddr,b staff supervising the work must confirm that the site conforms to the three selection criteria outlined in the technical protocol (e.g., four to 10 members per household, at least 10 steps distance from an existing latrine and not close to a body of water).
- icddr,b field staff will use a hand auger to dig a hole at the site identified for the offset pit. The hole will extend until the groundwater table is reached.
- icddr,b staff will measure the depth to groundwater table from the ground surface using a measuring tape or electronic probe (probe is preferable).
- Once the depth to groundwater table is determined, icddr,b staff will calculate the depth to the bottom of the pit considering the depth to groundwater measurement. This will ensure the bottom concrete ring in the pit sits in the unsaturated soil (on the day of construction)above the groundwater table.
- The number of concrete rings used at each pit will be a function of the depth to bottom of pit. The study team expects that all pits will have between three and five rings depending on the characteristics at the site. In keeping with the current design, one ring will be placed directly under the pan, which will protrude above the ground surface to give the slab a 1-foot-high pedestal for water seal and PVC pipe to bend accordingly from the pan.
- The study team will try to follow a standard design for all the study latrines, but if the groundwater level is higher in some locations, then the number of pit rings will be reduced to maintain the proposed distance with the bottom of the pit. The field research assistant (FRA) will inform the investigators before modifying the design and reducing the number of pit rings.
- After excavating the pit to the specified depth, the FRA will collect a 50cm soil sample from the center point of the pit bottom for all 68 latrine sites.
- The sample will be collected using a prelabeled 2-foot-long and 1.5-inch diameter PVC pipe. After collection, the pipe will be wrapped with aluminum foil to prevent spillage. The FRA will mark the sample with date and household ID.
- The soil removed by during sample collection will be replaced by fill soil removed during the excavation.
- Soil samples will be sent to Dhaka University for analysis.

Latrines without Barrier or Control Latrines

- Of 68 study latrines, 34 pits will not have a sand barrier.
- At these sites, the vendor will excavate a 75 cm diameter hole to the desired depth specified by the iddr,b supervisor. The depth of the pit will be above the water table on the day of construction.
- A varying number of concrete rings will be placed into the pit, following one ring extending to just above the surface.
- Concrete rings will be stacked on top of each other and not sealed with mortar.
- Care will be taken to minimize the annulus between the outer edge of the concrete rings and soil wall.
- There will be no other modification in the existing WASHplus design.

Latrines with Sand Barrier

- Thirty-four pits will have a 50 cm sand barrier in the bottom and surrounding the pit.
- At these sites, the vendor will excavate a 1.75 m diameter hole to the desired depth specified by the idddr,b supervisor. The depth of the pit will be above the water table on the day of construction.
- Once excavation is complete, coarse sand will be added to the bottom of the pit and compacted every 20cm using a handheld rammer. This process will continue until the sand layer is 50cm thick across the entire base of the pit. The study team will use a marked stick in the center to measure the 50 cm thickness of the soil. After reaching the desired thickness, the stick will be removed, and the center will be compacted to fill up the empty space.
- Vendors will then place the bottom concrete ring into the center of the pit, checking that the annulus between the concrete wall and the sides of the pit is equidistant on all sides.
- Sand will be poured around the ring and compacted every 20 cm until the sand reaches the top of the first concrete ring.
- This process will be repeated with the next ring until the rings and sand envelope reach the surface.
- A layer of 20 cm stone aggregate will be placed into the pit, resting on top of the sand layer at the bottom of the pit.

Monitoring Well Installation

- Four monitoring wells will be installed surrounding the pit in an "X" pattern to avoid the offset latrine superstructure.
- The monitoring well will be placed 50 cm beyond the sand barrier (for the test latrines) or 100 cm beyond the edge of the pit in the case of control latrines.
- Monitoring wells will be dug with a 6-inch diameter hand-operated auger.
- The hole will extend 3 m into the water table.
- Remove all cuttings from the hole so there is a clean, unobstructed path from the surface to the bottom of the hole.
- The study team will place a 1.5-inch PVC pipe up to the water table.
- Well screens will be purchased from the local market, where they are readily available.
- There will be annular space between the well screen and hole wall that will be filled with Sylhet sand (coarse sand) to facilitate water entering into the piezometer without clogging. Two cubic feet of Sylhet sand is required for each well screen.
- The annular space above the well screen (above the water table) will be filled with clay and silt that was removed during digging.

- The casing will be 2–3 m long up to groundwater level and a 3-m-long screen will be placed below the top of the water table.
- The total depth of the piezometer will be 5–6 m depending on the groundwater level.
- Vendors will encase the top of the well with a 1-foot by 1-foot concrete pad to firmly secure the well in place and prevent any surface water runoff from leaking into the tubewell.
- A tight-fitting steel or plastic cap will be placed on the top of the well to prevent tampering.