Environmental Science Water Research & Technology

PAPER

View Article Online
View Journal | View Issue

Cite this: *Environ. Sci.: Water Res. Technol.*, 2016, **2**, 726

Testing methods for new pit latrine designs in rural and peri-urban areas of Malawi where conventional testing is difficult to employ

R. C. G. Chidya,*[a] R. H. Holm,*[a] M. Tembo,[a] B. Cole,[b] P. Workneh[c] and J. Kanyama[c]

Received 21st October 2015,
Accepted 11th May 2016

DOI: 10.1039/c5ew00246j

rsc.li/es-water

There is a trend towards participation of users in the design of appropriate sanitation facilities for low-income countries. However, testing the safety and durability of these technologies for rural and peri-urban communities is a challenge in low-income countries due to the lack of resources and access to conventional tests. This paper highlights testing methods used for pit latrine designs developed through participatory design approaches in Malawi. Two designs were tested with devised and/or conventional methods: (i) a corbelled pit latrine targeted for rural areas and (ii) an improved transitional pit latrine targeted for peri-urban areas. Devised testing methods proved to be useful and easy to implement by masons in the rural and peri-urban areas of Malawi. Novel pit latrine designs in Malawi require robust and innovative approaches to address the limited access to conventional tests. Both the conventional and devised testing methods demonstrated that the two designs have a satisfactory life-span and can support the users' load. The findings of this paper can be a model for the scale-up of integration of community ideas for participatory pit latrine design testing based in low-income countries where conventional testing is difficult to employ.

Water impact

Worldwide, 2.4 billion people still lack improved sanitation facilities. The findings of this paper can be a model for pit latrine design testing, whether targeting rural or peri-urban areas for access to improved sanitation facilities, resulting from participatory design approaches within developing countries.

1.0 Introduction

The United Nations has recognized the human right to sanitation.[1] Worldwide, 2.4 billion people still lack improved sanitation facilities, including in Malawi where 54% of the urban population and 73% of the rural population are in this category.[2] Gutierrez outlined the water and sanitation provision challenges in Malawi and found that it includes various stakeholders, involving users, donors, aid organizations, non-governmental organizations (NGO), local and national governments, and grassroot communities.[3] Technical sanitation challenges in Malawi include collapse of the internal (unlined) pit or shifting of the pit latrine slab plus termites damaging building materials.[4,5] Cole *et al.* argue that the short lifespan (11–13 months) of many unlined pit latrines remains a key constraint in rural sanitation access.[5] Despite this challenge, this is coupled with previous studies showing that rural households in Malawi are willing to pay for household pit latrines up to 12 132 MWK (Malawi-Kwacha, *ca.* 22.50 EUR).[6]

Malawi has a strong National Sanitation Policy.[7] However, a number of pit latrine designs promoted in Malawi have been expert-led and adopted from outside, without involvement of the rural and urban poor. Cole *et al.* encourage participation of users in the design of appropriate sanitation facilities for low-income countries.[8] The newly launched Sustainable Development Goals (SDGs) on water and sanitation, particularly goal 6, may also scale-up the inclusion of participatory design approaches to overcome social and technical sanitation challenges.[9]

In 2011, UNICEF Malawi through participatory design approaches developed a low-cost rural household pit latrine design known as the "corbelled latrine".[4] The approach involved users, community leaders, masons, Mzuzu University (Mzuzu, Malawi), health workers, NGOs and government officials. The process target was to address the sanitation challenges faced by rural households. The corbelled latrine design is not

[a] *Mzuzu University, Private Bag 201, Mzuzu, Malawi.*
E-mail: russelchidya@gmail.com, rochelle@rochelleholm.com
[b] *Murdoch University, 90 South St, Murdoch WA 6150, Australia*
[c] *UNICEF, P.O. Box 30375, Lilongwe 3, Malawi*

intended for pit emptying. In 2014, UNICEF Malawi partnered with Mzuzu University to test the corbelled latrine design that originated from the participatory design approach sessions.

