Building Resilient Sanitation Systems in Malawi: Pit-latrine Costs, Collapse, and Management

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Abstract:

Despite widespread access to basic sanitation in Malawi, over 75% of the population lacks improved sanitation facilities. This national study investigates the resilience of pit-latrines across Malawi, focusing on the relationship between construction quality, facility lifespan, and collapse frequency. A survey of 268,000 pit-latrines revealed that high-quality latrines (lined and with a slab) collapse three times less frequently than low-quality latrines and last significantly longer. However, cost barriers remain substantial, with high-quality latrines costing five times more than low-quality facilities. Even when accounting for their extended lifespan, the annual cost of high-quality facilities is almost double that of low-quality options, highlighting a key financial challenge for widespread adoption.

Pit-latrine emptying, while offering a potential solution to extend the lifespan of latrines, is rarely practiced due to its high costs and cultural resistance. Manual emptying, the most common method, raises health and environmental concerns, while emptying costs remain prohibitively high for many households. The study emphasises the need for significant investment in resilient sanitation infrastructure, promotion of affordable emptying services, and the development of faecal waste management systems. Addressing these challenges is essential to ensuring equitable access to safe and sustainable sanitation in Malawi, ensuring climate resilience and sanitation justice.

Keywords: Sanitation, open defecation, climate change, resilience, circular economy, water quality, pit-latrine emptying

Graphical abstract:

41

42

Introduction

Pit-latrines are the major provision of sanitation in many low- and middle-income countries and are crucial to meet the sanitary needs of over 1.8 billion people globally (Gwenzi et al., 2023). They are often considered the 'first step on the ladder' in ending open defecation, a global priority as outlined in SDG 6 (UN General Assembly, 2015).

Whilst they have been invaluable in providing a low cost and accessible form of sanitation, poorly constructed pit-latrines present a nexus of problems including spatial challenges, limited accessibility, environmental and pollution concerns, and slippage in achieving open defecation free (ODF) status (Mills et al., 2020). The inexpensive constructions are repeatedly associated with high rate of collapse, often due to extreme rainfall, and subsequent abandonment (Mosler et al., 2018; Namwebe et al., 2008). Pit-latrines are also regularly abandoned due to filling up (Nakagiri et al., 2016.) An ever-growing number of abandoned sanitary facilities becomes more challenging in areas of high population density in which spatial limitations may prevent appropriate replacement and necessitate the continued use of inadequate sanitary facilitates (Kouassi et al., 2023).

High rates of abandonment, from collapse and filling up, can also trigger a return to open defecation for users who are unable to afford to replace the abandoned facility (Cavill et al., 2015; Kouassi et al., 2023; Mosler et al., 2018). Low quality pit-latrines can present a 'snakes and ladders' paradigm in which pit-latrines provide the first step towards sanitation but slippage back to open defecation is subsequently observed. Similarly, even where sanitation facilities are available, and where these are of poor-quality, there may still be a preference for open defecation, particularly among women and children who often find pit-latrines to be unsafe (Fihlani, 2018; Chinoko, 2023; Huda et al., 2021; O'Reilly, 2016). Such a lack of *safe* sanitation threatens to undermine the very aim of SDG 6.2; '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' (UN General Assembly, 2015).

Unless appropriately managed, poor-quality pit-latrines (both abandoned and in-use) can also present a public health concern in the form of groundwater contamination (Banks et al., 2007; Graham & Polizzotto, 2013; Tillett, 2013; Wright et al., 2013, Hinton et al., 2024a). This presents a particular public health concern in contexts where there is an intersection of high pit-latrine dependency and high reliance on groundwater, often untreated, for drinking water provision (Graham & Polizzotto, 2013). Maintaining appropriate distancing between pit-latrines and water points is the major mechanism by which pit-latrine-drinking water contamination is managed (Franceys, 1992; Graham & Polizotto, 2013; Sphere Association, 2018). But population growth and urbanisation make continuing to ensure appropriate distancing more challenging (Hinton et al., 2023a; Kariuki, 2003). Furthermore, not only does pit-latrine collapse increase under extreme precipitation events (Mosler et al., 2018), heavy rainfall also increases groundwater contamination from pit-latrines (Rivett et al., 2022). Construction of sanitation facilities that are more resilient to heavy rainfall, both in terms of collapse and contaminant leaching, will be critical in ensuring climate resilient sanitation provision (Mills et al., 2020).

In recognition of the need for *safe* sanitation, SDG 6 explicitly outlines the need for safely-managed sanitation (UN General Assembly, 2015). For pit-latrines, safely-managed sanitation requires the presence of a concrete slab to cover the latrine floor, improving hygiene, accessibility, and the structural integrity of the facility (Reed; Bob, 2014). Lining is another measure used to enhance structural integrity (Namwebe et al., 2008.; Reed, 2014) and minimise faecal groundwater contamination (Graham & Polizzotto, 2013; Gwenzi et al., 2023; Masindi & Foteinis, 2021). Whilst not specifically outlined as a requirement of safely-managed sanitation, it is recommended in pit-latrine construction (Reed; Bob, 2014).

Yet despite the emphasis placed on ensuring appropriate standards in pit-latrine quality for *safe* provision, this is often not seen. Progress to ensuring safely managed sanitation lags behind other WaSH targets (UNICEF & WHO, 2023) with access to safe sanitation even falling in multiple countries globally. A step change in progress to ensuring safely-managed sanitation access is needed globally to achieve SDG 6 (UNICEF & WHO, 2023). The high costs of improved sanitation (Daudey, 2018; Mamo et al., 2023; Peletz et al., 2017) and a low willingness to pay (Peletz et al., 2017) are often credited as the reasons for inadequate provision. As such, there is a need to evaluate systems with the potential to reduce the financial burden of higher quality sanitation.

