

Beyond 'improved' towards 'safe and sustainable' urban sanitation: assessing the design, management and functionality of sanitation in poor communities of Dar es Salaam, Tanzania

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ABSTRACT

This study assessed sanitation access in rapidly expanding informal settlements in Dar es Salaam (Dar) against eight proposed indicators of hygienic safety, sustainability and functionality, and in relation to the Millennium Development Goal (MDG) 'improved' sanitation definition. Information was collected on toilet facility designs, management and functionality through a structured interview and observations at 662 randomly selected residential properties across 35 unplanned, low-income sub-wards of Dar. Trends in access and associations with sharing, occupancy, latrine replacement, income, education and location factors were considered through statistical analyses. Surveyed sub-wards were open-defecation free. While 56% of households used a facility that met the MDG improved technology definition, only 8% had a functional facility that could be considered as hygienically safe and sustainable sanitation. Safe, sustainable, functioning sanitation access was 2.6 times greater among the richest quintile than the two poorest quintiles. Very poor sanitation services among Dar's urban poor arise from widespread lack of access to hygienically safe pit emptying services, unhygienic designs and functionality problems (affecting 67, 55 and 29%, respectively). As new goals and targets beyond 2015 are discussed, these findings may have important implications for defining what constitutes 'improved' sanitation for poor populations living in unplanned informal settlements.

Key words | equity, fecal sludge management, indicators, monitoring and evaluation, pit emptying, shared sanitation

INTRODUCTION

Sanitation is an important foundation for health, economic development and well-being (Bartram & Cairncross 2010; WSP 2010). In developing countries, urban areas are estimated to have higher sanitation coverage than rural areas (WHO/UNICEF 2012a) but these statistics often mask the severity and complexity of sanitation challenges affecting towns and cities and the urban poor in particular. Sanitation realities in slums and informal settlements where the urban poor live are inevitably diluted in representative national results of official monitoring surveys or may be under-represented or completely missed, for example

when they constitute small pockets within enumeration areas, are poorly defined, or enumerators are frightened to visit them (Fry *et al.* 2002; Hancioglu & Arnold 2013). A further limitation is that access within a city is rarely disaggregated spatially and economically (Fry *et al.* 2002; UNICEF 2012).

The current generalized approach of defining sanitation access as single household use of an 'improved' toilet technology (WHO/UNICEF 2013) may be less appropriate for rapidly growing cities where on-site sanitation technologies such as pit latrines, pour flush latrines and

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septic tanks continue to be used despite ever-increasing urban densities. In such situations, sanitation facilities are likely to be emptied rather than moved (Thye *et al.* 2011) so that the safety of sanitation systems depends at least as much on provisions for safe fecal sludge management including emptying, removal, treatment and disposal or reuse, as on safe fecal capture and containment (i.e. the design of the facility) (Barrenberg & Stenström 2010). Evaluating whether on-site sanitation facilities are functional, a measure of users' ability to maintain them, is also crucial for assessing access.

This paper presents a detailed assessment of household sanitation facilities in some of the poorest unplanned settlements of Dar es Salaam (Dar), Tanzania's largest city. It proposes and applies a set of new indicators to characterize and assess the hygienic safety and sustained functioning of existing on-plot systems, including locally available pit emptying and disposal (or waste reuse) methods, based on household survey data. New approaches are needed to properly characterize sanitation services in cities where on-plot sanitation continues to be the dominant service model for the urban poor. The study demonstrates this need for new urban sanitation monitoring approaches and offers one example for how this might be done.

Dar's population was estimated at 2.5 million in 2002 with a growth rate of 4.3% (DCC 2004). Approximately 70–80% of residents live in unplanned settlements that lack public infrastructure, basic services, proper roads and layout, and are often densely populated, resulting in very poor living conditions (UN-Habitat 2004). Poverty continues to be a major problem; 50% of the population live on <\$1 per day and recent data indicate the urban share of Tanzanians living below the basic needs poverty line has risen sharply from 19.6% in 2000 to 25.2% in 2007 (NBS 2009). The sewer system reached just 13% of the city's population in 2004 (DCC 2004) and 80% of all sanitation facilities in Dar were pit latrines (NBS 2009). The extent to which facilities are safe and sustainable remains unknown, although the Joint Monitoring Programme (JMP) reports that 40% of urban Tanzanians used an improved sanitation facility in 2010, half of whom shared with more than one household (WHO/UNICEF 2012a).