While the UNICEF approach led to a new rural pit latrine design, similarly, in 2013, the USAID-funded Strengthening Health Outcomes through the Private Sector (SHOPS) explored sanitation challenges faced by peri-urban households in Malawi.[10] The participatory approach also involved users, community leaders, masons, Mzuzu University, health workers, NGOs and government officials. The process resulted in a novel, improved, low-cost pit latrine design, intended for possible pit latrine emptying, called the "improved transitional pit latrine". The design of this latrine was also tested at Mzuzu University.

But, testing methods to determine whether a sanitation facility developed through a participatory design approach has a satisfactory life-span and will satisfactorily support the users' load in low-income countries have not been well developed. For example, the ASTM C780 (ref. 11) for sampling and testing mortar in the laboratory or in the field would be considered expensive in many low-income countries due to sophisticated testing equipment and consumable material requirements. In Malawi, conventional testing may further be constrained by literacy rates in rural areas to both run equipment and analyze output data.

This paper presents a case study in Malawi using devised testing methods for pit latrine designs developed through local participatory design approaches where conventional testing to exhibit life-span and satisfactorily support users' load is difficult.

2.0 Methodology

The overall study was designed to verify participatory design approaches used to develop sanitation facilities with close involvement of stakeholders and end-users that are more immediately suitable and usable to the rural and peri-urban population. Fig. 1 presents the conceptual framework for the work herein presented to move sanitation designs resulting from a participatory design process through testing methods to determine suitability and towards scale-up of the integration of community ideas.

2.1 Study area

The corbelled latrine has been piloted in households within rural communities in the Mzimba, Nkhata Bay and Salima districts (Fig. 2). The improved transitional pit latrine has been piloted within peri-urban households in the districts of Lilongwe and Blantyre (Fig. 2). Peri-urban households live in areas that often experience limited access to municipal services due to the informal nature and high density of the settlements, serving as transitional locations between urban and rural zones. The rural areas, however, constitute locations largely used for subsistence farming activities with poor or very limited supply of public services.

2.2 Testing methods

Fig. 3 shows the design of both the corbelled and improved transitional pit latrines. The devised testing methods were conducted at Mzuzu University. Both destructive and nondestructive conventional testing was performed with technical support by the Republic of Malawi, Ministry of Transport and Public Works, Mzuzu, Malawi.

A summary of the devised and conventional testing methods for this study is presented in Table 1. These methods sought to ascertain the strength of construction materials, safety and reliability of the designs. The innovative devised mud-mortar selection test was specifically intended to provide on-site testing for rural masons in the absence of conventional testing. The load testing and wet soil structural integrity were devised for new pit latrine designs in the absence of conventional testing methods. Ethical clearance for the study was obtained from the Republic of Malawi, National Commission for Science and Technology (protocol number P.09/15/58).

2.2.1 Corbelled latrine. The typical corbelled pit latrine consists of a 3 m-deep pit with a dome in the middle to reduce the diameter towards the top keyhole (squat hole). The pit has a diameter of 1.5 m from the surface down to a 1.5 m depth. The diameter is then reduced to 1.0 m further down to a 3.0 m depth. The design uses bricks purchased from local sellers predominantly made by preparing wet mud composed mostly of clay which is formed into a brick shape, dried, and then finally fired in a local kiln. The masonry work uses no cement.

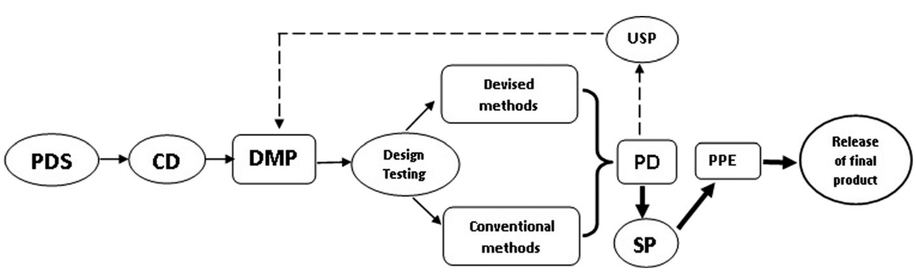

Fig. 1 Conceptual framework of study (PDS: participatory design of sanitary facility, CD: conceptual design, DMP: design modification and prototyping, PD: product design, USP: unsatisfactory product, SP: satisfactory product, PPE: product piloting exercise).

