SANITATION IN CHALLENGING ENVIRONMENTS IN CAMBODIA

Appropriate sanitation solutions for hard rock areas in rural Cambodia

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Executive Summary

Access to improved sanitation, which is important for community livelihoods, reduces health burdens and environmental impacts. In rural Cambodia, a large proportion of the population practice open defecation that has a detrimental effect on the environment and community health. To meet Cambodia's target of 100% improved sanitation coverage by 2025, pour flush pit latrines are the recommended sanitation solution. However, challenging environments make conventional latrines difficult to construct and increase the likelihood of contaminating the surrounding environment.

Engineers Without Borders (EWB) Australia have been working on Sanitation in Challenging Environments in Cambodia since 2014, taking a sector wide approach to improve knowledge and action on sanitation for communities affected by their challenging environment. In collaboration with EWB Australia, the purpose of this research is to evaluate technologies that could enable sanitation access in areas of rural Cambodia where hard rock is present while ruling out established approaches such as pit latrines. Recommendations in these challenging environments were curated through desk research and interviews with experts delivering sanitation solutions in Cambodia. The research considers appropriate solutions using selection criteria rooted in a solid understanding of the context, and establishes an approach to testing technologies and feasible pathways to scale given the policy environment and condition of the broader sanitation sector in Cambodia.

While hard rock is a less common challenging environment in Cambodia, hard clays and soils present similar challenges. The emerging themes around suitable sanitation solutions for hard ground profiles are above the hard ground profile and are watertight to prevent contamination into the environment from leaching. There are a number of sanitation solutions that fit these categories such as the 3C latrine, HandyPod and ATEC Biodigester, all of which have been suitable for other challenging environments in Cambodia.

The successful uptake and scaling of technically viable solutions can be affected by a number of drivers. These include behaviour change from open defecation and conducting faecal sludge management through community engagement, financial subsidies from public and private partnerships, making use of existing capacity and supply chains, household considerations such as affordability and privacy that make improved sanitation an aspirational product, and monitoring and evaluation, to ensure solutions are sustainable and to improve the uptake process.

Table of Contents

Introduction

Sanitation in Cambodia

Sustainable Development Goal (SDG) Target 6.2 aims to *achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations* by 2030. Achieving this target can be accomplished through access to improved sanitation, which is important for community livelihoods, reducing health burdens and environmental impacts. Improved sanitation is defined as facilities designed to hygienically separate excreta from human contact such as:

- Flush/pour flush to piped sewer systems, septic tanks or pit latrines, or;
- Ventilated improved pit latrines, composting toilets or pit latrines with slabs.

In Cambodia, the primary recommendations for improved sanitation include flush or pour flush to sewage, flush or pour flush to septic tank or pit, pit latrine with slab and Ventilated Improved Pit (VIP) latrines. The National Strategy for Rural Water Supply, Sanitation and Hygiene 2011-2025 aims to provide 100% of the rural population of Cambodia with sustainable access to sanitation services and a hygienic environment by 2025.[1] The National Strategy for Rural Water Supply, Sanitation and Hygiene 2011-2025 recognises from experience in Cambodia and globally that building infrastructure promotes behaviour change. Efforts required include:

1. **Hygiene behaviour change:** Through Community Led Total Sanitation.
   The first stage is to get people to consider their behaviour and create a demand for better sanitation; the second stage is to motivate people to build and use a basic level of latrine; the third stage is to motivate people to buy and use improved latrines.
2. **Marketing:** Promote latrines that are affordable and appropriate.
3. **Building capacity of the private sector:** Develop financing mechanisms to help poorer households buy latrines and support small entrepreneurs to provide services in rural areas.

The SDG monitoring of sanitation services, as of 2017 in Cambodia, is presented in Figure 1. The distribution of sanitation services present significant differences between the urban and rural demographics in Cambodia. While all of the urban population have access to some level of improved sanitation (96% at least basic and 4% limited), increasing access for the rural demographics is a notable challenge.

[1] Ministry of Rural Development, National Strategy for Rural Water Supply, Sanitation and Hygiene 2011-2025, 2011

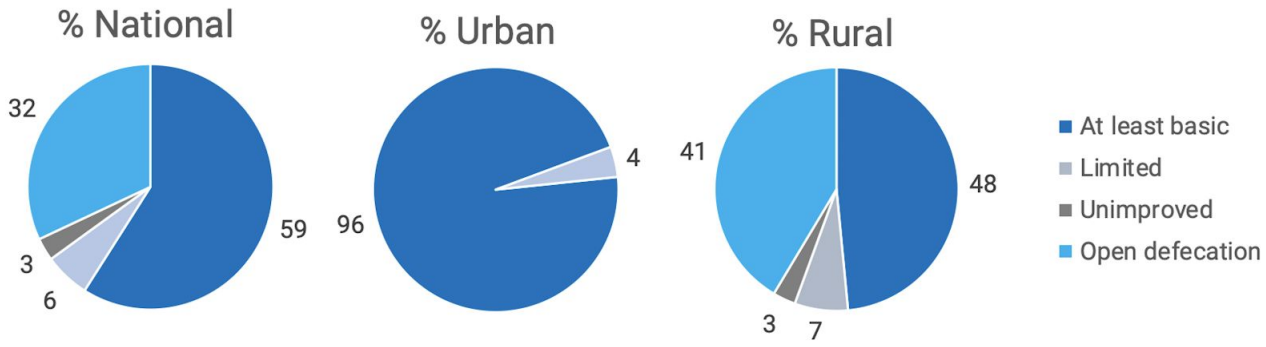

Figure 1: SDG 6.2 Sanitation Levels where: "At least basic" is the use of improved facilities which are not shared with other households; "Limited" is the use of improved facilities between two or more households; "Unimproved" is the use of pit latrines without a slab or platform, hanging latrine or bucket latrine; "Open defecation" disposal of human faeces into the environment.

Over half the rural population of Cambodia have access to improved sanitation (48% at least basic and 7% limited) which is a notable increase from Cambodia's target of 30% for 2015.[2] However there is still a large percentage of the rural population (42%) that practice open defecation (ODF). Behaviour change will remain an important part of any sanitation uptake into increasing improved sanitation use if the target of 100% improved sanitation use is to be met. Policy in Cambodia further acknowledges that the implementation of improved sanitation in rural Cambodia can be hindered by challenging environments in the country.