Pit-latrine emptying presents a potential solution to some of the intersecting challenges of high pit-latrine dependency. By removing waste from the latrine and preventing the latrine filling up, emptying sanitary facilities can extend the lifetime of the latrine (Mubatsi et al., 2021), thereby minimising ODF slippage, reducing the spatial repercussions of pit-latrine abandonment (Jenkins et al., 2015; Kariuki, 2003), and minimising groundwater contamination (Gwenzi et al., 2023). Pit-latrine emptying can also be used to minimise the greenhouse gas emissions of on-site sanitation (Manga & Muoghalu, 2024). Latrines are emptied either manually, using shovels and buckets, or mechanically utilising vacuum tanker trucks and pumps (Burt et al., 2019; Chipeta et al., 2017; Thye et al., 2009). Faecal sludge can be treated at wastewater treatment facilities or through other solutions that provide circular economy utilisation, including the production of organic fertiliser and biochar (Midega, 2022). The increased facility lifespan afforded by pit-latrine emptying also has the potential reduce the costs associated with sanitary access, providing that the costs of emptying do not outweigh to financial benefits of the reduced frequency of building new facilities.

Malawi is one such country in which innovation to enhance safe sanitation provision access is essential. Low quality pit-latrines are used by the majority of the population with high levels of abandonment and collapse; from 2020-2070 it is estimated that 31 million pit-latrines will be abandoned due to filling up (Hinton et al., 2023b). Where progress in sanitation access has been made, subsequent ODF slippage has been reported and attributed to pit-latrine collapse (Hinton et al., 2024b). Nationally, open defecation has also been seen to increase, rising from 6.2 percent in 2016 to 6.7 percent in 2022 (NPC, 2022). Pit-latrines have also been linked to high levels of groundwater contamination (Rivett et al., 2022; Back et al., 2019; Hinton et al., 2024a) which are forecast to increase with growing spatial challenges in sanitary provision (Hinton et al., 2023a). Despite the benefits of pit-latrine emptying practices to alleviate some of these challenges, there are no national level evaluations of pit-latrine emptying within Malawi, with the few studies that have explored emptying on a highly localised scale finding significant variation in prices, practices, and performance (Chipeta et al., 2017; Rochelle et al., 2015; WAC, n.d.)

This study uses an extensive survey of over 200,000 sanitary facilities to provide a nation-wide picture of some of the major challenges in sanitation provision, focusing on reasons for pit-latrine abandonment. The economic implications of moving to higher quality sanitation are explored and the financial feasibility of pit-latrine emptying to increase higher-quality pit-latrine access is explored. The research responds directly to stakeholder concerns, expressed in consultation with the Ministry of Sanitation, Malawi. Specifically, we address the following research questions: (1) Are higher quality sanitation facilities (lined latrines with a slab) more resilient to extreme weather in Malawi than low-quality facilities (latrines with no lining or slab)? (2) What are the affordability considerations of high-quality sanitation provision in Malawi? (3) Could pit-latrine emptying be used to increase the affordability of higher quality sanitation provision in Malawi?

Materials and Methods

Study area

Malawi is a South-East African country, Figure 1, with a population exceeding 20 million (World Bank). The country is undergoing high population growth, with the population projected to exceed 30 million by 2040 and 54 million by 2070 (KC & Lutz, 2017). Currently, around 23% of the population has access to improved sanitation (Hinton et al., 2023b), the Government of Malawi aims to ensure 100% access to safely managed sanitation (an improved, non-shared sanitation facility) by 2060 (NPC, 2021). Pit-latrines provide the main form of sanitation and are used by over 90% of the population (Hinton et al., 2023b). These have been linked to contamination of groundwater (Graham & Polizzotto, 2013.; Hinton et al., 2023a; Rivett et al., 2022), a major source of drinking water, with over 60% of improved sources of drinking water coming from boreholes and tubewells (NSO, 2021). Boreholes and tubewells in Malawi have high levels of contamination; over 60% of boreholes have *E. coli* contamination (NSO, 2021). In addition, high levels of non-functionality limit water access; 40% of boreholes are partially or completely non-functional (Hinton et al., 2021.; Kalin et al., 2019). Inappropriate provision of Water, Sanitation, and Hygiene (WaSH) places a significant health burden on the country; 52% of outpatients are estimated to seek treatment for water and sanitation related diseases (Chavula, 2021). This was further underscored in 2023 by Malawi's most deadly cholera outbreak, with widespread drinking water contamination being suggested as the major reason for the severity of the outbreak (Sokemawu Freeman et al., 2024).

Rapid urbanisation is also shaping Malawi's population demographics. Currently, 16% of the population resides in urban areas, this is projected to increase to 60% by 2063 (NPC, 2021). Most of the existing urban population reside in informal slum areas (NPC, 2021). High levels of poverty limit the potential for improved access to sanitation with over 70% of the population living below the international poverty line of $2.15 per day (World Bank). Sanitation facilities are primarily constructed by users themselves with high capital investment often not possible.

