Creating Demand for Peri-Urban Sanitation in Lusaka, Zambia

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Declaration

I, James Benjamin Tidwell, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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And finally, to my dad:

> *DATA: I do not sense the same feelings of absence that I associate with Lieutenant Yar, although I cannot say precisely why.*
>
> *RIKER: Just human nature, Data.*
>
> *DATA: Human nature, sir?*
>
> *RIKER: We feel a loss more intensely when it's a friend.*
>
> *DATA: But should not the feelings run as deep regardless of who has died?*
>
> *RIKER: Maybe they should, Data. Maybe if we felt the loss of any life as keenly as we felt the death of those close to us, human history would be a lot less bloody.*
>
> *-Star Trek: The Next Generation*

You taught me, in how you lived your life every single day and took me along for the ride, how much every person matters, regardless of the color of their skin or where they happened to be born. And you sacrificed, right up until the end, so that we would want for nothing. Everything I do, I do in the hope that my life in some small way reflects my gratitude for what you've done for me and how your example stays with me even to this day. I love you.

Abstract

Poor health and economic outcomes caused by a lack of adequate peri-urban sanitation are a growing global problem due to rapid urbanization in lower- and middle-income countries. While some interventions have been effective in improving rural sanitation, few have been tested in peri-urban settings, where poor infrastructure and the high prevalence of landlord-tenant shared on-site sanitation present a very different behavior change challenge. Previous trials have focused on providing subsidies, community mobilization, only attempted to create demand by sharing health benefit information, or have targeted only improved cleaning behaviors. However, previous work has demonstrated that improvements in sanitation quality may be effectively driven by other levers, such as emotional motivators, resolving information asymmetries, or improving the systems driving behavior. In addition, many programs have intervened on the demand and supply sides simultaneously, making rigorous evaluation of each component challenging. Though demand-side interventions alone are unlikely to be sufficient to attain full coverage of safely-managed sanitation, they may be a key component of more comprehensive programs.

This thesis included formative research to build context-specific local knowledge about motivations, preferences, and social influences on sanitation quality; development of a composite measure of peri-urban sanitation quality; design of an intervention using a theory-driven creative process; assessment of tenant demand for sanitation using stated and revealed preference methods; and evaluation of the demand-creation intervention via a randomized, controlled trial.

The papers that make up this thesis are the first of which we are aware to study shared sanitation improvement behaviors and processes through the lens of a behavioral science theory; develop and validate an outcome measure suitable to capture the overall quality of on-site sanitation; quantify tenant willingness to pay for improved sanitation quality; and generate rigorous evidence about the effectiveness of demand-side sanitation interventions in peri-urban settings across a range of behaviors of public health importance. This thesis demonstrates that a demand-side-only intervention can significantly improve sanitation quality in a peri-urban setting.

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Chapter 1: Introduction

Context of the Study

About one-third of the world's population, or 2.3 billion people, lack access to adequate sanitation facilities like toilets or latrines, with 892 million still practicing open defecation [1]. This lack of improved sanitation, defined as facilities that separate human excreta from human contact [1], has serious health consequences, with an estimated 280,000 annual deaths linked to poor sanitation [2]. Poor sanitation is also responsible for about half of global malnutrition [3] and results in economic losses of about $222B annually [4].

Some recent progress has been made in expanding sanitation coverage. From 1990 to 2015, about 2.1 billion people gained access to adequate sanitation and the proportion of people openly defecating has decreased from 24% to 13% [5]. However, while improved sanitation coverage increased for the Southern Asia region from 22% in 1990 to 47% in 2015, coverage in Sub-Saharan Africa only increased from 24% to 30% in the same timeframe [5]. One reason for this is shared sanitation, which is technologically improved sanitation used by more than one household, increased in Sub-Saharan Africa from 14% to 20% [5].

Though rates of inadequate sanitation are higher in rural areas, achieving sanitation gains in marginalized peri-urban areas involves overcoming complex challenges due to widespread shared sanitation, high population density, and the need to contain, remove, and/or treat fecal sludge [6]. In addition, though open defecation was once a primarily rural issue, urban open defecation is increasing as services struggle to expand to meet the growing urban population [7]. The overall urban population as a percentage of the global total population increased from 34% in 1960 to 54% in 2014 [8], though recent reports suggest that these numbers may drastically understated due to the inadequate nature of the metric used [9]. The number living in peri-urban areas, which is usually defined as having poor housing quality, inadequate water and sanitation infrastructure, insecure residential status, and overcrowding [10], has increased from 650 million in 1990 to an estimated 863 million in 2014, and could affect as many as 2 billion people by 2035 [11]. Those living in peri-urban areas, who are more likely to have poor sanitation services, also experience worse health outcomes [12].

Motivation of the Study

One initial barrier to agreeing on how to address the challenge of shared peri-urban sanitation is reaching agreement even on what constitutes "adequate sanitation." The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) defined improved sanitation primarily by the technology being used, rather than other factors like use or cleanliness, and shared facilities are not considered improved [5]. There is little evidence of which elements related to improving sanitation have health impact [13] and there is great concern that inappropriate definitions of improved sanitation may be drastically overstating true coverage [14]. There is not yet enough evidence to be certain about the health impacts of shared sanitation [15]. There is some evidence that facilities shared by more users are dirtier [16], while others argue that shared facilities may be of higher structural quality [17], can be adequately maintained [18], and may provide health benefits and so should not be excluded from consideration as improved sanitation on that basis alone [18]. As a result, there has been a recent call to avoid labelling all shared sanitation as limited, as this may encourage countries to focus their sanitation efforts on wealthier areas where achieving household toilets is more feasible [19], and to focus on understanding how to improve the hygiene of shared facilities [20].

Yet, even if consensus were reached about what makes peri-urban shared sanitation of an acceptable standard, little is known about how to improve the quality of peri-urban shared sanitation. Peri-urban areas have been the target of fewer studies, with some evidence that cleaning behaviors can be improved [21, 22] or that building high-quality toilet blocks maintained by a compensated individual may be feasible in some contexts [23]. Sanitation marketing has been suggested as one effective approach to improve sanitation quality, but has been difficult to evaluate rigorously as it generally seeks to increase demand for and improve the supply of sanitation products and services simultaneously [24]. More research is needed to understand the mechanisms by which peri-urban sanitation quality can be improved.

Study Aim and Objectives

The aim of the study is to determine the degree to which shared peri-urban sanitation quality can be increased by a demand-creating behavior change intervention alone. Meeting the following specific objectives will contribute to achieving this aim:

1. To investigate consumer preferences related to sanitation to understand potential motivational levers to use, the role of social influence, and appropriate products or hardware solutions to promote.
2. To develop and validate a scale for peri-urban sanitation quality that allows comparisons across types of sanitation.
3. To establish reliable methods for assessing consumer demand for sanitation and use them to understand existing demand in the study setting.
4. To experimentally test the hypothesis that increasing demand for sanitation can increase sanitation quality without any intervention on the supply side.

Significance of the Project

This study will make theoretical contributions in understanding what constitutes high-quality peri-urban shared sanitation and the attributes and processes that lead to its improvement. It will provide evidence towards a tangible solution to low quality peri-urban shared sanitation, including the creation of a theory-driven intervention that can serve as a basis for future programs. It will use innovative methods of behavioral-theory-driven formative research and econometric modelling to understand the key drivers of shared peri-urban sanitation quality, with substantive and methodological implications for researchers and policy makers working in peri-urban sanitation.

Overview of the Dissertation

I begin in chapter 2 with a brief review of what is known about creating demand for shared, peri-urban sanitation, including potentially useful references from rural and urban settings due to the limited work in this area. I also survey demand assessment methods to motivate the tools used in this study and some theoretical context to understand why the Behavior Centered Design (BCD) framework was selected to guide the intervention design and evaluation process and how it compares to other behavior change theories. I then present a series of papers describing the steps of the research project. Chapter 3 describes the formative research process, which consisted of semi-structured interviews with landlords and tenants in the study setting and provides suggested intervention targets resulting from thematic qualitative and descriptive quantitative analysis. Chapter 4 builds on user preferences related to sanitation quality discovered in the formative research to develop a generic theoretical framework for sanitation quality, which is then applied in the study setting to create a theoretically-grounded composite measure of sanitation quality to compare different types of sanitation across settings. Chapter 5 describes the process by which formative research insights and detailed measures of sanitation were used to create a theoretically-driven peri-urban sanitation demand creation intervention, with reflections on how this process led to empirical findings to inform practice as well as opportunities to reflect on the theoretical approach and the advancement of behavioral science as a discipline. Chapter 6 describes the use and comparison of a variety of demand assessment methods to quantify tenant willingness to pay for improved sanitation quality (thus validating one of the findings from the qualitative formative research) and discusses the impact of landlords' failure to incorporate this willingness to pay appropriately in their investment decisions, with empirical and methodological implications for improving sanitation quality in other settings. Chapter 7 reports the results of the 'Bauleni Secret' intervention, evaluated through a randomized, controlled trial where various sanitation quality improvements were encouraged with mixed success and includes discussion of a number of practical challenges that will need to be addressed in future trials. Chapter 8 then concludes with a summary of the findings from the project, with a discussion of implications for reaching the sustainable development goal for sanitation, and suggests a future research agenda for improving peri-urban sanitation quality.

Research Questions

The following specific research questions will be addressed in this dissertation:

1. What are the major determinants of peri-urban sanitation status, particularly related to root causes and factors that can be changed via targeted interventions?
2. What are the basic motivations that drive people to improve their sanitation status?
3. What preferences do landlords and tenants have for particular sanitation quality improvements?

4. What makes any particular sanitation system “high quality,” and thus should be considered “improved?”
5. How can shared, peri-urban sanitation quality be reliably measured?
6. How has sanitation demand been measured, and how reliable are these approaches?
7. What is the existing demand for peri-urban sanitation quality improvements by both landlords and tenants?
8. What economic case for sanitation improvement can be made based on return on investment compared to other investments available to landlords?
9. How should a peri-urban sanitation quality behavior change intervention developed to maximize its chance of success and learning to inform future programs?
10. How much can a demand-only behavior change intervention improve sanitation status?

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Chapter 2: Background

Chapter Overview

This background chapter situates the thesis within existing bodies of literature. As several of the chapters are papers that include a sufficient overview of the literature, some topics are covered only briefly here or described only elsewhere in the thesis. The background chapter covers or refers the reader elsewhere to understand how shared, peri-urban sanitation is defined and measured, the state of existing knowledge regarding creating demand for shared, peri-urban sanitation, what is meant by demand and how it is measured, the study context and setting, and an overview of the Behavior Centered Design framework used in this thesis and its relationship to other behavior change approaches.

Shared, Peri-Urban Sanitation

The Sustainable Development Goal (SDG) for Sanitation (6.2) calls for an end to open defecation (OD) globally by 2030, and the measure to be used is the percentage of the population using safely managed sanitation, defined as "an improved sanitation facility that is not shared with other households, and where excreta are disposed of in situ or transported and treated off-site" [1]. As of 2015, about 4.5 billion people globally lacked access to safely managed sanitation by this measure [1]. About 600 million more used a limited sanitation service, which is technologically improved, but shared by more than one household, and though global OD rates are decreasing, many of those who formerly practiced OD are moving to limited sanitation, especially in sub-Saharan Africa [5]. There is much discussion currently about whether limited sanitation should be counted as "adequate" if it meets certain criteria [19], as shared sanitation may be just as clean as household sanitation [18], and perhaps even of higher structural quality [17].

Better tools for measuring different types of sanitation are needed if we are to be able to assess when limited sanitation should be considered adequate, especially across household, shared, and public toilets. Recent frameworks that go beyond lists of technological definitions have focused on functions of sanitation in a wider, ecological sense [25], variations in intra-household sanitation use [26], establishing more in-depth toilet quality measures [17], and developing tools to capture the status of community- and city-level sanitation systems [27]. However, many of these tools do not have a solid theoretical foundation from which to derive a sanitation quality measure [28] or generate only summary data. This gap between high-level summaries and detailed tools also means that many components of sanitation are excluded—particularly those related to aspects like privacy and safety, rather than simply excreta management.

I conduct a thorough review of available sanitation quality frameworks and of individual measures of component quality in the supplementary material published along with the paper that represents Chapter 4, and so will postpone this part of the argument until then.

Creating Demand for Shared, Peri-Urban Sanitation

Determinants of sanitation quality in peri-urban areas present in the literature broadly fall into four categories: demographic and socio-economic factors, knowledge and attitudes, social influence, and peri-urban-specific factors. The earliest literature on sanitation quality generally consists of cross-sectional analyses of correlations between sanitation quality and demographic and socio-economic variables. Level of income or wealth has been reported as predicting sanitation quality in several studies [29, 30], and cost was found an important consideration in observational studies [30] as well as interventions related to subsidy provision [31] and improving access to microcredit [32]. Household size is also correlated with sanitation quality, though perhaps with confounding effects of level of income or other factors [29]; the location of one's neighborhood [33] and the amount of space owned [34] are also related to better sanitation.

The second major category of sanitation status determinants is knowledge and attitudes related to sanitation. General level of education and health knowledge in particular, which is a common target of public health interventions, can be positively correlated with sanitation quality [35], though this is not always the case [36]. Level of health insurance coverage, potentially a proxy for the importance of health, has also been found to have a positive association with sanitation quality [33]. In terms of attitudinal drivers, factors related to the ease of use of the sanitation solution are widely reported in the literature, including accessibility [37], convenience [38, 39], and comfort [39]. Personal safety is also a major concern [39, 40], though this may be less of an issue in peri-urban settings than in more remote rural settings, but the related desire for privacy [37, 38] is likely more relevant in the context of this study. Status has been identified as a major driver of improving sanitation quality [41], and some studies in peri-urban contexts have similar findings [38, 40]. Closely related senses of pride [40] and modern living [37] have also been found to be important drivers of sanitation in some studies. A sense of disgust with a dirty toilet has been used in successful cleaning interventions [42] and noted in shifts from public to private toilets [42] and manually emptying a pit driving the use of professional fecal sludge management services [43]. Finally, a general sense of dissatisfaction with one's current sanitation status has also been linked to positive outcomes related to improvement of sanitation status [36, 44].

There is strong evidence that social factors play a strong role in sanitation status and behaviors. Community-led Total Sanitation (CLTS), which has been effective in some settings [45], uses a community-driven shaming component at the heart of the intervention, but other studies have found that shame is an important factor even before intentional programmatic efforts [46]. Social norms, more general expectations of what others believe an individual ought to do and are for which others are ready to sanction that individual, also have been shown to be influential for sanitation status more generally [38]. Other general social influences include the experimental finding that creating a culture of cleanliness can result in improved sanitation [46] and that a sense of collective efficacy has a major impact on cleaning of shared sanitation [22]. Interestingly, these social influences or obligations exist beyond small geographic areas or individuals on the receiving end of social cues and pressures—in one study, those of a higher socio-economic status in one neighborhood were actually willing to pay a significant portion of the user fees associated with improving sanitation in a neighboring area [47]. More direct assessment of discrete peer influence has yielded some evidence that it is related to sanitation quality [48] and to triggering the timing of a purchase decision [49], and while diffusion theory has been suggested but not proven as a mechanism of action [50], there is some evidence of “spillovers” where those deciding to improve their sanitation likely influence their social contacts [31]. Recent work in social network analysis has revealed that social influence may work most effectively at the level of a “network community,” a social unit smaller than a household’s immediate contacts, but larger than a village or other geographic categorization, and that while more central individuals are more likely to own latrines, the sanitation statuses of those on the periphery of a social network are more strongly correlated with one another [51, 52].

Finally, factors specific to the peri-urban context may play a major role in sanitation quality. In many settings, insecurity of tenure is a major barrier to improved sanitation both for tenants, who may have no legal right to remain on the premises and are at the whim of the landlord, and for landlords, who may hold no formal or effective legal right to occupy the land on which they live [53, 54]. Specific investigations have shown that tenants may have little influence over their landlord even if they are unsatisfied with their circumstances [34]. The situation is sometimes viewed as so difficult to solve that some have concluded that the only way forward for promoting on-site sanitation in peri-urban areas is to encourage the construction and maintenance of widely shared sanitation facilities [54].

Demand for Sanitation

Demand is typically measured by estimating willingness to pay (WTP), which measures the maximum price a consumer reports being willing pay for a good or service [55]. However, many other constructs exist to measure demand, including acceptable prices (all the prices a consumer is willing to pay for a product [56]), reference price (the internal or external price with which consumers compare the observed price of a product [57]), and value (an evaluation of all the costs and benefits associated with a product over its lifetime [58]). In addition, demand changes over time and by context, with product-related attributes like satisfaction and customer-related attributes like risk aversion, variety seeking, age, and level of education all having a meaningful effect on WTP [59].

Measuring demand accurately is an exercise in estimating normative preferences—the actual preferences of an individual—but a proper application of methods from the wide variety of empirical techniques available requires a thorough understanding of their strengths and limitations. Methods for estimating consumer demand for products based on observing choice are generally divided into stated preference (SP) and revealed preference (RP) methods [60]. SP techniques directly elicit willingness to pay, as in the Contingent Valuation Method (CVM) [61, 62], or observe simulated choices using constructed sets of alternatives, as in Discrete Choice Experiments (DCEs) [63, 64]. SP methods are simple for a researcher to construct to solicit exactly the information of interest, and have been used to value sanitation in a variety of settings since the early 1990s (e.g., [30, 65, 66]).

There is a long history of criticism of the reliability of SP methods [67, 68], primarily centered around concerns that preferences are constructed only at the point in time respondent is confronted with a survey question. Empirical evidence to support this includes elicitation effects, differences between WTP and willingness to accept (WTA), and the "embedding problem." Elicitation effects mean that the format in which a WTP value is asked about affects the values reported, such as when asking if a respondent would pay a fixed amount yields results exceeding those found by asking an open ended question [69]. WTA is the amount an individual would be willing to accept to lose a good or suffer some harm, and though according to neoclassical economic theory these values should be equal, WTA was found to be much higher than WTP in SP surveys [70, 71]. The final criticism, the embedding problem, argues that when individual attributes are combined into "packages," the individual valuations add up to far more than the overall valuation of the package.

However, rather than necessarily demonstrating the weakness of SP methods, some of the disagreements between SP methods and neoclassical economic theory actually reveal problems with the latter [72]. Elicitation effects, shown to be equal to preference reversals studied in neoclassical economics [73], persisted even through rigorous attempts to generate explanations consistent with a neoclassical understanding of preferences [74]. The WTP/WTA gap was observed in real-money settings [75], and was actually one of the challenges to neoclassical economic theory that spurred the development of behavioral economics [76]. Even Hausman's criticism of initial piecemeal responses that do not allow for integration into econometric analysis [68] is being increasingly answered by advances in behavioral economic analysis and modeling [77]. Embedding similarly has been demonstrated in real-money settings using incentive compatible Becker-DeGroot-Marschak lotteries [78]. In fact, SP methods have even led to the uncovering of several violations of neoclassical economic theory only later identified in real-world data [72].

Revealed preference methods instead analyze choices made by consumers made in real-life markets. RP has high face validity and is not subject the criticism of hypothetical bias as reported for SP methods above. It is frequently assumed that this implies that revealed preferences are identical to normative preferences [79]. As tenants do not directly purchase sanitation, but instead gain access as a part of their choice of where to rent, the Hedonic Pricing Method (HPM) can be used to estimate the value associated with sanitation by calculating its price elasticity as a factor contributing to an overall rental price [80]. This approach has also been applied to sanitation in diverse settings, with results ranging from a 1.6% [81] to a 60% [82] increase in rent associated with the presence of a toilet, as well as increases of 16% from moving from a pit latrine to flush toilet [83] or 14% from moving from shared to private toilets [84].

However, there are many situations when revealed preferences and normative preferences differ. Several factors have been identifying as widening this gap, including when choices are "made passively," complex, between options with which an individual has little personal experience, involved tradeoffs between benefits at different points in time, or are influenced by marketing [79]. Market failure may also occur when the wrong mental models of producers (landlords) lead to excluding certain considerations (sanitation) from their production functions, implying that equilibrium values cannot be trusted [85]. Even incentive-compatible field experiments, where actual products are demonstrated and real purchase decisions are made, may produce poor estimates of normative preferences unless conducting in ways with severe practical challenges, such as requiring a long period of time be allowed to make a purchase decision (i.e., by giving a voucher) and large sample sizes due to the limited information generated by "take it or leave it" purchase offers [86, 87]. In general, the widespread use of decision-making heuristics raises a strong objection to relying on RP alone [88], especially if there is evidence of behavioral impacts on the market, as will be demonstrated below for peri-urban sanitation due to many landlords assuming tenants have no WTP, taboos affecting communication about sanitation between tenants and landlords, and the long-term return on investment calculations affecting choices about sanitation improvement.

HPM itself is also subject to several limitations. Theoretically, HPM assumes that the market is perfectly competitive, meaning that tenants have full information on rental prices and the quality of underlying components and that there are no transaction costs with moving, and these are both certainly untrue in an absolute sense [89]. However, some steps have been taken to extend Rosen's original model to account for unobserved characteristics and imperfect competition [90], and the magnitude of deviations produced by these inefficiencies may be empirically inconsequential [89]. However, there are other significant empirical challenges and practical limitations. Empirically, model selection itself is challenging, as there is little theoretical guidance about the form that a demand function should take. Simple linear, additive models have low face validity [82] and "missing" attribute levels or combinations of attributes and collinearity of attributes impede accurate estimation [91]. Practically, RP methods can only be used in existing markets, and so cannot be applied to new products to be introduced, and generally are useful only for projecting short-run deviations from the status quo within the same market [92].

One more serious concern with SP methods is hypothetical bias [68]. Hypothetical bias results when respondents answer survey questions differently than they would actually behave simply because of the lack of consequence of a survey response. One meta-analysis found that the median ratio of WTP derived from SP versus RP methods was 1.35 [93], and another reports that there is less bias for WTP (rather than WTA) estimates and for private (rather than public) goods [94]. While this is certainly a potential cause for concern, much of the original focus of CVM was on valuation of non-market goods like environmental quality—frequently, to inform the economic cost of damages done by pollution [95, 96], about which consumers may have no market experience. There is less evidence about the magnitude of hypothetical bias in DCEs, with some finding a difference in marginal WTP [97] and others failing to reject the hypothesis of equal marginal WTP [98, 99]. One transportation study comparing methods found that DCEs produce WTP values close to those obtained from RP methods, while CVM overstates WTP in the same setting [100]. Another transportation example even found evidence of DCEs producing lower WTP estimates than RP methods, with the role of habit suggested to account for users being unaware of their revealed WTP [101].

A combination of SP and RP methods may provide a more accurate, comprehensive picture of peri-urban sanitation. While hypothetical bias from using SP methods may be limited by respondents having familiarity with existing products by using DCEs closely related to actual choices made by tenants, RP can provide a check on the overall magnitude of WTP estimates produced [94]. However, due to the practical limitations of HPM and the likelihood of violations of neoclassical economic models used in RP in general because of asymmetric information in the landlord-tenant market for sanitation, SP may better identify outcomes of interest and illuminate the impact of any market failures on revealed WTP for sanitation.

In addition to simple comparisons of model estimates from SP and RP methods, more advanced models of choice can be developed by combining data sets and explicitly modeling demand by drawing from the strengths of both data sources. Three general approaches to the joint analysis of SP and RP data may be used: estimating parameters from both data sets separately within the same model to account for differences in scale from multiple data sets [102, 103], using SP data simply to improve the estimation of poorly specified RP parameters [104], and using trade-offs from SP data in combination with equilibrium results from RP data [105]. I am unaware of a combined approach being used previously in sanitation, though a few studies have used both SP and RP data to value water supply, either by comparing model outputs [106] or by estimating a combined model [107]. While a combination of methods may provide more reliable information for policy makers, it is difficult to collect the necessary amount of data and requires running complicated mathematical models, so evidence that SP methods produce valid results in this context or that RP methods alone are sufficient would allow more efficient demand estimation to inform peri-urban sanitation programs.

Zambian Context and Study Setting

Understanding the historical development of Lusaka's peri-urban areas and the study setting of Bauleni compound in particular will be key in designing a successful and transferable intervention. Zambia is a land-locked country in southern Africa with a population of 14.5 million people. The World Bank classifies Zambia as a "lower middle income" country, and the gross national income per capita is 3,070 (PPP int $) [108] and ranks 139th on the UNDP's Human Development Index, ahead of neighbors the Mozambique (180), Democratic Republic of the Congo (176), Malawi (173), Zimbabwe (155), Tanzania (151), and Angola (149), while trailing Namibia (126) and Botswana (106) [109]. The under-5 mortality rate per 1000 live births declined from 193 in 1990 to 87 in 2013, and life expectancy increased by 16 years during the period 2000-2012 compared to 7 years in the overall WHO region. However, while the percentage of the population using improved drinking water increased from 49% to 65% from 1990-2015, the urban use of unimproved sanitation or open defecation increased from 14% to 19% during the same time period [5].

Lusaka, the capital, was founded as a railway town in copper belt in 1905 and began to rapidly expand when chosen as the administrative center of the British colony of Northern Rhodesia in 1931 [110]. The development of Lusaka is heavily influenced by its colonial history, as the British South African Company established the city as an administrative hub without the intention of its population expanding. They envisioned Lusaka to be primarily inhabited by foreigners with a small Zambian civil service allowed to live in the city only while on short-term work contracts. Informal settlements grew up outside of the official city boundaries, but their unofficial status made it impossible for government services to be provided and it was not until the Improvement Areas Act of 1974 that these areas were considered authorized for habitation.

Though sanitation has not improved in recent years, efforts are underway to increase coverage, with the Lusaka Sanitation Master Plan aiming for 100 percent sanitation coverage in Lusaka Province as a whole by 2035 [111]. The World Bank Group approved a 5-year, $65 million USD loan to improve access to sanitation in Lusaka, including $14 million for on-site sanitation, fecal sludge and wastewater management, and sanitation and hygiene promotion activities to serve approximately 180,000 people in peri-urban areas [112].

Bauleni compound was chosen as the study site by LSHTM, CIDRZ, and local stakeholders as typical of peri-urban areas in Lusaka in terms of age, population density, demographic characteristics, and the lack of any recent or planned sanitation projects. It is an informal settlement in southeast Lusaka with a population of about 64,000. Bauleni has no sewer lines and so pit latrines or septic tank systems are the main forms of containment. Bauleni is subdivided into individually-owned plots averaging about 100 m^2, which were originally to be occupied by one household. However, most plots have been subdivided to provide small living spaces (or 'doors'), which are rented out to tenants by the owner.

Use of Behavior Centered Design in this Thesis

Using behavioral science theories to address public health problems is sometimes challenging due to the many available theories and a lack of clear methods for how to best select and apply them. This difficulty is made worse by both the long-standing proliferation of theories from within applied behavioral science (ABS) and the recent broadening of disciplines from which it draws. Within ABS, arguments for the best way to advance its theoretical foundations and methods have included an overall unifying synthesis [113], intentional, direct comparisons of empirical results obtained from divergent theories and methods [114], and allowing theories and methods to simply proliferate or fall out of favor naturally [115]. Complicating this debate are new contributions from disciplines that directly impact ABS, including spread of behavioral economics and advancements within neuroscience [116], which have varied definitions, evaluation mechanisms, and intended explanatory scope for theories. For example, economic theories are often narrower than general behavioral frameworks [117], while those of neuroscience bring a distinct natural science approach [118].

The task of selecting and applying theories from the wide range of available options is generally done in three ways. First, intervention development sometimes begins with a review of empirical findings, followed by a search for theories relevant to the kinds of results identified (e.g., [119]). These “theory-*aware*” interventions may be associated with their own internal “theories of change,” but these usually have little resemblance to the pre-existing theories from which they draw. Second, behavioral determinants theories are sometimes used to provide *a priori* assumptions about what might influence behavior. These may be come from a particular discipline (e.g., social psychology for the Health Belief Model [120] or behavioral economics for Behavioral Design [121]) or may be consolidated from a range of disciplines into a theory for a particular type of behavior (e.g., water, sanitation, and hygiene in the IBM-WASH model [122]). Using these determinant identification theories will be labelled “theory-*based*” intervention development. Third, more systematic “theory-driven” approaches move beyond determinants to prescribing processes for selecting mechanisms of change (e.g., the RANAS model [123]).

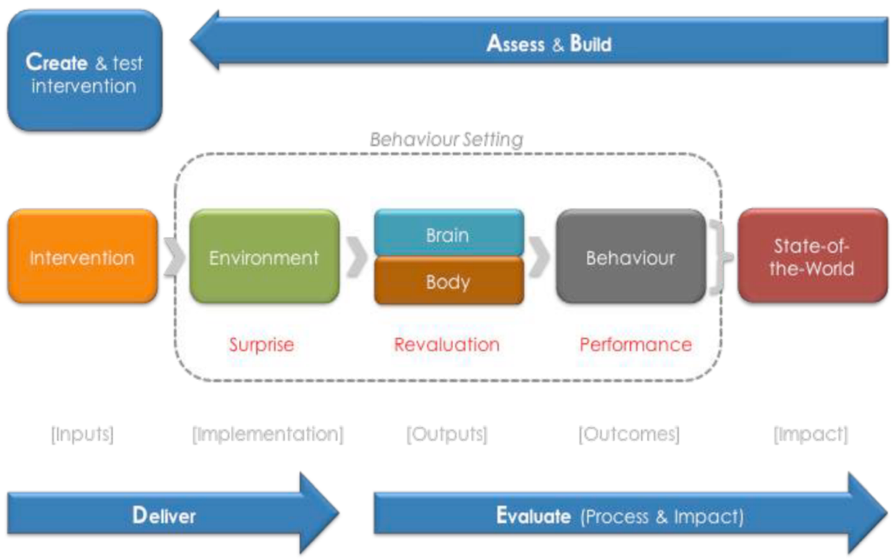
The goal of applied behavioral science research should be to maximize learning, not just about the behavior and setting being studied, but to understand the implications for other behaviors and settings and to advance ABS itself. Theory-aware interventions may lead to effective programs, but have limited ability to contribute to ABS, and may miss major candidate behavioral determinants that are under-utilized in the existing literature. For example, the commonly used Behavior Change Technique taxonomy was distilled from the psychological and public health literature on intervention strategies [124]. But, only 4 out of the 93 behavior change techniques identified were related to the behavior's environmental setting, despite the fact that most behaviours are significantly influenced by such non-psychological causes [125]. Theory-based interventions may provide some insight into which determinants were important in changing a behavior. But, null results yield little guidance into whether the wrong determinant was targeted or the wrong delivery mechanism or content was chosen when there is no explicit process guiding the entire process (e.g., behavioral design [126]). Therefore, theory-driven intervention development is the most effective way to generate insights about particular problems, while allowing reflection on the theory itself and allowing for the advancement of ABS more generally.

Behavior Centered Design (BCD) [127] is a framework that takes such a theory-driven approach, which generates knowledge about the targeted behavior setting that can be adapted to novel behaviors and settings. BCD is a generic framework for behavior change developed by Robert Aunger and Valerie Curtis. It is based on the Evolutionary-Ecological (or Evo-Eco) model of behavioral determinants [128], includes a theory of change for behavior based on a reinforcement-learning paradigm, and situates these components in design process consisting of five stages: *Assess* existing knowledge, *Build* up additional information to fill the gaps in general or local knowledge about the behavior, *Create* an intervention, and then *Deliver* and *Evaluate* the intervention (Figure 1). The theory of change also maps reinforcement learning constructs onto the typical categories of inputs, activities, outputs, outcomes, and impacts. Two key differentiators of BCD from many other theoretical frameworks are:

(1) While behaviors may be associated with demographic characteristics or levels of knowledge, behavior is controlled by a brain with distinct executive, motivated, and reflexive levels of control.

(2) BCD treats the brain as just one component of the behavioral control system, with an individual's body and social, biological, and physical environment exerting substantial control over many behaviors [129].