Cambodia's Ministry of Rural Development defines sanitation in a challenging environment as "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."[3] In Cambodia, conventional pit latrine technology can be considered a pour flush concrete ring pit latrine. Challenging environments in Cambodia include:

- Floating communities, where houses are floating for at least part of each year.
- Flood affected areas every day (severe), weeks at a time (medium) or short periods (moderate).
- Water scarce areas where conventional pour flush is not possible.
- High groundwater levels where conventional latrines are not possible.
- Hard rock areas where latrines cannot be dug by hand.

Challenges of Hard Rock

In geology, hardrock and soft rock refers to a particular setting where geologists work.[4] Generally, hardrock has metalliferous mineral deposits (containing metals or igneous and metamorphic (crystalline) compositions. While soft rock generally is synonymous with sedimentary settings. Based on this generalisation, Figure 2 presents areas of Cambodia where hard rock may occur.

[2] Ministry of Rural Development, National Strategy for Rural Water Supply, Sanitation and Hygiene 2011-2025, 2011
[3] Ministry of Rural Development, National Guiding Principles on Sanitation in Challenging Environment for Rural Households, 2019
[4] Hall, R. B. (1988). Hardrock versus softrock geology. In General Geology. Encyclopedia of Earth Science. Springer, Boston, MA. https://doi.org/10.1007/0-387-30844-X

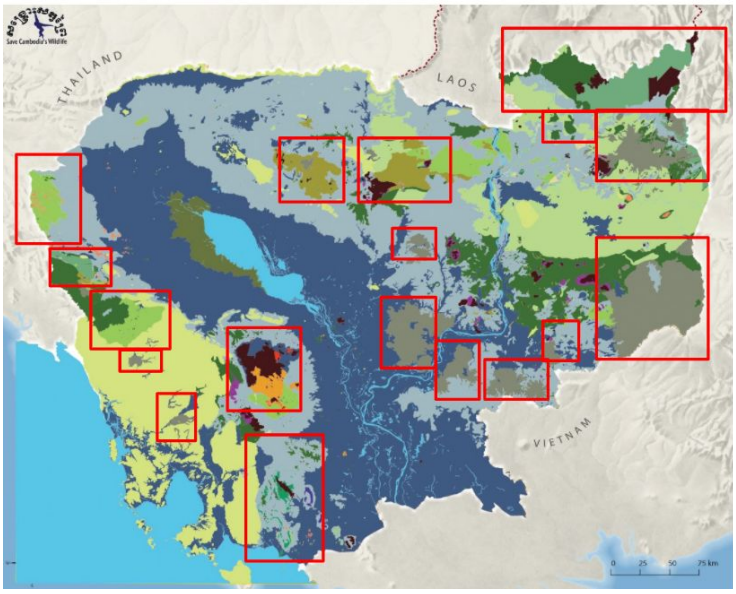

Figure 2: Potential hard rock encounters in Cambodia, outlined in red boxes; data available at Open Development Cambodia.

Hard rock specifically has been described by experts as a less commonly encountered issue when implementing improved sanitation in Cambodia, compared to other challenging environments.[5,6] However, hard or clay soils present a similar challenging environment to hard rock, as constructing latrines prove difficult. Research in Cambodia describes how seasonal changes in Cambodia impact soil hardness.[7] Deep soil profiles move from hard to soft in the dry season and rainy season, respectively. The variations in soil hardness seasonally potentially creates additional challenges in construction and contamination risks through fluctuating

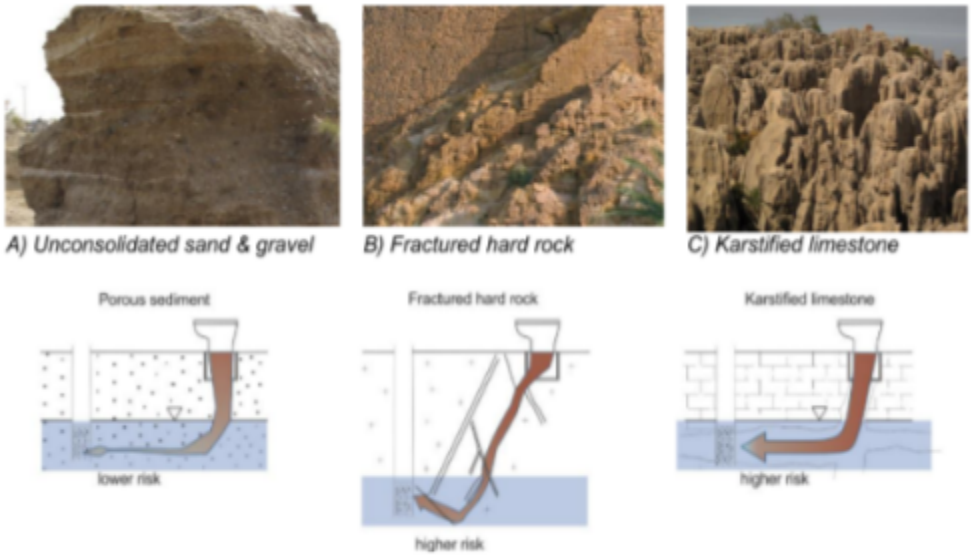

Figure 3: Contamination pathways through hard rock compared to porous sediment and karstified limestone.

[5] Interview with representative from Wetlands Work!, July 2020
[6] Interview with representative from iDE International, July 2020
[7] Ohnuki, Y., Shimizu, A., Chann, S., Toriyama, J., Kimhean, C., & Araki, M. (2008). Seasonal change in thick regolith hardness and water content in a dry evergreen forest in Kampong Thom Province, Cambodia. Geoderma, 146(1-2), 94-101. https://doi.org/10.1016/j.geoderma.2008.05.016

groundwater levels. As a result, hard rock should factor in distance to groundwater levels.[8] The soil properties in hard rock environments generally exhibit low percolation rates making it difficult for water to infiltrate the ground surface during flood events.