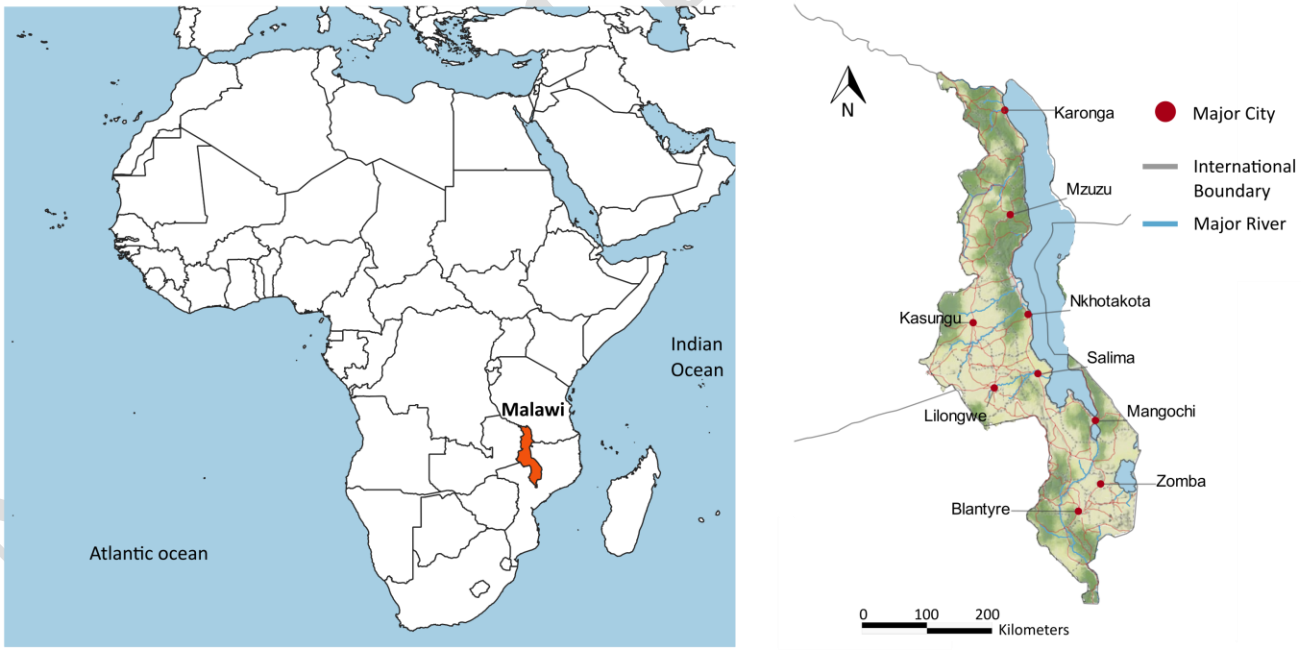


Figure 1: Map of study location, Malawi, with major features shown. Image made with QGIS using Stamen Terrain background.

Study design

A national survey of sanitary facilities across Malawi, was conducted by the Government of Malawi through the Scottish Government Climate Justice Fund Water Future Programme. A total of 268,180 sanitation facilities were surveyed by trained Government of Malawi surveyors with surveys conducted in Chichewa and English. Responses were recorded and hosted on the online platform mWater (mWater). Surveys investigated the type of facility, condition, typical usage, and the management of the facility (notably emptying procedures). The types of facility categorised in the survey were: Flush/ pour flush toilet, Ventilated Improved Pit (VIP) latrine, Pit-latrine without slab, composting toilet, hanging toilet/ latrine, pit-latrine without slab/ open pit, bucket, and other. Whether latrines were lined was asked as an additional question.

Questions were also asked regarding previously abandoned facilities that had been replaced by the surveyed latrine. Following data collection, all responses were quality controlled by the University of Strathclyde. Additional data cleaning was implemented to remove duplicate entries (where multiple visits through time were undertaken). This study is restricted to responses to surveys conducted between 2018–2019, resulting in 201,782 responses. Only data related to pit-latrines (VIP latrines and pit-latrine with/ without slab) was investigated, these made up the majority of responses with 201,381 complete pit-latrine surveys analysed.

Quantitative data analysis

All data collection of prices was in Malawian Kwachas (MK). To enhance understanding, and to account for significant devaluation of the Kwacha since 2019, 2024 US Dollar (USD) equivalents were calculated, taking an exchange rate of 1 MK 2019 = 0.001652 USD 2024.

Data on the cost and frequency of emptying was collected within a given bracket (range) of costs/ frequencies. The average cost and frequency of emptying was calculated by taking the average cost/ frequency for each bracket. For the upper price bracket (>20,00 MK, 2019), the maximum cost of pit-latrine emptying was taken as 40,000 MK (2019) (personal correspondence). For a pit-latrine emptying frequency of more than 3 years, the maximum pit-latrine emptying frequency taken was 15 years, based on literature estimates of pit-latrine emptying frequency (Jenkins et al., 2015). Average costs and frequencies were calculated based on the service provider. Standard error was calculated as the standard deviation divided by the root sample error for each service provider group.

Data on the cost of construction and risk of collapse was analysed by sanitary facility type. Construction costs were provided as brackets of cost, to calculate the average cost, the average price within each price bracket was taken and mean construction costs for each type of facility calculated. Standard error was calculated for each cost as the standard deviation divided by root sample number. To estimate the average costs for the upper bracket (>50,000 MK, 2019), a maximum cost of 100,000 MK (2019) was estimated based on stakeholder consultation.

To evaluate the risk of collapse based on the pit-latrine construction, the number of facilities that were partially or fully collapsed (including those still in use) as well as the number of facilities that were partially or fully collapsed (but not in use) were calculated for each construction type. Two-sided t-tests (5% significance level) were used to determine whether there was a statistically significant greater collapse risk between groupings.

To further evaluate the risk of collapse, and subsequent abandonment, based on construction, the reasons for pit-latrine abandonment were evaluated. The analysis focussed on whether pit-latrines were primarily abandoned due to collapse or filling up, the most common causes of latrine abandonment in Malawi (Hinton et al., 2023), based on their construction type. Respondents listed any reasons why facilities had been abandoned as qualitative responses. Content analysis was used to sum the total number of facilities where collapse from rainfall had contributed to why the

facility was abandoned as well as cases where the latrine filling up had contributed to abandonment, these were then broken into cases where the facility were pit-latrines with and without slabs (the most common latrines). Data was not available on the lining of abandoned facilities.

Qualitative content analysis

Qualitative content analysis was applied to investigate the responses to the questions 'Why has this pit-latrine been abandoned' and 'Why hasn't the pit-latrine been emptied?' For pit-latrine abandonment, respondents listed multiple reasons chosen from a list of suggested responses. For the purposes of this study, cases which listed that the pit-latrine had been abandoned as it had "Collapsed due to rainfall" and "It has filled up" were counted. This was used to provide an indication of the relative frequency of fill up and collapse for multiple types of sanitary facility.

To evaluate the reasons for pit-latrines not being emptied, a more thorough investigation of all reasons was undertaken. Respondents were asked to provide one primary reason which would be selected from a list of responses or which respondents could provide themselves. All responses from default responses were summed and unique responses were evaluated to identify their primary theme. Responses were initially grouped into subgroups based on similarities in the responses. Subgroups were then grouped into thematic groups, identifying three thematic areas: 'lack of capacity', 'not appropriate for/ desired by the community', and 'not appropriate for the latrine'.