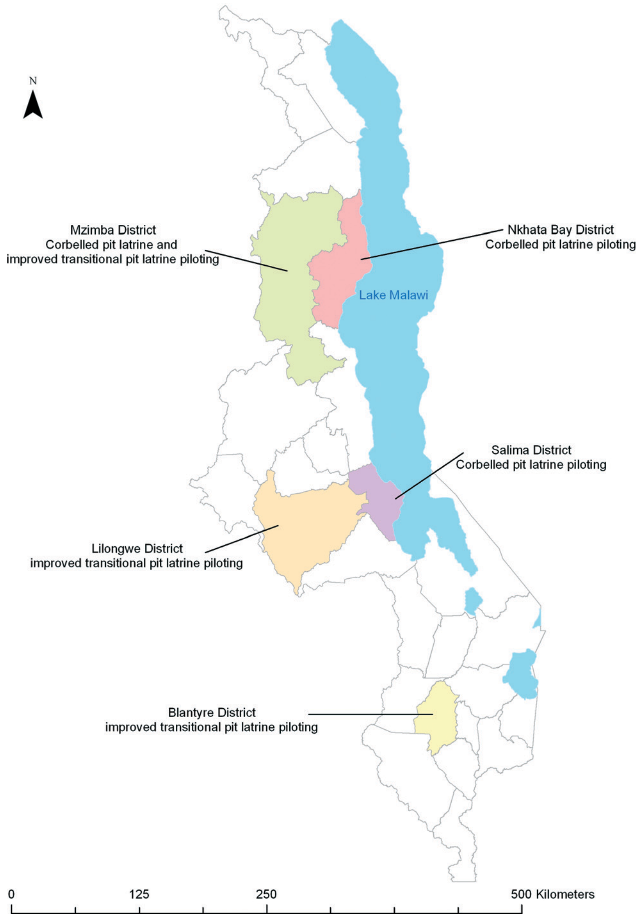

Fig. 2 Map of Malawi showing testing and pilot areas.

The devised testing processes for the corbelled latrine design were developed by UNICEF Malawi, along with masons and Mzuzu University to utilize indigenous knowledge and ideas on how to test the design in the absence of conventional methods.

Mud-mortar selection. The following field, or on-site, mud-mortar testing method was developed to assist rural masons in identifying suitable types of soil and mixture ratios for the mortar to be used in bonding the bricks in place for the dome. In the event of unsuitable mortar being used, the corbelled latrine may collapse. During construction, soil samples (approximately 200 g) were collected from midway (1.5 m) and at the bottom of the pit (3.0 m depth). Three 2 L containers were filled with water and labeled 'depth 1.5 m', 'depth 3.0 m' and 'mix' (Fig. 4). Soil samples from each depth were shaped into a "tennis ball" and placed in an appropriately labelled container filled with water. The 'mix' contained one handful of soil each from a depth of 1.5 m and 3.0 m. The balls in the three containers were submerged in water for 24 hours. After the soaking period, the balls were then evaluated for their "tennis ball" shape, which indicated the suitability of the soils for construction of a corbelled latrine. The mud that held its shape the best after soaking in water was the most suitable mortar material for the corbelled latrine substructure. If the balls in all three containers lost their "tennis ball" shape, the mortar at the construction site was not suitable for building a corbelled latrine on its own. In such cases, another method was formulated in which equal portions (1 : 1 ratio by volume) of sand and clay were mixed and formed into the "tennis ball" shape. If this withstood the mud-mortar selection test, then the mortar was determined to be acceptable for construction use. If the retest was unsuccessful, then the latrine was not recommended for construction at that location or there was a need to transport suitable soil from a nearby location for construction.