Figure 1: Theory of Change and Process for Behavior Centered Design



Source: [130]

While BCD is being used in this thesis, no claim is made that other theories would not have produced positive results and no direct claims for the superiority of BCD to other theories in all aspects are made. In particular, while the behavioral determinants model of BCD is theoretically comprehensive, changing social norms requires much theory beyond simply noting that the social environment is relevant—an approach such as Christina Bicchieri's norm measurement and influence process [131] may be helpful here. Also, while noting that the executive brain controls many behaviors, understanding the specific ways that it errs from a perspective of evolutionary psychology or behavioral economics [88, 121, 132] or from a categorized list of potential determinants [123] may be more helpful for the program designer. It should be noted, however, that the underlying theories of behavioral determinants and behavior change are not incompatible with these other theories and approaches, and rather are useful to understand how these other theories directly influence behavior and may be integrated with one another in a theoretically-consistent manner using BCD as the underlying model.

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Chapter 3: Formative Research

Chapter Overview

This chapter presents the results of the formative research step in designing the intervention. Relevant literature from the *Assess* step is summarized, and the results of the *Build* step are presented and discussed, with a particular focus on implications for intervention design.

Registry
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Thesis Title	Creating Demand for Peri-Urban Sanitation in Lusaka, Zambia

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Theory-driven formative research on shared sanitation improvement among landlords and tenants in peri-urban Lusaka, Zambia

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Abstract

Rapid, unplanned urbanization in low income countries is leading to increasing problems of dealing with human waste. On-site sanitation systems are often rudimentary, unhygienic and poorly maintained. In-depth, on-site interactive interviews were conducted with thirty-three landlords and thirty-three tenants in a neighborhood in peri-urban Lusaka. Respondents were asked about housing characteristics, toilet histories, and financial decision making. Improved, shared toilets were common (79%), but many were of low quality and poorly cleaned. Poor coordination among tenants, barriers to communication between landlords and tenants, and landlords viewing sanitation as a required basic service to provide instead of something for which tenants will pay more rent all limit the quality of sanitation in this setting. Landlord-directed interventions targeting non-health motivations for sanitation improvement and introducing effective cleaning systems may increase peri-urban sanitation quality.

Keywords: Zambia; Peri-Urban; Sanitation; Behavior Change; Behavior Centered Design; Intervention Development

Introduction

The provision of safe and affordable sanitation is a growing challenge in rapidly urbanizing low- and middle-income countries (LMIC). In 2014 about 890 million people lived in unplanned peri-urban areas (PUAs) globally [133], with "inadequate access to safe water, inadequate access to sanitation and other infrastructure, poor structural quality of housing, overcrowding, and insecure residential status" [10]. The number of people living in such conditions is estimated to more than double to about 2 billion by 2030 [10]. Unsafe sanitation is the second leading risk factor for disability adjusted life years (DALYs) lost due to diarrheal disease globally [134]. Furthermore, people living in peri-urban areas experience worse health outcomes than those in rural or other urban areas [12]. To meet Sustainable Development Goal 6.2, 'safely managed sanitation for all by 2030' [135], the problem of inadequate sanitation in PUAs must be solved.

In PUAs where open defecation is rare and most have access to a toilet, shared toilets of poor quality are common [136]. Evidence suggests that as the number of users of a toilet increases, the structural quality may increase [17], but cleanliness decreases [15, 16, 18], which is a public health concern [137]. The UNICEF/WHO Joint Monitoring Programme currently categorizes sanitation quality using a ladder: *basic* sanitation "hygienically separates human excreta from human contact," *safely-managed* sanitation adds to that the treatment or management of the excreta, basic sanitation moves down to *limited* if it is shared by more than one household, and drops to the bottom rung, *unimproved,* if the excreta isn't sufficiently separated from human contact [135]. There have been recent gains in the prevalence of basic sanitation globally, but Sub-Saharan Africa has lagged behind [5]. There, the number and proportion of people using unimproved or limited (shared) sanitation increased from 204 million (40%) in 1990 to 465 million (47%) in 2015 [5].

Attempts to improve sanitation globally have included outright provision, subsidies, regulation, and promotion. Providing improved toilets and sewage systems is costly [138] and often impractical, and delivering subsidies to reduce the costs of provision has been challenging [139]. Local government institutions in PUAs are often ineffective in enforcing regulations, and heavy-handed enforcement may simply displace residents to less regulated settlements [6]. Promotion has been successful in some rural settings [140], where the most common intervention, Community-led Total Sanitation (CLTS) brings together communities and motivates latrine construction through triggering disgust, facilitating group commitment, and triggering self-monitoring. However, there is a lack of comparable evidence in urban settings [141].

One approach that has been widely advocated is Sanitation Marketing [142, 143]. This aims to stimulate both the supply of, and the demand for, sanitation products and services. However, despite many grey literature reports, no peer-reviewed studies have evaluated its effectiveness [141, 144]. We hypothesized that it might be possible to improve the quality of sanitation provision by improving consumer demand, without improving supply, in informal African settlements. Such a program could be relatively cheap and might be feasible to scale to informal settlements elsewhere. With the idea of designing an intervention that could be tested in a trial, we carried out Formative Research on consumer behavior with respect to sanitation in a peri-urban settlement in Lusaka, Zambia.

The intervention was designed using Behavior Centered Design (BCD). BCD classifies the determinants of behavior as they relate to an individual's reactive, motivated, and executive brain; to their body; and to the social, physical, and biological environment in which behavior takes place. It further uses the concept of "behavior settings" to characterize the environmental and psychological determinants of behavior in their context [125]. Components of behavior settings include: routines, roles, scripts, norms, and competencies as well as stage, infrastructure, and props. BCD formative research process makes use of a checklist of behavioural determinants that the design team progressively refine as they learn about target behaviours. Using an explicit behavior change theory to drive formative research ensures that a comprehensive set of potential behavioral determinants, target actors and behaviors, and pathways to change are investigated, some of which might otherwise be missed by general qualitative approaches [145].

This paper reports the results of a formative research study that was designed to examine how toilets can be improved in a peri-urban area of Lusaka, Zambia. The main objectives were to understand the existing state of sanitation, the process by which sanitation quality is maintained and improved, the roles of landlords and tenants in those processes, and the main drivers of quality maintenance and improvement.

Methods

Context

Bauleni is an informal settlement in southeast Lusaka with a population of about 64,000. It was chosen to be representative of peri-urban settlements in terms of age, density, and demographics and the lack of any recent or planned sanitation projects. Bauleni has no sewer lines and so pit latrines or septic tank systems are the main forms of containment. Bauleni is subdivided into individually-titled plots averaging about 100 m^2 in size which were originally intended to be occupied by one household. However, most plots have been subdivided to provide small units (or 'doors') which are rented out by the plot owner. We therefore interviewed both adult landlords and their tenants.

Sampling

To achieve a sample representative of peri-urban slums in Lusaka, respondents were purposively selected from a large, pre-specified area within Bauleni (to avoid contaminating the later trial). The sampling unit was the plot (n=66). We ensured that males represented at least one-third of respondents in each category by only conducting interviews with males once the corresponding number of females for that category had been interviewed. If more than one toilet was present on a plot, we asked about the toilet used by the tenants most of the time.

Data Collection and Analysis

We developed interactive semi-structured interview guides based on the literature review. A team of four research assistants were trained by five members of the research team and the group piloted and revised the guides over a one-week period in peri-urban areas outside of the planned intervention area. Members of the research team were paired with research assistants to collect data for one week, and then research assistants collected data in pairs over three more weeks in September 2016.

We employed a variety of quantitative, semi quantitative and qualitative data collection tools that captured basic demographics, mapped plots and social networks, captured the construction history and current status of toilets, ranked the most desired aspects and motives for making toilet improvements, and examined financial decision making for improving the plot. The tools prioritized observation, forced choices, and retelling of experiences over questionnaire-based techniques. These are described in Table 1. The local research assistants, who spoke Nyanja and Bemba, visited respondents' homes, recorded responses using paper forms, and entered the data into a Microsoft Excel spreadsheet. We aimed to complete all tools for each interview except when tenants were uneasy about discussing their financial decision-making or grew weary. Members of the study team verified data entry, and audio recordings were consulted when anything in the notes was unclear. We coded the qualitative responses, produced descriptive statistics based on response frequency and organized results using the BCD categories of behavioral determinants. We also used exploratory thematic analysis on the richer detail of the full qualitative data set to explain trends discovered in the quantitative summaries.

Table 1: Data Collection Tools

Tools	Description	Sample Size
Demographics	Respondents were asked their age, gender, occupation, level of education, literacy, and monthly rental fees.	66
Plot Maps	Research assistants drew maps of the plot. Respondents were asked if the landlord lived on the plot; the number, composition, and tenure of households; and types of relationships between households.	65
Social Network Analysis	Names of people “most important to you now,” “somewhat important to you,” and “a little important to you” were placed into three concentric circles by research assistants. Respondents were prompted to identify who they had: (1) borrowed money from, (2) lent money to, (3) had assistance from in a medical emergency, (4) given advice to, (5) talked to regularly, (6) had parenting advice from, and (7) asked or would ask for help if their toilet broke [146].	20*

Toilet Histories	Respondents were asked about the process of building the toilet, changes made since initial completion, how it was cleaned, if there had been any challenges in accessing the toilet, and for what things the facility was used.	65
Toilet Observations	Research assistants assessed toilet quality by direct observation of components such as a roof or solid door. A few items, such as the type of pit lining, were obtained by respondent report.	63
Improvement Preferences	Respondents ranked 14 toilet components pairwise on cards from most to least important and discussed why choices were made.	63
Improvement Motives	Respondents ranked cards depicting the motives of Disgust, Create, Affiliate, Nurture, Love, and Status for their top improvement choice. Respondents were asked to rank and explain their top three motives.	59
Financial Decision Making	Respondents were asked about large purchases they had made, how they saved money for them, general savings practices, previous use of financial services (bank accounts, loans, informal sources), and who they consulted about financial decisions.	55

* Terminated prematurely due to rapid information saturation

Results

Results are categorized into topics relevant to the theory of change for the planned intervention. All are topic areas specific to the primary question of how to promote toilet improvements in a plot with landlords and tenants.

Sample characteristics

Table 2 shows the characteristics of the sample. Only 5 of the plots in the study had no tenants present, of which two were "family plots," where all resident households were kin. At least one other kin household lived on 21% of plots. Almost every plot had a functioning toilet, and the very few that had more than one had separate toilets for tenants and the landlord. Three quarters of plots had a landlord who was currently resident. Landlords (n=33) were generally older than tenants (n=33), had lived much longer on their current plot, and had larger household sizes. Tenants were more likely to be literate than landlords and had slightly more years of education. A typical plot had a median of 15 people (including children) residing on it at any given time.

Table 2: Sample Characteristics

Individual Characteristics	**Landlords (n=33)**	**Tenants (n=33)**
Sex: Male	33%	33%
Age (Median)	39	28
Literacy Rate	73%	82%

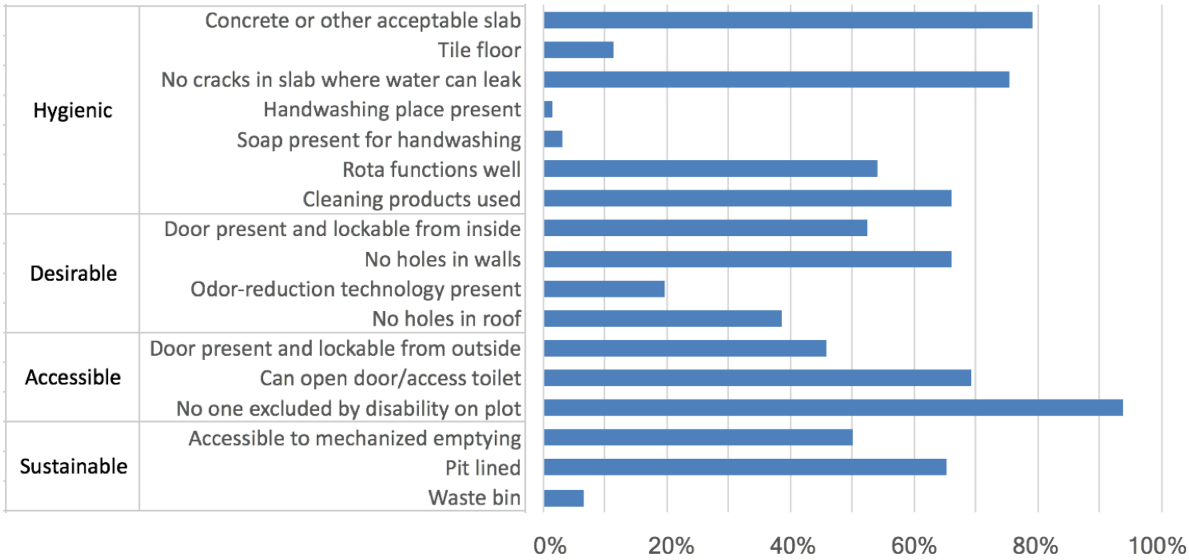
Years of Education (Mean)	7.6	8.7
Time since moving to plot (Median)	17.5 years	1.4 years
Household Size (Mean)	4.5	3.7
Plot characteristics (n=66)		
Plot composition	Median	Interquartile Range
Households per plot	4	3-7
People per plot	15	12-21
Monthly rent per tenant household	356 Kw ($37)	250-450 Kw ($26-47)
Total monthly rent per plot	1170 Kw ($123)	670-2250 Kw ($71-237)
Percent with resident landlord	77%	

Toilet Observations

Direct observation confirmed that most toilets would be defined as "limited sanitation" by the SDG guidelines (technologically sufficient, but shared); however, Figure 2 shows that there were large variations in the quality of the 63 toilets that were observed, with items grouped according to the "Peri-urban Healthy Toilet Index" developed for this trial [147]. Hygiene measures captured how well excreta was separated from human contact. Improved slabs were common (79%), but very few toilets had adequate handwashing facilities (3%). Desirability measures captured the experience of use, and toilets sometimes had a door that was lockable from the inside (53%) and well-constructed walls providing privacy (66%)

or a roof protecting from the rainfall or direct sun (38%). But, odor-reduction technologies were uncommon (20%), with the most frequently observed being ventilation pipes for VIP-style latrines. Accessibility captures how regular and equitable use of the latrine was. About half of plots had toilets that could be locked from the outside to prevent access by outsiders, while 31% had doors that couldn't be opened immediately at the time of the observation—usually because a landlord with a key was away from the plot and had to be called back. Sustainability examines how likely the quality of the toilet is to continue into the future. Lined pits were reported for about two-thirds of toilets. Only about half of toilets were accessible to mechanized emptying due to challenges accessing the toilet (due to the layout of the plot or nearby roads) or accessing the pit (due to the toilet design). Well-functioning toilet cleaning rotas were present on 54% of plots. When toilets were not built to be emptied (either without a strong lining or a point of access), landlords generally reported that space to build a new toilet was not an issue and that they wanted to build an emptyable one in the future.

Figure 2: Detailed Toilet Quality Breakdown



Percentage of Observed Plots or Respondent Responses with Given Toilet Component, Grouped by Peri-Urban Healthy Toilet Index Category [24]

Toilet Histories

Most toilets (54%) had been built within the last three years, while some (15%) had lasted ten years or more. Though some landlords started to build better quality toilets at times, construction was usually completed only when the previous toilet became unusable because it had filled up, became damaged, or collapsed. Most plots had enough space to build additional toilets, though landlords had little interest in moving towards individual household latrines and instead reported that they preferred to use spare land to build additional 'doors' rather than toilets. Many respondents reported that new toilets were constructed or finished in a hurry, being completed in a few days when necessary. One 35 year old female tenant said:

"The old toilet was very full, so we began to use one on another plot. The landlord had to look for money fast to build the toilet—maybe he took a loan. This was because the neighbors got upset that we were using their toilet in the night."

Toilets were usually built in stages by different individuals, ranging from professional masons to nearby family or household members with only general construction experience. Construction took anywhere from a few days to more than a year to complete, depending on the type of toilet to be constructed, weather conditions, availability of funds, and accessibility of temporary toilets constructed on the plot or nearby toilets on plots owned by the same landlord. Materials were purchased most often from markets in the city center, bought over time as funds allowed, and stockpiled on the plot or used to build incrementally as they were purchased. Temporary toilets, sometimes constructed for use until the permanent toilet is completed, consist of a simple hole with a superstructure made of stick and plastic tarpaulin or grass.

Landlords often reported the desire to have a better toilet in the future, but few had actually made any toilet improvements after construction was complete. Many toilets remained under construction for long periods, only being hastily finished when the need became urgent. A typical construction story was given by a young tenant on a family plot:

"We started building a new toilet 2 years ago when the old one collapsed. The new one has two stalls—the first is just a pit, but the other will be fancier. Our neighbor, who is a bricklayer, built [the first] in four months.

The other is under construction and is being used as a bathroom. We hope to connect a flush toilet inside with a septic tank in the second stall when the current one fills."

Landlords and tenants played different roles with respect to toilets building and maintenance. Landlords were in charge of planning changes and for paying for improvements to the structure. This included building new toilets or emptying existing ones when pits filled, and repairing damaged roofs, walls, or doors. Tenants sometimes provided labor in exchange for reduced rent payments, but didn't usually pay for improvements directly. The only cases where tenants expressed willingness to pay directly were for components not considered a part of the fixed structure, including exterior door locks and freestanding handwashing stands, those these were rarely observed. However, most tenants claimed to be willing to pay increased rent for better facilities. A few landlords had actually made such improvements and raised rental prices, but most landlords didn't believe that tenants would be willing to pay more. Some even stated that it was solely the landlord's responsibility to provide for his or her tenants, though only a basic toilet was seen as a "human right," and those aspiring to better toilets frequently claimed to be unable to make improvements due to a lack of funds.

Toilet Maintenance and Use

Toilet longevity varied greatly across plots, with some reported to have been in use for over 20 years, while others reported previous toilets collapsing or filling up and becoming unusable in just a few years due to variations in structural quality and pit emptyability. Two-thirds of latrine pits were lined to increase structural stability and facilitate mechanized emptying. Several landlords with unlined pits expressed a desire to incorporate a lining into the next toilet they built, but lined pits were generally built with spaces between bricks to allow liquid to drain from the pit, so that it would last longer (and evidently with little concern for, or awareness of, ground water pollution). Landlords also tried to allow plot residents only to access the toilet, often through installation of a solid door with an outside lock. Respondents generally reported being able to keep outsiders from accessing their toilets in this way, especially at night when non-residents might sneak into toilets unobserved.

Toilet cleaning responsibilities were usually shared by landlords and tenants. The landlord often formalized these duties by use of a rota, typically an unwritten rotation of the order of households responsible for cleaning the toilet. Each household was responsible for cleaning for 1-7 days at a time. Fines or other sanctions for tenants who did not participate were rare. Rotas with longer turns seemed to run more smoothly, since households were less likely to forget their turn, and to be more enforceable, since it was easier to determine if one of the tenants was regularly failing to clean the toilet. However, longer turns occasionally led to more conflict, and sometimes peace was prioritized over cleanliness. One female landlord reported:

> *"One household wouldn't do the work, so this meant that for the whole week there wasn't any cleaning. This just wouldn't work. We changed to one day only. We didn't push them out, but they eventually left."*

Landlords were sometimes included in the rota, while sometimes they simply cleaned the toilet when they observed that it was dirty.

Monitoring the proper use of the toilet was challenging for landlords. They reported that tenants commonly put waste materials into the pit, which would present a problem for pit emptying. Landlords had little idea how to prevent this other than asking that their tenants not do it. Child feces were sometimes disposed into the toilet by use of a small plastic bowl as a "potty," but tenants reported that covering their child's feces with dirt or sweeping it into waste piles was also common.

Improvement Preferences

Respondents were asked to rank toilet improvements in order of personal importance. The average toilet preference ranks by role (landlord/tenant) and sex are shown in Table 3 (ordered by average rank by landlords). Respondents reported that locks on the outside of the door were highly desirable because they prevent outsiders from using the toilet, particularly drunk men in the night, who would create a mess that the residents would then have to clean up. A toilet with a seat was ranked highly by some, and cited as more comfortable and accessible to those with disabilities. Others preferred a squatting toilet pan, with a particular concern, especially among women, that a poorly-cleaned sitting toilet was more disgusting than a poorly-cleaned squatting toilet pan. A place for handwashing was desired, but rarely present in shared spaces on plots. Lined pits were considered important to improve toilet longevity and to prevent collapsing during rainy seasons. Odor-reduction technology was considered important by many, as toilets were frequently located close to shared courtyard areas on plots, but they were rarely present. More women than men preferred cleanable tiles, likely because they engaged in cleaning activities more often than men.

Table 3: Toilet Improvement Preference Rankings

Improvement	Rank by Role		Rank by Sex	
	Landlord (n=29)	Tenant (n=27)	Male (n=20)	Female (n=36)
External lock	1	1	2	1
Sitting toilet	2	2	1	2
Lined pit	3	4	3	4
Place for handwashing	4	3	4	3
Place for waste disposal inside toilet	5	9	8	7
Smell reduction (vent or seal)	6	5	5	5
Floor cleaned with anti-bacterial soap	6	7	6	6
Cleanable tile floor	8	8	7	9
Pit is emptyable	9	6	9	8
Solid roof	10	11	14	10
Walls without holes for privacy	11	12	12	12
Toilet appears clean	12	14	13	13
Financing for improvements available	13	10	10	11
Pit not leaking onto neighbor's plot	14	13	11	14

Improvement Motives

We explored motives for making the improvements preferred by landlords and tenants using our motive mapping tool. In brief this consisted of showing respondents a series of cards corresponding to status, nurture, love, affiliate, disgust, and create motives [148] (Table 4). Respondents ranked the importance of these toilet improvement motives; their top three choices were then assigned points using a simple weighting, with a respondent's first choice receiving 3 points, the second 2 points, and the third 1 point. The number of points achieved out of a total of 3 points possible (if the same motive was ranked first by every respondent) are shown in Table 5.

Table 4: Motive Mapping Tool Prompts

Motive	Definition	Description
Status	Seek to enhance one's position in a social hierarchy	Church elder says: "Everyone in the community will admire you for doing that!"
Nurture	Rearing offspring	Respondent says to self: "Now my child will be safe!"
Love	Investment in a pair-bond relationship	Spouse says: "I love you for doing that!"
Affiliate	Participating in social community	Neighbor says: "You showed you're like the rest of us. Well done!"

Disgust	Avoiding substances and people that might transmit disease	Respondent says to self: "That was disgusting. I did well!"
Create	Improving one's local habitat	Respondent says to self: "I've really made the plot nicer now. I did well!"

For landlords, status was the most important motive for improving toilets, while nurture was the most important for tenants. Status, nurture, love, and affiliate, all interpersonal motives, scored higher than disgust overall. But, the responses (both "first choices" and overall, weighted results) appear to be well distributed among categories, with even the highest ranked motives overall not selected in the top 3 for about half of respondents. This suggests that variation by life stage and household composition may be important.

Table 5: Respondents Identifying Given Sanitation Improvements Motives as Important by Plot Role

Motive	Landlord	Tenant
Status	.74	.55
Nurture	.59	.64
Love	.64	.42
Affiliate	.53	.50
Disgust	.40	.48
Create	.10	.42

Social relationships

Though the population density was high, plot residents rarely worked together to achieve common aims. Few residents had pre-existing relationships with others on the plot. Three-quarters of plots had no residents from different 'doors' who were friends before moving there, almost half of all plots had no kinship relationships at all between doors, and about a quarter of plots had no relationships of either kind. For those without kin or friends on the plot, respondents mostly reported that their main source of advice or loans was family members living elsewhere in Lusaka or in their village of origin. Neighbors of the same role (landlord or tenant) were asked for help for minor issues like minding a child for a few minutes. The main community organizations that respondents attended were churches; however, people living on the same plot rarely went to the same church.

Financial Decision-Making

We sought to understand the process of financial decision-making on the plot to identify which individual(s) influenced which plot improvements. A single individual, usually a member of the owner-landlord's household, was generally responsible for financial investment decisions about improving a plot using rental income. The decision-maker sometimes sought input from tenants if the primary goal of the improvement was to increase rental income, such as when adding a water tap. But, such decisions were more frequently made without any such consultation, due to the high turnover rate of tenants. In cases where the decision maker was married, their spouse was often consulted in the decision making process.

Respondents generally reported that they saved money only for specific planned purchases. The most common savings mechanism reported was a *chilimba*, or "merry go round." These are informal agreements made by a fixed number of people with a fixed duration, payout frequency ("rounds"), and financial contribution level. Each participant pays in a fixed amount each round, and one winner is randomly selected per round until each wins. *Chilimbas* had been used by 50% of landlords and 62% of tenants. However, none reported using *chilimbas* to improve a toilet.

More formal financial services were less common in Bauleni. Bank accounts were used by about half of landlords and about a third of tenants, but formal loans were rare. Respondents feared that the loaning institution could seize the property of a delinquent debtor—a particular concern for those with irregular income. A few landlords gave the money to a non-resident kin and asked them to save it on their behalf. The remaining one-third of both tenants and landlords reported never using any kind of formal or informal savings or loan mechanism.

Regular rental income was the main source of funds for plot improvement. The average landlord made about Kw1,450 ($153 USD) per month from rental, or Kw350 ($37 USD) per tenant household. Several landlords reported that a high-quality toilet could be constructed for around Kw3,000 ($316 USD), including materials and labor for a lined pit, concrete slab, solid walls, door, and roof, and a pour-flush or flushing toilet pan. Rental increases of Kw50 ($5 USD) per month per tenant household were reported, so construction costs could be fully recouped in less than two years. One female landlord related the following story (paraphrased):

> *[We] live on one plot and own another one as well. We have two tenant families living on the other plot, which already has a toilet, and are building three more rooms there as well as two on this plot. This plot doesn't currently have a toilet, but we will build one after finishing the other plot. No one else is living on this plot, and they won't until we build a toilet…but my husband's company is not earning much and he's not getting much salary, so our plans are shattered.*

Sanitation was rarely seen as an investment by landlords, but instead as a required service to be provided, as tenants would not stay on plots without a working toilet for long.

Discussion

This study explored features of sanitation service provision in peri-urban Lusaka to inform the design of a behavior change intervention. Below we organize the findings according to the behaviors of interest and their determinants (environmental, psychological, and settings based).

Social Environment: Weak Social Cohesion

Social relationships and influences played an important role in toilet quality improvement and maintenance behaviors. However, social cohesion was weak both within the plot and at the community-level. Other than kin living on the same plot, landlords rarely consulted with those on their plot or others living nearby. Enforcement of formal regulations requiring functioning toilets to be present on the plot were non-existent, and few informal norms about sanitation quality existed. Landlords also ranked affiliation, the sense of belonging to the local community, as less important than comparative social motives (status) or kin-focused motives (love, nurture).

Motivated Brain: Drivers of Sanitation Quality

Motives that drive sanitation quality improvement varied substantially within this population and from those identified in other contexts without landlord-tenant shared toilets. Status was the highest ranked improvement motive, with nurture, love, and affiliation all also scoring higher than disgust. Disgust is a key motive for toilet construction in some contexts [149], but may be less important for improvements in Bauleni due to a higher baseline level of sanitation quality, shared cleaning responsibilities diluting each individual's direct contact with contamination, and perhaps becoming accustomed to the sight or smell of feces through being frequently in close proximity to toilets very close to living spaces. But, it is also possible that respondents were reluctant to even talk about disgust during the survey. Status is a major motive for improving sanitation in other places where users build their own toilet [41], and may be an effective way to drive upgrading in this context. But, it is unclear if landlords would gain status from improving a toilet used only by their tenants. The affiliation motive was also sometimes considered important, despite the weak social cohesion described above. It is plausible that a landlord's need to be perceived as fitting in in the community is strong enough to drive sanitation improvement behavior. Though not included in our sanitation motive mapping tool, the hoard motive (the desire to store up resources [148]), was reported as a driver for landlords investing in their plots for long-term financial security against income shocks, but this was infrequently associated directly with sanitation.

Executive Brain: Landlords don't Consider Sanitation an Investment

Landlords generally considered sanitation as a basic service to provide, rather than as a financial investment in their plot. Based on the costs of locally available improvements and potential for increasing rent we calculated that the return on investment for sanitation improvements may make it a worthwhile investment option for many landlords. As most toilet improvements cost far less than adding additional rooms to a plot, there is also less risk that they will sit incomplete for long periods of time and not generate any return on investment. *Chilimbas* (savings groups), which are generally used only for investments or necessary expenditures, could further expedite this process if sanitation were viewed as an investment.

Encouraging landlords to view sanitation as an investment may also bridge what appears to be a landlord-tenant motive gap. When landlords view sanitation as a basic service to fulfill the desires of tenants for increased comfort or decreased fear or disgust, sanitation spending competes with other expenditures that may more directly benefit the landlord. Landlords may prioritize sanitation improvements when they realize that they can use increased rental income to attain status, express love (for a partner), nurture (for offspring) or simply hoard resources as described above. This may be more effective than if interventions emphasize tenant motives or relational motives between landlords and tenants. Financial gain, rather than being the ultimate end, motivates landlords to improve tenants' sanitation experiences by leveraging tenants' willingness to pay to enable landlords to perform behaviors they are motivated to do.

Implications of the Formative Research

While most plots in the study area have some form of toilet, the infeasibility of eliminating shared sanitation, low quality of most toilets, lack of motivation to improve structural quality, and difficulty of ensuring proper cleaning and use of toilets are major barriers to improving sanitation to improve public health.

Weak social cohesion may limit the effectiveness of sanitation interventions as used in other contexts. One of the most widely practiced rural sanitation promotion programmes, Community-led Total Sanitation, leverages community cohesion to enforce social norms [150]. It has been suggested that this might be adapted to urban contexts, so-called Community Level Urban Environmental Sanitation [151], but the scope for such coordinated action seems limited in Bauleni. The weak relationships within plots may hinder intra-plot coordination, and weak inter-plot bonds may limit community-level action [152]. Additionally, the lack of strong local leadership may limit the effectiveness of such approaches.

Targeting appropriate motives through sanitation marketing may be more effective. Landlords have the primary role in driving sanitation improvement, but most are motivated to improve their plots by financial gain, increasing social status, and caring for their own families. These motives are not strongly related to the well-being of tenants. Our findings suggest that reframing sanitation improvement as an investment may allow landlords to leverage latent demand from tenants and use existing financing mechanisms to gain financially and improve their social status via provision of better sanitation services.

A further route for sanitation improvement may lie in better plot-based systems for cleaning. New and better rotas prompting tenants when it's their turn, allowing landlords to monitor participation, and perhaps even establishing sanctions when tenants fail to clean, may lead to improved interface cleanliness and benefit the landlord's own family.

A wide variety of actors, interactions, and decisions are involved in the process of sanitation improvement. We identified a range of problem behaviors that could be tackled through intervention. New toilets are usually built when existing ones failed. Many important behaviors of individual toilet users, whether failing to clean, putting undesirable waste into the toilet, or failing to put child feces into it, are challenging for a landlord to monitor. Cooperation is limited by barriers between landlords and tenants, with tenants failing to express sanitation improvement preferences or willingness to pay, and landlords failing to proactively solicit tenant feedback. It is difficult for households to keep consumable cleaning materials like soap and water in the shared public space on the plot without others taking them. Few governmental and informal regulatory mechanisms exert pressure to improve sanitation. The variety of kinds of problematic behaviors and actors identified shows the benefits of using a behavioral theory-driven process is to gain a comprehensive understanding of unexplored, behaviorally-driven health problems.

The best approach for a landlord to achieve sanitation quality improvement, either through unilateral action or coordination with tenants, may depend primarily on the type of plot. For plots where a landlord's kin or friends are present, identifying tenants' improvement priorities may be effective. But for many plots, it may be simpler for landlords to act unilaterally to improve plot sanitation, potentially offsetting costs by raising rent, and replacing any tenants who leave.

The use of a behavioral theory-driven framework for formative research around a set of sanitation behaviors, rather than a more general qualitative approach, enhanced the study. The process transformed sanitation quality improvement behaviors from broad generalities to specific kinds of improvements to be made by specific actors in relationships with other actors. We identified behavioral scripts and action selection processes that led us to specific intervention targets. We established which improvements were perceived as most important and what motives may be the most effective levers of behavior change. This theory-driven process can be useful for behaviors where little is known, to provide a framework for initial investigations, and for well-studied behaviors, to illuminate exactly what findings from other contexts might be most applicable.