Table 1: Thematic groupings of reasons given for the why pit-latrine emptying was not being practiced in national survey of latrine facilities. Responses were placed categorised according to whether they corresponded to the 12 sub-groups and associated 3 thematic groups.

Thematic group	Subgroup
Lack of **capacity**	Lack of money to pay service provider
	Lack of technical knowledge to empty latrine
	Someone else empties facility
	No materials
	No service provider
Not appropriate for the **latrine**	Latrine not yet full
	Latrine design inappropriate (structural design does not permit emptying)
	Temporary/ additional facility
Not appropriate for the **community**	Against cultural beliefs
	Dig new latrine/ enough land
	No interest

Ambiguous	Ambiguous

Results

Frequency of collapse and filling of pit-latrines

201,381 facilities had information on the type of facility and nature of construction. The number of latrines of each type that had collapsed were evaluated to estimate the risk of collapse according to construction type. Further information of the number of facilities that were partially or fully collapsed by type is found in Supplementary Information, Table 1.

The number of each facility type (low-quality and high-quality) that had recently collapsed due to rainfall or had filled is summarised in Table 2.

Table 2: Summary of extent, cost, level of collapse, frequency of filling, and age of low-quality and high-quality sanitation facilities based on national survey of latrines.

Latrine type	Percent of all sanitation facilities/ %	Average cost of construction/ 2024 USD	Percent of facilities (partially or totally) collapsed/ %	Average age of collapsed facilities/ years	Average age of filled facilities/ years
Low-quality latrine (unlined and without a slab) (n=153,437)	76.2	17.1 ± 0.03	21.9	4.08 ± 0.043	5.53 ± 0.074
High-quality latrine (lined and with a slab, including VIP latrines) (n=24,192)	10.7	87.9 ± 0.29	6.75	12.4 ± 0.84	10.7 ± 0.41

Low-quality latrines were the most common facility, making up 76.2% of all latrines and were also the most likely to collapse (21.9% of facilities were partially or fully collapsed). High-quality facilities had a 3.2 times lower incidence of collapse (6.75%). The age of collapsed latrines (totally collapsed or partially collapsed and not in use) was used to estimate the time taken for the latrine to collapse. Low-quality latrines collapsed more frequently than high-quality latrines (p-value < 2.2e-16) with low-quality latrines collapsing 3.04 times more frequently than high-quality latrines.

Pit-latrine lining was the most significant structural consideration in reducing the risk of collapse, with unlined latrines 3.1 times more likely to be partially or totally collapsed than lined latrines (average 21.6% and 7.04% of latrines respectively). Slabs also decreased the risk of collapse; pit-latrines without a slab were 1.7 times more likely to be partially or totally collapsed than pit-latrines with a slab (average 21.4% and 12.4% respectively).

The age of latrines that were recently filled is used as an estimate of the time taken for the latrine to fill up. High-quality facilities took significantly longer to fill than low-quality latrines (p-value < 2.2e-16), taking 5.5 years and 10.7 years respectively to fill up.

Content analysis reasons for abandonment

Further analysis of the implications of construction type of latrine abandonment was conducted by evaluating reasons given for why latrines had been abandoned (9,500 latrines). Most abandoned low-quality latrines were abandoned (at least partially) due to collapsing because of rainfall. In contrast, most abandoned high-quality latrines were abandoned (at least partially) due to filling up.

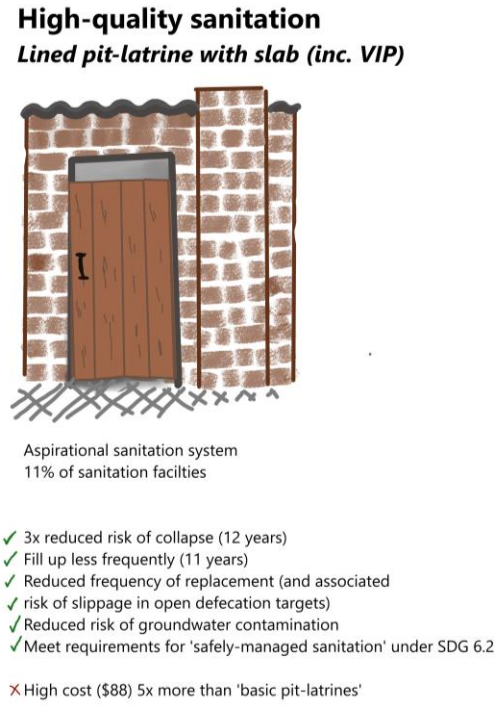
Table 3 summarises the number of cases in which collapse due to rainfall or filling up were cited as reasons for abandonment of low-quality and high-quality pit-latrines.

Table 3: Number of cases where collapse due to rainfall or filling up were given as a reason for why abandoned latrines had been abandoned by the type of pit-latrine facility. Multiple reasons could be listed as causes of abandonment.

	Collapsed due to rainfall listed as reason for abandonment	Percent of abandoned latrines listing collapsed due to rainfall	Filling up listed as reason for abandonment	Percent of abandoned latrine listing filling up
Low-quality latrine (unlined without a slab) (n= 6315)	4397	69.6	1641	26.0
High-quality latrine (lined with slab) (n=88)	32	36.4	49	55.7

Challenges for sanitation

Figure 1 summarises some of the main benefits and drawbacks of low-quality and high-quality sanitation in Malawi as identified in this study (and in literature).