Load testing and structural integrity. A load bearing and soil structural integrity test in wet soils was also performed. For this test, a 210 L drum of water (weighing approximately 232 kg) was placed directly over the keyhole of the corbelled latrine to rest on the dome structure. Photos of the surrounding soils were taken twice per day (morning and afternoon) from Monday through Friday for three weeks during March and April, 2014. This was done to evaluate the structural integrity and monitor the rate of settlement or development of surface cracks. As testing was performed during the rainy season, meteorological observations were taken to monitor the high rainfall experienced some days. The deliberate exposure of the latrine to rainfall also provided a test on soil structural integrity under wet conditions.

No conventional testing methods were conducted to validate the devised methods for the corbelled pit latrine. Conventional testing methods are unfeasible as the design does not use cement for its construction, plus a lack of conventional testing facilities and cost constraints in rural areas of Malawi.

2.2.2 **Improved transitional pit latrine.** After site selection and demarcation of the center (2 m × 2 m) a 1.2 m diameter pit was dug from the surface to a depth of 1.5 m. Inside this pit another 1.0 m diameter circular pit was dug a further 2 m, giving a total pit depth of 3.5 m. The substructure was lined with burnt clay bricks (24 cm × 11.5 cm × 9 cm) from the 1.5 m depth to the surface. The bricks, purchased from local sellers, were made in the same way as for the corbelled latrines. A cement-to-river sand mortar of ratio 1 : 8 by volume was used to construct the substructure. A square slab was placed on the surface around the pit lining. Construction steps of the slab included leveling the ground, mixing the cement-river sand mortar, constructing the formwork, pouring the mortar into the formwork, and then finally curing. Reinforcement bars (8 mm diameter) were cut into 9 pieces of 1 m long and placed crisscrossed at approximately 250 mm spacing during slab casting. The casting was done adjacent to the pit using a cement–sand mixture ratio of 1 : 6 by volume. The slab was cured for 7 days. The slab (1.2 m × 1.2 m × 0.07 m) was then placed on top of the lined pit and foundation where the superstructure would rest.

The devised tests performed for the improved transitional pit latrine design were mud and cement mortar selection, plus load and wet soil structural integrity. Conventional