Conclusion

This first study of a broad range of shared, on-site sanitation maintenance and improvement behaviors identified several barriers while suggesting feasible solutions. Major barriers included poor coordination among tenants, a lack of communication between landlords and tenants, and landlords viewing sanitation as only a required basic service to provide. Consumer-driven, sustainable improvements may be motivated by making the tenant experience of shared sanitation more tangible to landlords, leveraging tenant willingness to pay to drive intentional investments in toilet improvements, and introducing better shared cleaning systems. Overall, these findings imply that well designed, demand-side interventions may be able to increase both the structural quality and the hygiene of peri-urban sanitation systems and demonstrate the benefits of theory-driven formative research for behaviors about which little is known.

Declarations

Consent for publication: Not Applicable

Availability of data and materials: De-identified data is available upon request from study PI.

Competing interests: The authors declare that they have no competing interests

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Ethical Approval

Ethical approval and consent to participate: This study was approved by the London School of Hygiene and Tropical Medicine Research Ethics Committee (ref: 11714) and the University of Zambia Biomedical Research Ethics Committee (ref: 023-06-16).

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Chapter 4: Measure Development

Chapter Overview

This chapter steps outside the intervention development structure of the rest of the thesis to develop outcome measures for the randomized controlled trial. Existing frameworks and measures are surveyed, with a new general framework described and a localized measure for the trial operationalized and applied to the study setting. Implications for future research measure development and general sanitation measurement across contects are discussed.

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Assessing Peri-Urban Sanitation Quality Using a Theoretically-Derived Composite Measure in Lusaka, Zambia

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Abstract

Background

Despite on-going debates about what constitutes adequate sanitation, there is a lack of sanitation quality measures that are theoretically-grounded in ways that allow empirical comparisons of quality across different types of sanitation.

Methods

The Healthy Sanitation Framework (HSF) was developed to capture universal aspects of sanitation quality from a public health perspective. From this, the Peri-Urban Healthy Toilet Index (PUHTI) was created for measuring on-site, peri-urban sanitation quality. This PUHTI score was used to assess sanitation quality in a peri-urban area in Lusaka, Zambia.

Results

The HSF identified five categories for capturing sanitation quality: *hygiene, use*, *sustainability, desirability,* and *accessibility*. A composite index derived from these categories had high reliability and plausible validity, despite barriers to rigorously evaluating validity. Applying the PUHTI tool showed that while 87% of toilets were classified as "improved, but shared," there were frequent concerns about doors that couldn't be locked, dirty user interfaces, unhygienic containment, limited emptyability, and lack of handwashing facilities.

Conclusion

The HSF allows granular measures of sanitation quality to be developed in any setting using a reproducible and theoretically-grounded process. But, the lack of a unified basis on which to compare different types of sanitation overall or evidence to compare within narrower categories currently limits comparisons across types of sanitation.

Keywords: Measure, Peri-Urban, Quality, Shared, Sanitation, Toilet

Introduction

Poor sanitation is a major public health problem, but it is difficult to establish priorities to address it without a detailed measure of sanitation quality to understand what is adequate for different types of toilets in different settings. The Sustainable Development Goal (SDG) for Sanitation (6.2) aims to eliminate open defecation (OD) by 2030, and the global indicator is the percentage of the population using safely managed sanitation services, defined as "an improved sanitation facility that is not shared with other households, and where excreta are disposed of in situ or transported and treated off-site" [1]. As of 2015, about 4.5 billion people globally lacked access to safely managed sanitation, according to this standard, with 892 million still practicing OD [1]. An additional 600 million use a limited sanitation service, which is shared between households, but otherwise improved, and though rates of OD are decreasing globally, many are transitioning to limited sanitation, especially in sub-Saharan Africa [5]. There is on-going debate about whether some limited sanitation should be considered "adequate" [19], as is stated in the target for SDG 6.2, and evidence that it may be no dirtier than [18] and structurally better than household sanitation [17].

To understand when limited sanitation might be considered adequate, there is a need for more appropriate tools for measuring different types of sanitation, including household, shared, and public options, and for planning sanitation investments across different settings. Recent efforts to expand measurement beyond lists of "improved technologies" have focused on functional definitions that capture broader ecological aspects of sanitation [25], measuring variations in intra-household sanitation use [26], gathering more detail about toilet quality [17], and providing tools to understand community- and city-level sanitation status [27]. However, the major limitations of these tools are that they lack the foundation of a theoretical framework for sanitation quality needed for any composite measure [28] or provide only a high-level overview[1]. The gap between high-level definitions and comprehensive measurement tools also leads to the exclusion of many important components of sanitation, particularly those beyond the most straightforward implications of excreta management in the environment, such as privacy, safety, and sustainability.

To develop a detailed, comprehensive measure of peri-urban sanitation quality and examine its potential to be compared to measures of other types of sanitation, we created a general theoretical framework for sanitation abstracted from any particular context and used this framework to create a concrete composite measure of peri-urban sanitation quality via a systematic and reproducible process adaptable to other settings.

[1] A detailed assessment of several existing tools is available in the supplementary material

(Appendix A).

Methods

First, a general framework for measuring sanitation quality from a public health perspective was derived. Using this framework as a guide, we then conducted a literature review by forward reference searching from documents defining Millennium Development Goal (MDG) and SDG monitoring as well as consulting 10 sanitation measurement experts (Zambian and foreign academics as well as consultants) to identify other important measurement protocols. We identified key aspects of sanitation quality in our context, and chose appropriate measures from the literature where possible.

Based on this review, we created a composite measure of on-site, peri-urban sanitation quality and assessed its validity and reliability. Each field assistant independently observed the same set of toilets to assess measurement accuracy and reliability. The researchers agreed on “correct” measures in cases where objective distinctions that did not change over time were possible. However, the subjectivity of some measures (e.g., floor and pan cleanliness), as well as variation over time in fly presence, meant that the team did not assess the accuracy of these variables. Krippendorf’s alpha [153] was used to capture inter-rater reliability for each item because of its robustness to missing data, and a standard adjustment for prevalence was used to identify the effect of sample prevalence on reliability results [154]. Several other kinds of reliability were not evaluated. Test-retest reliability will be assessed using baseline and endline data from the trial, as temporal variation in measures such as cleanliness are important considerations.

As each item included in the final index was designed to capture a unique aspect of sanitation quality, internal consistency reliability was evaluated on a per-item basis when several potential measures existed (e.g., child feces disposal and handwashing with soap), but not across index items. The small number of potential measures also made assessing parallel-forms reliability infeasible.

Finally, we incorporated the PUHTI scoring tool into a baseline data collection for the "Creating Demand for Peri-Urban Sanitation" (SanDem) trial to assess the existing quality of sanitation in the Bauleni community. A team of 24 research assistants were trained for one week and collected data from landlords and tenants on the same plots from 9 Jun to 6 Jul 2017 [155][155]. Plots were selected by a random walk from the center of demarcated zones, and plots with a landlord and at least one tenant household living on them were eligible for enrolment. More detail about the data collection process is available in the full study protocol[155] [156]. The trial was reviewed and approved by the University of Zambia Biomedical Research Ethics Committee (ref: 023-06-16) as well as the London School of Hygiene and Tropical Medicine Ethics Committee (ref: 11714).

Results

Generic Framework

We propose the following working definition to motivate a "Healthy Sanitation Framework" (HSF) with an explicit theoretical foundation from a public health perspective:

To have a significant impact on population-level health, any sanitation solution must be effective at reducing exposure to pathogens, desirable and accessible to its users so that it is used, and is usable for a reasonably long time.

Breaking this statement down into elements suggests five major areas of public health concern: Hygiene, Desirability, Accessibility, Sustainability, and Use. We define and describe each of these constructs as follows:

Hygiene refers to the sanitation system separating human excreta from human contact. First, bodily wastes deposited into the environment must be safely contained. This covers aspects such as flushing toilets connected to sewer lines, lined latrine pits and additional components of the sanitation value chain such as the transport, treatment, and safe reuse or disposal of waste. Second, residual excreta should be safely removed, which includes handwashing and anal cleansing as well as having cleanable interface surfaces like a ceramic pan or a concrete slab. Both the cleanability of human and toilet surfaces and the effectiveness of cleaning practices impact the hygiene of sanitation.

Desirability encompasses all psychological factors associated with using a sanitation system. It must not be discomforting to use due to foul odor or nuisances (e.g., insects, lack of roof for shelter from bad weather). It should be private, so that users are not directly visible to others and private practices cannot be inferred. It should be reachable and usable safely without fear of predators (human or animal) or being injured during use, such as if a toilet collapses under the weight of a user because of poor construction. It should also be convenient, so that there are no major delays in use due to a high number of users or distance from daily activities of the user, and so that use fits into the user's daily routine. All of these aspects, while not related to the technological separation of excreta from the local environment, ensure that the sanitation solution is used, valued by its users, and improves public health.

Accessibility means that the sanitation facility *can be* used by the largest possible number of "in-group" members. In-group members may be members of a family, those living in an area with communal sanitation, or all children regardless of age or sex at a school. But, inappropriate users should be excluded since it may be undesirable for sanitation systems to be accessible to all without limitation, such as patrons at a local bar accessing a nearby private household's toilet [156]. Physical barriers should not prevent use, such as a full pit or a washed out bridge preventing a person from walking to access to a facility. Biological barriers such as disability due to age or illness should be overcome. Socio-cultural rules related to access, such as caste, gender, or kinship norms, must not prevent access. A solution must also be economically accessible, whether for direct costs of use (e.g., fees charged for public toilets) or indirect costs (e.g., availability of an acceptable sanitation solution at an affordable rental price).

Sustainability includes both the ability to maintain good condition and functionality of the sanitation system and the ability to recover good condition when failures occur. Maintainability includes durability of facilities, a functioning system for waste treatment, and a functioning system for maintaining hygienic condition (e.g., a responsible family member, shared cleaning rota, or a paid individual). Recoverability spans a continuum of repairs, ranging from simply fixing a door that has come unattached to the feasibility of replacement of the entire system using locally available and affordable parts, especially if the system has been provided or subsidized by the government or a non-governmental organization.

Use means that the appropriate population uses the sanitation system for the disposal of bodily waste. The disposal of bodily wastes can be either direct or indirect, such as depositing the excreta of children who use “potties” or other processes developed for people unable to access the sanitation system directly.

In this framework, hygiene, use, and sustainability are the main measures of the quality of a sanitation system *per se*. If a system is not desirable, it is not used; if it is not used, it is irrelevant; if it is not hygienic, using it provides no health benefit; if it is not accessible, significant portions of the population will go unserved and population-level health indicators will not improve; if it is not sustainable, any health benefit will not continue into the future. The specific procedures used to aggregate a measure based on the HSF should weigh all of these aspects, as we describe in the PUHTI score development below.

Development of the Peri-Urban Healthy Toilet Index

Setting

The goal of developing the PUHTI score was to create a valid and reliable measure of individual on-site sanitation system quality impacting health, broadly defined to include both physical and psychosocial aspects. Operationalization of the HSF for a particular setting took place in Bauleni, a peri-urban area in Lusaka, Zambia, with a population of approximately 64,000. The compound is divided into plots originally intended to be occupied by one family, but owners have become *de facto* landlords with 2 to 5 tenant households on a typical plot. Most toilets have concrete slabs and dry pits, and almost all are shared between multiple families. These toilets were the primary focus, rather than household toilets, used only by one family, or communal/public toilets, where access is generally unrestricted and maintenance is rarely shared among all users. Open defecation by those other than children was rare in the area. There is no sewerage present in the compound, though public and private pit emptying services were available. Few toilets could be connected to planned sewerage lines in their present form [157].

Adaptation of the framework into a usable index began with field-based qualitative formative research along with local expert consultation. The research was conducted to understand the state of sanitation in a high-density peri-urban area and the context within which it is practiced.

Measurement

An initial list of proposed indicators derived from the HSF for use in the PUHTI score were identified during our formative research, and existing quantitative measures for each element were selected. New measures were created when no suitable measure was found.[2]

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[2] An in-depth review of available measures, including those not selected for this setting, is provided in the supplementary materials (Appendix B) for consideration in other contexts.

Hygienic

As we aimed to assess on-site sanitation at the plot level, we measured the hygiene of waste containment and the safe disposal of solid waste. We assessed containment through landlord self-reports, as is common practice [158]. Special consideration was given to menstrual hygiene material disposal as solid waste. Waste bins were uncommon inside toilets and reported menstrual waste disposal behavior is likely to be problematic, and so a specific indicator for menstrual hygiene management was not included. A variety of measures of interface cleanliness were included in piloting, including observation of the cleanliness of multiple components and the cleanability of materials, self-reported cleaning behaviors, and presence of relevant props [159]. The presence of a place for handwashing with soap and water is recommended as a cost-effective measure for evaluations [160]. We included the "hygiene ladder" version of this measurement, where a place for handwashing with just one of soap or water present receives partial credit. Formative research revealed that resources purchased individually were rarely shared, so materials for handwashing will necessarily be kept in individual homes. Thus, assessing the validity of this measure in the peri-urban context is needed. No anal cleansing behaviours were targeted for the intervention, thus no anal cleansing item was included.

Desirable

Desirability is assumed to be related to the ability of the sanitation facility to provide a motivating experience. Motives mentioned in the formative research included comfort, privacy, and safety. Aspects of comfort included exposure to rain, presence of flies, and foul odor, with many overlapping measures available. To avoid rain and reduce internal contamination, presence of a roof without significant holes was observed. Nuisance insects and bad smell have both been found to affect use in peri-urban, shared latrines [161, 162]. Insect traps and smell measurement devices were too costly for the study, and subjective measurement seemed unreliable. Measures of the intensity of fly presence and of solid covers, water-seals, or ventilation pipes to reduce smell were included.

Privacy is important, not just as a mediator of use in some contexts, but as it relates to stress caused by using a sanitation system [163]. No quantitative measures associated with stress across the broad range of potential plot residents were found in the literature, so we measured the presence of a solid, attached door with an internal lock.

Safety from sexual abuse or violence would also be improved if such a door were present, and the other major fear of a toilet collapsing during use was alleviated by a lined pit (even if holes reduced its effectiveness for hygienic containment). No major issues of convenience were identified in formative investigations, and so no measure of perceived inconvenience was included in the index for this setting. Subsequent data collection revealed a fear of using the toilet at night, which did not come up in our semi-structured formative research interviews, but this oversight was corrected by including the presence of a light near the toilet in the score at endline (see Appendix B).

Accessible

Proper physical access requires that the "in-group" are able to access the toilet, while outsiders cannot. All toilets were located on plots such that no respondent had to walk more than 20m to access the toilet. But, to measure the impact of physical disabilities, landlords were asked about any residents currently unable to access the latrine on the plot due to disability. Excluding outsiders can be done through a variety of physical structures or social mechanisms, such as plot residents confronting outsiders. Simple observations of doors made of a solid material and functioning adequately along with the presence of a lock at the time of the observation were therefore included in the PUHTI score. We did not find any widespread exclusion for socio-cultural reasons and thus excluded it from the score. Economic access can be limited due to user fees for public sanitation, high costs of materials, and poor access to financial services such as loans, microcredit, or subsidies for sanitation. In this setting, communal facilities are rare, no formal financial services are available in the compound from public or private sources, and acquisition costs were unlikely to vary by plot, so no economic access measure was included in the PUHTI score.

Sustainable

Maintenance of good functionality in this context means that facilities are physically durable, waste can be treated or removed, and that there is an effective system for regular cleaning. A lined pit could be durable without being hygienic, so the type of lining was captured in the same question and scored separately for the two aspects of the PUHTI score. Since there is no sewerage system, waste is commonly dealt with by construction of a new pit latrine once the existing one fills or by emptying existing toilets. Self-reported mechanical emptyability was selected for the PUHTI score as the most appropriate measure, as landlords generally seemed aware of the kinds of trucks used for emptying in the compound, whether these trucks could access the plot, and whether there was sufficient room for access through the pan or otherwise. Though depositing solid waste into pits certainly hinders emptyability, and was reported in our formative research. However, no evaluation of an existing measure was found and the high likelihood of inaccurate self-reporting by tenants led us to exclude this from consideration, with the understanding that this remains an important area for further investigation.

The most common system for maintaining cleanliness was a rota, where households took turns cleaning. Self-reported presence of a cleaning rota was therefore selected for initial consideration in the PUHTI score, but additional items capturing the duration of each household's turns and how many times a day the toilet was usually cleaned were included with observed cleanliness to assess the validity of the measure.

System recoverability is largely affected by the availability of construction materials locally. No latrine components distributed or installed by sanitation projects were observed and no other sanitation promotion or infrastructure development programs were reported by residents or government officials, so no indicator of recoverability was included in the PUHTI score.

Used

Proper measurement of latrine use is essential, as increases in the availability of facilities have been shown in some cases to be poorly correlated with increases in use [164]. However, open defecation is uncommon in this context. So, we assessed whether toilets were full and child feces disposal practices, which are a major public health concern [165]. Since the PUHTI score was derived from questions asked only of the landlord residing on the plot, the recommended practice of asking caregivers was precluded. Landlords were asked about child feces disposal on their plot, and we validated this measure against tenant responses. See Table 6 for a summary of the final list of included measures.

Aggregation

The weighting and aggregation of variables into composite measures like an index or scale can have a significant impact on the relative rankings given to the things being measured. An evidence-based "common currency" for health impact was generally lacking, as the diarrheal disease impact of specific components is not well established and a QALY-like system for combining categories such as physical and psychological health into a single measure is not available. We therefore decided to construct one measure for each theoretically distinct aspect of the sub-scales and to use equal weights for measures within categories, unless there was a clear justification for doing otherwise.

A simple arithmetic mean was used to combine the five categories of the PUHTI score. This meant that a toilet that received low marks in one category could still receive a high overall score, as opposed to being strongly penalized like the geometric mean used in other community-level sanitation measures [166]. This allows an otherwise high-quality toilet that happened to be full (and thus receive a score of zero for Use) to avoid a drastically reduced score, because only a small change would be required to achieve a high-quality toilet.

Reliability and Validity

The only item dropped from the scale due to reliability issues was the presence of holes in toilet walls, as issues around what size of opening at what height and with what level of intentionality (e.g., a window/hole for ventilation) were insurmountable. The final value of Krippendorf's alpha for the scale was 0.885, considered highly reliable [167].[3]

While the criterion and content validity of the PUHTI score were ensured by the theory-based derivation of the measures, there is no concrete benchmark for evaluating the construct validity of the PUHTI score, as there is no simple measure of public health, broadly defined, and there is even limited evidence for the associations of individual components with diarrheal disease outcomes.[3] Tenant satisfaction with aspects of sanitation on the plot (e.g., privacy) was therefore correlated with observed PUHTI measures (e.g., presence of a solid door) to test measure validity. All associations were found to be statistically significant other than questions about if anyone on the plot was excluded due to disability for socio-

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[3] Additional detail on this process can be found in the supplementary material.

cultural reasons, which were not specifically about only the respondent. Adjusted R^2 values were generally between .2 to .4 when looking at the relationship between specific components and general feelings, which suggested reasonable validity.

A single summary measure for child feces disposal on the plot was collected from the landlord, along with items capturing open defecation rates and disposal practices from a tenant on each plot for comparison. Landlords (n=1096) reported that approximately 19.5% of child feces remained on the plot, while tenants (n=1085) reported that only 5.5% of their own child's feces did so, for a difference of 14.0 percentage points (95% CI: 11.3-16.8, p<.001). It is likely that landlords are more likely to notice feces remaining on the plot without a strong understanding of the underlying denominator of the total amount produced on the plot, but parents may also face a social desirability pressure to report less open defecation on the plot.

Final Scale Definition and Characteristics

The final PUHTI score was assembled from the items whose piloting is described above with only a few minor modifications. The multi-item toilet cleanliness measure combines a lowest rung of having no visible feces, a second rung of having cleanable materials (as those with no visible feces are still likely to be highly contaminated if made of uncleanable materials), and a highest rung of a water seal, implying no contact with excreta spread by flies from the containment. For the desirability sub-scale, seven items were combined with equal weights, regardless of the underlying sub-scale component (e.g., privacy or safety).

Desirability consisted entirely of observed measures other than one related to the sub-structure and had a reliability of .810 (using a ratio PABAK).

Table 6: Final PUHTI score measures and weighting

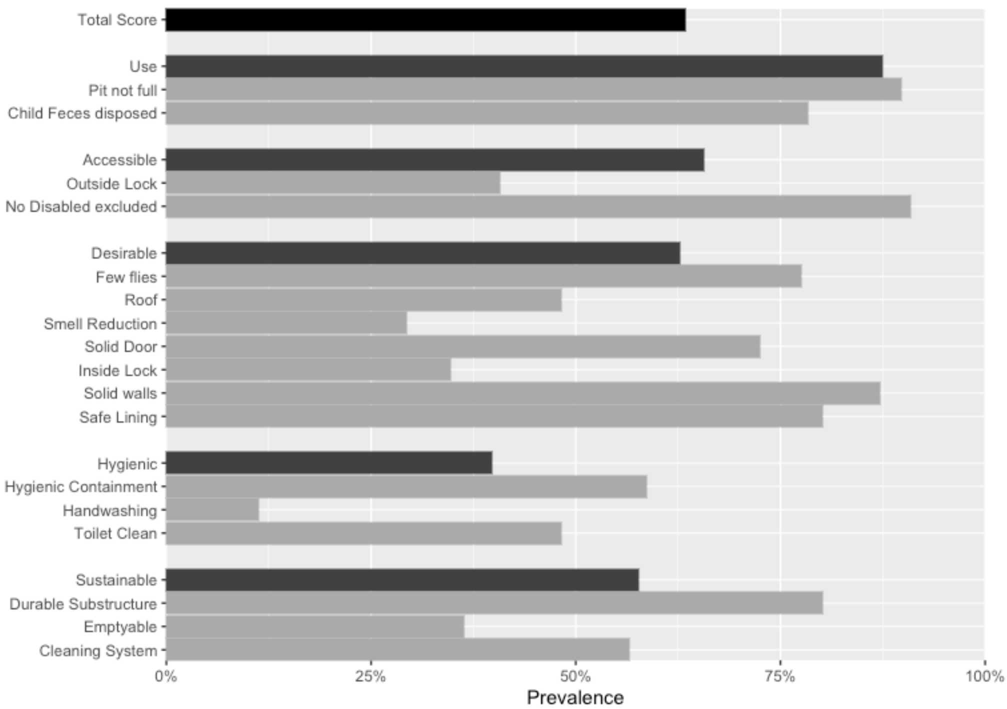
Sub-scale	Points Assigned	Weighting
Hygienic		
Cleanliness of interface	1 : Water seal (+ previous) .8 : Cleaning system in place (+previous) .4 : Interface made of cleanable materials (+ previous) .2 : No visible feces	33%
Excreta hygienically contained	1 : Concrete blocks and lining or septic tank .5: Concrete blocks and no lining	33%
Place for handwashing	1 : Place for handwashing with soap and water .5: Place for handwashing with soap or water	33%
Sustainable		
Durable pit lining	1: Concrete blocks used	33%
Containment mechanically emptyable	1: Containment mechanically emptyable	33%

Cleaning system in place	1: System in place	33%
Used		
Toilet usable	1: Pit not full	80%
Child feces disposed into containment	1 : All child feces goes into latrine or no children living on plot .67: Most child feces goes into latrine .33: Some child feces goes into latrine	20%
Desirable		
Few flies	1: 3 or fewer flies observed in toilet	14%
Solid door	1: Solid door present	14%
Inside lock	1: Solid door with internal lock present	14%
Solid walls	1: Concrete or Wood	14%
Solid roof	1: Roof present	14%
Strong substructure	1: Concrete blocks used	14%
Smell reduction	1: Flushing toilet, ventilation pipe, or simple cover	14%
Accessible		
Disabled accessibility	1: Anyone living on plot unable to access toilet due to disability	50%
Outside lock to exclude outsiders	1: Solid door with outside lock present	50%

Bauleni Situational Analysis

We tabulated scores for each PUHTI measure for 918 toilets in Bauleni. The median PUHTI score was .663 [IQR: .541-.770]. A detailed analysis of PUHTI measures revealed substantial differences in the presence of individual components and deficits in important aspects of each of hygiene, accessibility, desirability, and sustainability (Figure 3). Few problems with use were reported, and most plots had a toilet with solid walls (87%), a solid door (73%), and a lined pit (80%). About half didn't have a solid roof (52%) or a functioning cleaning system (43%), and few were mechanically emptyable (36%) or used a smell-reduction technology (29%). Almost none had a place for handwashing with soap and/or water present (11%). Accessibility to in-group users was not a problem for most, but many toilets (59%) were unprotected from use by outsiders and offered no privacy or safety of an inside lock to users (65%).

Figure 3: Bauleni Toilet Quality Summary by Overall PUHTI score, Sub-Score, and Measures



An assessment of toilets in Bauleni captured by the PUHTI score, its 5 sub-scores, and individual measures.

Discussion

Developing sanitation measures

Both routine monitoring and research measures should be derived from a sound theoretical framework via a rigorous and transparent development process. The Health Sanitation Framework (HSF) is proposed as the basis for such a process, but there may be arguments for including or excluding constructs or combining them in alternative ways. We hope that the HSF will serve as a starting point and catalyst for a wider discussion and contribute to an eventual consensus on a general framework for sanitation quality.

One useful aspect of coming to consensus on a framework like the HSF would be to develop measures for different types of toilets (e.g., shared, household, public). But, overall comparison would require an objective standard (e.g., diarrheal disease), which we see as using a subset of its abilities, or a development of a QALY-like common currency. Perhaps better would be to look at specific measures that could be directly translated across types and settings (e.g., cleanliness) or that might be measured in different ways, but could still be compared functionally (e.g., a variety of technologies geared towards creating privacy, with subjective psychometric assessment).

The Peri-urban Healthy Toilet Index (PUHTI) score was developed as an outcome for a specific trial, rather than a reusable tool in other settings. But, its development process can be replicated in other settings and for other composite measures, and the resulting PUHTI score should be easily adapted to other peri-urban contexts. The general steps of (1) deriving context-specific adaptations of constructs from a general theoretical framework, (2) selecting and validating measures of those constructs, and (3) creating and justifying a composite measure are uncontroversial, but rare in practice. Many other comprehensive measures of sanitation are not amenable to criticism due to the opaque underlying theoretical links.

Item measures are commonly used across contexts, despite the strong effect that underlying populations have on measure validity and reliability. Even seemingly straightforward measures, such as the presence of a roof, showed significant unreliability in initial pre-testing during this process, demonstrating the need for the explicit analysis of validity and reliability in almost any sanitation research project.

Composite measures are often aggregated by simple addition, and while detailed empirical data for justifying alternative weightings may be lacking, theoretical overlaps between measures can inform weighting of sub-scores or the number of measures included. As discussing what makes shared sanitation "healthy" becomes a more acceptable position in the public health discourse, theoretically-sound and well-constructed measures will be necessary to make sound, data-driven decisions [19].

The PUHTI approach and item selection

Several difficult choices had to be made related to individual measures, the selection of respondents, and the approach to data collection taken in attempting to develop a comprehensive, plot-level measure of sanitation quality. Some constructs simply have no commonly-accepted standard of measurement. Handwashing measurement has been discussed extensively in the literature, but the applicability of approaches such as observing a place for handwashing near the toilet is unclear in a shared-sanitation context. The presence of flies exhibits such inter-temporal variability that it seems unlikely any point observation will be reliable. Toilet cleanliness has been judged using a wide range of techniques, from observation of feces or materials used in the toilet to microbiological testing. However, standardized valid and reliable measures for such variables are needed.

The public health importance of other measures is also unclear. However, each item included could plausibly be linked to at least one item of broad health importance, and granular measurement allows for both a variety of analytical approaches depending on what an investigator favors as well as re-calculation as the evidence base expands. Hygienic containment is relatively easy to define, but the actual disease risk to a population depends on characteristics of the soil, water table, and water sources used by residents.

Other measures are complicated or compromised by directing the PUHTI score tool only at landlords. The standard practice is to ask caregivers about child feces disposal for example, and other measures like emptyability may be better judged by local technicians than by landlords who may be unaware of available technologies. However, the decision was made to allow the most efficient collection of data for the largest number of indicators, and special attention was paid to the triangulation of items for which simple observation or landlord reports were not fully trusted.

Some constructs may simply be impossible to measure accurately at the plot level in peri-urban settings, such as measuring access to toilets by those who have a disability. Though we asked landlords if any current residents were prevented from accessing the toilet, inaccessible toilets may have prevented people from living on a plot in the first place, so a straightforward measure of those currently living on a plot unable to access the toilet obscures the scope of the problem. But, few good alternatives exist for measuring this construct at the plot level. Measuring the accessibility of every toilet based on standardized construction parameters would be infeasible and excessive. Additional questions could be asked of the landlord to understand if people with disabilities have ever been prevented from living on the plot, have ever been accommodated by individual equipment, or have ever left due to damage to such equipment. But, these may be poor proxies to capture the size of the problem. Such issues may best be measured using alternative data collection procedures.

Despite the limitations and challenges identified above, the PUHTI score and a majority of individual items are reliable, valid, and easy to collect, and provide more detail than is currently collected on a range of important aspects of on-site, peri-urban sanitation quality.

Policy implications for Bauleni

Almost all toilets observed in Bauleni were shared, but would be considered otherwise improved—however, a wide variety of quality levels was found in the situational analysis. Though most toilets were not full and could be used, the lack of effective cleaning systems or handwashing facilities meant that hygiene in many of these shared facilities is a major concern. Further, serious issues of poor desirability (in particular, a lack of roofs, inside locks, or smell reduction technologies) make using these toilets unpleasant. As the government target for the area is sewered connections for all, these detailed data demonstrate how far the quality of these toilets need to be improved even if sewerage is provided by the government and the local utility company to allow connections as well as to truly offer high-quality sanitation to peri-urban residents.

Conclusion

The theoretically-grounded, general Health Sanitation Framework developed here provides a strong foundation for assessing sanitation quality. It also allows the rigorous development of population- and situation-specific measures of sanitation quality. The framework was used here to create the Peri-urban Health Toilet Index (PUHTI) score for investigating peri-urban on-site sanitation services, which was also used as an outcome measure for the SanDem trial [155]).

These developments have highlighted several important measurement challenges remaining in peri-urban contexts, but the transparent process used here openly acknowledges the tradeoffs made along the way and provides a roadmap for both future measurement research and a reproducible set of steps for creating similarly high-quality measures in other settings. Measuring sanitation quality using the PUHTI score has allowed for a detailed understanding of barriers to improving peri-urban sanitation in Lusaka in particular, and can enable policymakers to better understand their own contexts and select the most effective approaches to improve sanitation in diverse settings globally. More work is needed to provide a basis to compare different types of sanitation in the aggregate and stronger granular evidence to compare within narrower categories.

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Appendix A: Review of Existing Sanitation Frameworks

This supplementary material reviews existing measures and frameworks, which served as the basis for the development of the Healthy Sanitation Framework and Peri-Urban Healthy Toilet Index.

Joint Monitoring Program for MDGs and SDGs

Most modern frameworks and measures for sanitation status are derived from the JMP standards (definition and monitoring guidance) for improved sanitation in the MDG era. To standardize measurement, improved sanitation was defined technologically as shown in Table 7 [5]. In addition to the categories below, otherwise improved sanitation that was shared by more than one family is considered "Shared Sanitation," generally considered to be between improved and unimproved, while the lowest tier, "Open Defecation," is considered the least effective for separating excreta from human contact [168].

Table 7: JMP Standard Definitions for Sanitation MDG Monitoring

Improved Sanitation	Unimproved Sanitation
• Flush toilet • Connection to a piped sewer system • Connection to a septic system • Flush / pour-flush to a pit latrine • Pit latrine with slab	• Public or shared latrine (meaning a toilet that is used by more than one household) • Flush/pour flush to elsewhere (not into a pit, septic tank, or sewer) • Pit latrine without slab

• Ventilated improved pit latrine • Composting toilet	• Bucket latrines • Hanging toilet / latrine

Source: [168]

For the SDG era, one additional rung has been added to the top of the sanitation ladder, "safely managed sanitation," defined as: "Private improved facility where fecal wastes are safely disposed on site or transported and treated off-site; plus a handwashing facility with soap and water." SDG target 6.2 states that the global goal for sanitation is, "By 2030, 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." JMP has published a "normative interpretation" of this goal, reproduced in Table 8 [135].