239

Pit-latrine emptying 240

Costs of pit-latrine emptying were evaluated to identify whether they could effectively reduce costs associated with higher pit-latrine construction. Overall, 1.26% of pit-latrines were emptied (2,540 cases). Local service providers were the most common facilitators of pit-latrine emptying (56.1%). Manual emptying was the most common method used for emptying (80.2%) and the most common latrine emptying frequency was less than every 3 years. The averages of pit-latrine emptying frequency and cost are summarised in Table 4. 241 242 243 244 245

Table 4: Pit-latrine emptying practices summarising average costs and frequency of emptying practices by pit-latrine emptying provider. 246

	Emptying cost/MK (2019)	Frequency/ years	Percent of pit-latrines emptied by provider %
All emptying	**25.24 ± 0.43**	**5.57± 0.07**	
Owner	10.84 ± 0.46	3.34 ± 0.11	38.6
Local service provider	34.81 ± 0.55	6.98 ± 0.08	56.1
Other	27.11 ± 1.82	6.51 ± 0.32	5.32

Latrines emptied by owners were emptied more frequently than latrines emptied by local service providers (p-value < 2.2×10^{-16}), emptying an average of 2 times as frequently. Latrine emptying by owners was cheaper (p-value < 2.2×10^{-16}), costing 3.2 times less than by local service providers. On average, emptying was assumed to have an annual cost of 4.53 USD. 247 248 249 250

Costs of sanitation management

The average costs of construction and lifespan were taken for both high-quality and low-quality sanitation provision. Low-quality latrines were assumed to be abandoned due to collapse after 4.1 years. High-quality latrines were assumed to be abandoned due to filling up after 10.7 years unless they were undergoing emptying, in which case they were assumed to not fill up but to be abandoned due to collapse after 12.4 years. Table 5 summarises the costs for sanitation management in each case. The average cost of pit-latrine emptying is taken. On average, the reduced frequency of replacement of emptied pit-latrines is not sufficient to offset the cost of emptying as high-quality facilities still undergo collapse. High-quality facilities being emptied would have to have more than double the current lifespan of high-quality, not emptied, facilities (from 10.7 years to 23.9 years) for the current cost of emptying to be cost-effective in reducing the overall cost of sanitation.

Table 5: Average annual construction and management costs of alternative latrine construction and management scenarios taking average costs, lifespan, and causes of abandonment for each latrine type.

	Low-quality latrine, not emptied	**High-quality latrine, not emptied**	**High-quality latrine, emptied**
Construction cost/ USD	17.1 ± 0.03	87.9 ± 0.29	87.9 ± 0.29
Lifespan/ Years	4.08 ± 0.043	10.7 ± 0.41	12.4 ± 0.84
Annual cost from construction/ USD	4.19 ± 0.046	8.21 ± 0.12	7.09 ± 1.13
Primary reason for abandonment	Collapse due to rainfall	Filling up	Collapse due to rainfall
Annual costs from emptying/ USD	0	0	4.53 ± 0.5
Total annual costs/ USD	4.19 ± 0.046	8.21 ± 0.12	11.6 ± 1.63

Reasons against pit-latrine emptying

Table 6 summarises the reasons given for why pit-latrine emptying was not being carried out. 231,331 individual responses for why latrines were not emptied were provided and analysed (some surveys have more than one reason and were listed as separate responses).

Table 6: Reasons given for why pit-latrine emptying was not carried out, grouped by thematic groups and broken into sub-groups

Thematic reason	Sub-group	Number of responses	Percent of responses/%
	Lack of money to pay service provider	27,600	11.9

Lack of capacity (77.9%)	Lack of technical knowledge to empty latrine	152,000	65.8
	Someone else is responsible for facility emptying	141	0.06
	No materials	46	0.0199
	No service provider	158	0.0683
Not appropriate for the latrine (4.38%)	Latrine not yet full	9,720	4.20
	Design of latrine (locally made or structural design that does not permit emptying)	265	0.115
	Temporary or additional facility	148	0.640
Not appropriate to/ wanted by the community (17.4%)	Against cultural beliefs	28,800	12.4
	No interest	147	0.0635
	Dig new latrine/ enough land	11,200	4.84
Ambiguous (0.371%)		856	0.371

A lack of capacity was the biggest thematic reason for the pit-latrine not being emptied (77.9%) with a lack of technical knowledge listed as the primary subgroup (65.8% of all reasons given). The second most common sub-group within this thematic group was a lack of money to pay a service provider and was the second most common response across all categories with 11.9% of responses. 'Cultural beliefs' was the second most common subgroup (12.4% of all responses).

Discussion

Costs and resilience in sanitation provision

Despite widespread access to low-quality sanitation in Malawi, the use of high-quality sanitation provision is low, with over 75% of the population not having access to high-quality facilities (Hinton et al., 2023b). The extent of poor-quality sanitation has been linked to a nexus of challenges in Malawi, including accessibility limitations of sanitary facilities (Chinoko, 2023; Biran et al., 2018) ODF slippage, primarily attributed to pit-latrine collapse (Hinton et al., 2024b), and groundwater contamination (Rivett et al., 2022; Back et al., 2019; Hinton et al., 2024a). However, reports of the challenges of pit-latrine collapse have been highly localised and often anecdotal, providing little conclusive evidence of the role of pit-latrine construction to the resilience of facilities. This is the first national study to evaluate pit-latrine collapse and resilience.

Through a national survey of 268,180 latrine facilities across Malawi, we find that high-quality pit-latrines (lined latrines with a slab) collapsed 3 times less frequently than low-quality latrines (without lining or a slab), collapsing after 12.4 and 4.1 years respectively. High-quality latrines were 3 times less likely to be in a collapsed state; 6.8% of high-quality latrines were partially or totally collapsed compared to 21.9% of low-quality latrines. Many of these facilities were still in use despite being partially collapsed, creating a serious concern for public health and accessibility. Similarly, analysis of abandoned pit-latrines that were no longer used revealed that low-quality facilities were more than 2 times more likely to list rainfall-induced collapse as a reason for abandonment than high-quality facilities. *Low-quality sanitation facilities collapsed more frequently, were more likely to be in a state of disrepair, and were abandoned more frequently due to rainfall induced collapse than high-quality facilities.*