Pit latrines in hard rock environments present two primary challenges. Firstly, where hard rock is encountered, it can be difficult and costly to dig a latrine where hard rock is close to the surface.[9] Multiple experts in Cambodia have identified this as a problem where hard rock is encountered [10]. This can also be relevant in soil types with stone throughout the soil matrix.[11] Digging pit latrines in such areas may require the use of a drilling rig as manual digging can be insufficient, with some locations inaccessible to drilling rigs.[12] Latrines are therefore recommended to be constructed above surface level where hard ground is present through raising the ground level or raising the latrine. The second challenge is the risk of fractures in the rock, which can lead to rapid contamination of groundwater. Contamination takes place if there is a pathway between a source (leaching from on-site sanitation) and a receptor (groundwater). Water in an aquifer flows through pores and fractures in hard rock. These fractures (Figure 3) can present high flow and high risk to groundwater contamination,[13] and therefore risks to water supply wells. High groundwater levels have also been encountered due to high flow.[14]

Methodology and Data Collection

Desk Research

Initial research and data collection was conducted through desk research consisting of three areas:

1. **Hard rock as a challenging environment:** Defining hard rock, hydrogeological challenges, similarities with other challenging environments and potential locations of hard rock in Cambodia.
2. **Legislation and policy of rural sanitation in Cambodia:** Decentralisation through Community Level Total Sanitation (CLTS), private sector roles, environmental concerns for challenging environments and national guiding principles on sanitation in challenging environments for rural households.
3. **Sanitation solutions for hard rock emerging themes:** Existing technologies and emerging themes of technologies appropriate for hard rock and challenging environments, and considerations for scaling technology implementation.

Desk research also examined sanitation enterprises and solutions within the context of Cambodia's sociocultural context. This includes the identification and understanding of key community success factors, end-user preferences of technologies, and other cultural considerations which influence the uptake of sanitation solutions by households and local businesses. Findings of the desk research were then used to shape and feedback into interviews with experts on sanitation in Cambodia.

[8] Interview with representative from EWB Australia and Cambodia staff, June 2020
[9] WSP, Frequently Asked Questions: Rural Sanitation and Hygiene Practices, 2015
[10] Interview with representatives from East Meets West (EMW), June 2020; Wetlands Work!, July 2020; iDE International, July 2020
[11] Interview with representative from EWB Australia and Cambodia staff, June 2020
[12] Interview with representative from East Meets West (EMW), June 2020
[13] SusSanA, How to keep your groundwater drinkable : Safer siting of sanitation systems, 2015
[14] Interview with representative from Wetlands Work!, July 2020

In-depth Interviews with Experts

Semi-structured Interviews were conducted with 11 experts between June and August 2020. Interviewees included representatives from academia, NGOs and consultancies with experience working in the sanitation sector in Cambodia. The aim of these interviews was to understand the status of ongoing challenges and efforts concerning sanitation, lessons learnt from the implementation of sanitation technologies, and pathways to scale. Interviews were conducted via video conferencing, recorded, and transcribed. Data from interviews were codified into 97 data points within three key categories: Hard Rock, Sanitation Technologies, and Scale. Data points were further classified using a multi-tiered sub-category system. Interview data further clarified the state of hard rock as a challenging environment in rural Cambodia, and both informed and substantiated the determined selection criteria of suitable sanitation technologies. It also provided an in-depth exploration of key considerations and challenges regarding the scale-up of such technologies.

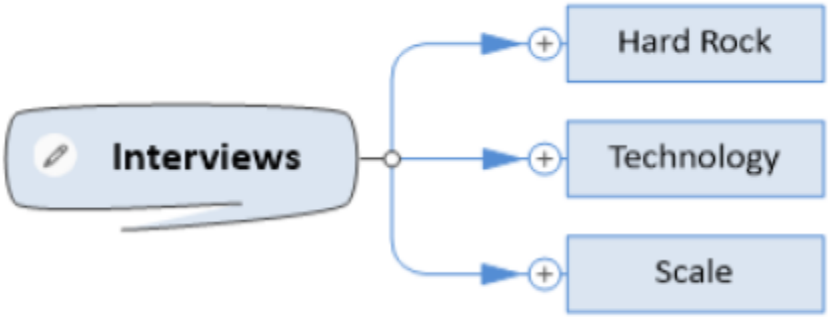

Figure 4: Interviews were codified into three key categories: i) Hard Rock, ii) Sanitation Technologies, and iii) Scale.

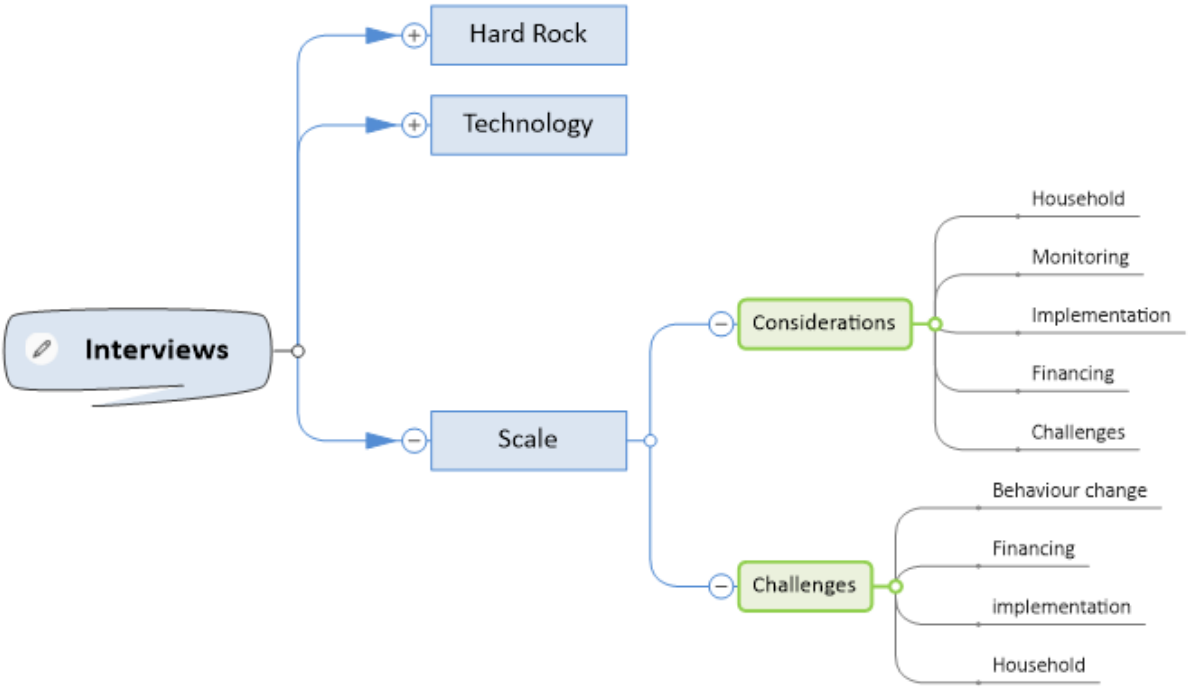

Figure 5: A multi-tiered sub-category system was used to codify and analyse interview data. This image illustrates the sub-categories of Scale into which data points were further classified.