Table 8: JMP "normative interpretation" of SDG Target 6.2

Target language	Definition
access	Implies facilities close to home that can be easily reached and used when needed

to adequate	Implies a system which hygienically separates excreta from human contact as well as safe reuse/treatment of excreta in situ, or safe transport and treatment off-site
and equitable	Implies progressive reduction and elimination of inequalities between population sub- groups
sanitation	Sanitation is the provision of facilities and services for safe management and disposal of human urine and feces
and hygiene	Hygiene is the conditions and practices that help maintain health and prevent spread of disease including handwashing, menstrual hygiene management and food hygiene
for all	Suitable for use by men, women, girls and boys of all ages including people living with disabilities
end open defecation	Excreta of adults or children are: deposited (directly or after being covered by a layer of earth) in the bush, a field, a beach, or other open area; discharged directly into a drainage channel, river, sea, or other water body; or are wrapped in temporary material and discarded
paying special attention to the ***needs of women and girls***	Implies reducing the burden of water collection and enabling women and girls to manage sanitation and hygiene needs with dignity. Special attention should be given to the needs of women and girls in 'high use' settings such as schools and

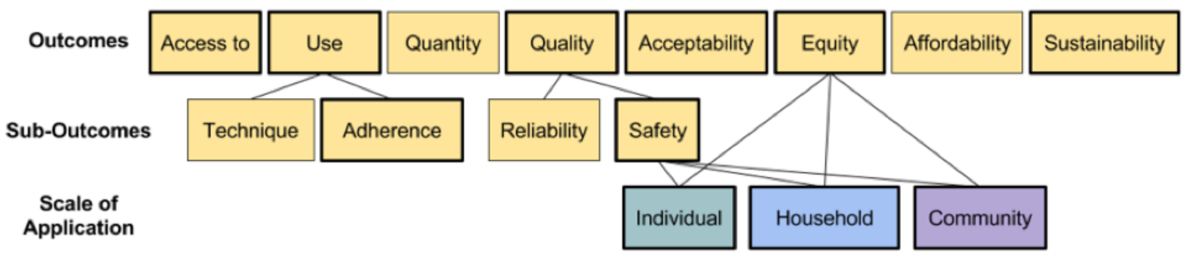
	workplaces, and ‘high risk’ settings such as health care facilities and detention centres.
and those in vulnerable situations	Implies attention to specific WASH needs found in ‘special cases’ including refugee camps, detention centres, mass gatherings and pilgrimages

Source: [135]

Though the exact monitoring indicators and measurement tools are not finalized, it is clear that this is a major expansion of the scope of the target, including both use/containment as well as treatment and personal hygiene. Still, it is not a purely theoretical framework for sanitation, as political values are included (gender/equity/vulnerable populations), and it excludes values related to broader definitions of health (safety/privacy). Therefore, there remains gaps to be filled both at higher (theory to target definition) and lower (target definition to implementation) levels. Many different kinds of extensions have been suggested for JMP, including alternative frameworks capturing a broader range of environmental health or economic and institutional indictors, more granular quality measures, and measuring systems at aggregate levels beyond individual households, which will each now be examined in turn.

One recent extension of note is provided a theoretical expansion of the meaning of “access” in the SDG definition [169] (Figure 4). Drawing from prior work by sociologists [170], this framework identifies the concepts underlying the SDG goal of “access” and suggests the degree to which each relevant concept is measured in the current sanitation ladder. This approach even suggests data collection methods and technologies for measurement, though the exact questions to be used are glossed-over, as the intention is to keep the framework generic rather than adapting it to a particular context.

Figure 4: Measuring Sanitation Based on a Theory of Access



Source: [169]

Alternative Sanitation Frameworks

A few frameworks have been suggested as alternatives or supplements to the MDG/SDG frameworks, proposing more functional definitions and broader conceptualizations of risks at system-wide levels.

"Revamped" Sanitation Ladder

The "revamped" sanitation ladder, suggested by Kvarnström et. al. (2011), is a reconceptualization of sanitation measurement from a functional perspective and also extends the ladder towards an ecological level to include greywater management, treatment, reuse, eutrophication risk reduction, and integrated resource management [171]. This approach proposes a more comprehensive and insightful understanding of health risk and opportunities throughout the sanitation value chain as well as arguing that such functional definitions allow for local solutions and incentivize innovation. However, there is little theoretical development of the bottom rung, excreta containment, or the reasons for the inclusion of the selected indicators and the exclusions of others, and no mention of sustainability other than at the level of inter-connected systems at the highest rung.

Table 9: "Revamped" Functional Sanitation Ladder

Environmental Functions	7. Integrated resource management	Indicators will differ and depend on flowstreams from the full environmental sanitation system (urine, faeces, greywater, faecal sludge, wastewater as below but also including water provision, stormwater management and solid waste management) and context
	6. Eutrophication risk reduction	Indicators will differ and depend on flow stream from the sanitation system (urine, faeces, greywater, faecal sludge, wastewater)
	5. Nutrient reuse	(i) X% of N, P, K excreted is recycled for crop production, (ii) Y% of used water is recycled for productive use
Health functions	4. Pathogen reduction in treatment	Indicators will differ and depend on flow stream from the sanitation system (urine, faeces, greywater, faecal sludge, wastewater)

		and also whether the flowstream will be used productively afterwards or not
	3. Greywater management	(i) No stagnant water in the compound, (ii) no stagnant water in the street, (iii) no mosquitos or other vectors
	2. Safe access and availability	(i) 24-hr access to facility year-round, (ii) facility offering privacy, personal safety and shelter, (iii) facility is adapted to needs of the users of the facility
	1. Excreta containment	(i) Clean facility in obvious use, (ii) no flies or other vectors, (iii) no faecal matter lingering in or around latrine, (iv) handwashing facility in obvious use with soap, (v) lid, (vi) odour-free facility

Source: [171]

Sustainable Sanitation

Another sanitation framework is "Sustainable Sanitation," proposed by the Sustainable Sanitation Alliance [172]. The basis for this framework is:

> *In order to be sustainable a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources.*

They propose the categories in Table 10 for evaluating the sustainability of a sanitation solution.

Table 10: Sustainable Sanitation Framework

Category	Description
Health and hygiene	Risk of exposure to health hazards along the sanitation value chain; includes hygiene, nutrition, and livelihood improvement
Environment and Natural Resources	Required natural resources for construction, operation, and maintenance of the system; Recycling and reuse of inputs
Technology and Operation	Ease with which system can be constructed, operated, and monitored; Robustness of the system
Financial and Economic Issues	Ability of households/communities to pay for system
Socio-cultural and Institutional Aspects	Acceptability and appropriateness of the system; Compliance with legal frameworks and; Strong institutional settings

Source: [172]

This is a helpful perspective to look at sustainability broadly and extends classifying sanitation beyond the household level to look at the overall system. Though there are few details in this framework about the health and hygiene category or a detailed understanding of use compared to other measures, its broader implications will be important to include in the development of a high-level sanitation framework.

Household-Level Measures of Sanitation Quality

Other extensions to the JMP definitions propose to provide a more detailed picture of the quality of household sanitation systems by capturing variations in actual use within households as well as more detailed assessments of individual toilet quality.

SafeSanIndex

One way of adding granular detail to JMP is by assessing intra-household heterogeneity in toilet use. The Safe Sanitation Index ("SafeSanIndex" or SSI) was developed to measure defecation and feces disposal practices in urban areas, with specific consideration of variations by age, disability, gender, and illness, as well as variations in practices by time of day [173]. This scale uses 15 items to form two sub-scales, Latrine Use Frequency and Open Defecation Rate, along with an aggregating procedure to generate an overall SSI score. The SSI was extensively tested for reliability across different visits to the same site and its validity assessed by comparing it to measurements of other factors that influence latrine use and open defecation rates identified in a literature review. Its utility was also demonstrated by its detection of poor correlation between latrine use frequency and report of any open defecation, low rates of safe disposal of the feces of children or those who were ill, and the low social desirability bias found in reported defecation practices, particularly when the respondent reported on the behavior of other family members. Thus, SSI suggests a useful way to capture sanitation system use, one of the many important aspects of sanitation to capture, though it can only fill a part of the need for a good, comprehensive measure.

Safe and Sustainable Sanitation

Another approach to extending JMP to peri-urban areas is to look at "hygienically safe and sustainable" and "functioning" sanitation as additional criteria to add to the JMP definition. "Safe and Sustainable Sanitation" (SSS) is a classification system designed to inform SDG monitoring development by providing a more detailed understanding of peri-urban sanitation conditions rather than specifically as an outcome measure [17]. The indicators used are shown in Table 11 below.

Table 11: Safe and Sustainable Sanitation Indicators

System aspect	Indicator description	Indicator type	Definition and measurement applied in this study

Facility design	1. Pit with slab or better	I, SS	Above-ground technology is basic pit with slab, ventilated improved pit, WC, ceramic bowl (pour flush), but not drum/tyre
	2. Waste contained in pit/tank	I, SS	Technology has waste pit, septic tank, or connects to sewer with no exterior waste drain pipe observed by enumerator (assumed if unable to observe)
	3. Below ground pit/tank lined	SS	Below-ground technology is part or fully lined, septic tank, or is connected to sewer, to allow for safe waste emptying, and protect shallow groundwater
Waste management (emptying, transport, disposal)	4. Hygienic emptying service locally available	SS	Vacuum tanker or Vacutug service to extract pit waste in sealed tanks and dispose into municipal treatment system reported as locally available, or user intends to use service to empty in near future
	5. Plot accessible to	SS	Enumerator observation of plot physical accessibility (car, tanker, or

	hygienic emptying service vehicles		tug) or actual use of tanker/tug to empty within last 3 years
Functional condition	6. Structurally safe to use	F	Enumerator observation that slab/floor is not collapsing into pit nor in state prohibiting safe use (assumed if unable to observe and not reported)
	7. Pit not completely full of waste	F	Enumerator observation of pit fullness by measuring depth from slab/top to surface of sludge (assumed if unable to observe and not reported)
	8. Facility has half height walls and half height door or more	F	Enumerator observation of toilet facility superstructure walls, roof, door presence and height
	8A. (high standard) Facility has	F	Enumerator observation of toilet facility superstructure walls, roof, door presence and height

	roof, full height walls & door		

Source: [17]

SSS adds in additional indicators primarily related to (1) Emptying (pit lining to allow for emptying, the availability of a local emptying service, and the accessibility of the plot to emptying services) and (2) Functionality (slab not collapsing, pit not full, and superstructure quality). There is no intent to create an aggregate score, and meaningful aggregation would be difficult due to the lack of overall theoretical framework describing the relationship between categories. For example, functional condition is judged by a safe slab, a pit not completely full of waste, and presence of half/full height doors and walls, but it’s not clear how to judge a full pit, which may perhaps be emptied and immediately achieve a positive score on each item, compared to wall/door height, which may lead to a variety of outcomes ranging from psychosocial stress to preference for open defecation. Thus, SSS clearly demonstrates the need for capturing the quality of a sanitation facility’s infrastructure, but the list is far from comprehensive, justifications for the measures included are not provided, and guidance about how to adapt SSS to other contexts is not provided.

Community-Level Measures of Sanitation Quality

Beyond household-level measurement tools, other approaches have been developed to understand the availability of critical, community-level components in the sanitation value chain (such as the presence of emptying services or treatment facilities) essential for health benefits from improved sanitation.

Sanitation Service Levels

The WASHCost project aimed to assess “full life-cycle service costs” associated with levels of a more detailed sanitation ladder described in terms of functions rather than technological components (as done by JMP) and for the ultimate purpose of evaluating cost-effectiveness across projects in multiple countries [174]. Drawing from both Kvarnström and the Sustainable Sanitation Alliance above, it proposes categories of accessibility, use, reliability, and environmental protection with several levels each. The inclusion of various “ladders” describing different aspects of sanitation that may not be correlated is an important advance, and the argument to rate sanitation systems by the weakest indicator is persuasive. However, the recommendation to use relevant national standards as well as the claim that comparisons across countries are meaningful are difficult to reconcile, and national standards may not adequately describe the realities of peri-urban sanitation in some settings. Still, the general approach as an operationalization of frameworks already discussed is a useful basis for adapting existing work to the study setting.

Table 12: Services and Levels associated with WASHCost

Service level	Accessibility	Use	Reliability (O&M)	Environmental protection
Improved service	Each family dwelling has one or more toilets in the compound. Easy access for all family dwellings.	Facilities used by all household members.	Regular or routine O&M (including pit emptying) service requiring minimal effort. Evidence of care and cleaning of toilet.	Non-problematic environmental impact/safe disposal and re-use of safe by-products
Basic service	Cement or impermeable slab at national norm distance from households (per household or shared).	Facilities used by some household members.	Unreliable O&M (including pit emptying) requiring high level of user effort. Evidence of care and cleaning of toilet.	Non-problematic environmental impact/safe disposal

Limited "service"	Platform without impermeable slab separating faeces from users.	No or insufficient use.	No O&M (e.g. pit emptying) taking place and no evidence of cleaning or care for the toilet.	Significant environmental pollution, increasing with increased population density.
No service	No separation between user and faeces, e.g., open defecation.			

Source: [174]

Sanitation Index for Monitoring

The Sanitation Index for Monitoring (SIM) was created to evaluate sanitation quality in urban communities in Sri Lanka [175]. The measure includes sub-indices for latrine security and hygiene as well as on-site/off-site treatment and disposal as appropriate. Each sub-index was then aggregated into 3 and 4 levels, respectively, and a two-way table capturing the 12 combinations was used to classify sanitation systems. Insights generated from the SIM beyond what would have been observed by JMP were discussed. The SIM is a useful operationalized measure, and the creation of categories for analysis rather than simply using a continuous score of for composite measures was innovative in spite of the somewhat ad hoc nature of the cut-off definitions. However, there was no discussion of reliability of individual scale items, the validity of the overall categorical scores to any particular outcome, and no explicit theoretical framework presented to justify item selection.

Urban Sanitation Status Index

The Urban Sanitation Status Index (USSI) was developed as a city-level method to quantify sanitation status [166]. Several detailed measures of individual toilet quality specifically focused on hygienic quality, potential environmental contamination, and safety were specified, and typical sanitation value chain measures (including solid waste and storm and grey water treatment) were included (see Table 13). The particular strength of USSI is that there is an explicit process for creating an aggregate measure with several useful steps included. First, indicators are selected, though mostly on the basis of appropriateness, ease of collection and interpretation, sensitivity to change, and policy relevance without an explicit description of how this process was carried out. Next, the indicator weighting process used the Analytic Hierarchy Process technique with local experts to capture the perceived importance of each. Finally, the aggregation process consists of additive aggregation within functions to allow for inter-item compensation followed by a multiplicative aggregation of the functions, based on the idea that a failure of one of the “links” causes a failure of the entire sanitation value “chain.” However, the measurement of specific toilet comments is limited and there is no strong theoretical basis for item inclusion. In addition, though the expert weighting process is one answer to the challenge of aggregation, it limits inter-location comparability and may be strongly biased by the experts’ interpretations of the underlying constructs (i.e., what makes something more or less important as a "key status indicator?"). Furthermore, consulting only with experts instead of directly including actual users during the measure development process may also lead to misunderstandings of existing practices and mismatched improvement priorities between policy makers and actual users of the toilets.

Table 13: USSI Component Functions and Indicators

USSI containment **Fecal material safely captured and stored**	**USSI emptying and transport** **Fecal material removed—latrine emptying—and transported hygienically and safely to treatment facility**
Access to Infrastructure type of toilet number of families sharing the toilet Safety structural stability of the facility type of lining of the pit or septic tank groundwater level Hygiene hygienic condition of the toilet	Access to emptying services type of equipment used for latrine emptying Transport safety percentage of fecal material lost during transport to the treatment facility
USSI treatment and disposal	**USSI complementary services**

Fecal material adequately treated and isolated without risk to public health or the environment	Stormwater system working efficiently, allowing effective functioning of the sanitation system
Level of treatment type of treatment used Final disposal quality of disposal management	Solid waste management local accumulations of solid waste solid waste disposal site Storm and grey water management efficiency of the stormwater and grey water systems local accumulation of storm water in-house grey water management

Source: [166]

Strengths and Limitations of Existing Approaches

Each of the approaches described above has important strengths, but each has limitations that prevents its use as a theoretically-grounded, detailed measure of sanitation quality (Table 14). JMP provides a straightforward, lowest common denominator-type approach that can be applied across contexts and captures important aspects of sanitation for improving health. The "revamped" sanitation ladder and sustainable sanitation provide alternative and supplementary frameworks to JMP. SSI and SSS both examine details masked by JMP in individual toilet quality and use. Sanitation Service Levels, SIM, and USSI suggest different methods for understanding sanitation more broadly and for aggregating measures for policymakers. However, there is no detailed measure that captures all of the diverse aspects of sanitation and is also derived from a general theoretical framework that suggests components to include and aggregation procedures. Hence, we suggest the Healthy Sanitation Framework (HSF) to fill the high-level void as well as the Peri-Urban Healthy Toilet Index (PUHTI, pronounced "potty") score as an example of a detailed measure appropriate for a specific local context.

Table 14: Suitability of Existing Sanitation Frameworks and Measures as Outcomes for this Study

Framework	**Description**	**Pros**	**Cons**
SDG "Normative Interpretation"	Technology-based framework for global monitoring	Universal monitoring standard; Simple to apply; Widely accepted by governments and organizations	Omits many important aspects of sanitation; Not enough detail for evaluating individual system quality
Aspects of Access	Theoretical expansion of the concept of "access" from SDG	Theoretically based framework for measuring sanitation; Detailed examination of data collection requirements	Little detail or guidance for choosing exact measures to use; Requires a wide variety of data collection techniques

"Revamped" Sanitation Ladder	Extends sanitation ladder to broader ecological levels and uses functional definitions	Expands scope of sanitation definition from limited SDG perspective; Function definitions can be adapted to any situation	Omits much detail of actual measures to use; Limited inclusion of sustainability
Sustainable Sanitation	High-level framework with multi-sectoral perspective on sanitation	Useful broadening of perspective on sanitation; Reasonably strong theoretical basis	Very little detail or guidance for measurement
SafeSanIndex (SSI)	Measures intra-household heterogeneity of toilet use	Extensively evaluated for validity and reliability; Sound basis for aggregation process	Captures only a narrow aspect of sanitation (use)
Safe and Sustainable Sanitation	Adds additional technological specificity to SDG list	Captures toilet quality in-detail; Simple to administer	Lacks clear justification for included items; No aggregation procedures specified

Sanitation Service Levels	Rates sanitation systems using multiple, independent scales and provides guidelines for aggregation and comparing across locations	Captures many important aspects of system quality; Transparent aggregation methodology	Difficult to reconcile local adaptation and comparability across settings; Little detail for capturing shared sanitation or toilet quality
Sanitation Index for Monitoring (SIM)	Assesses on-site toilet quality separately from treatment/removal to create monitoring framework	Independently captures different aspects of sanitation system quality; aggregation into easy-to-understand categories	Little detail for evaluating shared sanitation quality; no evaluation of scale validity or reliability
Urban Sanitation Status Index (USSI)	Measures important urban sanitation functions across the entire value chain with a	Transparent aggregation process; measures many important urban factors	Little measurement detail included for individual sanitation systems; No clear theoretical basis for item inclusion

	particular emphasis on community-level metrics		

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Appendix B: Detailed Review of Sanitation Quality Measures Considered

This supplementary material provides more detail regarding measures included and excluded as a resource for others undertaking similar measure development processes.

Hygienic

Containment of bodily wastes has been assessed throughout the entire sanitation value chain as described above, but due to the nature of our intervention (and inability to randomize above the level of the plot), only containment on the plot and emptyability of the waste storage were considered. There is much debate over the specific design specifications of containment systems for a hygienic latrine [176], with some studies even providing evidence against any significant public health impact from pit leaching [177]. A variety of factors including soil composition, proximity to ground water, presence of urine diversion, raised or lined pits, or even the color of the ventilation tube have been shown to have an impact on contamination caused by pit latrines. Bauleni compound has rocky soil and moderately vulnerable ground water [178], but most drinking water is provided by a municipal water supply, so the exact relationship between technologies used and health impacts is difficult to specify. Standard guidance to assess containment is to rely on self-reports to understand the type of containment used, and while suggestions have been made that observation could compliment these self-reports, some differences in underground containment are not easily observable [158]. A self-reported measure of pit lining type was therefore selected for the PUHTI score, with sealed pits (with or without being plastered) and septic tank systems viewed as most hygienic, pits partially lined with bricks (with holes to allow for drainage) as partially hygienic, and unlined pits as unhygienic.

Special consideration should be given to menstrual hygiene material disposal, since discarding such materials in the latrine pit may adversely affect emptyability and contaminate the environment due to its non-biodegradable nature. Though presence of waste bins may be a good observable indicator in some contexts, providing such items for the disposal of menstrual material was uncommon inside toilet structures in Bauleni and culturally unacceptable based on findings from the formative research. Reported behavior at the household or plot level is likely to be problematic, and so a specific indicator for MHM was not included, though further investigation into simple assessment methods is needed.

The cleanliness of the interface, floor, and walls have been measured in similar ways using measures including actual cleanliness (self-reported [16], observation using either simple classifications [179] or detailed item lists [180, 181], or presence of biomarkers [18]), cleanability of the types of materials used [158], and cleaning behaviors practiced (self-reported [137] and observation of relevant props [182]). Cleanliness of shared sanitation is likely to be a major public health concern and so adequate measurement is essential. Self-reports were considered inadequate and biomarkers prohibitively expensive. A combination of multi-component cleanliness observation, cleanability of materials, self-reported cleaning behaviors, and presence of relevant props were initially included in piloting the PUHTI score to determine their reliability and variability in this context.

A variety of measures exist for handwashing with soap, including asking the respondent for the frequency of handwashing in specific circumstances [183], "covert script" elicitation of self-reports through asking respondents to recount daily routines [184], structured observation [185], use of electronic sensors [186], and presence of a place for handwashing with soap and water present, either as a binary [187] or tiered, "hygiene ladder" outcome [188]. One review suggests that a rapid observation of the presence of a place for handwashing with soap and water is recommended for evaluations not specifically centered on handwashing as a cost-effective measure [160], and the update "hygiene ladder" version, where a place for handwashing with just one of soap or water present receives "partial credit," was included in PUHTI. However, there was concern among the study team that while this measure is seen as more of a useful upper limit on handwashing behavior than an accurate measure, it may be even less accurate in peri-urban settings. Formative research revealed that resources purchased individually are rarely left in common areas of the plot, and that landlords rarely provided handwashing materials for the plot, so materials for handwashing are generally not shared and will necessarily be kept at some distance from the toilet. Further comparative evaluation of methods previously mentioned is needed to identify the most valid measure in this context.

Anal cleansing was commonly reported during formative research to take place with paper rather than simply water; however as with soap, such materials are rarely kept in common spaces. An association between absence of anal cleaning materials and diarrhea rates has been observed in a school setting [189] and large variations in such behaviors have been noted in school settings [190]. However, less coping behavior is likely in the plot setting, though additional research in this context would be helpful. Ultimately, since anal cleansing practices were not a major focus of the SanDem intervention and asking respondents to show materials kept in their homes to research assistants might embarrass respondents, no anal cleansing item was included in the PUHTI score.

Desirable

Measures of desirability are psychological constructs that can vary widely by respondents in similar circumstances. Landlords may have much different perceptions of comfort, privacy, safety, and convenience of a sanitation system than tenants and variations by gender and age are likely. Therefore, objective measures of facility quality were sought as much as possible, with the intention of assessing the correlation between these observable characteristics and tenant perceptions of these aspects of desirability.

Aspects of comfort when using a toilet identified in Bauleni included exposure to rain, presence of flies, and foul odor, with many potentially overlapping measures. The presence of a roof is the most frequent measure found in the literature, with quality assessed using various observational measures, ranging from binary measures of presence of a roof as in Safe and Sustainable Sanitation [17] to scale measures of material quality [179]. In Bauleni, corrugated iron sheets are commonly used for roofs and no other material was observed unless the entire superstructure was made of cement blocks. So, a binary indicator of the presence of a roof without significant holes (the exact definition discussed below in the piloting and reliability discussion) was included in the PUHTI score.

The presence of nuisance insects and bad smell have both been found to affect use in peri-urban, shared latrines [42, 161]. Both can be measured through relatively direct measures such as insect traps [18] or smell measurement devices [191], respectively, and are linked to superstructure quality [192] and toilet cleanliness [42]. Despite the abundance of possible measures, practicality and reliability remain major challenges. Insect traps and smell measurement devices were too costly for the study, and the contribution of the hundreds of chemical compounds present in latrines to bad smell is also unclear [191, 193]. Subjective assessment of smell or observations of flies present are usually done with straightforward "intensity scales" [194], but most of these have not been evaluated for reliability (with a few encouraging exceptions [180]). Even observations of odor-reducing technologies may be poor indicators of smell, as evaluations of ventilated improved pit (VIP) latrines, developed to reduce smell through inclusion of a ventilation pipe connected to the pit, are highly dependent on specific construction details of the technology, such as the volume of air within the superstructure and vent pipe size, and environmental conditions, such as wind speed and direction relative to the latrine [195]. The use of various chemicals has also been shown to significantly reduce the presence of insects [196, 197], but the use of no such products was reported during formative research. Therefore, a measure of the intensity of fly presence and of either simple hole covers, water-seals, or ventilation pipes to capture smell were included in addition to measures of infrastructure quality and cleanliness with the intention of eliminating measures deemed unreliable during pre-testing.

Privacy is important, not just as a mediator of use in some contexts, but as it relates to stress caused by using a sanitation system [163]. Though such qualitative investigations into privacy have yielded valuable insights into individual experiences of stress, no quantitative measures associated with stress across the broad range of potential plot residents was found in the literature, and it is unlikely that one could be addressed to a single respondent. Instead, measures of structural quality and access restriction were common [17, 42, 198]. The presence of an attached door made of solid material with an internal lock was selected for inclusion in the PUHTI score.

Safety from predation by animals and other humans [41] as well as from injury [199] are important determinants of sanitation desirability. Some of these considerations are already covered by other measures. The presence of a door that locks from the inside would partially limit predation. One factor that never came up in our qualitative formative work was fear of using the toilet in the dark, and thus potentially the importance of lighting on the plot and near the toilet for safety. Though lighting may be important in public facilities, toilets in this setting are generally shared by only a few families, and so it was thought poor lighting may be less of a fear and safety issue here. However, one item in the baseline asked respondents to agree or disagree with having a fear of using the toilet at night without a secure door. A majority of respondents reported that they strongly agreed that this was a fear, so in the future the investigation of importance of lighting should be explicit in any such formative research and landlord-reported presence of a light outside the toilet will be included at endline. The chief fear of injury reported in formative investigations was that a toilet would collapse while in use. This was most commonly associated with concrete slab collapsing into a pit not lined with cement blocks, and hence measures about the kind of pit lining likely apply to perceived safety as well. This relationship was evaluated quantitatively when assessing measure validity below.

The convenience of a sanitation system is likely an important mediator of its use, particularly given the particular features of the system [39], or in our context where OD is rare, at least a source of psychosocial stress [163]. Delays due to queueing, distance travelled to access sanitation, and ease of access within regular daily routines may affect use, but no major issues of convenience were identified in formative investigations. There were occasionally issues of caused by difficult physical exertion when using a toilet, especially among elderly plot members. However, the toilet bowls available in the market were only ideal for toilets connected to a sewer line, which the majority of toilets were not. With no available sanitation feature eliminating this issue of exertion in pit latrines, no measure of perceived inconvenience was included in the index.

Accessible

Proper physical access requires that only the “in-group” (plot residents) are able to access the toilet, while outsiders are not. Measuring prevented access due to disability for a plot-level toilet shared by renters presents a dilemma. For communal facilities, the standard guidance is to advocate for "inclusive design," with measures including proximity and difficulty of route of travel, entrance characteristics, and internal dimensions and layout [200]. The alternative is to assess if there are any residents currently unable to access the toilet and to evaluate if individual-specific accommodations or equipment have been provided. The former seems unrealistic in this context, but the latter risks obscuring the plots where a person with a disability does not live because he or she would not have been able to access the toilet. Hence, rather than try to observe and catalog aspects of an inclusive design, landlords will be asked about any residents unable to access the latrine on the plot due to disability, but additional questions will be asked of a sub-sample to understand if people with disabilities have ever been prevented from living on the plot, have ever been accommodated by individual equipment, or have ever left due to damage to such an object.

Excluding outsiders can be done in several ways. Physical structures, such as fences around the entire plot or doors and locks on the latrine itself, can prohibit access. Social mechanisms can also be effective, such as plot residents directly confronting outsiders, or even the perception that this may occur through putting the latrine in plain view of the common area of the plot when there is a normative perception that outsiders shouldn't use the toilet on a plot. Solid doors and locks were associated with cleanliness in two studies [179, 201], and a similar result was observed in the formative research for this study. Many other factors may affect the relationship between excluding outsiders and cleanliness, in the Bauleni context, including the accessibility and visibility of the toilet from outside of the plot, the proximity to markets or bars, and lighting on the plot, but the reliability and validity of these measures would require extensive study. Simple observations of doors made of a solid material and functioning adequately along with the presence of a functioning lock at the time of the observation were therefore included in the PUHTI score.

Exclusion from toilet access due to socio-cultural factors (e.g., caste, gender, kinship) is common in some settings including rural Zambia, where male heads of household cannot share a latrine with his mother-in-law or even adult children of his own household [202]. Formative investigations did not reveal any widespread exclusion for socio-cultural reasons in this setting, including respondent reports that the “in-law taboo” was overruled due to practical issues—most landlords simply did not see any incentive in constructing more than one toilet on their plot, other than in the few cases where landlords had a toilet for use by their household only [203]. So, no items related to socio-cultural exclusion were included in the PUHTI score.

Economic access can be related to user fees for public sanitation, local acquisition costs, and the existence of financial services such as loans, microcredit, or subsidies for sanitation. In this setting, communal facilities were rare, no formal financial services were available in the compound from public or private sources, and changing acquisition costs is not a target of the intervention, so no economic access measure was included in the PUHTI score. A measure like “toilet owner knowledge of low cost products” might be interesting in some contexts with newly introduced, affordable technologies, but was excluded as too peripheral to our study. In a peri-urban compound, the best measure of economic access is likely related to the level of sanitation available for a given rental cost, but this would be incompatible with our desired plot-level measure and is being investigated through other means [204].

Sustainable

Maintenance of good functionality in this context means that facilities are physically durable, waste can be treated or removed, and that there is a feasible system for regular cleaning. Durable construction materials were considered to have considerable overlap with both cleanable materials from measures for hygiene (i.e., cleanable slabs, floors, and walls in this setting are also durable) and comfort (i.e., well-constructed roof). A lined pit could be durable without being hygienic, as many pits are lined with blocks for durability while gaps are left so that liquid can drain out of the pit to increase the time for a pit to fill. Hence, the kind of lining was captured in the same item and applied to two aspects of the PUHTI score.

Since there is no sewerage system in Bauleni, waste is commonly managed either by construction of a new pit latrine once the existing one fills (which seems most frequent despite claims from some that there is insufficient space for additional toilets to be constructed) or by manual or mechanical emptying. Assessing available plot space for the possibility of constructing a new pit latrine seems difficult and counter to the goals of improving toilet quality. If a new toilet must be constructed every time a pit fills up, it seems likely that the quality will be poorer, though this association will be investigated in our study. Manual emptying occurs when someone creates a hole in the slab or lining and removes waste using buckets, but this is often more expensive over time, damages the facility, and can cause the pit to collapse. While manual emptying may increase the useful life of the toilet, these drawbacks led us to focus on mechanical emptyabillity for measuring toilet quality. Landlords generally seemed aware of the kinds of trucks used for emptying in the compound, whether these trucks could access the plot, and whether there was sufficient room for access through the pan or otherwise.