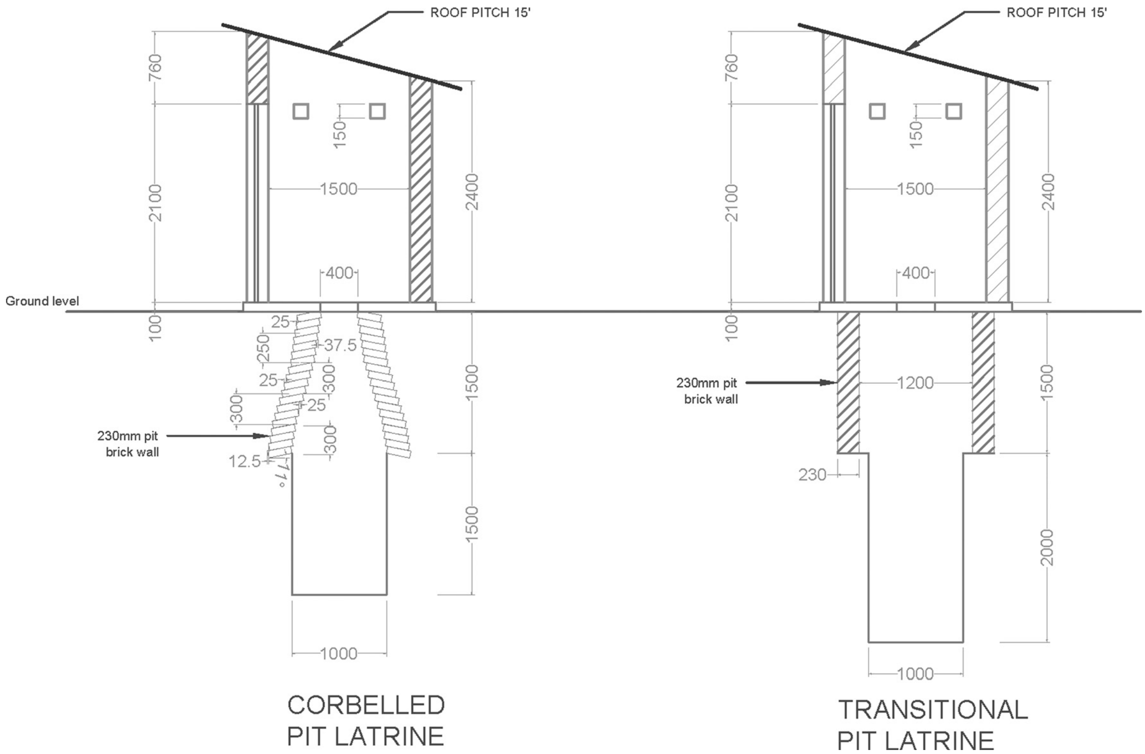

Fig. 3 Corbelled and improved transitional pit latrine representation.

Table 1 Pit latrine design testing methods (devised and conventional) used in the study

Method type	Testing method	Type of latrine ITPL	Type of latrine CL
Devised	1. Mud-mortar selection	✓	✓
	2. Load testing (210 L drum test)	✓	✓
	3. Wet soil structural integrity	✓	✓
Conventional	1. Bricks strength (compression test)	✓	✗
	2. Cement–sand mortar	✓	✗
	3. Slab strength (rebound hammer test)	✓	✗

ITPL: Improved transitional pit latrine. CL: Corbelled latrine. ✓: Test done. ✗: Test not done.

Fig. 4 Containers filled with water to test the "tennis ball" shape.

testing, as available at the time of the study, was also performed.

Mortar testing. To determine the strength of the cement mortar used for construction of the sub-structure, a soaking test was used. This method was validated by conventional crushing and compressive tests. For the soaking tests, researchers molded cylinders using the mortar used for both lining the substructure and slab casting. The cylinders were left to dry for 24 hours and were then soaked in water for 14 days (10 to 24 June 2015). Following this, the cylinders were visually checked for cracks.

Load testing. Similar to the procedures followed for the corbelled latrine devised testing, the strength and load capacity of the improved transitional pit latrine were evaluated by loading the slab with a 210 L drum of water centered on the keyhole. The slab was observed for the emergence of cracks and malfunctions for 28 days at a 7 day interval. After the 28 day monitoring period, the slab was white-washed to aid observations for cracks or other malfunctions. Total pressure (P_{dw}) exerted on the slab by the 210 L drum was evaluated by eqn (1):

$$P_{dw} = \frac{F_{dw}}{A_d} \quad (1)$$

where, F_{dw} is total force (load) exerted by the drum of mass (m) 22.7 kg and the water of density (D_w) 1000 kg m^{-3}. The value of gravity, g, used in the calculations was 9.81 m s^{-2}.

The A_d is the base area of the drum calculated by the formula $\frac{\pi D^2}{4}$, where the diameter (D) was 592 mm.

From the calculations, the slab was subjected to a load (W_d) of approximately 2283 N and a pressure of 3.0×10^9 N m^{-2} by the 210 L drum of water. Observations were also made by evaluating the diameter of the pit lining, malfunctions in the pit lining and hairline cracks on the slab. Evidence of settlement and surface cracks of the substructure masonry were also observed through photos taken from inside the pit.

To evaluate the total weight (W_{ss}) exerted by the superstructure, in particular bricks and mortar, eqn (2) was used:

$$W_{ss} = \sum_{i=1}^{n} \{M_{mb} \cdot g\} i \tag{2}$$

where M_{mb} is mass of mud mortar and burnt bricks of standard dimensions 24 cm × 11.5 cm × 9 cm; and 'g' is gravity. An assumption was made that the mass of the iron roofing sheets and wood for both the door and roof was negligible. About 415 bricks (of mass 2061 kg) were used for construction of the improved transitional pit latrine. The total mass of mortar used for the 415 bricks was estimated to be 164 kg.