There is a persistently high environmental disease burden associated with cholera, malaria, lymphatic

filariasis, dysentery and diarrhea in Dar and other Tanzanian cities (UNICEF 2012). A third of children under five years of age in Dar were ill in the four weeks preceding the 2007 National Household Budget Survey, suffering from fever (50%), malaria (40%), diarrhea (12%), in addition to other symptoms of infection (NBS 2009). More recent data for Tanzania indicate that diarrhea among children under five living in urban areas has increased markedly between 2004 and 2010 from 10 to 18% (two-week prevalence), surpassing the rate in rural areas (2010 two week prevalence of 13%) (UNICEF 2012). Cholera cases continue to occur annually in Dar with the last major outbreak of over 9,000 cases in 2006, concentrated in wards with the greatest poverty, population densities and percentages of informal residents (Penrose *et al.* 2010).

METHODS

An extensive survey undertaken in Dar in June 2008 (the start of the dry season) of household sanitation facilities and associated practices, costs, preferences, perceptions and plans forms the basis for this study. The survey was designed to gather consumer insights and a baseline to develop demand-responsive sanitation upgrading strategies for Dar's urban poor.

Sampling design

Thirty-five unplanned, low-income, high-density sub-wards (average 379 persons/hectare) were identified by Dar's three municipal councils (MC) for upgrading, representing approximately 20% of the unplanned population. Residential properties were chosen as the sampling and analysis unit, since on-plot sanitation facilities are organized and managed at property level. Population proportional sampling, following a two-stage process, was used to select a representative random sample of 662 residential properties across the 35 sub-wards (2% of all properties). Each sub-ward (i) was assigned its share (S_i) of the sample, according to its 2002 population. Starting at a random 10-cell group of houses, a skipping interval was used to select S_i 10-cells in sub-ward i . A single property was randomly selected from each 10-cell list.

Household survey

The survey consisted of a structured questionnaire administered verbally to the property owner or the oldest tenant in the absence of the owner, supplemented by structured spot observations of the toilet facility and plot. Following exploratory focus group discussions with owners and tenants, the survey was designed to characterize sanitation facilities (below and above ground design), age and condition; to document latrine use, operating and maintenance practices; and to collect past and anticipated expenditures and plans for construction, replacement, improvement and pit emptying. The survey also assessed facility design and emptying preferences and perceptions of sanitation conditions and problems. At each property, GPS coordinates and respondent socio-economic characteristics were collected. Trained professional surveyors from Research International conducted the survey. This study draws on a sub-set of the survey data related to facility design, management and functionality to assess the safety and sustainability of on-site sanitation systems in study settlements.

Structured observations

'Flooding out', also known as 'vomiting' is a method of partial emptying of pits which involves inserting a drain or opening into an exposed or elevated portion of the latrine pit wall, below the slab in order to release fecal sludge into the open environment to be washed away by storm water during rains. In some cases, rising water tables during rain events and excess flooding may increase pit sludge levels to the level of the opening, where it is divulged or 'vomited' out. In light of growing concerns over this unsanitary pit-emptying practice, surveyors were trained to look for and record the presence of a 'flooding out' pit waste drain pipe during structured spot observation of each facility. They also observed the functional state of facilities in terms of slab structural condition, fullness of the waste pit/tank and status of the superstructure. Pit fullness was judged by observing the height of void space between the slab or cover and the surface of the sludge. To understand barriers to safe pit emptying, surveyors observed physical accessibility of the property to a small car or tanker vehicle.

Indicators of improved and safe and sustainable sanitation

Table 1 describes eight indicators developed to assess the safety and sustainability of on-site sanitation systems in study communities. The first three (1–3) assess the technical design of the facility, the next two (4 and 5) assess availability and access to safe fecal waste management services, and the last three (6–8) assess the functionality of the facility at the time of the survey.