The most common system for maintaining cleanliness was a rota, where each household took a turn that varied from one day to one week and landlords frequently were included in this turn taking in addition to their general monitoring duties. The drivers of cleaning system effectiveness were the subject of considerable formative work [205] and reflection during intervention development [206]. Both self-reported presence of a cleaning rota [207] and presence of a formalized written rota [22] have been used in other studies, but formative investigation revealed no such formalized, written rotas in this setting. Self-reported presence of a cleaning rota was therefore selected for initial consideration in the PUHTI score, but additional items capturing the presence of a written rota, the duration of each household's turns, and how many times a day the toilet was usually cleaned were included for analysis along with cleanliness observations to assess the validity of the measure, as interviews with landlords and tenants suggested that rotas produced superior results to ad hoc cleaning.

System recoverability, an important aspect of sustainability, is largely affected by the reliable availability of construction materials locally. No latrine components distributed or installed for specific sanitation projects were observed and no other sanitation promotion or infrastructure development programs were reported by residents or government officials, so no indicator capturing the availability or ease of access of toilet components was included in the PUHTI score.

Used

Proper measurement of latrine use is essential, as increases in the availability of facilities have been shown in some cases to be poorly correlated with increases in their use [208]. However, as open defecation was uncommon in this context, it seems that able-bodied adults choose use any accessible and functional facilities while they are on the plot (and when they are elsewhere, are not scored in our outcome measure—see HSF development, above). So, if a toilet is functional, the major potential source of toilet non-use observed during formative research was children defecating openly on the plot, which is a major public health concern (see discussion in [165]). O'Connell analyzes in detail the variety of available measurement options for child feces disposal, including reported behavior from caregivers, whether "at last time of defecation" from JMP or "how often do you put their feces in the toilet" from the SafeSanIndex [173]; structured observations of child defecation behavior; spot observations of the presence of child feces; and detailed qualitative approaches. For the purposes of this study, the PUHTI score is derived from questions asked only of the landlord residing on the plot, and so an adaptation of the measure from the SafeSanIndex to ask about the plot, rather than the household, was selected. This measure was found to be reliable in the original context, and the method of child stool disposal is one of the most consistent hygiene behaviors, despite concerns that behavior is dependent on the location where a child defecates and which of possibly multiple caregivers are present at the time (Cousens, 1996). During the baseline, questionnaires will be administered to selected tenants as well, and the exact question from the SafeSanIndex will be asked of them as well as a gross measure of validity. It may be that the design constraints of the PUHTI score preclude an accurate measure of child feces disposal, as direct caregivers are usually seen as the most accurate source of child feces disposal behavior information, but such procedures are common in many large-scale surveys [165]. In addition, in this context it may be that children defecate in the open, but caregivers remove the feces into the toilet nearby, as such child feces would be in close proximity to the home than in some rural contexts, so an additional item was added to assess this behavior. Certainly, much more data should be collected by a variety of methods for a targeted intervention, such as structured and spot observations and disaggregation of data by age and collection only from the primary caregiver.

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Appendix C: Details of Validity and Reliability Assessment

Item Reliability

Assessing the validity and reliability of any newly created measure is essential to properly interpret any statistical analyses based on such measures [209], and any intervention evaluated without a sufficient justification for the validity and reliability of its measures cannot meaningfully contribute to knowledge [210].

Inter-rater reliability is calculated by assuming that variance observed in ratings is due to a combination of variance in the underlying subjects of measurement as well as the act of assigning the ratings themselves [211]. However, a variety of conditions may result in low reliability values, despite the measure being generally reliable. Statistical corrections exist for some of these situations, such as when there is consistent bias in individual raters or very high or low prevalence values of the outcomes being measured in the measured population [212]. A general issue with using reliability measures is that raters may agree and yet each be incorrect, so where possible, accuracy should also be considered in judging the usefulness of a measure. However, it is possible for a measure's reliability and usefulness to vary even with fixed accuracy, depending on how much agreement there is across raters or time for inaccurate measurements. Hence, a measure should be judged both by accuracy and reliability to assess usefulness for a trial.

The study data collection team of 28 research assistants individually observed the same 8 toilets to assess measurement accuracy and reliability. The specific items chosen, as described above, are shown as observed measures in Table 15.

Table 15: Observation Pretesting Questions

#	Question	Measure values
1	Is there a door made of solid material (wood, iron sheets) and attached to the walls?	1 (Yes) 0 (No)
2	Is the door lockable from the inside (with deadbolt)?	1 (Yes) 0 (No)
3	Is the door lockable from the outside (i.e., there is a lock currently being used)?	1 (Yes) 0 (No)
4	Is there any kind of seal on the toilet?	1 (Water seal) .5 (Simple cover or flap) 0 (None)
5	Is there a place for handwashing near the toilet?	1 (Yes to all three questions) .5 (Yes to 5 and only one of 5a/5b) 0 (Otherwise)
5a	Is water present at the handwashing place?	
5b	Are soap or ash present at the handwashing place?	
6	What is the main material used for the floor of the toilet?	1 (Concrete, Ceramic Tiles, or Wood) 0 (Dirt/Mud or Other)

7	What is the main material used for the pan?	1 (Concrete, Ceramic, or Plastic) 0 (Dirt/Mud or Other)
8	Is the floor of the toilet easy to clean (i.e. tile, polished concrete)?	1 (Yes) 0 (No)
9	Is there a brush or broom for cleaning the toilet located inside/near the toilet?	1 (Yes) 0 (No)
10	Is there visible feces on the pan?	1 (Appears clean) .5 (Appears dirty/sandy/floor made of dirt) 0 (Visible feces present)
11	Is there visible feces outside the pan on the floor?	1 (Appears clean) .5 (Appears dirty/sandy/floor made of dirt) 0 (Visible feces present)
12	Are there flies present inside the toilet?	1 (3 or fewer flies visible on floor) 0 (4 or more flies visible on floor)

13	What type of smell-reduction system is in place? (Choose all that apply)	1 (Water seal, simple cover, or piped ventilation) 0 (Window, Other, or None)
14	Are there holes in the walls/doors at head level or below?	1 (No) 0 (Yes)
15	What is the main material used for the walls?	1 (Wood or Concrete) 0 (Plastic, Straw, Grass, or Mud)
16	Is there a roof without major holes?	1 (Yes) 0 (No)
17	Is the pit full up to the level of the pan?	1 (No) 0 (Yes)

The research team agreed on "correct" measures in cases where objective distinctions that did not change over time were possible. However, the subjectivity of floor and pan cleanliness as well as variation over time in fly presence meant that the team did not assess the accuracy of these measures.

Due to logistical issues affecting the number of toilets observed by each assistant, Krippendorf's alpha [153] was used to capture inter-rater reliability for each item because of its robustness to missing data. A weighted calculation for indicators with multiple possible values (following the rationale of Cohen [213]) did not have any notable effect on relevant items. Burt's prevalence-adjusted, bias-adjusted kappa (PABAK) [212] was calculated by item for each pair of raters where an observation was made and then averaged to assess rater bias and item prevalence effects, with further investigation using the prevalence and bias indices in cases where large discrepancies were observed between the PABAK and Krippendorf's alpha. Results are displayed in Table 16.

Table 16: Accuracy and Reliability of PUHTI Score Pre-testing

Measure	**Accuracy**	**Krippendorf's Alpha (ratio)**	**Byrt's PABAK**	**Prevalence Index**
Solid Door	1.000	0.913	0.916	0.192
Inside Lock	0.970	0.676	0.833	0.758
Outside Lock	0.970	0.551	0.693	0.620
Containment Seal	0.994	0.941	0.945	0.963
Handwashing Place	0.982	0.393	0.990	0.991
Material of Floor	0.933	0.736	0.819	0.573
Material of Pan	0.988	0.704	0.862	0.732
Cleanable Floor	0.896	0.643	0.660	0.233
Cleaning Materials	0.945	0.618	0.672	0.441
Pan Dirty		0.056	0.837	0.911
Floor Dirty		-0.012	0.923	0.962
Flies		0.240	0.698	0.778

Smell Reduction	0.976	0.541	0.680	0.542
Holes in Walls	0.890	0.152	0.245	0.328
Wall Material	1.000	0.941	0.951	0.438
Solid Roof	0.902	0.516	0.596	0.412
Containment is Full	0.970	0.170	0.901	0.939

The only measure with initial significant accuracy issues was the presence of a seal, as the original definition was drawn too narrowly as "a seal in place at the time of observation separating the observer from the fecal containment" due to worries that miscellaneous objects inside the toilet might be considered as seals. After adjustment to account for toilet lids not in use due to simply being in the up position, the accuracy increased from about 70% to about 90%. Using the final definitions, all of the measures judged by accuracy were at least 89% accurate.

Measure reliability calculated by Krippendorf's ratio alpha was low for many of the measures, as values above 0.8 are usually considered to allow "definite" conclusions, with values between 0.67 and 0.8 yielding "tentative conclusions" [167]. While some sources argue that conclusions can be drawn from lower values (see discussion in [214]), a more rigorous approach is to estimate the impact that reliability has on statistical tests and sample size calculations. One study demonstrates that improving reliability from 0.7 to 0.9 is equivalent to increasing the sample size 28% [209], though if particular kinds or relationships exist between measurement errors, failing to account for reliability may actually reduce statistical power [215]. Hence, maximum reliability should be sought wherever possible, either through additional training to improve individual item reliability (perhaps much more cost effective than increasing sample size [216]) or by combining measures, as the authors also report that the mean of two measures with a reliability of 0.7 will be 0.8. This increased reliability for combined measures is a general principle, as reliability is calculated as the amount of error that is thought to be true measurement error rather than random error, and random errors will cancel each other out to the degree that they are uncorrelated.

Additionally, reporting of additional measures to assess the effects of bias and prevalence are recommended [217]. Bias index values were all low (<.036), and so are not shown here, but prevalence had a major effect on reliability. Therefore, items expected to have substantial differences in prevalence between this pre-testing situation and the field setting of the trial should be explicitly discussed in the trial results, while those expected to have similarly skewed prevalence should either be dropped from the score (as low overall variation also reduces their usefulness in a composite measure) or combined with other items, perhaps in an ordered, multi-item measure.

Concerns over measures for inside and outside locks, a place for handwashing, materials used in the floor and pan, presence of a smell reduction technology, and fullness of the pit are all improved when accounting for prevalence effects. Measures for cleanability of the floor and presence of cleaning brush have scores just slightly below .67, but do not exhibit strong prevalence effects. These should be considered for a composite measure of cleanliness, or in the case of a roof, desirability. Low reliability of roof and walls without significant holes were originally observed in an initial pre-test, and even establishing a definition of "holes" as any opening larger than the size of the (identically-sized) tablets did not improve the measure. However, despite the high accuracy of judging both of these measures, the reliability of roof observations is low (0.52) and of holes and walls is very low (0.15) without significant improvement when accounting for prevalence. Thus, judging roofs was included in a composite measure of desirability, while observing holes in walls was discarded in the composite PUHTI score in favor of the more reliable measure of material used for the walls of the toilet, with the corresponding relationship with privacy of this potentially less-specific measure analyzed below.

Floor cleanliness, pan cleanliness, and the presence of flies both had low values of Krippendorf's alpha, which were subsequently improved when considering prevalence effects. Latrine cleanliness has been used as an outcome measure in several studies, with some assessing and finding high reliability [180, 218], others have neglected to report any such testing [22, 198]. The likely public health importance of this measure of shared sanitation suitability, along with the possibilities of prevalence and inter-temporal variability effects, merit significant additional investigation.

Krippendorf's alpha was also used to investigate the overall reliability of the PUHTI score, as inter-cluster correlation adjusts for missing data by deleting in a listwise manner, resulting in a poor measure for this data set [219]. The reliability of the actual PUHTI score calculated as described above was not assessed, as a number of items are self-reported. Investigating the reliability of measures by questioning multiple respondents on a single plot was inappropriate due to the high suspected difference in the levels of plot knowledge by respondent (where those spending most of their time on the plot surveyed likely have better knowledge than those working off the plot, for example). However, inter-temporal variability in measures derived from the same individuals based on items not likely to change (such as pit lining or emptyability) can be used to assess the reliability of such measures in the trial itself. Hence, observed measures were combined as in the actual PUHTI score calculation with reported measures excluded. The reliability of this overall set of measures was 0.885, but the general finding that indices with more measures have a higher reliability means that the reliability of the overall final PUHTI score is even higher and a sufficiently reliable measure of peri-urban sanitation quality in this context.

Item Validity

As both reliability and validity are major concerns when evaluating a measure's utility [220], some consideration must be given to the validity of the PUHTI score. Several kinds of validity are important to consider, including criterion, content, and construct validity. Criterion validity (how well a measure reflects the underlying attributes it seeks to measure) and content validity (how well a measure represents all the underlying attributes of the construct being measured) were addressed by the theoretically-based derivation of the measures. However, construct validity (how well a measure captures the underlying meaning of the concept to be measured) is difficulty to assess, as finding a concrete benchmark for evaluating the validity of the PUHTI score is fraught with challenges. First, there is not a simple measure of health broadly conceptualized, which includes stressors like perceived privacy and safety in addition to traditional disease considerations. Efforts such as calculating disability adjusted life years seem the best route for deriving such a measure, but this would be a significant undertaking, and incorporating non-disease components is still done on the basis of respondent reports, which may vary significantly based on the underlying population. Second, even restricting validation to something like diarrheal disease outcomes is difficult, as the general evidence for the impact of sanitation on health is certainly not precise enough to allow validation of many of the scale items [141].

Hence, associations between assigned constructs and tenant perceptions were used to assess the validity of individual PUHTI score items. For example, tenant satisfaction with an aspect of sanitation on the plot (e.g., privacy) was correlated with observed PUHTI measures (e.g., presence of a solid door) in the SanDem baseline survey (Table 17).

Table 17: Relationship between PUHTI measures and tenant satisfaction

Satisfaction question/ PUHTI construct	**Measure**	**Adjusted R^2**	**95% CI**	**p-value**
Privacy	Solid door	0.442	[.391,.490]	<0.001
	Internal lock	0.379	[.325,.432]	<0.001

Safety	Solid door	0.340	[.284,.394]	<0.001
	Inside lock	0.318	[.261,.373]	<0.001
	Lined pit	0.326	[.271,.380]	<0.001
Access	Any excluded by disability	0.033	[-.028,.093]	0.288
	Outside lock	0.226	[.166,.285]	<0.001
	Any excluded by socio-cultural reason	0.022	[-.039,.083]	0.475
	Pit is full	0.162	[.101,.222]	<0.001
Cleanliness	PUHTI cleanliness measure	0.351	[.295,.404]	<0.001
	Floor material	0.238	[.175,.298]	<0.001
	Pan material	0.203	[.142,.263]	<0.001
	Floor easy to clean	0.303	[.246,.358]	<0.001
	Cleaning system in place	0.232	[.174,.289]	<0.001
	Pan observed to be clean	0.353	[.297,.406]	<0.001
	Floor observed to be clean	0.331	[.275,.385]	<0.001
	Cleaning brush nearby	0.343	[.288,.397]	<0.001
	Cleaning reported	0.154	[.094,.212]	<0.001
Handwashing	PUHTI handwashing ladder	0.235	[.175,.293]	<0.001

Overall, statistically significant relationships were found between PUHTI measures and tenant satisfaction with associated constructs. Adjusted R^2 values were relatively high considering the assumption that satisfaction scores may be affected by many different measured and unmeasured factors.

One additional item whose validity was investigated was the reporting of the amount of child feces remaining on the plot by landlords for the entire plot. As discussed above, best practice is to ask a particular child's caregiver about what happens to their feces, with suggestions that detail be incorporated to cover different times of days or caregivers. A single summary measure reported by the landlord was collected, along with two items from the selected tenant on each plot for comparison based on the SafeSanIndex (how much OD on the plot; how much of this is put in the toilet). Landlords reported that approximately 20% of child feces remained on the plot, while tenants reported that only 5% of their own child's feces did so. It is likely that landlords are more likely to notice feces remaining on the plot without a strong understanding of the underlying denominator of the total amount produced on the plot, but parents may also face a social desirability pressure to report less open defecation on the plot.

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Chapter 5: Intervention Development

Chapter Overview

This chapter describes the *Create* step, where findings from formative research are used in an iterative, theory-driven design process to produce the intervention to be evaluated in the randomized, controlled trial. A brief discussion of why a theory-driven process was used is included, followed by a detailed description of the intervention and implications for the planned intervention.

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SECTION A – Student Details

Student	James Benjamin Tidwell
Principal Supervisor	Robert Aunger
Thesis Title	Creating Demand for Peri-Urban Sanitation in Lusaka, Zambia

If the Research Paper has previously been published please complete Section B, if not please move to Section C

SECTION B – Paper already published

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Stage of publication	**Submitted**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	Co-led intervention design process, Independently investigated theoretical domains of intervention development, Authored first draft, Managed revision process

Student Signature: [redacted] **Date:** 31 Aug 18

Supervisor Signature: **Date:** 2/9/18

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Using a Theory-Driven Creative Process to Design a Peri-Urban Sanitation Intervention

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Abstract

Background

Behavior change interventions have been developed by drawing from many different theories using a variety of processes. We describe the development of a behavior change intervention to improve peri-urban sanitation quality in Lusaka, Zambia using the Behavior Centered Design (BCD) framework. BCD was used to drive intervention content creation, delivery mechanism selection, and evaluation design to maximize effectiveness, learning, and application to other settings.

Methods

We used the BCD behavioral determinants model to synthesize the data from our literature review and formative research. Then, we partnered with creative professionals to use a design process to develop a theory-driven peri-urban sanitation intervention. Particular attention was paid to the implications of using BCD for intervention development on improving its effectiveness, increasing the contributions to knowledge for other behaviors and settings, and advancing the discipline of applied behavioral science.

Results

We created the “Bauleni Secret” intervention to encourage landlords to improve their toilets by making them more accessible, desirable, hygienic, and sustainable. The intervention involved landlords meeting in facilitated groups every two weeks with individual follow-up after each meeting. The meetings presented surprising “hidden camera”-style videos to reveal tenants’ perspectives, used

participatory activities to help landlords reevaluate the benefits they would derive from improving sanitation on their plots, and provided practical guidance and mechanisms to facilitate the performance of construction and cleaning behaviors.

Conclusions

Using the BCD framework provided an easy-to-follow intervention design process. The evaluation of this theory-driven intervention will advance applied behavioral science by determining how effective each of the behavior change techniques and the overall delivery mechanism were in changing the target behaviors, how useful the design process itself was, and how these findings for sanitation can be applied to other behaviors and settings.

Keywords: Behavior Change Intervention, Applied Behavioral Science, Theory, Behavior Centered Design, Peri-Urban, Sanitation, Demand

Introduction

The Problem of Peri-Urban Sanitation

Poor peri-urban sanitation is a large and growing public health problem, and the lack of strong evidence for how to improve it will make it difficult to meet the sustainable development goal (SDG) 6.2 of safely managed sanitation for all. About 4.5 billion people lack access to safely managed sanitation globally, and 29% of those live in urban areas [1]. The population of peri-urban areas, partially defined as urban areas lacking adequate sanitation, experiences worse health outcomes than rural or other urban areas [221]. It is estimated that the peri-urban population will more than double to about 2 billion by 2035 [133].

Despite global progress in reducing open defecation, the prevalence of shared sanitation is actually increasing in many regions, and is common in per-urban areas. While the discussion of whether high-quality shared sanitation can be considered to meet SDG 6.2 is ongoing, it is clear that the quality of much shared sanitation is insufficient to do so regardless [19].

Funding and programs to improve peri-urban sanitation have largely consisted of supply-side initiatives such as government- or donor-driven infrastructure investment [138], and there is little rigorous evidence about what works to increase demand for the improvement of sanitation in peri-urban settings [24]. Sanitation marketing programs are common, but generally seek to create demand while improving the available supply [143]. This makes randomized trials of sanitation marketing programs infeasible, so that little is known of their impact, or the impact of demand and supply components separately [24].

This paper documents the theory-driven design process of creating an intervention to be evaluated to produce such evidence for Lusaka, Zambia, with the potential to inform programming in other settings. About 70% of the 2 million residents of Lusaka, Zambia live in peri-urban areas, where the majority use shared pit latrines [222]. The Lusaka Sanitation Master Plan (SMP) calls for access to sanitation for all of Lusaka by 2035, but with only a small budget allocated to sanitation promotion and little guidance about the actual content to be used [223].

Use of a Theoretically-Driven Intervention Design Process

Using behavioral science theories to address the problem of poor peri-urban sanitation quality is difficult due to the many theories potentially relevant to this under-studied behavior and a lack of clear methods for how to best select from among them and apply them [224]. This difficulty is made worse by both the long-standing proliferation of theories from within applied behavioral science (ABS) and the recent broadening of disciplines from which it draws. Within ABS, arguments for the best way to advance its theoretical foundations and methods have included an overall unifying synthesis [113], intentional, direct comparisons of empirical results obtained from divergent theories and methods [114], and allowing theories and methods to simply proliferate or fall out of favor naturally [115]. Complicating this debate are new contributions from disciplines that directly impact ABS, including spread of behavioral economics and advancements within neuroscience [116], which have varied definitions, evaluation mechanisms, and intended explanatory scope for theories. For example, economic theories are often narrower than general behavioral frameworks [117], while those of neuroscience bring a distinct natural science approach [118].

The task of selecting and applying theories from the wide range of available options is generally done in three ways. First, intervention development sometimes begins with a review of empirical findings, followed by a search for theories relevant to the kinds of results identified (e.g., [119]). These “theory-*aware*” interventions may be associated with their own internal “theories of change,” but these usually have little resemblance to the pre-existing theories from which they draw and their analysis can contribute little to advancing ABS theory. Second, behavioral determinants theories are sometimes used to provide *a priori* assumptions about what might influence behavior. These may come from a particular discipline (e.g., social psychology for the Health Belief Model [120] or behavioral economics for Behavioral Design [121]) or may be consolidated from a range of disciplines into a theory for a particular type of behavior (e.g., water, sanitation, and hygiene in the IBM-WASH model [122]). Using these determinant identification theories, “theory-*based*” intervention development, can contribute to the advancement of behavior-specific knowledge. But, null results yield little guidance into whether the wrong determinant was targeted or the wrong delivery mechanism or content was chosen when there is no explicit process guiding the entire process (e.g., behavioral design [126]). Third, more systematic “theory-

driven" approaches move beyond determinants to prescribing processes for selecting mechanisms of change (e.g., the RANAS model [123]).

We argue that the best way to advance ABS is by developing theory-based interventions. Such a process allows the adaptation of findings to different settings, provides sufficient explanatory breadth to allow the investigation of new behaviors, allows integration of more narrowly-focused, behavior-specific theories, and facilitates rigorous evaluation of all potential points of failure in a process evaluation. While theories focusing narrowly on psychological determinants may be helpful, the context-specific nature of behavior [225] makes theories that do not capture these factors less useful. Theories that describe only certain kinds of behaviors (e.g., habits) or only specific behaviors (e.g., exercise) may generate important insights, but without an integration into a broader framework, they provide little guidance on investigating behaviors outside their specific domain. Behavior Centered Design (BCD) [127] is a framework that takes such a theory-driven approach, which generates knowledge about the targeted behavior setting that can be adapted to novel behaviors and settings. The overview of this process presented below will demonstrate the scope of potential learning from this intervention and serve as an example of creating a theory-driven intervention using BCD.

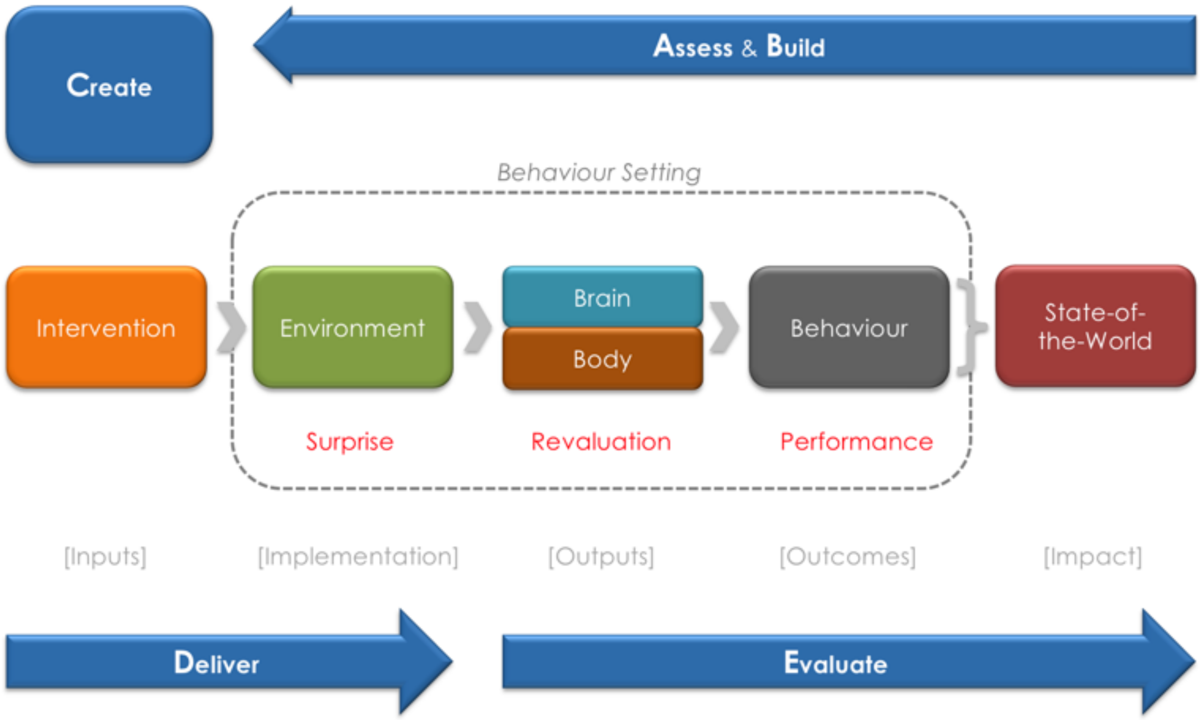
Behavior Centered Design Overview

BCD's generic theory of behavior change is based on the reinforcement learning paradigm. Any behavior change intervention must make a change in the physical, social, or biological environment that serves as a stimulus (surprise), which alters the brain or body of an individual (revaluation), which leads to the selection of the desired behavior (performance), which is presumably rewarded. Surprise most clearly describes when conscious attention is drawn to a new stimulus, though it is possible to alter behavior through environmental changes processed only subconsciously [226]. Surprise is essential, because the brain is designed to react to inputs that are different than it predicted and ignore those that conform to prior expectations [227]. The stimulus must then cause revaluation of the target behavior, either by making existing motives more salient or adding new motives to a behavior. Finally, the individual must select the desired action, and if the value of the behavioral reward is sufficient, continued performance of the behavior will be encouraged. For behaviors that have not been previously performed, behavior can be motivated even by an expected reward based on observing others' personal rewards (e.g., see others who are pleased with sanitation improvements they have made) [228] or their anticipated approval (e.g., making a new sanitation improvement because one perceives that others will approve of it) [229]. However, reinforcement learning fails when rewards (or punishments) are inconsistent, delayed, rare, or not clearly linked to the behavior [230, 231].

The BCD framework also uses a design process consisting of (1) Assessing existing knowledge, (2) Building knowledge to fill gaps identified, and then (3) Creating, (4) Delivering, and (5) Evaluating the intervention (Figure 5). The overall process and findings from the first two steps of this "ABCDE" process for the

SanDem intervention are summarized here, with the outputs of the Create step discussed in the results below.

Figure 5: BCD Theory of Behavior Change and Design Process



The BCD design process works backwards from the desired change in the state of the world to find changes in behaviors, the brain/body, and the environment to be made through an intervention, which is then delivered and evaluated in reverse along the same theory of change. With Permission from Robert Aunger and Val Curtis from [127].

Assess and Build Steps

We conducted a systematized review of available literature on the drivers of peri-urban sanitation improvement and included evidence from other settings as suggestive to supplement the limited research in peri-urban settings. Evidence for the impact of improving health knowledge was limited, with little evidence that it prompted adoption of better sanitation in Brazil [37] and its ranking below a variety of other factors for acquiring a higher-quality toilet in Senegal [39]. Comfort [33, 34], status [38, 41], fear [39, 40], disgust [43, 162], and affiliation [45, 46] were all suggested as motives for improving sanitation. Several studies focused on the importance of the social environment, whether through a sense of collective efficacy [22], direct peer influence [48, 49], or the role of community-level social networks [52]. Access to subsidies, financing, or existing financial wealth were also associated with better sanitation quality [29-32]. Land tenure security in peri-urban settings was found to be a strong determinant of sanitation quality [34, 53, 232].

Our formative research focused on the processes, roles, and priorities for landlords and tenants for improving peri-urban sanitation quality [233]. The key findings were:

- Landlords typically only made structural changes to toilets when existing structures got damaged or latrines got full or collapsed.
- Tenants were responsible for cleaning the toilet while landlords had the responsibility of financing the improvement of the physical elements of the toilet. However, if a tenant broke any features of a toilet (commonly door handle or lock) then they were responsible for replacing it.

- Landlords viewed their plots as a way to generate income, and would prioritize the building of another room to rent out than to improve their toilet.
- The top five toilet improvements identified were locking doors, sitting toilets, handwashing stands, lined pits, and smell reduction.
- With respects to shared sanitation roles, the relationships between landlords and tenants were weak, with landlords seeing tenants as the means to generate income from their plot and tenants feeling unable to express their desires to landlords.
- Tenants expressed a willingness to pay (WTP) for these sanitation improvements through rental increases, but landlords underestimated this WTP and overestimated construction costs. Taboos surrounding the discussion of toilets likely contributed to landlords underestimating WTP. These gaps were quantified during the baseline data collection [234] and the results informed the intervention's theory of change and were incorporated directly into the intervention messaging.

Methods

The Create step began with the study team hosting a creative workshop to present findings from the Assess and Build steps to local government leaders and experts from local organizations working in sanitation. The initial day consisted of presenting literature review and formative research findings along with extensive discussion.

During a brainstorm session on a second day, each attendee wrote down as many factors as they thought were important to understand how to create demand for sanitation to feed into an idea selection process [235]. These factors were collected and laid out on the floor. Individuals sorted them into groups of similar factors, and participants came up with labels for these groups. This process was repeated to generate 15 high-level clusters, which were then placed by the attendees onto a two-dimensional set of axes representing causal importance and ease of change for creating sanitation demand. A focal insight was identified—"Your toilet is indecent (so you better do something to make it decent!)"—capturing the ideas that tenants wanted better-constructed toilets, but landlords were unaware of it and that existing shared cleaning systems did not function well. Potential touchpoints (or contexts within which the target population might come into contact with the intervention) were also discussed.

The outputs of this process were compiled into a creative brief, which was presented to a local professional creative agency for the development of the campaign idea, content, and materials. This brief contained a broad array of findings from the formative research including key stakeholders, background, current situation, target audience, focal insights, theory of change, objectives, design principles, deliverables, budget, and timeline. Behaviors were selected for the intervention based on public health importance, association with diverse aspects of sanitation quality, the feasibility of changing the behavior within the study timeframe, and the desire to include a variety of kinds of behavior with differing hypothesized determinants to test the effectiveness of different behavior change techniques through our delivery mechanism [236].

Several design principles were mandated by the project's research objectives. First, the remit for this intervention was to determine the degree to which a behavior change approach could improve household sanitation quality with no action on the supply-side. Second, due to funding the intervention period was to last a period of six months, so the targeted change had be feasible within this period. Third, the outcomes had to be evaluated through an individually randomized design, and so mass media or whole-community approaches were excluded. Additional design specifications coming from the formative research included targeting landlords rather than tenants, not focusing on health messaging, using a real-life tone in campaign materials, and framing the campaign with positive messaging. The intervention delivery mechanism design process was driven by the desire to engage the attention of the participants with a surprising message that caused revaluation of each behavior along with facilitating behavioral performance, corresponding to the Surprise, Revaluation, and Performance steps of the BCD theory of behavior change [127]. With reference to touchpoints, there was no place where landlords met exclusively for the purpose of interaction. Thus, places for mobilization had to be created.

The research and creative teams worked together to design the intervention through a series of revisions on the central intervention theme and delivery mechanism and the campaign manual, branding, and materials. Each stage was scrutinized based on the theoretical constructs of BCD to ensure that a streamlined intervention was produced whose evaluation would contribute to knowledge of peri-urban sanitation as well as improve the BCD process to advance ABS. The results of this creative process are described below.