Yet despite the benefits of pit-latrine lining and slab construction, many pit-latrines do not meet these standards. Of the analysed subset of 201,782 pit-latrines, 11% met the criteria of high-quality (lined and with a slab) whilst low-quality facilities made up 76% of the latrines. Cost plays an important role in latrine construction standards (Banana et al., 2015; Kariuki, 2003), high-quality facilities were 5 times more expensive than low-quality facilities. The increased capital costs of construction of higher quality facilities present an obvious and significant barrier to access to safe sanitation. Higher construction costs of high-quality facilities have sometimes been justified by their enhanced lifespan, reducing the annual cost of the higher service provision (Mills et al., 2020; Mitchell, 2007). Within this study however, accounting for the extended lifespan (3 fold) of high-quality facilities, the associated costs of higher-quality sanitary provision was significantly higher than low-quality sanitation (annual costs of $8.21 and $4.19 costs respectively). Whilst both scenarios still fall within what would be considered to be the upper limit of affordable sanitation provision for urban households in low-income areas of $3 to $4 (Banana et al., 2015), the difference between low-quality and high-quality sanitation is stark. *Costs of high-quality sanitation are prohibitive in Malawi, innovation and investment is necessary to enhance access to high-quality sanitation facilities.*

Our findings are consistent with literature identifying collapse of latrines with poor construction quality as a major challenge worldwide (Kouassi et al., 2023). They also feed into a growing body of study identifying resilient sanitation construction as a critical consideration in building climate resilience and supporting the call for a greater focus on sanitation justice within the climate justice conversation.

Pit-latrine emptying practice

Sanitation management practices can bring multi-faceted solutions to the nexus of challenges surrounding sanitation provision. Alongside playing a role in reducing chemical and microbial groundwater contamination (Gwenzi et al.,

2023;Templeton et al., 2015), pit-latrine emptying can increase the lifespan of latrines by reducing the rate of abandonment due to filling up. This presents a potential solution to some of the challenges facing high-quality sanitation facilities which are most often abandoned due to filling up (over 56% of abandoned high-quality facilities citing this as a reason for abandonment).

Despite the benefits of pit-latrine emptying, it is very rarely being implemented in Malawi; only 1.26% of pit-latrines were emptied nationally in 2019. This is consistent with literature finding low adoption of pit-latrine emptying in Malawi (Chipeta et al., 2017; Rochelle et al., 2015). Further analysis of the 2,540 cases of pit-latrine emptying was used to provide insight into the nature of pit-latrine emptying, this revealed a high cost of emptying, with an average cost of over $25 USD per event, and emptying being carried out once every 5.6 years. Local service providers were the most common facilitators of emptying and charged a higher price, although did not require as frequent emptying, as owner emptied facilities (respective costs of $35 and $11 and frequencies of once every 7.0 and 3.3 years respectively). These fall within the range of recent literature estimates of latrine emptying cost and frequency both within Malawi (Holm et al., 2018) and other low-income settings (Balasubramanya et al., 2017; Burt et al., 2019). Manual emptying was the most used method for emptying by local service providers, owners, and other practitioners; 80% of all emptied latrines were emptied manually. This finding agrees with global literature identifying manual emptying as the most common method of emptying within sub-Saharan Africa. The high level of manually emptied latrines raises health and wellbeing concerns for practitioners (Riordan, 2009a; Thye et al., 2009) as well as environmental contamination due to the common inappropriate disposal of manually emptied faecal waste (Capone et al., 2020).

Comparison of the costs of pit emptying to abandonment or replacement further emphasised the prohibitive costs of pit-latrine emptying. The annual average costs of pit-latrine emptying ($4.53) were higher than the annual average costs of low-quality pit-latrine construction ($4.19). Comparing the costs of emptied high-quality facilities (which benefited from an increased lifespan) and non-emptied high-quality facilities also found the cost of pit-latrine emptying to be prohibitively high, the 2 years lifespan gained from pit-latrine emptying was found to be insufficient to warrant the costs incurred making pit-latrine emptying only cost effective for the most expensive facilities. As such, at the current prices, *pit-latrine emptying is unable to provide a way to subsidise the high costs of high-quality pit-latrine construction.* For pit-latrine emptying to provide a mechanism to subsidise the high costs of high-quality sanitation provision, emptying costs would need to reduce to a third of current prices.

Promotion of a competitive private sector market and increased sanitation disposal site provision could help to drive down the price of pit-latrine emptying, enabling it to become an economically viable solution to some of the challenges in waste management (Kariuki, 2003). In Dar es Salaam, Tanzania, promotion of emptying did successfully cause pit-latrine emptying prices to halve (Kariuki, 2003). Alternatively, municipal pit-latrine emptying services could provide a method to promote pit-latrine emptying and reduce some of the costs of high quality sanitation usage. An example is seen in the eThekwini Municipality in KwaZulu-Natal, South Africa, in which municipal workers provide emptying services of VIP pit-latrines at no cost on a 5-year cycle (Beukes & Schmidt, 2022). Whilst costless emptying services may not be economically feasible, providing subsidies for emptying could incentivise increased pit-latrine emptying practice (Burt et al., 2019; Kariuki, 2003), potentially further driving down prices.

However, even if pit-latrine emptying were free, for many Malawians the increased costs of constructing high-quality sanitation would remain prohibitively high. To enable safer, equitable, and resilient sanitation in Malawi, significant investment will be necessary. Replacing the 150,000 unlined pit-latrines without slabs currently in use in Malawi with high-quality facilities would involve a $13.5 million investment. The costs of meeting the sanitation needs of the country are significantly higher with ongoing costs required to replace facilities, meet the needs of those currently without

even low-quality sanitation, and keep up with the ever-growing sanitary requirement of the country (Hinton et al., 2023).

Whilst the costs of improving sanitation provision are high, the national economic benefits of high-quality sanitation are central to considerations (Van Minh & Hung, 2011). Indeed, cost of sanitary provision is dwarfed by the cost of inaction and current financial burden of inadequate sanitation provision; in 2012, poor sanitation was estimated to cost Malawi approximately 1.1% of its GDP ($US 57 million) (WSP, 2012).

Beyond the community level, a lack of clear guidance and regulation on the emptying, transportation and management of faecal waste has been identified as a major barrier to pit-latrine emptying capacity within East Africa (Jayathilake et al., 2019; Nanyonjo et al., 2022). Not only does the lack of guidance result in highly variable prices (Jayathilake et al., 2019), but also the process of emptying poses a health concern due to the pathogenic nature of faecal sludge (Riordan, 2009; Thye et al., 2009), making insufficient regulation and guidance a public health concern. Limited infrastructure to enable emptying, both a lack of disposal sites as well as urban and road infrastructure being incompatible with tanker trucks, further hold back pit-latrine emptying.