Inclusion of pit lining as a safe and sustainable design indicator (#3) accounts for two considerations. First, lining is structurally necessary to prevent pit collapse in areas with flooding, poor drainage or high water tables, conditions widely present in poor neighborhoods of Dar (see Table A1 in the Supplemental Material available online at <http://www.iwaponline.com/washdev/004/180.pdf>) and frequent characteristics of undesirable lands where the urban poor reside. Second, lining also facilitates emptying of full pits while unlined pits, for the most part, cannot be emptied using hygienic mechanized suction methods and risk damage or collapse even when manual means are used (Koné & Strauss 2004).

A preliminary review found five pit-emptying methods in use in Dar. Two are considered sanitary services, the vacuum tanker and Vacutug (Thye et al. 2011), in which fecal sludge is hygienically suctioned, transported and disposed of at authorized municipal treatment and disposal sites. Three are unsafe methods where fecal sludge is drained into a temporary pit (pit diversion), manually excavated and released or buried on-site (manual emptying), or intentionally released into the neighborhood (flooding out). Access to vacuum tanker or Vacutug services (indicators 4 and 5) is thus necessary for hygienic emptying and sanitary disposal of pit waste in Dar.

Analyses

Facility design, waste management and functionality indicators were evaluated and combined to measure JMP improved and safe and sustainable sanitation access across the study population. Associations between access and facility sharing, occupancy type, replacement latrine, income, education and location-related factors were examined. Using self-reported monthly income, respondent households were divided into income quintiles, to examine access

Table 1 | Indicators for classifying on-site sanitation systems as improved (I) (JMP definition), hygienically safe and sustainable (SS), and functioning (F) in low-income, unplanned communities in Dar es Salaam

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 hygienic emptying service vehicles	SS	Enumerator observation of plot physical accessibility (car, tanker or 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 roof, full height walls & door	F	Enumerator observation of toilet facility superstructure walls, roof, door presence and height

equity. Tests of association were performed in SPSS v.19 using the chi-squared likelihood ratio test for differences in proportions and the chi-squared linear-by-linear association test of trends in proportions. Differences in group means were tested with the analysis of variance F-statistic. Unless noted otherwise, significant results are reported at $p \leq 0.05$ for a 2-sided test. Where noted, odds ratios and 95% confidence intervals were calculated using binary logistic regression. Monetary values are adjusted to 2008 values and presented in US dollars (TSH1,175 = US\$1 in 2008).

RESULTS AND DISCUSSION

Sample description

A majority of properties (51%) were family-owned and occupied, with the balance consisting of landlord-tenant

(39%) and tenant-only (absentee landlord) (10%) properties. On average, 3.5 households and 10 people, including 2.2 children ≤ 3 years, resided at each property. Family-owned/occupied properties compared with landlord-tenant and tenant-only properties, respectively, had significantly fewer households (2.7 vs. 4.3 and 4.1), non-child residents (7 vs. 8.6 and 8.3) and total residents (9.0 vs. 10.8 and 10.9). They represented 46% of the study population. A communal tap was the most common main water source (50.4%); just 10.6% had a house tap. Respondents were mostly the property owner (88%) or a tenant (12%). Tenant households paid average rent of \$12/month (range \$3–128). Median monthly household income was \$106, ranging from \$40 (quintile 1, poorest) to \$255 (quintile 5, richest). Eighty-two per cent reported monthly income below the Dar 2007 average of \$184 while 17% had incomes below the 2007 national basic needs poverty line of \$12 (NBS 2009).

Descriptive statistics are provided in Table A1 (this can be found in the Supplemental Material available online at <http://www.iwaponline.com/washdev/004/180.pdf>).