Results

Behavior-specific and intervention delivery mechanism theories of change

The four behaviors identified were:

1. Regular cleaning of the toilet interface to reduce direct user exposure to pathogens
2. Installation of a lock on the inside of the door to increase safety and privacy
3. Installation of a lock on the outside of the door to allow access to plot residents while excluding outsiders
4. Installation of a water-sealed pan or cover to reduce smell and the spread of pathogens through vector contact with fecal material

The main intervention delivery mechanism was the creation of a “secret society,” which selected landlords would be invited to join so they could receive “insider knowledge” of how to build wealth and reduce conflict by improving their plots. They would meet at a central location near where they lived at either a school hall or church rented for a minimal price by the proprietors. These meetings were led by facilitators trained in the intervention content as well as activation styles. High status was associated with meeting attendance and behavioral performance, as Invitations were made using high-quality, branded materials and name badges displayed stars during the meetings to indicate the degree to which landlords made the targeted improvements.

The opportunity for social reward, learning, and reinforcement was identified as a key behavior change mechanism. Formative research indicated that landlords did not interact socially much with their tenants or even nearby landlords. In piloting, landlords praised even the opportunity to talk in an undirected manner about common challenges they faced as a helpful activity that rarely occurred otherwise. Hence, the intervention created a new "social environment," integrating aspects of learning by observing others from social learning theory [228] into the BCD framework. In these meetings, landlords could learn from the successes of others, ask for advice from others in dealing with barriers faced, and in cases where few successes were reported in one group, stories from other group meetings could be used to provide additional insights. Landlords worked together to solve problems and to help each other to make improvements (affiliate), but were also given name badges with the stars indicating the quality of their toilet to bring a sense of hierarchy (status) [148].

Another purpose of the repeated group meetings was to facilitate behavioral performance through encouragement and monitoring. Monitors conducted home visits to observe if improvements were made and to troubleshoot barriers faced. This information was given to the facilitators who used it for discussion at the start of the subsequent meeting. In addition, cards describing the main improvement were distributed to participants at the end of each meeting, which they were supposed to get a tenant to sign, indicating that they have taken relevant action after each meeting. These cards served as a tangible indicator of behavioral performance that could be monitored in the group setting, and monitor visits provided additional verification.

These cards also demonstrated the final purpose of the intervention structure—encouraging increased interaction between landlords and tenants to reveal unexpressed demand. Each card represented a particular improvement that was made, and the required signature by a tenant hopefully led to an increasing number of discussions about working together in additional ways to improve sanitation on the plot. In particular, the “improved cleaning rota” card required a signature verifying that a meeting had taken place between the landlord and his or her tenants for the explicit purpose of discussing sanitation improvement via installing a rota system (available at the project website [155]).

Specific messages and activities were developed for each target behavior within the overall surprise, revaluation, and performance framework of each meeting’s content as well (Table 18). For “Surprise,” we chose to create live action, “hidden camera”-style videos, surprising participants with both edgy content that they may rarely observe (such as a man failing to aim properly while using a toilet due to his concern about holding a door closed) and information that is not generally communicated to them as landlords (such as tenants admitting that a poor toilet has scared them away from renting a room).

For revaluation, the SanDem intervention used “emo-demos,” or emotional demonstrations designed to revalue behaviors through emotional responses [237]. It also used “exo-demos,” an extension developed for this intervention, of “executive-level demonstrations” aimed at revaluing behaviors through activities requiring conscious group deliberation in areas such as calculating potential profits from toilet investments [238]. The overall theme of the revaluation sections was that a poor quality toilet costs a landlord good tenants and steadier, higher monthly rental income. Specific revealed desires of the tenants (e.g., privacy, cleanliness) were always translated directly into motivations for landlords (e.g., reduced plot conflict, more rental income). Exact details of the intervention can be found in the facilitator guide [155].

Table 18: Key Messages and Segment Content for Each Landlord Meeting

Outcome		Improved Cleaning Rota	Inside Lock	Outside Lock	Covered or Water-sealed Toilet
Surprise	Key Message	An improved rota keeps the toilet clean and makes your tenants happy.	Without an inside lock on your toilet, your tenants are robbed of their privacy.	A toilet without an outside lock will be abused by others and anger your tenants.	A smelly toilet full of flies will scare away paying tenants.
	Video Description	Tenants gossip about who doesn't clean the toilet, and this boils over into full-blown conflict and blaming the	Tenants struggle to keep the toilet door closed, culminating with a man walking in on a woman using the toilet. An	Drunk men stumble in to use the toilet at night, but when the landlord finds it dirty in the morning and	A series of potential tenants come to look at a room for rent, ask to see the toilet, and then abruptly leave, confusing

		landlord for not handling the problem.	argument ensues, and both end up blaming the landlord for the lack of a lock.	yells at a tenant, she turns it back on him for not securing the toilet from outsiders.	the landlord about what the problem was. The tenants privately discuss that they will go rent a more expensive place with a better toilet.
Revaluation	Key Message	Your toilet stays clean when the rota is simple and visible	A lack of privacy will drive good tenants away.	Asking tenants to do disgusting things will drive good tenants away.	A toilet is a wise investment that brings you more money quickly.
	Activity Description	Two teams were chosen with a landlord and 3 tenants each, and the tenants are assigned numbers—one team in blocks (i.e., 1-10) that are visible, and another in a more complicated,	The facilitator asks for a chosen landlord to open their handbag and reveal every detail of the items inside and emphasizes the discomfort this lack of privacy causes.	Several participants were asked to come up one at a time to hold a tissue while the facilitator pretends to blow their nose loudly and messily. The facilitator translates this	Two participants are assigned to invest either in improving the toilet or building a new room to rent. The toilet generates income sooner, rental gains are multiplied by the number of tenants, and a

		unwritten manner (i.e., every 3rd number). Landlords take turns identifying the tenant with a given number.		into the disgust tenants feel in having to clean up after outsiders who are messy and aren't responsible to clean.	scenario where income is reduced shows that this is a more reliable and way to generate wealth.
Performance	Key Message	Give your tenants the power to remind one another of their responsibilities.	It is easy to install an inside lock by yourself or with your lock-buddy.	Remember to call on your 'landlord lock-buddy' to help you install an outside lock.	Invest in a decent cover pan (or a pour-flush toilet) to keep your plot full of tenants and build your wealth.
	Activity Description	Landlords are given a badge to hang outside the door of the tenant responsible for cleaning the toilet that week and asked to have a meeting with all tenants to	A handy man demonstrates installing a lock and then has landlords take turns practicing. "Lock buddies" are paired up to	Same as performance for inside lock.	A handyman describes how to build a simple cover and the process and cost of installing various flushing toilet options. Merry-go-rounds suggested to spread out the

		institute the new system.	purchase and install locks.		cost over time and encourage accountability to each other.

Behavior-specific performance facilitation varied by the kind of behavior. For cheaper, one time actions (installing outside and inside locks), a buddy system was used where pairs of landlords helped each other purchase and install the locks at a set time following the meeting. For cheaper, ongoing actions (initiating an improved cleaning rota), an initial meeting with tenants was reported, and use of a visible, durable symbol of the cleaning system was verified during monitoring visits described below. For more expensive, one-time actions (improving the seal of the toilet or building a door, perhaps necessary prior to lock installation), a handyman provided information about products available and the range of installation costs based on existing infrastructure. "Merry go rounds," a common local mechanism where each participant contributed money each round and one participant received the contributions (rotating each round), were also suggested to ease the amount of one-time savings required and to provide peer accountability for making pledged improvements.

Design process

The intervention design process combined the ABS expertise of the London School of Hygiene and Tropical Medicine (LSHTM) researchers, the local knowledge and experience of the team from the Centers for Infectious Disease Research in

Zambia (CIDRZ), and the creativity of the local creative agency. The agency provided a series of five reverts on the campaign concepts, two on printed materials, and two on live action videos; pre-tested campaign concepts and content with the target audience; and conducted a full pilot of the intervention with a single group of landlords. LSHTM and CIDRZ provided feedback on materials, pre-tests, and piloting based on research design considerations, formative research findings, and pre-test/piloting participant responses. They also streamlined the campaign manuals and lesson content based on the surprise/revaluation/performance paradigm and created emo- and exo-demos for behaviors that were lacking them.

The creative agency initially suggested several intervention ideas that had to be discarded as either logistically infeasible in the time allotted (creating a toilet evaluation system featured in a publication designed for tenants to browse homes for rent) or compromising the individually randomized evaluation plan (a "talking toilet" installed in the central market that drew attention to its own poor quality). These were later incorporated into the final intervention via stars given to landlords to allow peer comparison and the insight that landlords weren't aware their toilets were of an unacceptable quality to tenants. Additional ideas, such as financial literacy training for landlords, were discarded when pre-testing revealed that most landlords viewed their plots as businesses, but this discovery led to profit and conflict-reduction focused campaign messaging. The campaign manuals were also full of promising ideas, including some that provided "secret" information to landlords collected from tenants, some that allowed landlords to experience the emotions of their tenants, and some that gave practical tips. These were quickly identified and sorted by the researchers into the final overall structure of surprise (videos), revaluation (games and demonstrations), and performance (practical guidance).

However, there was tension between the expectations and processes of the creative agency and the researchers. These groups have very different perspectives on methodological rigor and expectations for the degree to which a campaign could change based on information from field testing. In addition, despite their "local" status, the intervention targeted areas of town and socio-economic classes a bit distant from some of the creative agency staff, and ensuring an adequate knowledge of and interaction with the target population was challenging. Though we prefer to involve local creative agencies, the BCD framework provided sufficient guidance to allow the researchers to generate additional intervention components and evaluate these components from both theoretical and practical perspectives, meaning that some components of the final intervention were produced by the creative agency, while others were generated by academic researchers.

The overall process from framing workshop to intervention delivery took 8 months, including 4 months to develop campaign concepts and materials and 4 months to complete video production. Several reasons for delays from the original 5-month timeline could be eliminated by other teams using this process to easily cut that timeline in half—we experienced slow administrative processes at both institutions and local government levels, procurement delays, and included an extended period for generating concepts based on the formative research data due to the lack of previously available information or interventions.

Discussion

Using a theory-driven intervention development process improved the development of this intervention in two major ways. First, compilation of a collection of behavioral determinants, drawn from the empirical literature in the Assess step and from the BCD behavioral determinants model during the Build step, resulted in an in-depth understanding of the behaviors involved in sanitation improvement despite little previous work in the area. Hypotheses were generated for the local context unobserved in published literature on sanitation demand, but with a strong likelihood of effectiveness based on empirical findings in behaviors with similar characteristics.

Second, the insight generation process produced a variety of creative ideas via a straightforward, but not deterministic process. Many intervention design frameworks provide little guidance on how to generate appropriate insights or how move from insights to intervention. BCD, however, highlights specific contextual factors that may be important and suggests an iterative process of generating intervention ideas, analyzing them with specific practical and theoretical considerations, and repeating the process until an acceptable intervention meeting the criteria of the creative brief is created. This process allows creative agencies to do what they do best—come up with many novel, locally acceptable ideas—while allowing academics to do what they do best— ensure the intervention reflects principles from behavioral science and evaluation design for each piece of the intervention. It should be noted that this is still far from a deterministic process. Recent findings from evolutionary psychology applied to human reasoning suggest that generating possibilities, followed by deliberative reasoning to analyze them, is how the mind most naturally comes up with creative, workable ideas [238, 239].

The future evaluation of this intervention will also help advance behavioral science theory in three ways. First, behavior-specific theories of change will be investigated by measuring each of the primary outcomes along with mediating attitudes and barriers and individual attributes. Data collection before and after the intervention from intervention and control groups will allow highly credible analysis of which changes resulted in the desired sanitation improvement behaviors. These will be particularly useful in addressing the problem of poor peri-urban sanitation, because much more is known about motivations for improving one's own sanitation than for landlords improving plot sanitation, and so hypotheses considered common to both situations as well as those specific to landlords can be compared.

Second, several intervention delivery mechanisms will be investigated to reflect on how successful the design process was. The decision to only target landlords will be evaluated in light of which tenant characteristics are associated with successful behavior change. The delivery mechanisms of group meetings, their effects on social cohesion within the groups and trust in the community more broadly, and the specific constructs targeted for each targeted behavior will yield crucial insights. The overall cost-effectiveness of the intervention will provide evidence on the general appropriateness of a behavior change approach, as the importance of consumer demand for sanitation has been recently challenged in a high-profile, controversial study [31].

Third, reflection on the intervention development process produced learning about the BCD design process itself—specifically, on how best to utilize creative agencies. When given little guidance and wide latitude, the creative agency tended to move forward in ways that deviated from the formative research findings (such as health messages creeping into video dialogue), inserted typical campaign components not found in the brief (such as standard financial literacy training), and drifted towards the flashy rather than the practical (such as an app rather than videos). When closely supervised and given specific guidance (such as developing a rota symbol with explicit design criteria), the agency excelled, and they were also amenable to feedback. The efficiency of the design process could be improved by involving a creative agency team member in all aspects of formative research, requiring quicker reverts on smaller sections of the intervention, encouraging informal feedback from the research team after creative agency brainstorming sessions, and including a research team member in all material production meetings or video production activities.

Conclusion

We used a theory-driven process based on the Behaviour Centred Design (BCD) framework to design an intervention to improve peri-urban sanitation quality. We followed the BCD steps of literature review (Assess), formative research (Build), and designing the intervention alongside creative professionals (Create), which resulted in an intervention that has explicit theories of change for each behavior and for the overall delivery mechanism. Videos revealed surprising information to landlords, repeated group meetings created opportunities for social learning and revaluation of the target behaviors, and accountability mechanisms facilitated behavioral performance. Improved rota systems provided accountability for toilet cleaning and reduced inter-tenant conflict. Door locks improved tenants' privacy and the toilet's cleanliness. Sealed toilets were promoted by revealing tenants' existing willingness to pay.

This intervention was developed in an efficient manner even for a behavior with little prior study. We adapted findings from similar kinds of behaviors using the BCD list of behavioral determinants and collected additional data via tools tailored to likely determinants. Theoretically-driven intervention development using behavior change frameworks that incorporate learning theories, behavior-specific theories, and a design process are likely to create more effective interventions and better advance applied behavioral science.

List of abbreviations

ABS	Applied Behavioral Science
BCD	Behavior Centered Design
CIDRZ	Center for Infectious Disease Research in Zambia
LSHTM	London School of Hygiene and Tropical Medicine

WTP Willingness to Pay

Declarations

Ethics approval and consent to participate: No ethical approval was needed for the process of the creation of this intervention. The formative research and trial were approved by the London School of Hygiene and Tropical Medicine Research Ethics Committee (refs: 11714, 12157) and the University of Zambia Biomedical Research Ethics Committee (refs: 023-06-16, 002-02-17).

Consent for publication: Not Applicable

Availability of data and materials: Data sharing is not applicable to this article as no data sets were generated or analyzed during the current study.

Competing interests: The authors declare that they have no competing interests

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Authors' contributions: All authors participated in the creative process for developing the intervention. JT drafted the initial manuscript, and all authors read, suggested revisions, and approved the final manuscript.

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Chapter 6: Assessing Demand for Sanitation

Chapter Overview

This chapter deviates from the ABCDE process to measure tenant demand, reported in the qualitative formative research, using rigorous quantitative methods. Two different methods are used, based on stated and revealed preference approaches, with empirical implications for the study setting discussed along with methodological implications for other settings where weaker, inappropriate approaches are often used in the WASH sector.

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SECTION A – Student Details

Student	James Benjamin Tidwell
Principal Supervisor	Robert Aunger
Thesis Title	Creating Demand for Peri-Urban Sanitation in Lusaka, Zambia

If the Research Paper has previously been published please complete Section B, if not please move to Section C

SECTION B – Paper already published

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Stage of publication	**Submitted**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	Conceived of the work, Conducted all analysis, Drafted manuscript, Managed revision process

Student Signature: [redacted] **Date:** 31 Aug 18

Supervisor Signature: **Date:** 2/9/18

Understanding demand for higher quality sanitation in peri-urban Lusaka, Zambia through stated and revealed preference analysis

Abstract

Poor peri-urban sanitation is a significant public health problem, likely to become more important as the world rapidly urbanizes. However, little is known about the role of consumer demand in increasing sanitation quality in such settings, especially for tenants using shared sanitation as only their rental choices can be observed in the market. We analyzed data on existing housing markets using the Hedonic Pricing Method (HPM) to capture the percentage of rent attributable to sanitation quality. We then conducted discrete choice experiments (DCEs) to obtain willingness to pay (WTP) estimates for specific sanitation components, and the implications of the results were explored by estimating the proportion of plots for which improved sanitation quality would generate a higher return on investment for landlords than building a place for an additional tenant to live. The HPM attributed 18% of rental prices to sanitation (~US$8.10 per month), but parameters for several components were poorly specified due to collinearity and low overall prevalence of some products. DCEs revealed that tenants were willing to pay $2.20 more rent per month for flushing toilets on plots with running water and $3.39 more rent per month for solid toilet doors, though they were willing to pay little for simple hole covers and had negative WTP for adding locks to doors (-$1.04). Solid doors and flushing toilets had higher monthly rent increase to cost ratios than other ways landlords commonly invested in their plots, especially as the number of tenant households on a plot increased. DCEs yielded estimates generally consistent with and better specified than HPM and may be useful to estimate demand in other settings. Interventions leveraging landlords' profit motives could lead to significant improvements in peri-urban sanitation quality, reduced diarrheal disease transmission, and increased well-being without need for subsidy or infrastructure investments by government or NGOs.

Keywords: Willingness to pay; Hedonic Pricing; Discrete Choice Experiments; Sanitation; Landlords; Tenants; Peri-Urban; Zambia

Introduction

Importance of Sanitation Demand

While there are clear public health and economic benefits from investment in sanitation, a deficient understanding of the role of consumer demand could reduce the effectiveness of global efforts to ensure access to sanitation for all. Poor sanitation worldwide leads to an annual loss of approximately $222.9 billion USD [4] and is the second leading cause of DALYs lost due to diarrhea [134]. The World Bank estimates the overall cost of bringing safe sanitation to all by 2030 to be $70 billion dollars per year, with 70% of that amount needed for urban areas and most of the burden falling on national governments and international donors, as little consumer contribution is anticipated for improving sanitation [138]. However, in peri-urban settings, where up to 2 billion people are expected to live by 2035, many existing toilets are of poor quality and would be unable to take advantage of improved infrastructure [10].

Residents of peri-urban areas experience poorer health outcomes across a variety of measures [12]. Although recent work has shown some links between sanitation and health outcomes, including diarrheal disease, there is limited granular evidence of the impact of sanitation quality beyond having an improved slab, having a sewer connection, and moving from shared to single-family toilets [240, 241]. If we view the health impact of sanitation quality through a broader conceptual lens -- such as the Healthy Sanitation Framework, which goes beyond simple prevention of infection to include hygiene, accessibility, desirability, sustainability, and use as key constructs [242] -- there is also strong evidence of sanitation quality affecting psychosocial stress and well-being via aspects like safety, privacy, disgust at unhygienic conditions, and interpersonal conflict due to collective action failure [243].

Increasing consumer demand is a critical component of improving sanitation to reduce costs to governments and donors and to improve sustainability. Social marketing has shown promise in increasing demand for water and sanitation services [244], In rural areas, the most widely-used approach (Community-led Total Sanitation, or CLTS) focuses on motivating communities to construct latrines, generally without subsidies or material provisions [150], and programs seem to have achieved success in some locations [45]. There are some concerns that such demand-driven approaches may have unintended negative consequences, however, such as worsening inequality and or reducing well-being [245]. The Total Sanitation Campaign in India took the opposite approach, sanitation provision without accompanying promotion, but there is some evidence of a lack of use of many of these latrines [246]. In urban areas, it has been shown that the uptake of sewerage connections was not simply driven by socio-economic status, but that attitudes towards sanitation played a key role [37] and residents would not even pay a small fee to connect to sewerage if demand was sufficiently low [247]. However, rigorous trials of the potential impact of increasing demand for peri-urban sanitation are limited [144].

In peri-urban Lusaka, Zambia, about half of residents are currently without adequate sanitation [136]. The SanDem trial is designed to demonstrate the potential role of demand-enhancement strategies to improve sanitation quality. Formative research identified tenant willingness to pay (WTP) increased rent for sanitation and a lack of awareness by landlords as possible levers for an intervention [233]. Quantifying tenant demand for specific sanitation components is needed to understand if increasing tenant demand is necessary, or if landlords simply need to be made aware of existing demand, which might in turn lead them to improve their toilets. But, measuring tenant WTP is more difficult than when direct purchases of products can be observed (as in [248]), because tenants cannot be observed directly purchasing sanitation goods in a market; they simply make rental choices where sanitation quality is one of many relevant characteristics. We specifically wanted to measure WTP for simple hole covers, flushing toilets, solid doors, and inside and outside locks to use in the behavior change messaging of the trial.

Sanitation Demand Measurement

A variety of empirical techniques are available to estimate WTP, generally divided into revealed preference (RP) and stated preference (SP) methods [60]. Revealed preference methods analyze the actual choices made by consumers in markets. As tenants do not directly purchase sanitation, but instead gain access as a part of their choice of where to rent, the Hedonic Pricing Method (HPM) can be used to calculate implicit prices for each attribute based on the parameters of a regression analysis [80]. This approach has been applied to sanitation in diverse settings, demonstrating increases in rent associated with the presence of a toilet ranging from 1.6% [81] to a 60% [82], as well as increases of 16% from moving from a pit latrine to flush toilet [83] or 14% from moving from shared to private toilets [84]. However, revealed preferences may be biased if choices are complex [79], and market equilibrium values cannot be trusted when there is market failure [85]. RP methods can only be used in existing markets, and so cannot be applied to new products, and they are generally useful only for projecting short-run deviations from the status quo within a market [92]. HPM itself is also subject to several limitations related to choosing the correct model for demand, "missing" attribute levels or combinations of attributes, and estimating WTP separately for collinear attributes [82, 91].

SP techniques can directly elicit willingness to pay, as in the Contingent Valuation Method (CVM) [61, 62], or observe simulated choices using constructed sets of alternatives, as in discrete choice experiments (DCEs) [63, 64]. SP methods can be designed to obtain the exact information of interest, and though we are aware of no DCE studies estimating WTP for sanitation, CVM has been used to value sanitation in a variety of settings since the early 1990s. For example, tenants have been willing to pay from 2% of monthly household income for a flushing toilet with sewer connection in urban Ghana [65] to 14% of their mean monthly expenditure for high-quality on-site sanitation in urban Burkina Faso [30]. Rural households reported WTP of 30% of a year's income for a flushing toilet in Vietnam [66].

There is a long history of criticism of the reliability of SP methods, especially with regards to hypothetical bias [68], which occurs when respondents answer survey questions differently than they would actually behave because of the lack of consequences from a survey response. There is good evidence for hypothetical bias in SP methods [93, 94, 249], but most comes from CVM studies to value non-market goods like environmental quality [95, 96], about which consumers may have no market experience. There is less and inconsistent evidence about the magnitude of hypothetical bias in DCEs, with some finding higher marginal WTP from SP methods [97], others suggesting they are equal [98, 99], and one even concluding that DCEs produced lower WTP estimates, with the role of unconscious habits biasing RP values upwards [101]. In addition, DCEs have been found to reasonably predict some health behaviors [250].

Accurate WTP estimates may be useful to policymakers to calculate the potential uptake of new sanitation products in a market [66] or optimal government subsidy levels to increase coverage [65]. HPM may provide a good estimate of the overall magnitude of WTP for sanitation by tenants, but due to the empirical and practical limitations of HPM, DCEs may better identify WTP for specific sanitation components [94].

Methods

Study Setting and Population

This study was conducted in Bauleni, a peri-urban area in Lusaka, Zambia. Government demarcated plots were originally intended to be occupied by a single family, but an average of four households now live on each plot. The owner lives on the plot 80% of the time ("resident-landlord plots"), with others living nearby within the compound or neighborhood (about 10%) or outside of it (about 10%). A small number of plots are lived on only by the owner ("owner-occupied plots"), but in almost all cases, these owners are in the process of making the plot suitable for tenants as well. More detail about this setting is provided elsewhere [233]. The study population was limited to adult tenants and landlords on resident-landlord plots as this allowed data from both a landlord and tenant on the same plot to be collected.

Data Collection and Analysis

Data was collected for tenant-landlord pairs in August and September 2017 during baseline data collection for the SanDem trial [251]. The landlord and a randomly selected adult tenant head of household were surveyed on each plot. Trained enumerators collected data using tablets and ODK collect software [252]. Enumerators were trained on administering study tools, pilot testing was conducted to ensure that procedures were understood and questions were unambiguous, and pilot data was used to assess the reliability of observational measures and to establish prior estimates for use in the discrete choice experimental design. All data were analyzed using R version 3.4.1 [253].

Ethical Approval

Prior to enrollment, enumerators read an information sheet to respondents in English or one of two local languages (Nyanja or Bemba) as requested by the respondent, answered any questions raised, and obtained written consent for participation. Respondents were given a copy of the information sheet to keep, and no compensation was provided for participation. Names and government-issued plot numbers were collected for the purpose of surveying the same respondents at baseline and endline, but were removed from final data sets to protect anonymity. Ethical approval for this study was provided by the London School of Hygiene and Tropical Medicine (ref: 11714) (London, UK) and the University of Zambia Biomedical Research Ethics Committee (ref: 023-06-16) (Lusaka, Zambia).

Hedonic Pricing Method

Hedonic equations related the rental value of the property to characteristics of the property [254], including house-specific (number of rooms, rent paid) and general plot characteristics (presence of electricity and/or water on the plot, presence of toilet accessible to tenants on the plot, number of tenant households on the plot, location of neighborhood). The study covered an area with relatively homogeneous construction characteristics and only plots with resident landlords, so other variables commonly included in such analyses, such as distance to nearest clinic or city center, building materials used for home construction, and residential status of landlord were excluded. The contribution of sanitation quality to rent was estimated using two different regression models. In the first, we used a binary indicator of whether a toilet of any kind was present on the plot (HPMToiletBinary). Second, specific measures of sanitation quality were incorporated (HPMToiletQuality) using relevant components from the Peri-Urban Healthy Toilet Index (PUHTI) score (Table 20) [147], and measures relevant for the

SanDem trial discussed separately from the rest in the results. These measures were selected in part because of the range of impacts they have on healthy sanitation from the viewpoint of the Healthy Sanitation Framework: a simple cover or flushing toilet reducing smell or fecal contamination due to flies (Desirability/Hygiene); a flushing toilet allowing a sewer connection when the proper infrastructure is constructed (Hygiene); a solid door and lock on the inside of the door providing safety and privacy (Desirability); and a lock on the outside of the door limiting access to outsiders to preserve a toilet's cleanliness and encourage tenants to clean the toilet (Accessibility).

HPM assumes that rental properties are differentiated products purchased in a perfectly competitive market at the equilibrium price, which is taken by consumers as exogenous. Several of the potential forms for the hedonic price function were assessed, including linear, log-linear, and generalized linear models. For the linear and generalized linear models, when price (or a function of price) are estimated by linear regression, the implicit prices for each component are given by the regression parameters for that component. For the log-linear model, the parameter is multiplied by the individual's value of P, with the resulting values then averaged over all individuals in the sample (to get the average implicit price for the sample) or the parameter is multiplied by the mean value of P for the sample (to get the implicit price for the average rental price in the sample). The Generalized Linear Model (GLM) is estimated by applying a link function to the price variable, which is modelled using a member of the exponential family, with both chosen to align with empirical observations. We estimated each of these models using OLS and assessed their robustness to understand how to best capture the structure of rental prices. Variance inflation factors were calculated to assess multicollinearity using a cut-off value of 2. Ramsay's RESET test was used to investigate the appropriateness of the functional forms of the models. After specifying the model, the overall variation in rent associated with the presence of a toilet and for specific components were calculated and are reported in Appendix A.

Discrete Choice Experiment Design

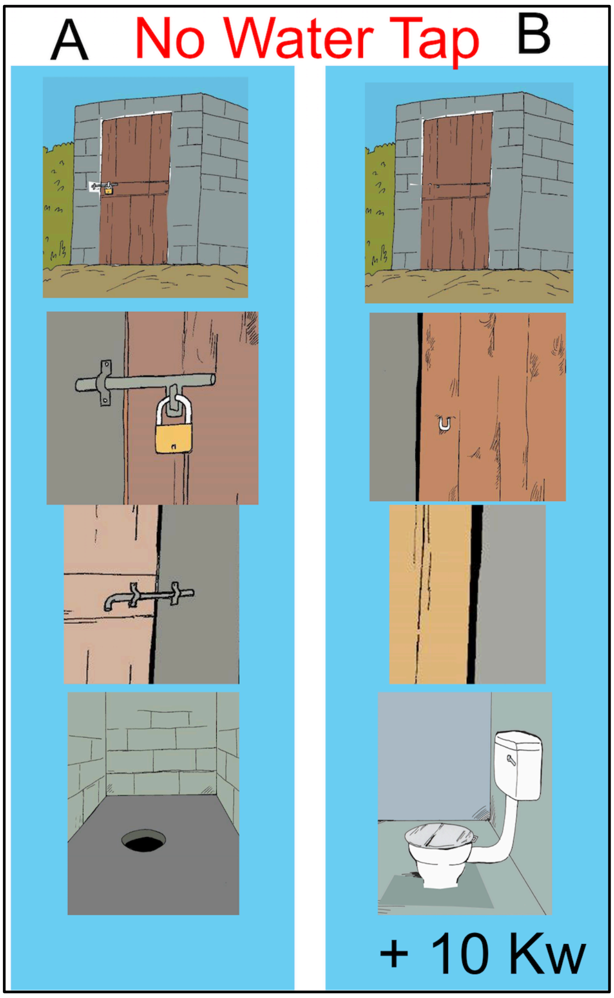
Discrete choice experiments were developed according to published guidelines for good experimental design practices by clearly explaining attributes with which participants would already have been familiar, using realistic attribute levels, limiting the number of alternatives, eliminating implausible sets, and minimizing the number of choice tasks [255]. The primary objective was to measure WTP for specific sanitation components for tenants. DCE pre-piloting was conducted among 10 respondents during a much more comprehensive formative research study to design a sanitation demand-creation intervention [256] in September 2016. Pre-piloting aimed to gain a qualitative understanding of the desired characteristics for improved toilet quality and to gauge respondent limits on the number of choice tasks and attributes to vary within each task. Attributes were then selected based on the primary outcomes identified for the trial (Table 19) and piloted on 25 respondents in August 2017.

Table 19: Discrete Choice Experiment Attributes and Levels

Attribute	**Levels**
Door/Locks	(1) No door or locks (2) Solid door with no locks (3) Solid door with inside and outside locks
Toilet Seal	(1) Uncovered hole (2) Simple hole cover (3) Flushing toilet
Relative Monthly Rental Price Difference	(1) 0 Kwatcha (2) 10 Kwatcha (3) 20 Kwatcha (4) 30 Kwatcha (5) 40 Kwatcha (6) 50 Kwatcha

Tenants were asked to choose between two toilet profiles shown on cards (see Figure 6: A Sample Card Used for the Discrete Choice Experiments for an example) representing the toilets offered at two rooms available on adjacent, otherwise identical plots to reduce the impact of assumptions about room quality, plot-level amenities, and neighborhood effects. Each choice task presented different attribute levels, while holding fixed a general situational description representative of a typical plot in Bauleni. The only situational variable systematically altered was the presence of a water tap on the plot, as formative research revealed that flushing toilets were less desirable to tenants when water was scarce. Half of respondents were randomly assigned to tasks featuring plots that either both had water taps or both did not. Price differences were presented in increments of 10 Kwacha (Kw, about 1 USD) and as positive values in relative terms to reduce framing effects.

Figure 6: A Sample Card Used for the Discrete Choice Experiments



We created the piloting choice sets to be D-efficient using a Modified Federov algorithm [257] in *dchoice* for Stata, which improves parameter specification if accurate priors are used (e.g., by removing choices with very unlikely alternatives). Initial parameter values were suggested by the study team based on the rental price parameter being 1 for 10 Kw and others set based on hypothesized WTP values. The piloting results were used to produce to updated priors and revised choice sets for the main data collection using the same process. The only prior that varied between the water tap/no water tap tasks was the value of a flushing toilet.