Cultural and social context of pit-latrine emptying

Though currently not cost effective, the additional benefits of pit-latrine emptying with regard to spatial limitations, ODF slippage following abandonment, and environmental pollution could still make pit-latrine emptying a tool in safe sanitation provision. Qualitative analysis supports the call for the promotion of affordable pit-latrine emptying services. Pit-latrine emptying costs were the third most cited reason for why pit-latrine emptying was not conducted (cited by 11.9% of respondents), suggesting that investment to reduce pit-latrine emptying costs could lead to an increase in adoption. This echoes literature finding cost to be prohibitive to pit-latrine emptying in Malawi (Holm et al., 2018) and Rwanda (Burt et al., 2019). Similarly, the most cited reason, a lack of technical knowledge for latrine emptying (65.8%) could be overcome by promotion of affordable pit-latrine emptying services enabling emptying without owners requiring technical capacity.

Whilst promotion and regulation of affordable pit-latrine emptying services may provide a method to promote higher quality pit-latrine construction, socio-cultural limitations to emptying cannot be ignored (Buxton & Reed, 2010; Olapeju et al., 2019). Cultural beliefs was the second most common reason for why pit-latrines were not emptied (12.4%). Cultural factors must be considered within the development of appropriate pit-latrine emptying policy and practice (Rochelle et al., 2015; Buxton & Reed, 2010; Olapeju et al., 2019). Leveraging social capital is central in promoting community level sustainable WaSH practices in Malawi (Hinton et al., 2021). Such promotion will require enhanced community knowledge and engagement of the benefits of faecal sludge management (Rochelle et al., 2015; Strauss & Montangero, 2004).

Study Limitations and further considerations

This study presented a national level evaluation of sanitation and pit-latrine emptying practices. As such, there were limitations to the level of detail possible to gather for every latrine. Estimates of latrine construction costs as well as the cost and frequency of emptying were based on categories with the average of each category taken in the calculation of the overall average. The upper estimates for the highest category was based on literature estimates of the upper limit. There may not be a normal distribution of values within each category resulting in the potential for under or over estimation of averages for these values.

In addition, whilst different fill-up times were calculated for lined to unlined latrines, the latrine lining itself can result in very different fill up times (Reed, 2014). Similarly, the study assumes a continuous rate of pit-latrine emptying, however, older facilities may require more frequent emptying, potentially underestimating pit-latrine emptying costs over longer time periods (Jenkins et al., 2015).

The scenarios here provide comparative costs between scenarios, accounting only for pit-latrine construction and emptying prices as the main costs. Maintenance, cleaning, and supplies are not factored into the estimated pricing as these are assumed to be equal under all scenarios. As such, these results should not be taken as absolute values of the estimated costs of sanitation provision. Finally, it should be noted that since the survey completion (2020), Malawi has undergone high levels of devaluation, therefore prices in Malawian Kwacha are not applicable to current costs. Prices are given in the equivalent value of current (2024) US dollars based on the 2019 value of the Malawian Kwacha. In addition, whilst three national-level scenarios are evaluated there is likely to be spatial heterogeneity in pit-latrine management and emptying, with regional variation in pricing and usage patterns making some scenarios more or less likely in different regions (Mills et al., 2020). Indeed, higher levels of pit-latrine emptying were noted along roads and in urban areas where there may be greater service provider provision alongside increased pressure on space, necessitating emptying over replacement (Kariuki, 2003). Further research should explore the sub-national patterns and trade-offs in pit-latrine management practises, accounting for regional differences in pricing, spatial pressures, and cultural dynamics.

Policy recommendations

Provision of more resilient sanitation systems will be critical to meeting the needs of the population of Malawi. However, such systems come at a premium with significantly higher costs, both initial capital investment and average annual pricing. Promotion of micro-loans should be used as a method to reduce the higher capital costs that act as a road block to building more expensive infrastructure (Afrane & Poku, 2013; Coli et al., 2021; Satterthwaite et al., 2015). However, these should be couped with additional investments, including in the form of subsidies. Increased investment in sanitation to ensure higher quality construction should take into account the significant costs of inaction in upgrading sanitation supply (Van Minh & Hung, 2011). Alleviating the significant burden of inadequate sanitation in Malawi, of over 50% (Chavula, 2021), necessitates greater investment from both Governmental and NGO funding bodies, such investment must consider the *quality* of sanitation infrastructure alongside *quantity.*

Alongside the current financial burden of inadequate sanitation, investment into resilient, high-quality infrastructure must be considered within the future challenges of growing spatial constraints within urban contexts (Kouassi et al., 2023) and building climate resilience. These aspects should be emphasised in sanitation promotion initiatives, such as the widely used community led total sanitation (CLTS) strategy, focusing on safe and sustainable sanitation provision over low-quality provision (Kouassi et al., 2023). If the costs associated with high-quality sanitation were reduced to enable high-quality sanitation infrastructure more accessible, currently economically unfeasible methods such as pit-latrine emptying could have potential to reduce the associated investment needed. However, at current costs of both high-quality latrine construction and pit-latrine emptying, this is unfeasible.

Promotion of pit-latrine emptying as a waste management solution in Malawi will necessitate not only a reduction in user costs (such as through subsidies) but also significant investment in pit-latrine emptying infrastructure, notably, disposal sites. Increasing pit-latrine emptying infrastructure could aid in driving down the prices of emptying by reducing the significant transportation costs of emptying services. In addition, facilitation, and promotion of safe and sustainable usage of faecal waste, such as for fertiliser or biochar production, has potential to drive down the price of pit-latrine emptying (Midega, 2022), but is currently limited. Alongside infrastructure and economic considerations,

promotion of pit-latrine emptying, recognition of the cultural considerations surrounding faecal waste management are imperative. Management strategies to manage the growing burden of faecal waste management in culturally appropriate ways will be essential. Ensuring culturally appropriate faecal waste management will involve community engagement in strategy design and implementation (Buxton & Reed, 2010; Olapeju et al., 2019).