Defecation places

Two residences (0.3%) had no toilet facility while at three (0.5%) the facility was inoperable. Residents at these properties reporting using a neighbor's toilet ($n = 4$) or public facility ($n = 1$). Residents at all other properties used a private toilet facility (99%), sharing it with an average of nine other users (range 1–29) and 3.5 households (range 1–14). These findings align with 2007 data indicating 1.1% of Dar households had no toilet (NBS 2009) and 2010 Tanzania JMP data reporting 2% urban open defecation (WHO/UNICEF 2012a).

Under-reporting of the use of a neighbor's toilet seemed likely. At 5.6% of properties, neighbors were currently using the toilet facility (without paying). On the other hand, under-reporting of open defecation seemed unlikely, given that enforcement by environmental health officers of by-laws requiring toilets and prohibiting open defecation were mentioned frequently during preliminary focus group discussions. Essentially, poor, unplanned areas of Dar appear to be free of open defecation. This finding may be the result of many years of campaigns for latrine building and use in Tanzania during the colonial and Ujamaa periods (UNICEF 2012) and supports the

claim of Tanzania's long-standing urban open defecation rate of 2% (WHO/UNICEF 2012a).

Facility replacement

At 41% of residences the toilet facility was a replacement for the original facility. Replacements reflect re-investment by owners in a new facility to replace an old, full or otherwise no longer functioning latrine, while original construction reflects population growth (new residences). Dar's high growth rate and sustained rates of facility replacement since the 1980s are visible in the breakdown by decade built of the current stock of sampled toilets into original and replacement facilities (see Figure A1, which is available online in the Supplemental Material at <http://www.iwaponline.com/washdev/004/180.pdf>).

Above and below ground design

The above (AG) and below (BG) ground design of each facility (Table 2) and slab material were used to assess facilities in terms of improved and safe and sustainable fecal capture. Simple slab over pit designs ('traditional pit latrine') were the most common AG design. About 36% of facilities had unlined pits. Most facilities were operated as wet systems owing to anal cleansing with water and no separate bathing place, posing increased fecal

Table 2 | Residential sanitation facility designs in use in low-income, unplanned communities of Dar es Salaam (June 2008)

Shares (% total) Below-ground design	Above-ground design					Row total
	Traditional pit latrine	VIP pit latrine	Ceramic bowl (pour flush)	Drum/tyre latrine	Other ^a	
Unlined pit	35.3	0.6	–	–	0.2	36
Partially lined pit	31.9	2.3	1.2	–	0.2	36
Fully lined pit	18.4	4.2	0.5	–	–	23
Drum/tyre lining	0.6	–	–	1.5	0.2	2
Septic tank	–	0.3	0.2	–	0.5	1
Sewer	–	0.5	0.2	–	–	0.6
Don't know	1.4	–	–	–	0.2	1.5
Column total	88	8	2	1.5	1.1	100

VIP = Ventilated improved pit.

^aIncludes WC (flush toilet), seat and don't know.

contamination risks to shallow groundwater (Howard *et al.* 2006) which is a source of drinking water for 6–23% of Dar residents (NBS 2009). Water seal facilities ('ceramic bowl', 'WC') represented about 3% of AG designs, while 1% of BG designs were septic tank and <1% were connected to a sewer.

Facility construction expenditures

Expenditures for on-plot sanitation facilities, including initial construction and subsequent improvement, were evaluated for facilities built in the 10 years preceding the survey (see Table A2, which is available online in the Supplemental Material at <http://www.iwaponline.com/washdev/004/180.pdf>). The average reported capital cost per latrine varied little across income quintiles, reflecting a consistent cost for construction of a basic pit latrine (\$272). Unimproved drum or tyre latrines required significantly less investment (\$112) while water-based, pour-flush and flush technologies required substantially more (\$450–500).

Facility condition

Over 40% of facilities were full or nearly full (<25 cm of full); only 5% were >1 m empty. One in five had a badly cracked or collapsing slab, or was in a state that prohibited safe use. Three-quarters lacked a roof, 19% lacked a door and 6% lacked walls. Owners of facilities in poor structural condition or with inadequate superstructures had significantly lower incomes compared with others. No income difference was found between owners with and without completely full pits, suggesting factors beyond ability to pay account for the high rate of full pits.