The total pressure (P_{ss}) exerted by the superstructure on the slab with an estimated surface area (A) of 0.4807 m^2 was evaluated by dividing the total force (F_t) of superstructure (bricks and mortar) with the surface area (A):

$$P_{ss} = \frac{F_t}{A} \tag{3}$$

The estimated value of P_{ss} was 45 422 N m^{-2}.

Wet soil testing. The latrine was additionally subjected to wet soil testing to simulate rainy season conditions. This test was performed by flooding the surrounding area of the pit with water in a basin-like set-up. The flooding was performed for 8 hours per day for two days, and then the latrine was observed for cracks and malfunctions in the masonry structures (substructure and superstructure).

Brick strength. To determine the quality of the local bricks used to construct the latrine, 12 bricks (24 cm × 11.5 cm × 9 cm) were selected. The bricks were soaked in water for 24 hours and crushed using a hydraulic crusher (ELE Compact-1500: Wykeham Farrance Engineering, England) at the Republic of Malawi, Ministry of Transport and Public Works. This was performed to establish the compressive strength on a gross area of the bricks. The compressive test was performed in line with national standards.[12]

Following the success of the devised soaking method, the mortar cylinders were subjected to conventional testing for further validation. In this method, a similar set of the cylinders were prepared, dried for an additional 7 days, and then tested for compressive strength using the hydraulic crusher used in the brick testing.

Slab strength. The strength of the slab was determined using a non-destructive method, namely, the Schmidt hammer test where a steel plunger strikes the concrete surface. Standard procedures for operation of the rebound hammer (Schmidt) test (ELE International Ltd, England) were followed.[13] Ten rebound hammer readings were taken each on the vertical and horizontal slab surface.

3.0 Results and discussion

3.1 Corbelled latrine design testing

Generally, the corbelled latrine testing methods were performed successfully. The keyhole and pit lining showed no cracks or structural failures during the 210 L water drum load bearing and soil structural integrity testing under wet conditions. The findings show the corbelled latrine design is strong enough to withstand a comparable household user load estimated as ultimate limit state (ULS). Although the current work did not evaluate the adoption rate of the new design, it was found that the devised testing method of mud-mortar selection was easy for rural masons to learn and implement where conventional testing methods could be difficult. This was evident during training sessions with masons from the pilot districts of Nkhata Bay and Salima. During these training sessions, a majority (>75%) of the participants (masons and users) expressed satisfaction with both the new design and devised mud-mortar selection and testing method. This is consistent with earlier reports on design piloting.[4]

While conventional testing methods would require local government technical support, the results from the devised method showed that with simple orientation, masons can determine suitable mixture ratios of soil for securing bricks during construction. The innovation provides an easy, and on-site, testing method for masons in rural areas that lack conventional testing methods.

3.2 Improved transitional pit latrine design testing

Cement–sand mortar cylinders (10 cm height by 10 cm diameter) observed after soaking for 14 days did not show signs of failure or cracks. These findings show that the concrete mixture used for the slab casting and cement mortar for the pit lining exceeded the minimum strength needed to withstand wet conditions. The results of the devised testing methods were also compared to the conventional tests for validation.

Results for load testing showed the slab was able to withstand a minimum load of 2283 N by the 210 L drum of water. No deformations of the pit or pit lining were observed upon exerting the load on the slab. Furthermore, no hairline cracks were observed on the slab. Estimating the mass of a single person visiting a pit latrine once per day with a family of five members, the slab had enough strength to hold a 100 kg object five times a day. These findings were considered to satisfy the serviceability limit state (SLS) of the new design in line with routine use. This suggests the design is strong enough to support a typical household user load. Furthermore, the slab strength observed during load testing is also sufficient to handle the weight of two to three people during pit latrine emptying operations. This shows that the slab was strong enough to hold a weight of approximately 230 kg, as the ULS, in use.