Conclusions

The high frequency, and associated challenges of, pit-latrine abandonment and collapse Malawi highlight a critical need for higher resilience in infrastructure. High-quality pit-latrines which featured pit-latrine lining and a slab, were found to collapse 3 times less frequently than low-quality latrines, without lining or a slab. Yet despite the reduced frequency of collapse and the increased lifespan of high-quality sanitation, a significant cost barrier remains a major obstacle to wider adoption of quality sanitation infrastructure. The prevalence of low-quality sanitation in Malawi, used by over 75% of the population, not only present a challenge to achieving the requirements of safe sanitation outlined in SDG 6.2 (Hinton et al., 2023) but also make the region vulnerable to extreme weather events and climate change.

Pit-latrine emptying offers potential benefits, such as extending the lifespan of facilities and reducing groundwater contamination, but the high costs associated with emptying, combined with cultural resistance and logistical challenges, prevent it from being a viable solution in its current form, implemented at 1.3% of sanitation facilities nationwide. For Malawi to achieve more equitable and sustainable sanitation solutions, a multifaceted approach is necessary. This will require substantial investment in both the construction of resilient sanitation infrastructure and the promotion of affordable sanitation management, such as pit-latrine emptying. Policy initiatives should focus on reducing user costs through subsidies, micro-loans, and the development of faecal waste management infrastructure. Additionally, addressing cultural factors and engaging communities in sanitation management will be essential to promote long-term adoption of high-quality practices. Inaction bears a high cost to public health and the economy, and addressing these challenges will be key to supporting both climate resilience and sanitation justice in Malawi.

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Ethics

Informed consent was obtained from all subjects involved in the study. All data collected was in line with the Government of Malawi ethics and was agreed with each participant.

Data availability

Confidential data were provided by the Government of Malawi. All data summarised is provided here.

Conflict of Interest

Modesta Kanjaye is Director of Sanitation and Hygiene, Ministry of Water and Sanitation, Government of Malawi

Abbreviations

MK (Malawian Kwacha)

CLTS (Community Led Total Sanitation)

WaSH (Water Sanitation and Hygiene)

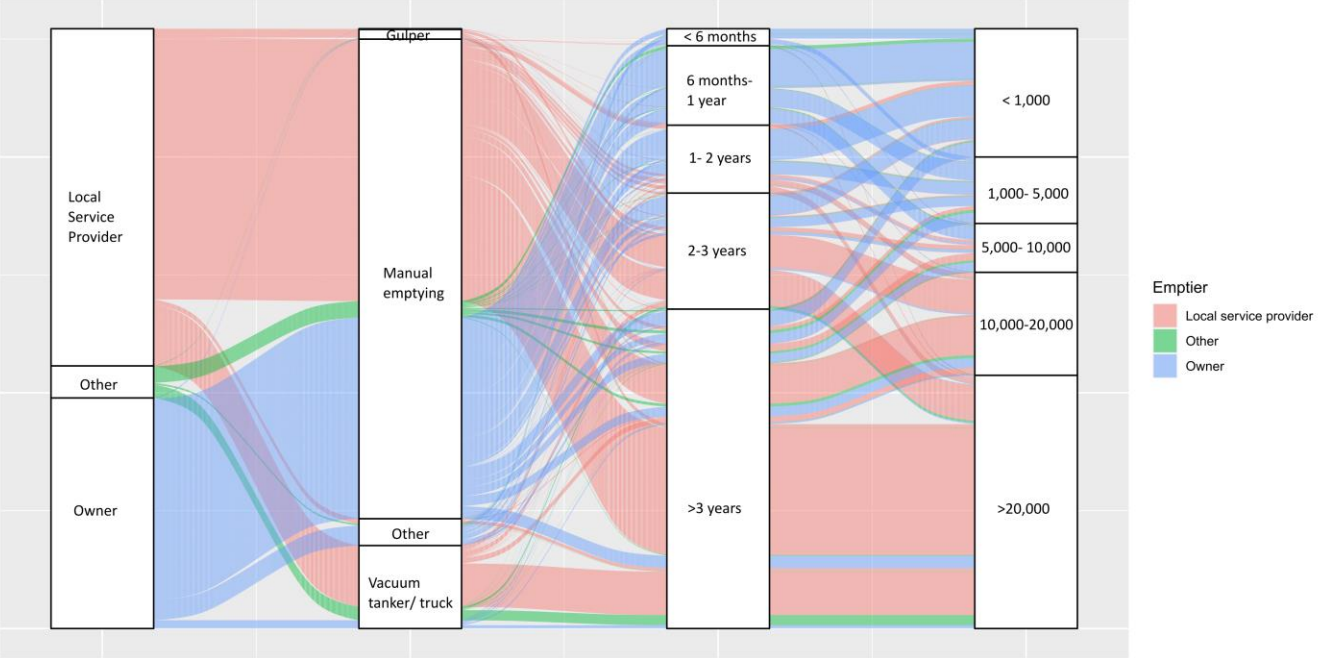
USD (US Dollar)

VIP (Ventilated Improved Pit-latrine)

Supplementary information

Supplementary Information Table 1: Structural status of pit-latrine by the construction type. Cases marked with an asterix (*) are considered high-quality facilities in this study.

	Number of latrines totally collapsed/ partially collapsed	Number of latrines totally collapsed/ partially collapsed and not used	Number of latrines structurally stable
All latrines	39,178	8,813	162,154
Lined latrines	2,090	55	27,643
Unlined latrines	37,088	8,758	134,369
Pit-latrine without slab	34,574	7,505	127,208
Ventilated Improved Pit-latrine (VIP) *	208	72	4,818
Pit-latrine with slab	4,080	1,140	28,780
Lined pit-latrine with slab *	1,056	30	15,430
Unlined pit-latrine without slab	33,686	7,485	119,815



Supplementary Information Figure 1: Pit-latrine emptying practices of facilities practicing pit-latrine emptying. Emptying provider, method, frequency and cost are summarised.

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