Testing Appropriate Sanitation Technologies in Cambodia

Hard Rock Emerging Themes

This study identified key emerging themes from available sanitation solutions,[15] and from the assessment of the different types of sanitation technologies available in Cambodia. These themes are important because they consider the functionality of each technology in addressing hard rock challenges.

These emerging themes are:

1. **Containment**: Watertight/Controlled leaching
2. **Evacuation/Discharge:** Dry/Waterless
3. **Sitting position**: Above hard ground/water table

These sanitation solutions were explored by reviewing lessons learnt from other challenging environments, such as terrains predisposed to flooding and high groundwater levels.[16] These other challenging environments present overlapping themes, particularly where the extent of digging can be limited and contamination to the surrounding environment is likely using traditional solutions.

Table 1 compares the applicability of each sanitation option based on these emerging themes, so that households and solution providers can select the most suitable solution. The table recognises that the level of functionality will differ depending on the specific hard rock environment due to variations that need to be considered which include but are not limited to soil hardness, geography, and fluctuating groundwater levels.

Table 1: Applicability of sanitation option based on emerging themes

Option	Requires existing toilet facility	Containment		Evacuation Discharge	Sitting position
		Watertight	Controlled leaching	Dry / Waterless	Above hard rock / ground at surface level
Easy Latrine	No	Yes	No	No	No
2-Ring Latrine	No	Yes	No	No	No
3C Pit Latrine	No	Yes	Yes	No	No
HandyPod	No	No	Yes	No	Yes
ATEC Biodigester	Yes	Yes	Yes	Yes	Yes
Paradise Shelter	Yes	N/A	N/A	N/A	Yes
EcoSan	No	Yes	No	Yes	Yes

[15] Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C., 2014, Compendium of Sanitation Systems and Technologies, 2nd Revised Edition, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.
[16] Interview with representatives from EWB Australia and Cambodia staff, June 2020; iDE International, July 2020

Comparative Analysis of Sanitation Technologies for Hard Rock Environments

The comparative analysis of sanitation technologies provided a framework for the development of a user-friendly selection criteria based on the performance of each option, shown in Table 2. The table was designed to assess the applicability of different options against common physical and sociocultural conditions to enable comparison against baseline parameters. These parameters are substantiated from desk research and interviews in order to embed rigor towards its practicality in supporting solution providers and other organisations to recommend sanitation options which meet the needs and profiles of target households. Additionally, households can also refer to the table to increase their own understanding and aid their decision-making processes.

Table 2: Applicability of sanitation solution in hard rock environments based on physical and sociocultural conditions

Solution	Effort of digging [a]	Groundwater contamination risk [b]	Complexity of constructability [c]	Maintainability [d]	Easy-to-use	Relative cost [f]	Lifecycle [g]
Easy Latrine	High	Medium	Low	Medium	Yes	Low	5 - 10 years
2-Ring Latrine	Medium	Medium	Low	Medium	Yes	Medium	5 years
3C Pit Latrine	High	Low	Medium	High	Yes	Medium	2 - 4 years
HandyPod	Low	Low	Medium	High	Yes	High	5 years
ATEC Biodigester	Low	Low	High	High	No [e]	High	25 years
Paradise Shelter[h]	Low	N/A	Medium	Low	Yes	High	10 years
EcoSan	Low	Low	Medium	Low	No	Low	Depending on material

a. Effort defined as a function of depth to be dug (in non hard rock environments) with 'Low' being less than 0.8m.
b. Based on standard installation and perceived risk posed on impact to groundwater.
c. Complexity of constructability defined as a function of construction familiarity, perceived tolerances, and manufacturing methods.
d. Maintainability refers to the technical competency required by persons to correct defects or repair components
e. Unfamiliar to new users requiring user training and after-sales-service programs.
f. Based on the absolute cost of construction of the option. Noted that available subsidies and payment schemes can make costlier alternatives more affordable.
g. For latrine solutions, lifecycle refers to the indicative time period until emptying.
h. Although the Paradise Shelter is not explicitly a hard rock solution, it is included in this analysis as its implementation highlights pathways to scale, particularly subsequent sections: *Financial Subsidy and Payment Plans* and *Household considerations*.

To establish a practical guide that was useful and accessible to households and solutions providers, a level of service ranking (low, medium, high) was adopted to signify different scale ratings. The levels of service rankings of each criterion is rooted in a solid understanding of the context. Wherever possible, levels of service rankings were premised on quantifiable parameters otherwise, qualitative data was converted to semi-quantitative data

for the purpose to gauge relative performance (e.g. complexity of constructability).

This approach in determining the selection criteria and summarising findings was deemed suitable to visually compare sanitation solutions within the context of expanding sanitation access to the poor. This type of data representation is based on previous practice demonstrated by the International Finance Corporation (IFC), which similarly used a level of service rankings approach to compare the performance of different types of sanitation solutions in the Philippines with readership in mind.[17]

Sanitation Technologies for Hard Rock Environments

Variations of Pit Latrines

Improved sanitation recommendations in Cambodia primarily include some form of pit latrine use.[18] These include simple pit latrines with a slab, Ventilated Improved Pit (VIP) latrines and pour flush to a pit latrine.

A simple pit latrine is the cheapest, most widely used and most basic form of improved sanitation available. A pit is dug and lined. This prevents collapse and provides support to the superstructure. A slab with a hole is placed to cover the pit. Excreta and anal cleansing material (such as water or solids) are deposited into the pit. The bottom of the latrine is permeable to allow liquid to infiltrate into the soil, to reduce pathogens before entering the groundwater. Once full, the pit must be emptied or sealed.

The user acceptability of the pit latrine is a challenge as odour can escape through the hole in the slab and attract flies. To mediate the challenges of pit latrine acceptability, there are two recommended adaptations of the pit latrine. A VIP latrine is essentially a simple pit latrine but with the addition of a ventilation pipe to mediate the adverse characteristics of pit latrines, such as odour and flies. The pour flush latrine goes a step further in combating the acceptability of improved sanitation. Water is poured into the bowl to flush excreta into the pit latrine through a curved water seal. This water seal prevents users from seeing or smelling excreta, does not attract flies and allows for a general clean and comfortable use. This makes the pour flush latrine generally well-accepted by users. The primary concern in Cambodia with pour flush latrines, similar to pit latrines, is the liquids permeating into the soil that could contaminate the groundwater.[19] However, this method can also be connected to other containment or treatment technologies rather than solely pit latrines that could mediate the contamination risk to groundwater.