Results obtained through conventional testing methods showed brick strength ranged from 1.1×10^6 to 5.3×10^6 N m^{-2}. Only one-third of local bricks (33%, $n = 12$) were rated above the mean clay burnt brick crushing strength of 3.0×10^6 to 3.5×10^6 N m^{-2} specified by the Malawi Standards Board.[12] This suggests local bricks may contribute to poor design performance if standard bricks are not appropriately selected and used. Following these findings, local masons should be advised to use bricks from quality providers to avoid compromising the pit latrine design strength, though this may not be practical to implement.

The conventional compression tests on cylinders displayed minimal strength. This was expected since the cylinders were made without aggregate. Also, the hydraulic cylinder crusher is usually used to determine the strength of concrete used in buildings, hence though a locally available conventional method, it may not have been applicable for testing construction of latrines.

Vertical and horizontal rebound values ranged from 8.0×10^6 to 9.0×10^6 N m^{-2} and 0 to 9.0×10^6 N m^{-2} respectively. There were no significant differences ($p > 0.05$) in the 10 rebound hammer readings taken at each test area, for both horizontal and vertical positions. Variations in the rebound hammer readings were probably attributed to factors such as the location of the reinforcement, smoothness of the surface and internal moisture (moisture gradient). These factors are in line with ASTM guidance.[13] The zero rebound values in the horizontal readings were attributed to the plastering the sides of the slab after constructing the superstructure. The slabs performed well during the load test and could be considered adequate for household use.

3.3 Scale-up of design development and testing

There must be options for better pit latrine designs for use in rural and peri-urban areas in order to reach improved sanitation targets, and with this comes the need for better design testing. Although two participatory design approaches were used and included involvement of the rural and urban poor, neither latrine design used water in its operation.

A search of patents from the World Intellectual Property Organization (https://patentscope.wipo.int/search/en/search.jsf) related to pit latrine design and testing indicates that neither the corbelled latrine nor the improved transitional pit latrine have been patented, *i.e.* they are open-source. Both designs use local materials available for the designed target household market, whether rural or peri-urban respectively, to reduce construction cost. The devised design testing approaches used and recommended herein promote local innovation as well as research and development success. Yet, if only conventional testing standards are used, it may have an unnecessarily high cost for testing and may deter innovation or result in no testing in the case of rural areas. The novel testing approaches presented herein can help households benefit from research, quickly, efficiently, and safely, to build better sanitation facilities from the ground up. For each pit latrine design, testing protocols at Mzuzu University (conventional and/or devised) cost approximately 5700 EUR. Exactly who recovers the testing costs under similar work with other new pit latrine designs is a question of safety. Proper latrine placement to avoid erosion due to poor surface water management is essential regardless of design.

This study has contributed to the achievement of the National Sanitation Policy towards improved sanitation.[7] Lessons from this research can be replicated in other Malawian rural and urban areas, as well as other countries, to reach the SDGs. However, it may be difficult to replicate this research in other countries, such as Zambia where the Public Health Act[14] has latrine legislation that mandates a technology-based approach inclusive of a specific design for household latrines. While a technology-based regulatory approach has the benefit of rigid conventional standards, it may deter innovation of low-cost, locally appropriate, and tested pit latrine designs developed through participatory design approaches. As such, Kvarnström *et al.* has argued for a function-based approach *versus* a technology-based approach.[15]

4.0 Conclusion and recommendations

This paper presents testing methods applied to cater to participatory design approaches for improved sanitation facilities in low-income countries. The devised testing methods, appropriate for the context of Malawi, are particularly suitable for the integration of participatory design community ideas. In Malawi, conventional testing methods by the government are only available on a limited scale.