Interrupted use

More than one in six toilet facilities had been unusable at some point in the past because it had collapsed, the pit was full or improvements were being made (see Table A3, which is available online in the Supplemental Material at <http://www.iwaponline.com/washdev/004/180.pdf>). Non-usable durations averaged 26 days, varying from 10 (improvements) to 55 (full pits). Long periods of interrupted use indicate barriers to residents' ability to maintain their

sanitation facilities in study areas. Similar problems occur in rural Tanzania (McCubbin 2008).

Pit emptying

Given the ten-year median age of toilet facilities, it was surprising that 64% had never been emptied. Among facilities that had been emptied, however, nearly half (44%) had been emptied multiple times. While nearly two-thirds reported local availability of a hygienic emptying service, only 23% of emptied latrines used one of the two hygienic methods to empty the last time. Nearly half (43%) of residents reported that flooding out was practiced in their community. Flooding out was the third most frequently reported emptying method, used on 12% of emptied latrines, following pit diversion (59%) and vacuum tanker (18%). While just 4% of respondents admitted to flooding out their latrine, 28% of latrines were observed to have an emptying pipe, suggesting the practice may be more common than reported. Under-reporting likely reflects awareness that the practice is both illegal and considered anti-social, and because it tends to occur in high water table and frequently flooded areas in Dar with little effort by owners, apart from installation of a flood-out pipe (UN-Habitat 2004). About one in 20 latrines was emptied manually, mainly just the top portion. Average emptying expenditure, including slab repair (a common additional expense incurred), was \$57. It varied by method, but differences were not significant.

Access to safe and sustainable facilities

Sanitation facility designs were assessed against indicators 1–3 (Table 1) to estimate safe and sustainable facility access rates (Table 3). While 59% of facilities met the JMP improved technology definition, fewer (41%) met our hygienically safe and sustainable criteria. In population terms, 45% had access to a safe and sustainable sanitation facility. Pit waste drain pipes (28% prevalence) associated with flooding out were a significant cause of failure to meet both improved and safe and sustainable design criteria, while use of unlined pits further reduced safe and sustainable facility access.

Table 3 | Indicator prevalence and rates of access to improved (I), safe and sustainable (SS) and functioning (F) sanitation facilities, waste management and systems in 35 low-income, unplanned areas of Dar es Salaam (June 2008)

Indicator (see Table 1)	% with	Improved (I) Design	Safe and sustainable (SS)			Functional (F) Facility	Safe, sustainable and functional (SSF)	
			Design	Waste mgmt	Sanit. system		Facility	Sanit. system
1 Pit with slab	82.5	*	*		*		*	*
2 Waste contained	72.3	*	*		*		*	*
3 Below-ground lined	63.3		*		*		*	*
4 Hygienic service	67.5			*	*			*
5 Plot accessible	40.0			*	*			*
6 Structurally safe	92.4					*	*	*
7 Not completely full	92.7					*	*	*
8 Half wall/door	78.7					*	*	*
(8 ^a Roof, full wall/door)	(18.0)					a		
Access, % properties		59	41	34	13.5	71	29	10.5
N valid properties		652	651	662	651	619	608	608
% Households		56	40	36	11	73	26	8
% Population		62	45	33	14	71	33	11
% Children (≤ 3 yrs)		58	40	32	12.4	72	29	8

Note: Improved technology and private (JMP access) = 23% (148/652); Improved technology and shared = 36% (237/652); Unimproved (private or shared) = 41% (267/652); Open defecation = 0% of residential properties. For households: improved private = 14% (312/2250), improved shared = 42% (943/2281), unimproved = 44% (995/2250). For unplanned area population: improved private = 20% (1315/6448), improved shared = 42% (2713/6448), unimproved = 38%.

^aOnly 16% of facilities would be considered 'functional' if a higher standard of superstructure functionality for indicator 8 were applied, requiring the cabin to have full height walls, a full height door and a roof.

Access to safe emptying services

More than half of properties reported local availability of at least one of the hygienic emptying services; however, physical plot access by a small car or tanker vehicle was low (Table 3). Consequently, only 33% of the population in study areas had access to safe emptying services.