Notably, an interview with iDE acknowledged that latrines are seen as an aspirational product over ODF practices that signify dignity, status and convenience in the community.[20] This suggests that there is a user preference for improved sanitation over ODF practices.

In all cases, the construction of pit latrines is challenging in hard rock, and clay soils,[21] due to the cost difficulties when digging latrines. Recommendations when hard rock is encountered is to build a raised latrine where the pit

[17] IFC, Expanding Access to Improved Sanitation for the Poor, 2018
[18] Ministry of Rural Development, National Strategy for Rural Water Supply, Sanitation and Hygiene 2011-2025, 2011
[19] ADB, Cambodia: Water Supply and Sanitation Sector Assessment, Strategy, and Road Map, 2012
[20] Interview with representative from iDE International, July 2020
[21] Interview with representative from Wetlands Work!, July 2020

is partially above the ground level.[22] However, this does not solve the significant risk to groundwater contamination in hard rock areas through leaching. The challenge is making improved sanitation accessible and acceptable for users, while also being suitable in challenging environments such as hard rock.

2-Ring Latrine

The 2-Ring Latrine is an adaptation of the Easy Latrine, discussed in more detail below. The 2-Ring Latrine was designed to incorporate the familiarity of locally available materials and construction techniques. This familiarity also enables the solution to be simple, easy-to-use and affordable which are identified as key community success factors. By removing a ring, the digging effort required is reduced. Digging up to depths less than 0.8 m depth is considered easy allowing for increased cover for groundwater protection.[23] As the solution does not provide controlled leaching, Fecal Sludge Management (FSM) is managed onsite and must be undertaken at least once every 5 years. For this reason, latrine slabs are to be installed 20-30 cm above flood level and sealed watertight to prevent risk of contamination during flooding.

While the 2-Ring Latrine is not optimal in environments where hard rock is located at surface levels or high groundwater levels are present, it offers an alternative latrine solution which is more affordable, and easier to install, construct and maintain than the 3C Pit Latrine.[23] Its purchase also provides time for households to save and upgrade to a double pit latrine in future.

Easy Latrine/3C

The 3C Pit Latrine (or Easy Latrine) preceded the 2-Ring Latrine, and is the most prevalent sanitation solution in Cambodia. The low-cost sanitation system allows for multiple rings (less than or greater than 3 depending on available depth) and multiple connected pits. This sanitation solution is primarily provided by local businesses, which mainly comprise of producers of prefabricated concrete products and construction material shops who have capacity to produce latrines.[24]

Figure 6: EasyLatrine/3C

While human-centred design is at the core of the 3C Pit Latrine, its shortcomings are derived from its lack of

[22] WSP, Frequently Asked Questions: Rural Sanitation and Hygiene Practices, 2015; WEDC, Pit latrines for special circumstances, 2014
[23] Interview with representative from East Meets West (EMW), June 2020
[24] Murta, J., & Willetts, J., 2017, Business development services for sanitation enterprises in Cambodia, Enterprise in WASH– Research Report 8, Institute for Sustainable Futures, University of Technology Sydney

future provisioning for expansion to the detriment to the end-user. This is because end-users must purchase the product at its relatively higher cost price but do not have the option to upgrade, especially as the household or its user base grows.[25] Furthermore, it is also technically complex to construct and maintain for local trades due to its tight manufacturing tolerances and complex moulds required for the hydrological design.[26] These maintenance costs are passed onto end-users. Therefore, while the 3C Pit offers increased groundwater protection due to controlled leaching, it is the most costly latrine solution for businesses and households.

EcoSan

Ecological Sanitation (EcoSan) is an approach to sanitation that views human excreta as a valuable resource, rather than a waste product to be disposed of, which can involve composting and the separation of urine from the main sanitation containment. This process allows excreta to be treated on site for reuse for agricultural purposes, or disposed of safely. Existing pit latrines can be converted into EcoSan by constructing a second latrine nearby and alternating uses, allowing the generation and production of fertiliser and exploration of EcoSan options.[27]

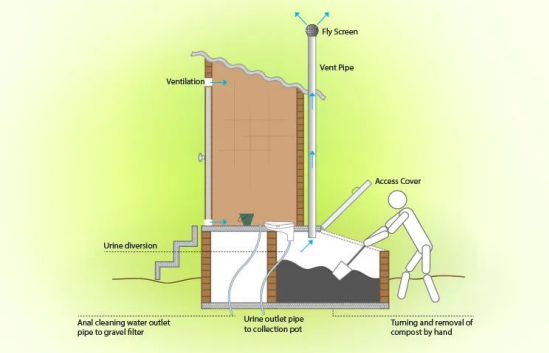

Figure 7: EcoSan

While the concepts of EcoSan are appropriate to the hard rock problem, i.e., dry, watertight and controlled leaching, the characteristics of EcoSan can make it off-putting as a technology in Cambodia hindering uptake.[28] Composting technologies are considered very difficult and labour-intensive compared to other sanitation options.[29] Construction and maintenance of EcoSan systems are costly and complex to operate and maintain. There have been considerations of buy back schemes from local businesses selling the fertilisers to incentivise adoption and implementation of EcoSan solutions.[30] However, there is little evidence that these implementation models have been successful in implementing EcoSan in Cambodia.

The complexity of constructing EcoSan can affect the sanitation system's functionality. Where solutions are not fully watertight the environment could be contaminated, particularly during flooding events. FSM may also

[25] Interview with representative from iDE International, July 2020
[26] Interview with representative from iDE International, July 2020
[27] Interview with representative from East Meets West (EMW), June 2020
[28] Interview with representative from Wetlands Work!, July 2020
[29] Interview with representative from EWB Steering Committee, June 2020
[30] Interview with representative from EWB Australia and Cambodia staff, June 2020

present notable challenges as the activities can be off putting due to the odour and handling of excreta.