We validated the safety and strength of two novel pit latrine designs targeted for rural and peri-urban areas of Malawi. The devised testing approaches for novel pit latrine designs are appropriate for low-income countries in areas where sophisticated and expensive conventional design testing is not available. The devised testing methods were evaluated by available conventional testing methods. From the findings, it is evident that both the corbelled latrine and the improved transitional pit latrine designs meet the overall testing standards and appear to be satisfactory for release to the public. Methods of testing new pit latrine designs in the field in low-income countries requires new approaches that are robust, but constrained by limited testing capacity and cost. Specifically, the mud-mortar selection and testing during construction of pit latrines could be adopted in rural areas of Malawi and other countries. Further studies are needed to confirm perceptions, user friendliness, adoption rate and satisfaction of the pit latrine designs as well as to investigate the capacity of staff and whether other conventional tests could be adapted. The findings of this paper can be a model for the scale-up of integration of community ideas for participatory pit latrine design testing based in low-income countries where conventional testing is difficult to employ.

Acknowledgements

This research was part of the Testing of Sanitation Designs SHOPS WASH Project funded by USAID and the Sanitation Marketing Project funded by UNICEF Malawi. The authors also appreciate the laboratory support from the Ministry of Transport and Public Works, Mzuzu, Malawi.

References

1 United Nations, *Realizing the human rights to water and sanitation*, A Handbook by the UN Special Rapporteur Catarina de Albuquerque, UN Special Rapporteur Catarina de Albuquerque, Portugal, http://www.ohchr.org/EN/Issues/WaterAndSanitation/SRWater/Pages/Handbook.aspx (accessed 7 August 2015).
2 WHO/UNICEF (World Health Organization and United Nations Children's Fund), *Progress on Sanitation and Drinking Water – 2015 update and MDG assessment*, World Health Organization, Switzerland, 2015, http://www.unicef.org/publications/index_82419.html (accessed 13 July 2015).
3 E. Gutierrez, *Geoforum*, 2007, **38**, 886–900, DOI: 10.1016/j.geoforum.2005.09.010.
4 UNICEF Malawi, WASH Field Note: *Going Beyond ODF: Combining Sanitation Marketing with Participatory Approaches to Sustain ODF Communities in Malawi*, 2015.
5 B. Cole, J. Pinfold, G. Ho and M. Anda, *J. Water, Sanit. Hyg. Dev.*, 2012, **02.4**, 266–278, DOI: 10.2166/washdev.2012.014.
6 R. Holm, V. Kasulo and E. Wanda, *Sustainable Sanitation Practices*, 2014, **20**, 27–31, http://www.ecosan.at/ssp/issue-20-capacity-building/SSP-20_Jul2014.pdf (accessed on 15 October 2015).
7 Malawi Government, *National Sanitation Policy*, Ministry of Irrigation and Water Development, Lilongwe, Malawi, 2008.
8 B. Cole, J. Pinfold, G. Ho and M. Anda, *J. Water, Sanit. Hyg. Dev.*, 2014, **04.1**, 51–61, DOI: 10.2166/washdev.2013.166.
9 United Nations, *Sustainable Development Goals*, http://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed on 15 October 2015).
10 D. Michael, *Malawi Peri-Urban Sanitation Project Report*, Strengthening Health Outcomes through the Private Sector Project, Abt Associates Inc., Bethesda, MD, 2014, http://abtassociates.com/AbtAssociates/files/1c/1c1d1530-5132-4441-b157-1d3fad6342af.pdf (accessed on 27 February 2016).
11 ASTM C780, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry*, ASTM International, West Conshohocken, PA, 2013.
12 Malawi Standards Board 6:1994, *Burnt clay bricks – specification*, 2nd edn, Malawi, 1994.
13 ASTM C805/C805M-13a, Standard Test Method for Rebound Number of Hardened Concrete, ASTM International, West Conshohocken, PA, 2013.
14 Zambia Government, *Public Health (Drainage and Latrine) Regulations*, 1994.
15 E. Kvarnström, J. McConville and P. Bracken, *et al.*, *J. Water, Sanit. Hyg. Dev.*, 2011, **1**(2), 3–12, DOI: 10.2166/washdev.2011.014.