Discrete Choice Experiment Modelling

We modelled choices using random utility models and both multinomial logit (MNL) and mixed logit (MMNL) model. An MMNL model was used to allow regression parameters to be modeled by a random variable (a "taste" parameter), incorporate unobserved factors that are common across choice sets (such as when one respondent makes several choices in succession), and estimate WTP in a straightforward manner [92]. The model assumed that the presence of a water tap would impact WTP for water seals, but that any effects on parameters for hole covers or doors with and without locks would be small (perhaps due only to small income effects). A high_income dummy was created, with all tenants with reported income above the median (1000 Kw, or $100) coded as high income. Thus, the indirect utility function used was:

$$V_{tenant;wnsj} = \beta_{toilet\_simple\_cover;w} * toilet\_simple\_cover_{sj} +$$

$$
\gamma_{toilet\_flushing;w} * toilet\_flushing_{sj} +
\beta_{toilet\_solid\_door} * toilet\_solid\_door_{sj} + \qquad (DCEIncome)
\beta_{toilet\_solid\_door\_and\_locks} * toilet\_solid\_door\_and\_locks_{sj} +
\beta_{price} * price_{sj} + \beta_{high\_income} * high\_income_{sj} * price_{sj}
$$

with water tap status w; generic parameters β for attributes that do not vary by presence of a water tap; and attribute-specific parameters γ for those that do. An additional model (DCEMain) included main effects only by dropping the high_income dummy. No "opt-out" choice was included, and alternatives were unlabeled. WTP was calculated by dividing each improvement parameter by the price parameter (β_{price}) to obtain the mean WTP for tenants in the sample. Confidence intervals for these WTP values were constructed using the delta method [258]. Analysis was conducted using the *mlogit* package version 0.2-4 for R [259] and maximum likelihood estimation with 500 Halton draws was performed.

Impact of WTP on Sanitation Quality

We assume landlords seek to optimize the rental income from their plots. To quantify the potential impact of landlords' optimizing behaviour, we calculated the estimated rental increase per tenant household to improvement cost ratios for flushing toilets, solid doors, and building a living space for an additional tenant. The potential increased rental incomes for toilet improvements were calculated for different numbers of tenant households. Further, we compared the prevalence of plots having sanitation with solid toilet doors and flushing toilets that would be observed in the community if landlords invested optimally compared to sub-optimal current levels.

Results

Sample Characteristics

The final combined data set of paired landlords and tenants (n=930 pairs) with complete data for each variable included in the model was used to estimate the implicit prices of housing components using HPM. Tenants paying no rent (usually family members of the landlord) were excluded from the analysis.

Table 20: Variables included in willingness to pay models

Variable Name	Description	Coding	Included in which models			Sample Characteristics	
			HPM (ToiletBinary)	HPM (ToiletQuality)	DCE	Landlords	Tenants
Age	Age in years	Integer				45 [IQR: 34-56]	29 [IQR: 24-36]
Gender: Female	Gender of respondent	Binary				70.6%	77.4%
Education: Primary or Less	Has completed no more than primary school	Integer				28.9%	17.9%
Education: Some or Completed Secondary	Has completed more than primary school	Integer				66.3%	75.9%
Tenant Monthly Rent	Total rent paid by tenant—included in HPM as dependent variable	Integer	x	x			450 Kw [IQR: 350-550]

Tenant Monthly Income	Total monthly income for tenant—used to determine high_income below	Integer			x		1000 Kw [IQR: 750-1700]
Plots							
households	Number of separate tenant households living on plot in addition to landlord	Integer	x	x		Median: 3 [IQR: 2-4]	
rooms	Number of rooms in surveyed tenant household	Integer	x	x		1: 24.6% 2: 61.4% 3: 10.3%	
electricity_on_plot	Presence of an electrical connection on the plot and used by the tenant	Binary	x	x		38.2%	

water_on_plot	Presence of a water connection on the plot and used by the tenant	Binary	x	x	x	41.4%
zone	Neighborhoods defined by survey team using natural boundaries (roads, markets)	Categorical (A-F)	x	x		A: 15.8% B: 15.1% C: 13.9% D: 19.2% E: 17.8% F: 18.2%
Toilet components from PUHTI, but not of interest to trial						
has_toilet	Presence of a place for tenants to defecate on the plot, regardless of type or quality	Binary	x	x		97.2%
toilet_solid_walls	Concrete or wooden walls surrounding toilet	Binary		x		87.5%

toilet_solid_roof	Solid roof without holes above toilet	Binary		x		49.6%
toilet_improved_slab	Improved toilet slab	Binary		x		76.8%
toilet_vent	Ventilation pipe	Binary		x		17.7%
Toilet components from PUHTI, and of interest to trial						
toilet_simple_cover	Simple hole cover (plastic flap or piece of wood or metal)	Binary		x	x	6.3%
toilet_flushing	Water-sealed, flushing toilet	Binary		x	x	15.8%
toilet_solid_door	Solid door on toilet structure, attached and without holes	Binary		x	x	74.7%
toilet_solid_door_and_locks	Solid door attached, without holes, and with both internal lock (sliding bolt)	Binary		x	x	27.7%

	and external lock (sliding bolt and padlock)					
high_income	Tenant income greater than sample median	Binary			x	
price (dependent variable)	Total rent paid by tenant (HPM) or relative difference in rent prices between choices (DCE) measured in Zambian Kwacha (~10 Kw = 1 USD)	Integer	x	x	x	

* water_on_plot only included as interaction with flushing toilet

Revealed Preference: Hedonic Pricing Model

Monthly rent was highly skewed, and even a log transformation failed a Shapiro-Wilk test of normality (W=.962, p<.001), so a generalized linear model was used for each of the hedonic pricing models. The WTP results for DCEIncome are also reported here for ease of comparison, but described in the subsequent section.

Table 21: Willingness to pay estimation results - HPM with different toilet measures (binary, quality) and DCEs

	Dependent variable:					
	price (Willingness to Pay in Monthly Rent)					
	HPMToiletBinary		HPMToiletQuality		DCEIncome	
	Estimate	(std. err.)	Estimate	(std. err.)	Estimate	(std. err.)
households	-3.73**	(1.74)	-2.93*	(1.73)		
rooms	176.42***	(5.69)	169.58***	(5.78)		
electricity_on_plot	26.33***	(8.38)	21.69***	(8.38)		
water_on_plot	49.24***	(7.73)	38.50***	(8.46)		
zone: A (ref)						
zone: B	-1.69	(12.47)	5.78	(12.46)		
zone: C	-15.83	(11.89)	-20.10*	(11.80)		
zone: D	-14.69	(11.72)	-6.32	(11.71)		
zone: E	4.11	(12.87)	11.05	(12.76)		
zone: F	-4.50	(11.56)	4.08	(11.64)		
Toilet Characteristics (not of interest to trial)						
has_toilet	79.13***	(14.06)	22.58	(15.94)		
toilet_solid_walls			47.78***	(11.79)		
toilet_solid_roof			22.08***	(7.44)		
toilet_improved_slab			4.94	(9.18)		
toilet_vent			13.31	(10.47)		
Toilet Characteristics (of interest to trial)						
toilet_simple_cover			7.10	(15.35)	3.99**	(1.65)
toilet_flushing			8.11	(20.46)	12.66***	(3.00)
toilet_flushing * water_on_plot			8.38	(24.48)	9.39**	(3.89)
toilet_solid_door			3.50	(10.18)	33.78***	(1.81)
toilet_solid_door_and_locks			-8.82	(10.28)	-10.69***	(2.86)
Constant	38.21**	(17.43)	44.50**	(17.37)		
Observations	933		933		1,087	
Log Likelihood	-5,751.95		-5,728.52		-3,625.22	
Akaike Inf. Crit.	11,525.91		11,499.04		7,294.43	

Note: *p<0.1; **p<0.05; ***p<0.01

Parameter estimates for all plot and house characteristics, but not neighborhood effects, were significant at the 95% level for HPMBinary (Table 21). The impact of having a toilet on the plot was large and statistically significant (mean: 79.1 Kw, $p<.001$). The estimated WTP per room present in the rented space is the largest contributor to overall WTP (176 Kw/room), and the presence of electricity (26 Kw) and water (49 Kw) on the plot are also statistically and practically significant. Though the number of tenant households on the plot is statistically significant, its total negative impact on price is small, as the median number of households per plot is 3 (IQR: 2-4).

The magnitudes of parameter estimates for HPMQuality were generally similar to those of HPMBinary for plot, tenant, and neighborhood effects. However, the value of simply having a toilet on the plot dropped dramatically, with the presence of solid walls and a solid roof driving a large portion of WTP associated with sanitation quality. None of the parameters for toilet components included in the associated trial were statistically significant, possibly due to small overall magnitudes of the estimates (for simple hole covers, ventilation pipes, and inside locks), low overall prevalence reducing parameter specificity (for flushing toilets), and collinearity (for solid doors with solid roofs and solid walls—a model estimated without the latter two parameters leads to large WTP for a solid door). Presence of an outside lock is not far from statistical significance ($p=.094$), but the negative estimate suggests that it is actually a disincentive for tenants to live on a plot, perhaps because it restricts access to outsiders but also makes their own access more difficult. As the WTP estimates for specific components were of particular interest for the study, references to HPM results for the remainder of this paper refer to HPMToiletQuality values unless otherwise specified.

Formative research suggested that tenants had lower WTP for a flushing toilet if there was no water tap on the plot, and HPMToiletQuality suggests that WTP on a plot with a water connection (16.5 Kw) may be higher than one without a connection (8.1 Kw). But, the rarity of flushing toilets in in the sample general (15.9%), and especially flushing toilets with no water tap on the plot (4.6%), means that parameters for flushing toilets and the interaction term are poorly specified.

While HPMToiletBinary and HPMToiletQuality provide strong evidence of tenant WTP for sanitation, hedonic pricing poorly estimates parameters for many components of interest to the trial and to policy makers.

Discrete Choice Experiments

A series of four models were estimated using fixed and random parameters with and without income interaction terms (Table 22). All main effects parameter estimates were significant across the four models. Due to model 4 having the lowest AIC3 value [260], subsequent analysis is based on its results.

Table 22: Estimation Results for Discrete Choice Models

	Dependent variable:			
	choice			
	Fixed main effects	Mixed main effects	Fixed with interactions	Mixed with interactions
	(1)	(2)	(3)	(4)
toilet_simple_cover	0.11 (0.05)**	0.10 (0.05)*	0.13 (0.06)**	0.12 (0.06)**
toilet_flushing	0.39 (0.10)***	0.36 (0.10)***	0.40 (0.12)***	0.36 (0.12)***
toilet_solid_door	1.23 (0.10)***	1.21 (0.10)***	1.39 (0.11)***	1.36 (0.11)***
toilet_solid_door_with_locks	0.90 (0.14)***	0.84 (0.14)***	0.97 (0.16)***	0.90 (0.16)***
price	0.34 (0.03)***	0.33 (0.03)***	0.39 (0.03)***	0.38 (0.03)***
toilet_flushing * water_on_plot	0.28 (0.09)***	0.31 (0.09)***	0.36 (0.11)***	0.39 (0.11)***
price * high_income		0.01 (0.02)		0.01 (0.02)
toilet_simple_cover (sd)			0.002 (3.19)	0.002 (3.04)
toilet_flushing (sd)			-0.002 (4.54)	-0.002 (4.47)
toilet_solid_door (sd)			-0.01 (2.17)	0.02 (1.58)
toilet_solid_door_with_locks (sd)			0.95 (0.08)***	0.93 (0.09)***
price (sd)			0.10 (0.04)***	0.11 (0.04)**
toilet_flushing * water_on_plot (sd)			-0.003 (3.45)	0.004 (3.60)
price * high_income (sd)				0.01 (0.49)
AIC3	7638.9	7401.5	7522.9	7298.1
Observations	6,313	6,127	6,313	6,127
Log Likelihood	-3,810.47	-3,690.26	-3,743.46	-3,628.06
Note:				*p<0.1; **p<0.05; ***p<0.01

The results of estimating WTP from the mixed model with income interactions (model 4) based on the delta method are given in Table 21. All WTP values were statistically significant and well estimated, and suggest positive and practically significant WTP for solid doors and flushing toilets, negative WTP for the addition of inside and outside locks as well that WTP for a flushing toilet is greater on plots with water taps present, consistent with our hypotheses.

Implications: Ranking Sanitation Investments

We then assessed how sanitation investment was prioritized among other common plot improvements compared to which produced a better return on investment. Based on interviews with landlords and masons in the area, we estimated that a typical 2-room home costs about 10,000 Kw to build, a solid toilet structure with a simple lined pit costs about 2,000 Kw to build, and installing a flushing toilet in addition to the solid structure costs about 3,000 Kw total. Using figures from the models above, we estimated the monthly rent paid per 2-room home on plots with electricity and water (444 Kw, less 3 Kw for each home on the plot, from HPMToiletQuality), marginal rent for simply having a toilet (22.6 Kw, from HPMToiletQuality), having one with all improvements made (56.5 Kw, from subtracting the average value of a toilet in HPMToiletBinary from the value in HPMToiletQuality), and having a toilet with an improved superstructure (36.3 Kw, from subtracting DCEIncome's value for a flushing toilet from the previous value for a toilet with all improvements made).

The amount of additional rent received in a year given the number of households on the plot were calculated without a time-discounting factor, as they are for comparison across investment options only (Table 23). This slightly understates the advantage a cheaper improvement might have, as it may take longer obtain funds or build a more costly investment. There may also not be enough space on plots to build more living spaces, so toilet improvements may be the only option in some cases. As toilets are quicker and cheaper to construct than additional living space, we find that any plot with at least three households should invest in a both a solid structure and a flushing toilet. This would increase the prevalence of solid superstructure, including walls, roofs, and doors, from 42% to 72% and flushing toilets from 15% to 58%. Though these figures are only estimates, the potential magnitude of the impact is clear, especially for the important government priority of constructing toilets that can connect to future sewerage improvements.

Table 23: Percent of Landlord Investment Recovered Annually for Plot Improvements and Baseline Prevalences

Number of Tenant Households on Plot	**Cost recovered in one year for building:**			**Prevalence of Plots with Given Number of Tenant Households**	**Proportion of Plots with Given Number of Tenant Households That Have:**	
	Another Living Space	**Solid Superstructure**	**Flushing Toilet**		**Solid superstructure**	**Flushing Toilets**
1	53%	22%	26%	22%	66%	15%
2	53%	44%	53%	28%	73%	15%
3	52%	65%	79%	20%	70%	12%
4	51%	87%	106%	12%	77%	14%
5 or more				18%	80%	17%

Discussion

Comparison of Willingness to Pay Estimates

DCEs and HPM produced generally similar WTP estimates, though some HPM parameter estimates were poorly specified. This was expected, since collinearity of toilet components and low prevalence of certain toilet components led to poorer parameter specification compared to the statistical efficiency possible through stated preference designs. DCEs yielded practically and statistically significant estimates for WTP for flushing toilets and solid doors, and even a small, but statistically significant WTP estimate for a simple hole cover. The same patterns of increased WTP for flushing toilets on plots with water taps present and decreased WTP for adding both an inside and outside lock from HPM occurred in DCEs. WTP values for flushing toilets were similar between HPM and DCEs. WTP for doors with no locks appears higher in the DCEs than in HPM. However, the high correlation observed between solid doors and solid walls (R^2=.56) as well as the relative infrequency of solid doors without solid walls (1.4%) suggests that values for doors and walls from HPM may be poorly separated.

Improving Health through Increasing Peri-Urban Sanitation Quality

It is feasible that public health gains can be achieved by targeting landlords with messages about investing in sanitation quality improvements, so such messaging should be considered for all city-wide sanitation plans. Improving peri-urban toilet quality was a more profitable investment for landlords with several tenant households on their plot than more common options such as constructing new or expanding existing tenant living spaces. Tenants valued both toilet structural components of the toilet superstructure (including roofs, walls, and solid doors) and flushing toilets, which offer a more hygienic interface, reduced pathogen transmission from flies, and reduced odors during use. This finding suggests a major opportunity to improve sanitation by increasing demand, as 40% of landlords in this setting believed that tenants were unwilling to pay anything for any increase in sanitation quality [233]. Existing demand may close half of the gap that exists for reaching full coverage of toilets with solid superstructures and flushing interfaces, resulting in sizable reductions in diarrheal disease transmission [240, 241] and improvements in well-being [243]. The remaining gap will also cost less to eliminate, through both a reduced number of households to be reached and the smaller per-household magnitude of any necessary subsidies, and demonstrates the possible additional impact if demand creation programs also seek to increase levels of tenant WTP. It is also more likely that these sanitation gains will be sustained if there is consumer demand for such improvements. Further data will be collected about changes in landlord perceptions of WTP and its association with SanDem trial outcomes to strengthen the evidence for the role of demand in improving sanitation quality.

This has major implications for improving peri-urban sanitation globally with some limitations based on local conditions. First, there is formal, documented land ownership in this setting, but we think it is likely that targeting profit motives for improvement may be less effective in areas where residents fear that the government may displace them at will. Second, the magnitude of the variables affecting the economic case for improving sanitation may differ elsewhere, either because materials or labor are more expensive or because tenants have less income or are relatively less interested in improving sanitation. Further investigation into these aspects of peri-urban sanitation may inform the significance of these findings for meeting the SDGs. Still, it seems likely that targeting landlord profit motives will be an essential component of peri-urban development at some point in time in most settings.

Measuring Peri-Urban Sanitation Demand

This study revealed several shortcomings of using HPM to measure demand for aspects of sanitation. HPM has been used successfully to assess WTP for the presence of a toilet in a peri-urban setting [261], and the price-taking assumption seems reasonable based on the limited power for tenants to negotiate rent prices due to high turnover and low inventory observed in the study setting [233]. However, collinearity, low prevalence, and the small magnitudes of WTP for some components of interest limit its usefulness to assess WTP for sanitation quality. The effectiveness of HPM is further impeded by the challenge of pre-specifying an appropriate demand model and the likelihood of market failure in a context where large numbers of landlords perceive no tenant demand for sanitation quality. Still, it is a useful procedure to establish an estimate of the overall magnitude of the total contribution of sanitation to rental prices, which may be combined with relative values from DCEs to improve estimates of WTP for sanitation components. Unfortunately, more advanced joint model estimation is hindered by a lack of data on the available housing options not chosen by tenants, and more complicated analytic approaches stretch the validity of the underlying data and assumptions [262].

Discrete Choice Experiments may be a useful tool in future sanitation demand assessments. Though the number of components to include must be limited for respondents to make meaningful choices, the small hypothetical bias observed in this setting is encouraging. DCEs likely lead to respondent fatigue more quickly than more straightforward questions, but the specificity and quality of information generated make them a valuable tool for future applications. In particular, they are reliable demand assessment tools without requiring actual purchases to be made in a way that is able to detect small changes due to the high accuracy of parameter estimates generated. They are also simple to administer and the impact of messaging is assessed immediately. The potential use of these techniques for assessing demand for new or uncommon technologies also makes them ideally suited to understanding the potential for transferring demand creation interventions to new settings and as market research tools for both the public and private sectors.

Conclusion

We have estimated tenant willingness to pay for several important aspects of peri-urban sanitation quality in our study setting. We find that landlords on any plot with at least three households should invest in a both a solid structure and a flushing toilet to maximize their profits. If all landlords practiced this, the prevalence of solid superstructure, including walls, roofs, and doors, in our study community would increase from 42% to 72% and flushing toilets from 15% to 58% without any subsidy or donated infrastructure. The magnitude of these results imply that a demand-side intervention may motivate landlords to improve their own sanitation by revealing sizable latent demand from tenants and that the potential gains of such an intervention are significant for reducing diarrheal disease transmission and improving well-being. Further, the consistency of the results with estimates from revealed preference techniques suggests the usefulness of Discrete

Choice Experiments to estimate willingness to pay for other aspects of sanitation or the same components in other settings. Based on these methodological and empirical findings, consumer demand approaches can play a major role in achieving safely managed sanitation for all, and thus improve public health.

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Appendix A: Robustness Checks

A studentized Breusch-Pagan test [263] indicated that heteroscedasticity was present in both hedonic pricing models (HPMToiletBinary: BP=140.80, df=10, p<.001, HPMToiletQuality: BP=146.89, df=20, p<.001). Because of this, we estimated both models using a generalized linear model with a gamma distribution, based on the distribution of the dependent variable, and identity link function, which minimized the AIC values out of the identity, inverse, and log link functions analyzed. Variance inflation factors were all far less than the suggested cutoff of 2, with the highest values for HPMToiletBinary for electricity on the plot (1.13) and for HPMToiletQuality for solid walls (1.52), a solid door (1.48), and locks outside (1.40) and inside (1.35) the door. Ramsay's RESET tests for functional form were not statistically significant for either model (HPMToiletBinary: RESET=.765, df1=2, df2=920,p=.466; HPMToiletQuality: RESET=2.307, df1=2, df2=910,p=.1002) [264].

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Chapter 7: Randomized Controlled Trial Results

Chapter Overview

This chapter reports the design and results of a randomized, controlled trial of the peri-urban sanitation demand creation intervention. Particular attention is paid to the generalizability of these findings to other context and recommendations for future peri-urban sanitation trials given the challenges inherent in working in such settings.

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Student	James Benjamin Tidwell
Principal Supervisor	Robert Aunger
Thesis Title	Creating Demand for Peri-Urban Sanitation in Lusaka, Zambia

If the Research Paper has previously been published please complete Section B, if not please move to Section C

SECTION B – Paper already published

Where was the work published?			
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Where is the work intended to be published?	The Lancet Global Health
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Stage of publication	**Not yet submitted**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	Co-led all aspects of intervention design, led trial design, evaluation tool development, conducted all analysis, drafted manuscript, managed revision process

Student Signature: [redacted] **Date:** 31 Aug 18

Supervisor Signature: **Date:** 2/9/18

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Effect of a behavior change intervention on the quality of peri-urban sanitation in Lusaka, Zambia: A randomized controlled trial

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Abstract

Background

Poor sanitation in peri-urban areas is a growing public health problem. There are no simple solutions, while substantial planned investments to address it primarily consist of supply-side infrastructure improvements. As a consequence, little is known about the potential impact of promoting demand. We tested a scalable, demand-side behavior change intervention to motivate landlords to improve the quality of shared toilets within their plots, using a combination of emotional motivators, improved cleaning systems, and revealing the higher profitability of toilet improvements to more common investments. No subsidies or materials were provided.

Methods

We undertook an individually randomized controlled trial in a peri-urban area in Lusaka, Zambia between August 8, 2017 and February 15, 2018. We enrolled 1085 adult resident landlords on plots where at least one tenant household lived. We allocated landlords 1:1 to intervention and control arms based on a generated random number sequence. The intervention design was informed by formative research findings and a creative design process following the Behavior Centered Design model. The intervention consisted of a series of group meetings designed to motivate sanitation quality improvement as a way to build wealth and reduce conflict; the control group received no intervention. We measured outcomes one month before the start of the intervention and four months post-

intervention through repeated surveys of landlords, tenants, and toilets. We compared intervention and control groups on an intention-to-treat basis using a difference-in-differences logistic regression. The study was registered with ClincalTrials.gov, number NCT03174015.

Findings

The intervention was associated with improvements in the prevalence of inside locks (for privacy) (RR: 1.34, $p<.001$), outside locks (for security) (RR: 1.27, $p=.001$), toilets with simple covers or water seals (to improve smell and reduce contamination) (RR: 1.25, $p=.006$), and cleaning rotas (to improve hygiene) (RR: 1.16, $p=.001$). Use of the promoted weekly cleaning rota system—which was associated with higher observed rates of toilet floor and pan cleanliness—was higher in the intervention arm (RR: 1.26, $p=.010$). There was also evidence that more landlords were in the process of making improvements in the intervention arm, suggesting that the short timespan between exposure and follow-up, low exposure of the intervention arm to some aspects of the intervention, and loss to follow up all reduced the size of the observed effects.

Interpretation

It is possible to improve the structural quality and cleanliness of shared sanitation by targeting landlords with a relatively cheap, scalable, theory-driven behavior change intervention rather than via subsidy or provision of the relevant infrastructure.

Introduction

Unplanned peri-urban settlements are growing rapidly with populations expected to more than double to two billion people globally by 2035 [10]. Residents of these peri-urban areas (PUAs) suffer multiple deprivations associated with poor infrastructure, social problems, weak local governments [10], economic failures resulting in poverty traps [265], and the health status of residents is typically poorer than for populations of planned urban and rural areas [12] . Sanitation presents a particular challenge both from the perspective of public health and for the quality of life in slums. Though toilet coverage rates are relatively high, the quality of sanitation provision remains poor, sewer connections rare, on-site solutions often poorly constructed and unhygienic, shared sanitation presents maintenance challenges and creates conflict, and emptying remains expensive and is frequently done manually [163, 194].

While the Sustainable Development Goals' call for universal access to safely managed sanitation [19] have increased the political will to tackle the problem of sanitation in unplanned urban areas, it still remains unclear how to go about doing so. Municipalities, health authorities and the private sector all need to play a role, whether in planning, regulation and/or the provision of financial subsidies and emptying services [6]. In the meantime, households also have a role to play in improving their own sanitation. In this project we set out to find out how far sanitation provision could be improved by the residents of an informal settlement in Zambia themselves, through behavior change promotion alone, in the absence of institutional change or financial subsidy.

There have been a limited number of trials of interventions to improve sanitation in resource-poor settings, whether in urban or rural areas. While Community-Led Total Sanitation has been widely used in rural areas to improve demand for sanitation, evidence for its effectiveness remains inconclusive [140], and its applicability to urban contexts unproven [266]. A few studies have demonstrated that the cleanliness of shared sanitation can be improved through plot-level discussions [22] or by providing cleaning materials and behavior change messages [21], but none have examined how to improve the structural quality of toilets.

Of the 2 million residents of Lusaka, Zambia, 70% live in so-called peri-urban areas (PUAs) [222], which are unplanned, informal settlements. These areas are growing at such a fast rate globally that the number living in them is expected to more than double to over 2 billion people by 2035 [133]. The situation in these areas with respect to sanitation is poor. Official figures suggest that open defecation is rare (1% of the population) [222], but the quality of toilet superstructures, interfaces, and containment systems varies substantially [242]. Some toilets are used by only a single household, but most are shared by multiple households on the same plot of land, which may lead to higher risks of disease transmission, especially if they are poorly maintained [15]. While the Lusaka Water and Sewerage Company (LWSC) is planning investment in sewerage lines and treatment plants, it also aims to provide higher-quality shared toilets, but lacks an evidence-based plan for increasing demand to provide for cost-sharing or improved sustainability [136].

Motivating the improvement of peri-urban sanitation is a complex behavioral challenge. We used the Behavior Centered Design (BCD) framework [127] to analyze the existing sanitation situation and determinants of sanitation-related behavior and to design an intervention to improve the quality of urban sanitation [233]. Our situation assessment and formative research showed that most toilets were shared by multiple households, with a resident landlord responsible for toilet provision for the multiple households living on each plot. The poor quality of toilet provision was related to the fact that landlords undervalued tenants' willingness to pay for quality improvements [267]. Poorly cleaned toilets resulted from coordination failures caused by cleaning systems that were difficult to remember and provided little accountability. Landlords were unaware of how improving sanitation could reduce the burden of managing a plot both financially and socially and viewed it as a basic service to provide instead of as an investment to build wealth and reduce conflict. This suggested that an intervention targeted at landlords, based on the motives of profit and conflict reduction could be more effective than using health-based messages [256]. We identified four key behaviours as being feasible, desired and important for public health, these were: having a sealed toilet (for reduced smell and improved hygiene), a lock on the inside of the door (for privacy), a lock on the outside of the door (to restrict access by outsiders), and a well-functioning cleaning system (for cleanliness and sustainability).

Working with a creative agency, we designed an intervention targeted at landlords in Bauleni – an informal settlement area of some a peri-urban area in southeast Lusaka with a total of approximately 4,000 plots. The intervention, called 'the Bauleni Secret', was based on a theory of change employing surprise, revaluation and performance [127]. Landlords were invited to meetings where they were exposed to films, emotional demonstrations ('emo-demos'), interactive games, and learnt practical skills based on a reinforcement learning model [268]. We report the results of a randomized controlled trial of this intervention on the four primary outcomes.

Methods

Study design and participants

We conducted a randomized, controlled trial from August 2017 to February 2018 in Lusaka, Zambia. We mapped the entire Bauleni area and demarcated it into zones based on health facility derived boundaries. Data collectors selected every fourth plot by walking down each street from the center of these zones. Only landlords were enrolled in the intervention, but both landlords and tenants were surveyed for the evaluation. Eligibility criteria for plots were: having a landlord living on the plot who was at least 18 years old having at least one tenant household living on the plot with an adult who was at least 18 years old. We randomly selected an adult tenant head of household on the plot to gather data on mediating variables and any indirect program effects on tenants. We surveyed the same landlords at baseline and follow-up; however, a tenant was randomly selected at each point.

Randomization and masking

A statistician with no access to study data randomly allocated plots to the intervention or to a control group receiving no intervention at a 1:1 ratio. Data collectors did not have a role in program delivery and were masked as to the allocation of survey respondents at baseline and until the completion of the last set of questions covering exposure to the intervention during endline data collection. Participants were masked as to their allocation status during baseline and were told only that they were taking part in a study to understand sanitation in the area. Intervention participants were contacted soon after baseline and invited to participate in the intervention and could not be masked to the intervention during endline data collection. Control plots received no intervention.

The Bauleni Secret

The Behavior Centered Design (BCD) framework [127] was used to design the intervention. BCD is based on a reinforcement learning paradigm and includes a generic theory of change in which planned changes to the environment stimulate an individual ("Surprise"), which alters that individual's brain or body ("Revaluation" of the behavior) in a way that results in "Performance" of the behavior, and ultimately changes some desired state of the world. Reinforcement learning occurs when Performance rewards the individual, causing a feedback loop between Performance and Revaluation. BCD also includes a design process that assesses existing knowledge, fills gaps in knowledge through formative research, and then creates, delivers, and evaluates the intervention. We worked with a local creative agency, Iris DDB, to develop a campaign based on a creative brief derived from the formative research. The creative agency generated concepts, campaign manuals, and branding. These were iteratively refined with input from the study team based on theoretical considerations, research design and logistical constraints, as well as pilot tests of materials and the entire intervention.

Landlords were invited to participate in the Bauleni “Secret Society” intervention as a “selective” program that would share secrets about how to build their wealth and bring peace to their plots. Participants attended a series of meetings, each of which concerned one of the 4 primary outcomes. Based on the initial mapping process, 4 meeting venues located close to landlord plots were secured. Meetings followed the RL-based, surprise-revaluation-performance structure and were facilitated by a trained actor and a neighborhood health committee member working as a pair. This allowed exciting and entertaining, non-health messages to be presented via a trusted community leader. Videos showing tenants’ perspectives on each of the outcomes provoked discussion, while demonstrations and games facilitated revaluation of the target behaviors, and practical sessions provided knowledge, practice making improvements and commitments to an “improvement buddy,” where pairs of landlords planned times to go together to purchase and help each other install smaller improvements . The intervention promoted adoption of a specific kind of rota—a *pamodzi* rota (meaning “together” in Nyanja), with weekly turns and a visible symbol identifying the household responsible for cleaning at a given time. Follow-up monitoring visits by program staff helped participants to troubleshoot any barriers they faced and provided material for discussion in subsequent meeting. Landlords were instructed to get tenant signatures on a card given at the end of each meeting, verifying that the relevant improvement was made; these were collected and discussed at the following meeting. To stimulate attendance at subsequent meetings, a prize draw was offered to landlords who attended all 4 meetings and had 4 signed secret cards from their tenants. Meeting components tailored to each primary outcome are described in detail elsewhere [155].

We scheduled additional "catch-all" meetings for landlords that were unable to attend at their scheduled time or location, and delivered the intervention to individual landlords at their homes if they were unable to attend any gathering.