EcoSan is a relatively new concept and not particularly common in Cambodia[31] and community pushback has been identified as a challenge making it difficult to implement EcoSan in this context.[32] An interview with East Meets West suggested that the EcoSan pushback may have resulted from historic events. During the Khmer Rouge regime between 1975 and 1979, the administrations failed 'agriculture first' policy led to eight million people being killed or dying from starvation. As part of this policy, the population in Cambodia were forced to handle and collect their excreta in jars for the purpose of agriculture.[33]

The negative historic connotations and complex technical nature of EcoSan would prevent challenges of acceptance as a viable solution. Overall, significant behaviour change and education, at both local level and high political level, is required for any significant uptake of EcoSan in Cambodia.[32]

HandyPod

The HandyPod is a wastewater treatment system used by floating communities, which operates by capturing raw sewage from the household's toilet and treating it within a pod using microbial biofilm processes. Its latest iteration is 'amphibious' to cope with the dry conditions incorporating a treatment system, which can float with the house or work equally well on land as required.[32]

Figure 8: HandyPod

As a result, this solution used by floating villages and stilted homes is also suitable for hard rock environments because it is based above ground and requires negligible ground penetration.[32] HandyPod presents minimal risk to groundwater contamination, and aims to shift behaviours on open defecation.

However, unlike latrine options, the maintainability and constructability are more arduous and relatively higher in cost when compared to pit latrines. Government subsidies, sanitation marketing and capacity building are enabling factors required for the increased uptake of this solution.[32] Its high relative cost is reflective of the additional support required of alternative technologies to pit latrines, in order to make them more accessible to households and therefore, incentivise local businesses to be involved. Withstanding, the HandyPod has experienced positive social acceptance in various communities, which is attributed to the organisation's engagement with local leaders, alongside the training of schools and teachers to promote the increased

[31] Interview with representative from WaterSHED Ventures, July 2020
[32] Interview with representative from Wetlands Work!, July 2020
[33] WaterSHED, Behavioral drivers of fecal sludge management in rural Cambodia: A qualitative study, 2018

awareness and education of water, sanitation and hygiene practices.[32]

ATEC Biodigester

The ATEC Biodigester is a sanitation solution that converts green waste, such as human and animal waste, into biogas for cooking, and organic fertilizer for crops and soil. The system is marketed towards farming households, however, it can also be applicable for households as it has been tested and connected with a toilet connection.

Figure 9: ATEC Biodigester

Previous research by EWB Australia, has shown the appropriateness of this technology in flooding environments and significant household savings (average 750 USD over three years) when using the biogas instead of other fuel sources.[34] Payment plans are part of the marketability of the ATEC Biodigester as monthly savings on gas and fertilizer can be used to pay off the system, without the risk of taking out a loan or micro-financing.

The watertight, flood resistant and above ground setting of the ATEC Biodigester makes this product very suitable for hard rock environments.[35] The design of the biodigester removes the stigma of emptying, composting and handling of sanitation material[36] that is apparent with EcoSan technologies. Furthermore, during interviews it has been described as the most recognised sanitation product in Cambodia.[37] The familiarity of this technology among Cambodia can therefore aid marketing strategies that can help influence behaviour change for improved sanitation uptake.

Paradise Shelter

The Paradise Shelter is a modular superstructure for toilet systems, designed to provide an alternative option for communities to gain access to durable, aesthetic and affordable toilet shelters to brick shelters. One of the primary barriers impacting a household's purchase of a toilet system is the community's desire for an expensive and labour-intensive, custom-built brick shelter,[38] highlighting how the uptake of sanitation solutions as an aspirational product is influenced by sociocultural factors.

[34] EWB Australia, Small-scale Wastewater Treatment Technologies for Challenging Environments, 2017
[35] Interview with representative from Wetlands Work!, July 2020
[36] Interview with representatives from EWB Australia and Cambodia staff, June 2020
[37] Interview with representative from WaterSHED Ventures, July 2020
[38] WaterSHED, WaterSHED Ventures Launches Quick-Install Toilet Shelter Into Rural Market in Cambodia, 2017

Figure 10: Paradise Shelter

Human-centred design processes were employed to develop the Paradise Shelter with the provision of a dignified toilet structure being the main design driver. The product is durable and easy to install as it is prefabricated above ground using durable material. The Paradise Shelter only (without toilet) costs USD 330 while the full toilet system costs USD 570.[39] To make the product as accessible as possible, WaterSHED leverages its existing networks of trusted masons and trades who have the capabilities to manufacture the design with greater cost efficiencies. Furthermore, WaterSHED implements sanitation marketing strategies to appeal to aspirational desires of households[40] and offers installment plans to households in partnership with micro-financing institutions.[39]

Challenges of Improved Sanitation

When considering suitable technologies to mediate the challenges of hard rock, there are a couple of important factors to consider that impact the uptake among users. These primarily include the technical complexity to construct sanitation solutions and the technical complexity to maintain them.

Pit latrines can be easily constructed by users. However, the challenge of constructing latrines in hard rock means pit latrines are not viable solutions. Construction then becomes increasingly complex. In the case of the 2-ring, 3-ring latrine and EcoSan, the concrete rings require specialist mason work to ensure the rings are watertight to prevent leakages and contamination. In the case of the HandyPod and ATEC Biodigester, this cannot be constructed by users and can only be purchased.

The emptying sanitation technologies can become a significant FSM issue if not operated safely. Latrine users in Cambodia have been known to empty and flood their latrines during the flood seasons to quickly regain the functionality of latrines.[41] This is a notable problem to the surrounding environment. Any sanitation that discharges into the environment needs to be safely done to avoid contamination into the environment and to

[39] Interview with representative from WaterSHED Ventures, July 2020
[40] Interview with representatives from WaterSHED Ventures, July 2020; Isle Utilities, Philippines, July 2020
[41] Interview with representative from iDE International, July 2020

protect surrounding human health.[42] Safe discharge into the environment must be considered alongside sanitation solutions to avoid these issues. This could come in the form of leaching pits or appropriate emptying services.

Pathways to Scale

Alongside sanitation solutions that are applicable for hard rock environments it is important to consider what drivers aid the uptake and scaling of such solutions. Through interviews with experts, challenges, limitations and practices for pathways to scale were highlighted. Figure 11 represents various drivers that influence the scaling of sanitation solutions in Cambodia.

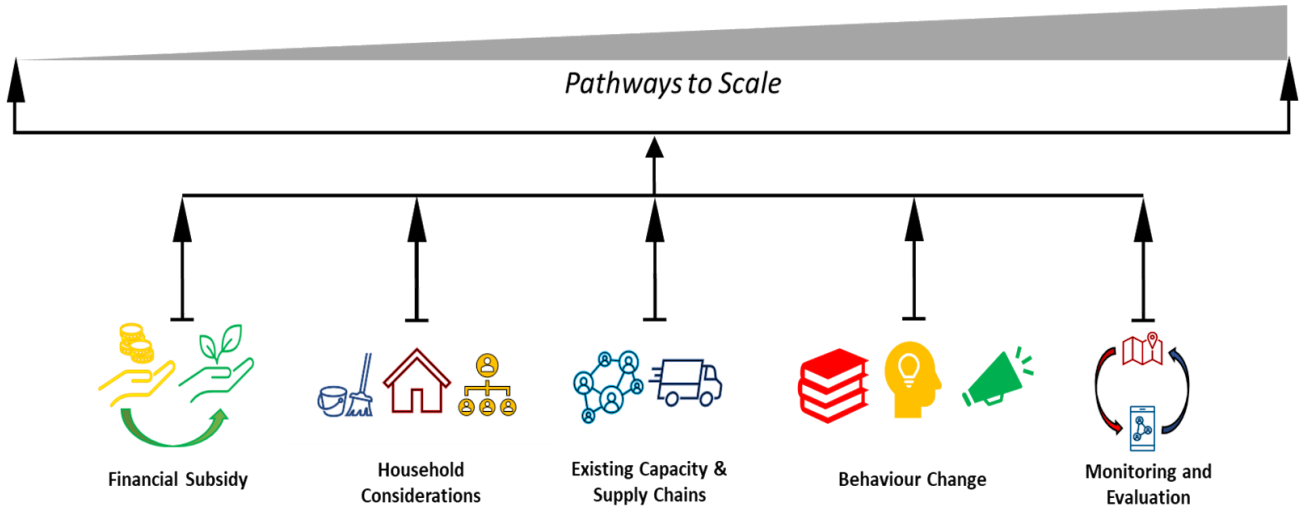

Figure 11. Pathways to scale

Behaviour Change

A substantial proportion of the rural populations sanitation practices are ODF (41%). ODF and poor FSM practices impact water quality and surrounding community livelihoods.[42] To make the transition to improved sanitation requires behaviour change of sanitation practices. This is important to ensure the uptake of sanitation solutions and to ensure those solutions are sustainable over the long term so communities do not return to ODF practices.

Behaviour change comes easier if users have prior experience with improved sanitation such as pit latrines.[42] Therefore users who practice ODF and have no prior experience with pit latrines will require more marketing for improved sanitation uptake. During interviews, both Isle Utilities and WaterSHED expressed their experience regarding the difficulty in marketing improved sanitation products due to the availability of land for ODF.

The maintenance of sanitation services is also a significant barrier to behaviour change. Many improved sanitation solutions in Cambodia that are appropriate to hard rock solutions, require an element of FSM and

[42] Interview with representative from Wetlands Work!, July 2020

emptying practices. Adverse smell and the manual handling of waste is a significant adverse factor in rural Cambodia that requires substantial efforts to enforce that behaviour change.[43]

For example, pour flush latrines have been previously described as a recommended technology by the Cambodian government, and are generally acceptable by users due to a reduction in odour due to the water seal. However, there are also negative behaviours associated with the pour flush pit latrine. In water scarce areas, the use of water to flush excreta into the pit latrine is off putting. Furthermore, while the technology reduces the odour during use, there are still off putting characteristics with odour and the manual handling of waste during the maintenance of the connected pit latrines.[43] Even with acceptable characteristics when using sanitation technologies, there is still a fundamental behaviour change required with the FSM practices and maintenance requirements to make these solutions sustainable over the long term.

Improved sanitation is seen as an aspirational product to households, however any upgrades to sanitation are hindered by ODF and FSM practices.[44] It is important to educate communities on the benefits of improved sanitation through informal and formal tools and campaigns. During interviews with EWB Cambodia and WaterSHED, communication, education and promotion for latrines through tools such as social media were mentioned as being useful to promote uptake, particularly to tackle the perceptions towards FSM and continuing ODF. Framing improved sanitation as an aspirational product in marketing and communication strategies can additionally aid uptake in households.

Financial Subsidy and Payment Plans

Affordability was identified by interviewers as a key barrier for households, particularly low-income households in upgrading their sanitation system.[45] Although there is high interest to improve sanitation and high demand for sanitation solutions, this interest does not translate to the ability to pay. In Cambodia, micro-financing is considered very accessible, but it also increases the household's debt. Loans are considered ineffective with preference expressed towards payment plans organised between the end-user and service provider as this allows for relationship-building[46] and is faster to set up, compared against the longer processes, unclear commitment and capacity for micro-finance institutions (MFI) to provide sanitation financing at scale.[44]

For example, WaterSHED Ventures have partnered with MFIs to provide Paradise Shelters to poor households via installment plans between the organisation and user. By taking on financial risk as the party responsible for payments to MFIs and third party local trades engaged to construct the product,[47] WaterSHED Ventures has increased the accessibility of their product for the masses, who are otherwise ineligible for micro-financing. That being said, the organisation carries out its due diligence working with local authorities and undertakes credit assessments to check if the household is capable of paying back the full amount. Similarly, iDE International trains and supports various local sanitation businesses in conducting credit assessments.[44]

[43] Interview with representatives from EWB Australia and Cambodia staff, June 2020
[44] Interview with representative from iDE International, July 2020
[45] Interview with representatives from iDE International, July 2020; WaterSHED Ventures, July 2020; Isle Utilities, Philippines, July 2020; East Meets West (EMW), June 2020
[46] Interview with representative from EWB Steering Committee, June 2020
[47] Interview with representative from WaterSHED Ventures, July 2020

Government subsidies were also highlighted as a solution towards enabling the success of sanitation in challenging environments.[48] Interviewees cited that families from the poorest backgrounds cannot afford sanitation solutions, which is attributed to a combination of factors including low income, budget pressures, inability to save and poor credit options. As a result, open defecation is still largely practised, particularly in floating villages, where above ground sanitation solutions like the HandyPod are proven to be effective but are too expensive for households. Subsidies are expected to incentivise local businesses to uptake training and develop manufacturing capabilities due to higher cost savings and profit potential gained.[49] For example, iDE supported the growth of local businesses by de-risking market entry and generating demand through the provision of subsidies. Therefore, the sanitation sector in Cambodia would largely benefit from increased partnerships and collaboration between government and non-government organisations to share knowledge, exchange data and provide subsidies targeted at poor households in select localities.

Household Considerations

Scaling sanitation solutions require an understanding of socioeconomic, sociocultural and physical characteristics of households, as these factors are considered by end-users when upgrading their sanitation system. This also includes an understanding of competing priorities of poor households living in hard rock environments, as this impacts their willingness to pay for various products.