Outcomes

We selected four primary outcomes: (1) Having a rotational cleaning system in place (self-reported); having a solid door on the toilet used by tenants with (2) an inside lock and (3) an outside lock (observed); and (4) reducing smell and preventing the spread of fecal material by either a simple cover or a pour-flush toilet, collectively called a "sealed toilet" in this study (observed). These were chosen because they covered different aspects of sanitation quality (sustainability, privacy, safety, and hygiene) [242], different types of behavior (one-time/on-going), different responsible individuals (tenants/landlords), and were feasible to change within the intervention time period. No health outcomes were measured. We assessed the validity and reliability of these measures elsewhere in an area of Bauleni not covered by the intervention [147]. We defined our secondary outcomes as having amassed materials or having carried out partial construction of improvements (observed), having saved money towards an improvement (self-reported), or having taken up aspects of a *pamodzi* rota (meaning “togetherness” in Nyanja), an improved system which included turns for cleaning lasting a week (instead of the more common daily turns) and using a visible marker/emblem to identify the responsible household. All primary and secondary outcomes were pre-registered at ClincalTrials.gov (NCT03174015) in June 2017.

Sample Size

We calculated the sample size using a power of 80% and a Family-wise Error Rate (FWER) of .05. FWER was used because the multiple primary outcomes were not assumed to be independent; it was calculated using the following formula, where *h* is the number of outcomes:

$$\alpha = 1 - (1 - 0.05)^{(1/\sqrt{h})}$$ [269].

The FWER-adjusted α was .0227 based on an initial plan of including five outcomes, though one was removed during the formative research process. Sample sizes were calculated for each of the five planned primary outcomes using a 5-percentage point change for sealed toilet and 10 points for the others as the minimum targets of practical significance. The largest required sample size was selected, and revised target levels were calculated for the four final primary outcomes (FWER α=.0253, 80% power) (Table 24).

Table 24: Sample Size Calculations

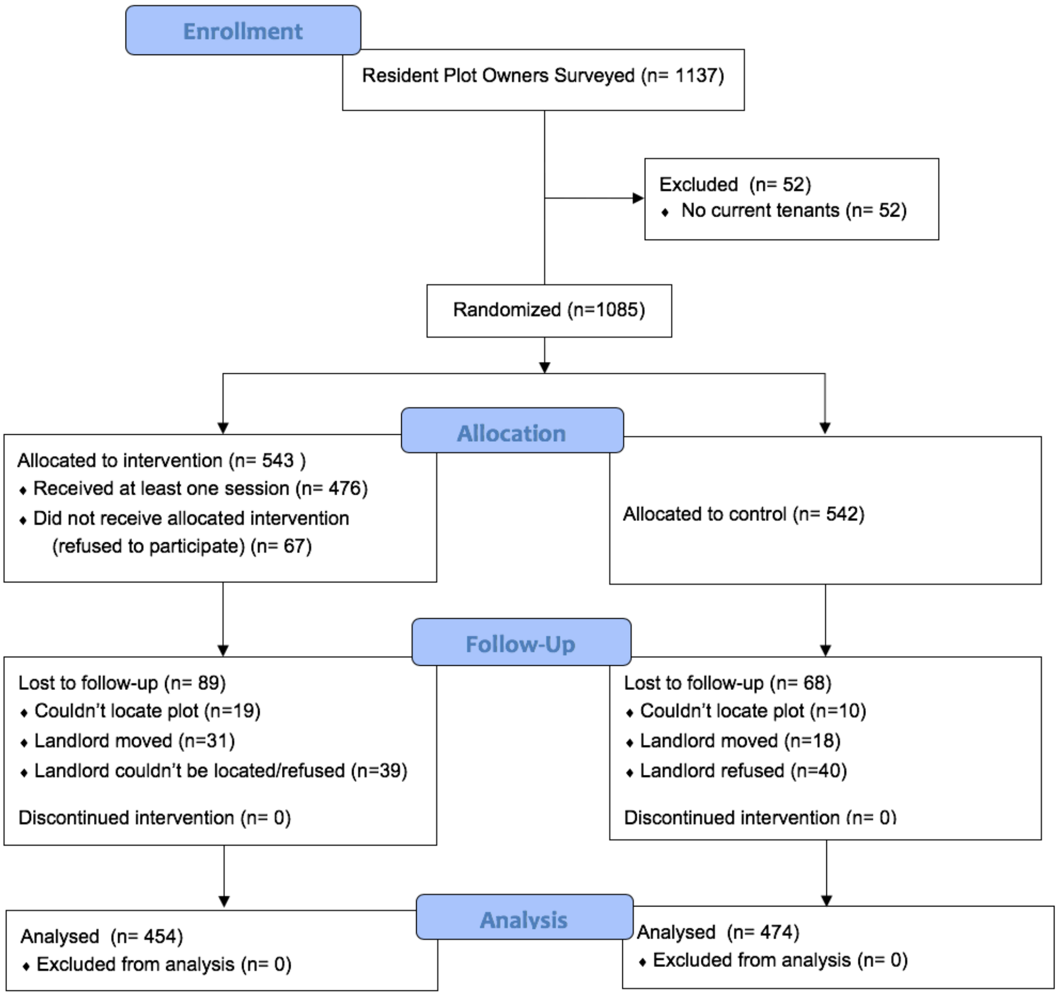
Primary Outcome	Existing Level	Initial Target Level	Sample size required (per arm)	Final Target Level
Sealed Toilet	5%	10%	539	9.9%
Inside Lock	52%	62%	476	61.3%
Outside Lock	46%	56%	486	55.4%
Cleaning Rota	54%	64%	470	63.2%

Ethics and Consent

All data collectors received human subject protection training and certification. Prior to enrollment, data collectors read an information sheet to respondents in English or one of two local languages (Nyanja or Bemba), answered any questions raised, and obtained written consent or a witnessed thumbprint. No compensation was provided for participation. Names, government-issued plot numbers and GPS coordinates were collected for the purpose of surveying the same respondents at baseline and endline, but were removed from final data sets to protect anonymity. Ethical approval for this study was provided by the London School of Hygiene and Tropical Medicine (ref: 12157) and University of Zambia Biomedical Research Ethics Committee in Lusaka, Zambia (ref: 002-02-17).

Procedures and Outcome Measurement

Figure 7: Trial Profile



We enrolled owners of plots who were living on them (which account for about 80% of plots in Bauleni [233]) and surveyed owners and randomly selected tenants from their plots at baseline (Figure 7). We excluded plots where no tenants were currently living from the study, as the intervention focused on landlords. We allocated landlords to intervention or control arms and the intervention lasted two months. Primary and secondary outcomes were measured at enrollment, about one month before the first meeting, and at endline, which was about 4 months after the last meeting (excluding the catch-all meetings). We directly observed the presence of internal and external locks, sealed toilets and use of the suggested rota emblem, while presence of a functioning cleaning rota was reported by the landlord. If more than one toilet was present on the plot, the landlord was asked to identify and answer questions about the toilet most frequently used by tenants.

We collected additional data from landlords on demographics, plot characteristics, characteristics of the toilet, attitudes towards sanitation, and tenant rental fees and turnover. We also asked landlords about exposure to the intervention at endline. We collected data from tenants on demographics, housing characteristics, toilet improvement preferences and willingness to pay, satisfaction with living on the plot, rental fee history, and about some aspects of sanitation that we had also asked landlords about to compare their responses.

Data collectors all had prior experience with working on research studies and received a week of classroom and field-based training, with particular attention being paid to analyzing and improving the reliability of toilet observations.

Statistical Analysis

Data was collected using ODK collect (version 1.4.10) and analyzed using R (version 3.4.1). Data completeness and integrity was ensured by requiring responses to all questions (with “doesn’t know” and “won’t say” options), avoiding freely entered text responses when possible, and validating and range-limiting numerical entries.

We analyzed the primary outcomes on an intention-to-treat basis. We used log binomial regression to assess the differences between intervention and control arms at endline using the multiple-comparisons-adjusted (FWER) alpha values described above. We followed a similar analytic approach for most secondary outcomes, including a per-protocol analysis that evaluated the intervention based on meeting attendance, rather than study arm allocation; an analysis incorporating plot income, education, initial sanitation quality, and number of tenant households on the plot as covariates; and analyses of the uptake of outcome components (such as adopting the improved cleaning rota) and taking steps towards making improvements.

Multiple imputation was performed using the full data set with baseline and endline combined using Full Conditional Specification, where missing values are computed for one variable at a time sequentially, allowing baseline values (which were missing less frequently) to be used to impute endline data. Analysis was done using the Multiple Imputation using Chained Equations (mice) package in R version 3.1.0 [270].

Role of the funding source

The funders of the study reviewed an initial proposal for developing and evaluating an intervention, but had no role in the creation of the intervention, study design, data collection or analysis, or writing of the report. JT, JC, and RA had access to all the data in the study and JT made the final decision to submit for publication.

Results

Characteristics of participants

A total of 1085 landlords were enrolled in the study at baseline (control: n=542, intervention: n=543), and 928 were surveyed at endline (control: n=454, intervention: n=474). Loss to follow-up in this highly mobile and informal environment was mainly due to landlords moving, inaccurate plot addresses, or in rare cases landlords being unable or unwilling to respond to the endline survey despite repeated attempts to interview them (Figure 7). Some landlords (n=67) allocated to the intervention failed to attend any meeting or to receive any program message, with some reports of a lack of interest in sanitation or conversely already having high-quality sanitation, so a multiple imputation analysis was conducted to ascertain any bias this created in the complete records analysis.

Landlord, tenants, and plots were broadly similar (see Table 25). A majority of landlord respondents were women (intervention: 68% vs control: 71%). A majority had completed at least some secondary education (intervention: 68% vs control: 64%). The typical landlord generated about 1400 Kw (~140 USD) from the plot each month. Slightly more than one-third of all plots had electricity and water. Almost all had toilets on the plot, and most had a solid door on which they could easily mount the locks promoted in the program. About a quarter of plots in the sample had more than one toilet, usually because the landlord had a separate toilet from the tenants.

Table 25: Baseline Characteristics by Study Arm

Demographic Variable	Intervention (n=542)	Control (n=543)
Landlord Respondent Age in years: mean (SD)	45.8 (15.2)	46.6 (15.3)
Landlord Respondent Gender: Female (%)	68.3	70.8
Landlord Respondent Education: Primary or Less (%)	27.3	31.2
Landlord Respondent Education: Some or completed secondary (%)	68.0	63.7
Tenant Age (years): mean (SD)	30.9 (9.0)	30.9 (9.3)
Tenant Gender: Female (%)	76.4	75.6
Tenant Education: Primary or Less (%)	19.7	16.6
Tenant Education: Some or completed secondary (%)	75.5	76.4
Monthly Rent (Kw): mean (SD)	456 (189)	464 (188)
Tenant Monthly Income (Kw): mean (SD)	1,303 (941)	1,339 (984)
Doors per Plot: mean (SD)	3.07 (2.23)	3.03 (1.98)
Rooms per Door: mean (SD)	1.85 (0.75)	1.94 (0.71)
Electricity (%)	38.9	34.1
Water on Plot (%)	40.5	38.6
Toilet characteristics		
Has a Toilet on Plot (%)	97.8	96.9

More than one Toilet on Plot (%)	24.7	24.9
Solid Walls (%)	86.8	87.5
Solid Roof (%)	46.3	50.1
Floor Easy to Clean (%)	73.6	75.0
Solid Door (%)	70.7	74.3
Vent Pipe (%)	17.4	16.5

Primary outcomes

Two months after the conclusion of the intervention, 43.6% in the intervention group had an inside lock and 32.5% in the control group (RR: 1.34, 95% FWER CI: 1.10 – 1.64, p=.002) (Table 26). 47.0% in the intervention had an outside lock compared to 37.0% in the control group (RR: 1.27, 95% FWER CI: 1.06 – 1.52). Installing either an inside or an outside lock required the presence of a solid door as well, so for the 72% of those who had a solid door at enrollment, this corresponds to about 40% of those with solid doors at baseline installing an inside lock and about 30% an outside lock.

Landlords reported the presence of a cleaning rota on 72.3% of intervention plots and 62.1% of control plots (RR: 1.16, 95% FWER CI: 1.05 – 1.30, p=.001). The presence of a sealed toilet was 45.8% in the intervention compared to 36.7% in the control (RR: 1.25, 95% FWER CI: 1.04 – 1.50, p=.006). There was no evidence for the impact of the intervention on either flushing or pour flush toilets (RR: 1.25, 95% FWER CI: 0.90-1.75, p=.128) or toilets with simple covers installed (RR: 1.21, 95% FWER CI: 0.79-1.86, p=.327) when examined separately.

Due to the high loss to follow-up (14.5%), multiple imputation of the missing data was performed to supplement the complete records analysis to improve statistical power and assess any bias due to differential loss to follow-up (Appendix B: Multiple Imputation Results). However, all primary outcome estimates were similar and led to no changes in interpretation.

Table 26: Log Binomial Regression Results for Primary Outcomes: Intention-to-treat and Per-protocol

Intervention Group	Cleaning Rota			Inside Lock		
	n (%)	Unadjusted RR (95% FWER CI); p-value**	Adjusted RR* (95% FWER CI); p-value**	n (%)	Unadjusted RR (95% FWER CI); p-value**	Adjusted RR* (95% FWER CI); p-value**
Control (n=454)	275/ 443 (62.1%)	ref	ref	141/ 434 (32.5%)	ref	ref
Intervention (n=474)	339/ 469 (72.3%)	1.16 (1.05,1.30) p=.001	1.12 (1.02,1.23) p=.006	196/ 450 (43.6%)	1.34 (1.10,1.64) p<.001	1.26 (1.07,1.49) p=.002
Intervention Group	**Outside Lock**			**Sealed Toilet**		
	n (%)	Unadjusted RR (95% FWER CI); p-value**	Adjusted RR* (95% FWER CI); p-value**	n (%)	Unadjusted RR (95% FWER CI); p-value**	Adjusted RR* (95% FWER CI); p-value**
Control (n=454)	161/ 435 (37.0%)	ref	ref	160/ 436 (36.7%)	ref	ref
Intervention (n=474)	212/ 451 (47.0%)	1.27 (1.06,1.52) p=.003	1.24 (1.04,1.46) p=.005	207/ 452 (45.8%)	1.25 (.104,1.50) p=.006	1.17 (0.99,1.38) p=.032

** Estimates were adjusted for monthly rent, landlord education level, presence of a separate toilet for the landlord, presence of water on the plot, and the number of households living on the plot*

*** FWER p-value cut-offs: p<.1=FWER p<.0506; p<.05=FWER p<.0253; p<.01=FWER p<.00506*

Secondary Outcomes

The intervention encouraged not just on having a cleaning rota of any kind, but on starting the potentially more effective *pamodzi* rota system. *Pamodzi* rotas were started by 70.8% of intervention landlords, with 88.1% of those reporting it still operating at endline. Weekly rota turns, a component of the *pamodzi* rotas that was more commonly followed by intervention landlords at endline (RR: 1.26, p=.010), made it more likely that daily cleaning occurred (99.4% vs 96.3%, p=.001) and made it more likely for the floor (82.9% vs 76.6%, p=.013) and pan (81.5% vs 75.4%, p=.024) to be clean.

Since the time between the delivery of the sealed toilet lesson and the endline data collection was only 4 months, we also pre-specified a secondary outcome assessing whether landlords had saved funds for, collected materials for, or begun construction on toilet improvements (Table 27). Though differences for each of the individual categories were not statistically significant, landlords in the intervention group were 9.1 percentage points more likely to have taken a step towards making an improvement (95% CI: 3.0 - 15.1, p=.003). While the planned improvements were not all sealed toilets, it does more generally suggest that the short timeline was a challenge for observing larger changes in sanitation quality.

Table 27: Steps taken towards sanitation improvement

Steps taken towards improvement	**Intervention**	**Control**	**Difference (95% CI)**
Has taken no steps towards an improvement	61.8%	70.9%	-9.1% (-15.1 – -3.0)*
Has saved money towards an improvement, but not started construction	6.5%	4.6%	1.9% (-1.1 – 4.9)
Has purchased building materials, but hasn't begun construction	12.4%	8.8%	3.6% (-0.4 – 7.6)
Has begun construction,	19.2%	15.6%	3.6% (-1.2 – 8.5)

but hasn't finished			

*Note: *: p<.01, **: p<.05, ***: p<.01*

Effect of covariates on primary outcomes

We also explored how the intervention results varied by landlord or plot characteristics using logistic regression to understand inequities in impacts on participants and how this intervention might work in other settings (Appendix A: Detailed Results of Regression Analyses). Plot income, a measure of a landlord's total rent revenue from the plot, was positively associated with each of the outcomes. The presence of a water connection on the plot was also positively associated with each outcome, but this is largely due to its correlation with plot income. The number of rooms was negatively associated with each of the outcomes, though this is reasonable as the more rooms for a given plot income (hence, the lower the rental cost per room), the lower quality the housing was in general. Some change in the control between baseline and endline was observed for cleaning rotas and sealed toilets, though there was no change in the interpretation of the statistical significance of the primary outcomes.

Discussion

We found plots in the intervention group had significantly better quality of toilets when compared to those in the intervention group, on our four dimensions of quality improvement. Inside and outside locks were 11.1% and 10.0% more common, cleaning rotas were 10.2% more often in place and toilets were 9.1% more likely to be covered. The primary outcomes were selected to cover a range of sanitation aspects (hygiene, desirability, accessibility, and sustainability) and to represent a range of kinds of behavior (one-time vs. on-going, unilateral by the landlord vs. coordinated with tenants, and inexpensive/quick vs. expensive/time consuming), and the intervention was effective in driving improvements in each of these aspects. In addition, we found that landlords in the intervention group were more likely to have saved money, purchased materials, or begun construction of toilet improvements.

Several potential sources of bias arose during the execution of this study. Random allocation should mitigate any differences between study arms at baseline. Despite losing about 15% across arms to follow-up, a multiple imputation analysis conducted to look at how observables may have predicted a differential impact on those not included in the complete cases analysis resulted in no changes in the interpretation of the study results. Observed measures were used where possible for primary outcomes, which were conducted while data collectors were still blind to treatment status. It therefore seems likely that the improvements in toilet quality in the intervention group were due to the Bauleni Secret intervention.

We suspect several reasons for the intervention's success. We think that the use of a systematic and theory-based process to understand the problem, isolate key behaviours to be changed, and design and carefully evaluate an intervention strengthened the intervention's ability to directly impact key drivers of sanitation quality behaviors. The intervention's design to cause surprise, revaluation and aid performance likely facilitated acceptance of program messages. The incorporation of social learning and influence through landlord group meetings and accountability mechanisms to facilitate behavior were also likely key in ensuring that desired improvements were carried out . Initial findings suggests that the intervention was successful in each of these aspects, but a detailed process evaluation will be conducted in the future to understand the contributions of the many different aspects of the intervention.

Improvements requiring collective and coordinated action (such as changing the duration and mechanics of cleaning rotas) were also effective. At least one other intervention focused exclusively on shared cleaning has been effective [22], but the long-term impact of either intervention on cleaning behaviors is unknown. We hypothesize that altering the cleaning system to reduce potential free-rider problems may be more effective in the long term than interventions lacking this kind of functionality. However, future work on the sustainability question, as well as potential health impact (discussed below), is needed. It may also be that the cholera outbreak, which occurred in Lusaka during the study [271], increased awareness of the importance of proper sanitation, resulting in overall higher rates of cleaning or in self-reports due to heightened social desirability bias. Though the study design does not allow this possibility to be independently investigated, the randomized, controlled design helps to mitigate that background effect in the evaluation results.

We would have liked to observe the impact of the intervention on improving sealed toilets over a longer time period. However, it became clear that working in this peri-urban context brought trade-offs between duration and loss to follow-up and additional complications like landlords choosing to purchase or move to new plots with better toilets, rather than improving their own toilet. Rates of landlords refusing to participate in the endline may not have changed with a longer time to follow-up, but the high turnover rate would have led to continued attrition. For future work, we suggest focusing specifically on larger infrastructural improvements with either repeated endline measures using a lighter-touch instrument or looking at immediate impact on incentive-compatible willingness to pay measures.

Several contextual elements likely affected our results that may or may not be present in other peri-urban contexts. Owners of plots in the study area had secure land tenure backed by official government documents and records. Though plots were originally only intended for occupancy by one household, and so there was some uncertainty about the legality of the status quo, it did not seem to be a barrier to plot investments. A large percentage of landlords also lived on these plots, and many shared the same toilet. Both of these may have likely made the intervention more effective. However, the median number of households on a plot (three) may be much lower than other settings, where the return on investment for toilet improvements may be even higher, and the general motivation of landlords to increase profits and reduce the hassle of management seems likely to be applicable in other settings.

Our study is the first to show that a purely behavioral intervention can improve the quality of shared toilets in peri-urban areas. It remains to be seen if such approaches can be scaled up so as to contribute to solving the huge and growing problem of sanitation in unplanned urban settlements. As global rates of shared sanitation have increased from 7% to 10% between 1990 and 2015, with raw numbers using such systems increasing from 204 to 465 million in the same time period in Africa alone [5], an understanding of what constitutes safely managed shared sanitation and how to achieve it are crucially important. Governments should consider including demand-side aspects to their sanitation improvement projects, though other drivers of sanitation quality, like the availability of effective technologies and land tenure are crucial to address as well. Though we think aspects of this intervention may translate to other contexts, others should take care to design interventions tailored specifically to their target audiences and consider if other behavioral determinants may be more important to target in other contexts.

As this trial was designed to be a proof-of-concept for the possibility of improving sanitation quality through demand generation alone, we did not attempt to measure changes in health outcomes. The trial was not powered to reasonably detect such effects, and there is insufficient evidence related to these granular measures of peri-urban sanitation quality to estimate any such impacts at present. However, the results of this trial suggest that a creatively designed demand-side-only intervention may play a significant part in improving peri-urban sanitation quality.

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Appendix A: Detailed Results of Regression Analyses

Table 28: Impact of the intervention on primary outcomes based upon intention to treat analysis

	Dependent variable:			
	Cleaning Rota (1)	Inside Lock (2)	Outside Lock (3)	Sealed Toilet (4)
Intervention	0.152 (0.060, 0.244) $p = 0.003^{***}$	0.293 (0.122, 0.465) $p = 0.002^{***}$	0.239 (0.082, 0.396) $p = 0.006^{**}$	0.222 (0.063, 0.380) $p = 0.013^{**}$
Constant	-0.477 (-0.550, -0.404) $p = 0.000^{***}$	-1.124 (-1.260, -0.989) $p = 0.000^{***}$	-0.994 (-1.117, -0.871) $p = 0.000^{***}$	-1.002 (-1.126, -0.879) $p = 0.000^{***}$
Observations	912	884	886	888
Log Likelihood	-570.853	-581.804	-598.473	-598.297
Akaike Inf. Crit.	1,145.705	1,167.607	1,200.946	1,200.594
Note:	*p<0.1; **p<0.05; ***p<0.01 (Significance tests adjusted for Family-wise Error Rate)			

Table 29: Impact of the intervention on primary outcomes when adjusted for covariates based upon intention to treat analysis

	Dependent variable:			
	Cleaning Rota (1)	Inside Lock (2)	Outside Lock (3)	Sealed Toilet (4)
Intervention	0.115 (0.033, 0.198) $p = 0.007^{**}$	0.231 (0.084, 0.378) $p = 0.003^{***}$	0.212 (0.063, 0.360) $p = 0.006^{**}$	0.159 (0.014, 0.305) $p = 0.032^{*}$
\`Rent Charged in Thousands\`	0.083 (0.034, 0.132) $p = 0.001^{***}$	0.226 (0.153, 0.300) $p = 0.000^{***}$	0.165 (0.037, 0.292) $p = 0.012^{**}$	0.053 (-0.066, 0.173) p = 0.381
\`Education Level.x\`Some or completed secondary	0.125 (0.019, 0.231) $p = 0.021^{**}$	0.138 (-0.050, 0.325) p = 0.151	-0.014 (-0.174, 0.145) p = 0.860	0.046 (-0.124, 0.216) p = 0.595
\`Education Level.x\`Beyond secondary	0.033 (-0.206, 0.272) p = 0.789	0.121 (-0.144, 0.386) p = 0.371	-0.121 (-0.496, 0.254) p = 0.528	0.194 (-0.115, 0.504) p = 0.219
\`Separate LL Toilet\`a	-0.025 (-0.137, 0.087) p = 0.662	0.442 (0.258, 0.627) $p = 0.00001^{***}$	0.402 (0.232, 0.571) $p = 0.00001^{***}$	0.229 (0.059, 0.399) $p = 0.009^{**}$
\`Separate LL Toilet\`b	0.037 (-0.084, 0.158) p = 0.547	0.128 (-0.221, 0.477) p = 0.473	0.192 (-0.131, 0.515) p = 0.244	0.289 (0.041, 0.537) $p = 0.023^{**}$
Water_CategorizedPlot	0.055 (-0.039, 0.149) p = 0.249	0.218 (0.036, 0.401) $p = 0.020^{**}$	0.283 (0.113, 0.453) $p = 0.002^{***}$	0.464 (0.293, 0.635) $p = 0.00000^{***}$
\`Doors on Plot.x\`	-0.017 (-0.043, 0.008) p = 0.186	-0.109 (-0.161, -0.058) $p = 0.00004^{***}$	-0.101 (-0.163, -0.039) $p = 0.002^{***}$	-0.080 (-0.141, -0.018) $p = 0.012^{**}$
Constant	-0.601 (-0.720, -0.483) $p = 0.000^{***}$	-1.365 (-1.589, -1.140) $p = 0.000^{***}$	-1.111 (-1.320, -0.902) $p = 0.000^{***}$	-1.107 (-1.326, -0.889) $p = 0.000^{***}$
Observations	875	846	848	850
Log Likelihood	-513.241	-514.727	-538.999	-538.803
Akaike Inf. Crit.	1,044.482	1,047.455	1,095.999	1,095.606
Note:	*p<0.0506; **p<0.0253; ***p<0.00506 (Significance tests adjusted for Family-wise Error Rate)			

Appendix B: Multiple Imputation Results

Table 30: Comparison of Multiple Imputation to Complete Records Analysis for Primary Outcomes

Component	Primary Intention to treat estimate (s.e.)	Multiple Imputation estimate (s.e.)	p-value (unadjusted)
Cleaning Rota	1.164 (.047)	1.154 (.047)	.002
Inside Lock	1.341 (.087)	1.287 (.087)	.004
Outside Lock	1.270 (.080)	1.227 (.081)	.012
Sealed Toilet	1.248 (.080)	1.225 (.080)	.011

The multiple imputation (MI) analysis resulted in slightly smaller parameter estimates for each parameter, but with equivalent or slightly smaller standard errors, indicating that MI was statistically beneficial without significantly altering the interpretation of the results for the primary outcomes. The MI results suggest that there may have been some bias in the complete records analysis, demonstrating the importance of conducting such an analysis in studies with high loss to follow-up, as is likely in challenging settings like peri-urban areas.

Chapter 8: Conclusion

Chapter Overview

As each individual paper has its own discussion and conclusion sections, I will here briefly map how the thesis aims and objectives have been achieved by the included papers (addressing the research questions along the way), describe some limitations of the current project in general, and remark on possible ways that this research could be built upon in the future.

Thesis Aims and Objectives

The aim of the study was to determine the degree to which shared peri-urban sanitation quality can be increased by a behavior change intervention. The following specific objectives were identified as contributing to achieving this aim:

1. To investigate consumer preferences related to sanitation to assess potential motivational levers to use, to understand the role of social influence on sanitation, and to identify appropriate products or hardware solutions to promote.

The formative research study found that landlords and tenants were distinct groups to consider when investigating sanitation preferences. Status and profit were identified as key motives for landlords, while nurture was identified as most important for tenants, though a variety of motives were considered important by different respondents. The profit motive was selected as the most efficient way to leverage tenant demand as landlords have weak relationships with tenants and do not prioritize satisfaction of tenant desires. Social ties were relatively week within and between plots. External locks, sitting toilets, lined pits, and a place for handwashing were all highly ranked by both landlords and tenants, but these expressions of demand were unrelated to costs and so primarily qualitative insights into why certain components were preferred (or, especially in the case of sitting toilets, sometimes not preferred).

2. To develop and validate a scale for peri-urban sanitation quality that allows comparisons across types of sanitation and over time.

A general framework for healthy sanitation in a broad sense was developed that can serve as the basis for operationalizing measures of different types of sanitation, as we did in our study setting. Though some aspects of peri-urban shared sanitation quality had appropriate existing measures, new measures were developed for several aspects not previously investigated, and overall the correlation between the hypothesized roles of those aspects and the observed impacts on respondents served as a general validation of the approach.

3. To establish reliable methods for assessing consumer demand for sanitation and use them to understand existing demand in the study setting.

Assessing tenant demand through willingness to pay measures led to useful methodological and empirical conclusions. Discrete choice experiments were established as best suited for assessing tenant willingness to pay for sanitation, and the overall magnitude of willingness to pay implied that substantial landlord investment in their own sanitation may be achieved by making them aware of their tenants' implicit demand.

4. To experimentally test the hypothesis that increasing demand for sanitation can improve sanitation status without any intervention on the supply side.

The trial demonstrated that a behavior change approach could produce sanitation quality improvements to a degree that has practical significance, while highlighting the challenges of working in a peri-urban context and of delivering and evaluating an intervention targeting a variety of sanitation behaviors.

Limitations

There were several key limitations of the individual studies and the overall findings of the thesis. The formative research (Chapter 3) suggested likely intervention targets, but the sample size and method of data collection should not be taken as ruling out other possible intervention mechanisms in future studies. The degree to which the component-level sanitation measures (Chapter 4) correspond to changes in health, defined as either the presence of an infection or more broadly, is unclear, but may be pursued separately and combined with forthcoming health evidence, or even used as the basis of further investigation. The intervention development process (Chapter 5) was innovative and led to a highly creative intervention, but cannot be taken as making a direct argument for the superiority of this approach as it was not compared to other approaches. A multitude of other interventions consistent with the formative research findings might have been developed and proven equally successful. The development of willingness to pay measures for tenants (Chapter 6) was very successful, but directly eliciting landlord perceptions of tenant willingness to pay proved ineffective. Finally, while the trial results were positive and informative (Chapter 7), the many different methods and strategies used and behaviors targeted make it difficult to point to specific aspects of the intervention that were successful or should be improved in the future.

Another general limitation relates to the generalizability of these results, where two major factors probably mediate these findings in other contexts. First, while tenant willingness to pay may be common across contexts, the exact costs associated with improvements and tenant willingness to pay may lead to different conclusions about the potential impact of resolving this information asymmetry. Second, while tenants were not generally legally authorized to live on plots, landlords did possess some degree of tenure security and, in theory at least, formal documentation of land ownership. This certainly affected landlord willingness to invest in plot improvements, and may be considered a precursor to any such consumer-directed intervention.

Implications for Future Research

The following key areas for future investigation emerged from the work conducted for this thesis, with an emphasis on the most important ideas coming out of the overall findings across the different papers:

- More work is needed to understand the health implications of shared peri-urban sanitation quality, perhaps using DALY-like measures or common currencies like well-being to deal with challenges of comparing across different types of sanitation in different settings, as behavior change messages targeting components other than those included in the intervention might be significantly different.

- Trials in peri-urban settings are difficult to conduct for a number of reasons described previously, and so more narrowly focused interventions with outcomes that can be evaluated in a shorter timeframe may be more effective in optimizing learning to inform scalable program design. Techniques such as delivering messages to landlords and offering products for sale immediately afterwards and/or focusing on particular products should be considered in subsequent work, taking advantage of stated preference methods validated in this thesis or revealed preference, incentive compatible approaches such as real-money transactions with landlords.
- The high ranking of handwashing stations as a desirable improvement in the formative research led to us consider including it in the trial, but the low observed prevalence and availability in the market-place caused us to hesitate as it did not seem there was an existing technological solution that we could promote. However, demand for such a solution should be assessed and similar messaging considered in improving the availability of places for handwashing with soap in peri-urban settings.
- While this intervention proved successful in a focused, high-intensity research setting, the messages should be tested outside the context of group meetings to understand the potential for delivery in more cost-

effective ways, such as mass media communications as a part of the several large-scale, on-going urban sanitation pushes across sub-Saharan Africa.