Of these key factors, affordability was identified as the primary driver limiting the ability of households to upgrade their sanitation system.[50] The IFC defines affordability as the share of monthly household income that households have to pay for utility services.[51] Low-income households, particularly rural settlements, are likely to have a lower capability to afford and are less willing or able to pay the cost of constructing sanitation systems due to financial constraints (e.g. seasonal income due to agricultural occupations).[52] As a result, acceptable price ranges are expected to differ between regions; however, poor communities living in challenging environments who have minimal capacity in affording these solutions are usually those in greater need. For this reason, options like micro-financing, government subsidies and payment plans help increase access and maximise affordability.[50] Even if there is a demand, solutions like the HandyPod and ATEC Biodigester are out of reach without financing mechanisms in place.

Household demand for a sanitation system is largely driven by aspirations over health considerations.[48] Interviewees indicated how solutions improving sanitation at the household level were marketed as systems that promote comfort, privacy and affordability.[49] The success to date of the Paradise Shelter is attributed to its marketing which appeals to these household aspirations.[53] The prevalence of the pit latrine nowadays was influenced by its promotion as an aspirational market solution years ago.[54] As a result, service providers can generate demand and willingness to pay for products by designing and marketing solutions which maximise other valued qualities in addition to affordability, which are cleanliness, privacy, comfort, easy-to-use, as well as

[48] Interview with representative from Wetlands Work!, July 2020
[49] Interview with representative from iDE International, July 2020
[50] Interview with representative from WaterSHED Ventures, July 2020
[51] IFC, Expanding Access to Improved Sanitation for the Poor, 2018
[52] Interview with representative from EWB Steering Committee, June 2020
[53] Interview with representative from iDE International, July 2020; Wetlands Work!, July 2020
[54] Interview with representative from EWB Steering Committee, June 2020

familiarity with the technology.[55]

Consumer societal structures must be considered to educate and promote sanitation products. Of particular importance is consultation with the head of households who is responsible for purchasing the product.[56] Apart from training households how to use products, particularly complex solutions, sanitation marketing should aim to educate households and local businesses about the construction capabilities needed to build or carry out maintenance works, as households may attempt to carry out these works themselves resulting in future issues (e.g. pit latrine failure).[57]

The physical characteristics of the land also influences the ability of a household to purchase or construct particular solutions. While latrine solutions are generally more affordable, they require higher efforts of digging and are therefore, not appropriate in challenging environments where hard rock is at the surface level. Unfortunately, alternative options are more costly which is why ODF and groundwater contamination is still a problem across Cambodia.

Capacity and Supply Chain

When implementing and scaling sanitation solutions it is important to ensure local business capacity to provide sanitation solutions and the appropriate due diligence.[58] This aids the successful long term sustainability of a sanitation solution.[56] WaterSHED noted that supply chain and transportation costs for sanitation implementation are a hindrance. Making use of existing networks of suppliers can aid the implementation of improved sanitation and the pathway to bringing solutions to scale.

Technical training may also be required of masons and suppliers to construct latrines to ensure latrines are properly built,[57] specifically as certain sanitation solutions, such as the Easy Latrine/3C Latrine, require technical expertise to ensure that containment is watertight.

During an interview with Isle Utilities, similarities were drawn from other Southeast countries like the Philippines where communities refer queries on sanitation to locally-trusted engineers knowledgeable of building codes and local and municipal regulations to aid households plan sanitation solutions.[59]

The local circumstances should be considered when utilising existing capacity. In Cambodia, The rainy season impacts marketability as people tend the fields during the rainy season. This can impact door to door sales and supply chains.[56]

Monitoring and Evaluation

Providing improved and sustainable sanitation to the population is not a short term goal. In order to determine if sanitation solutions are promoting behaviour change and uptake, there needs to be monitoring and evaluation.

[55] Interview with representative from Wetlands Work!, July 2020; East Meets West (EMW), June 2020; iDE International, July 2020
[56] Interview with representative from WaterSHED Ventures, July 2020
[57] Interview with representative from East Meets West (EMW), June 2020
[58] Interview with representative from iDE International, July 2020
[59] Interview with representative from Isle Utilities, Philippines, July 2020

Long term monitoring and evaluation improves the design and implementation process,[60] and ensures implemented services are sustainable.[61] This process is very important in challenging environments to identify what solutions are working and identify additional factors that influence uptake and pathways to scale.

Conclusions

Key Findings

- Hard rock is a less common challenging environment in Cambodia, however, hard/clay soils present similar challenges. The hard rock challenging environment can therefore be described as 'Hard ground'.
- Sanitation technologies must be above hard ground profile and be dry and/or watertight to avoid water table contamination.
- There are a number of existing sanitation technologies in Cambodia that are appropriate for hard rock environments, such as 3C latrines, the HandyPod and ATEC Biodigester.
- Successful uptake and scale can be affected by a number of drivers such as behavior change, financial subsidy, existing capacity and supply chains, household consideration, and continuous monitoring and evaluation.
- Community engagement with businesses and households can be effective for sustainability and uptake, particularly when there is wide agreement between stakeholders in implementing education campaigns aimed at facilitating changing behaviours.
- Public and private partnerships should be explored to identify and implement innovative and suitable financing solutions that increase the affordability of solutions for low-income households. In Cambodia, such solutions, which are often too expensive for households, include the provision of government subsidies and payment plans between households and service providers, which have been found to make sanitation improvements possible for low-income households.
- New or modifications to existing sanitation solutions should employ human-centred design processes, to ensure that the end-user's perspectives and experiences are incorporated.

Future Work

- **Engagement with users at local level:** Due to the scope of this research, the majority of engagement was with sanitation experts and manufacturers in Cambodia. There is opportunity to further this research by engaging with local sanitation users, to better understand the drivers for behaviour change, sanitation solution uptake and experience with hard rock challenging environments.
- **Safe discharge and leaching pits:** The sanitation solutions investigated as part of the research collaboration were primarily containment technologies. During the research collaboration, safe discharge from sanitation containment into the environment was a notable theme. Future work could include the investigation into leaching technologies and its appropriateness for hard rock environments as part of an

[60] Interview with representative from WaterSHED Ventures, July 2020
[61] Interview with representative from Wetlands Work!, July 2020

improved sanitation strategy.

- Soil and hard ground variability: During the research, it was noted that hard soil profiles presented similar challenges to hard rock and are more commonly encountered. This may vary seasonally between the dry and wet seasons. Future work could include investigating how the variations of soil profiles throughout the year influences sanitation implementation.

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