Access to safe and sustainable sanitation systems

Properties with both a safe and sustainable sanitation facility and access to a safe emptying service (hence, to a safe and sustainable sanitation system), made up just over 13% of properties and served 14% of the study population (Table 3). To validate our indicators and classification method, we tested whether access to a safe and sustainable sanitation system increased the odds of choosing a hygienic method to empty a full pit (among those emptied), and found a fivefold increase in the hygienic emptying

rate of those with safe and sustainable system access compared with those without, adjusting for income (adjusted odds ratio: 4.78; 95% confidence interval (CI): 2.22, 10.36).

Access to safe and sustainable functioning sanitation systems

About 7% of facilities had a partially or completely collapsed floor and a similar share had a completely full pit (Table 3). About 80% had walls and a door covering at least half-height (indicator 8), but just 18% had a complete superstructure (indicator 8^a). Only 71% met all three basic functionality criteria of structural safety, remaining pit capacity and minimal superstructure. Sanitation systems which were functional and safe and sustainable represented just 11% of properties, serving a similar share of the study population but a smaller share of young children (8%).

Shared versus single household access

At 61% of residences, toilet facilities were shared by >1 household, with very high rates of sharing at mixed landlord-tenant (92%) and tenant-only residences (90%) compared with family-owned/occupied residences (30%). Sharing was positively associated with safe and sustainable facility access and with facility functionality (see Table A4, which is available online in the Supplemental Material at <http://www.iwaponline.com/washdev/004/180.pdf>). Those sharing their facility were about 40% more likely to have a functional, safe and sustainable sanitation system than those using non-shared facilities ($p = 0.17$). We hypothesize economic factors may explain some of these observations: greater cash resources from multiple poor households are available for building, maintaining and operating a shared facility than from a single poor household for their own facility, and landlords in poor, unplanned areas of Dar are able to obtain higher rents when they offer better quality sanitation facilities to their tenants. The latter hypothesis is borne out by our data on reported rents among the small subset of tenant respondents ($n = 79$), showing an average premium of TSH4,500 to 6,100 more in rent per month paid by tenants with access to an improved sanitation facility and to a safe, sustainable and functional facility, respectively. Neither improved nor safe pit-emptying access was associated with sharing.

A positive association between sharing and safe and sustainable system access runs counter to the JMP assumption that facility sharing diminishes public health safety and renders sanitation 'unimproved'. While shared facilities were used on average by significantly more users (11) than single household facilities (8.4), the difference was relatively small (2.6 people). Shared facilities were nearly all private, on-plot residential facilities (99%) shared among extended family members (25% of sharing) or among non-related households residing at the same property (75% of sharing).

Tenant-only houses were significantly more likely to have access to an improved facility compared with mixed landlord-tenant and family-only houses, but their facilities were significantly less likely to be functional (Table A4). Tenant-only houses also had greater access to safe and sustainable facilities and safe emptying services than family-only properties, but these differences were not significant. Tenant-only

properties in Dar do not appear to be disadvantaged in terms of the hygienic and sustainable standard of facilities or safe emptying service access, but rather encounter challenges with maintenance resulting in lower functionality.

Replacement facility and residency plan access

Replacement latrines were more likely to have safe and sustainable designs ($p = 0.18$) than original latrines, and were significantly more likely to have safe emptying service access ($p < 0.001$), resulting in a nearly 50% greater rate of safe and sustainable sanitation system access for replacement over original latrines ($p = 0.06$). However, replacement latrines were somewhat less likely to be functional mainly because they were more likely to be full than original latrines. Households may be motivated to replace and upgrade their facilities with safe and sustainable designs when safe emptying services are plot-accessible and locally available to empty them.

Residency plans were associated with access in several ways (Table A4). Those uncertain about plans (36%) were least likely to have access to an improved or safe and sustainable facility but had better access to safe emptying services, compared with properties where the respondent had long-term plans; these differences were significant. Landlords uncertain about their residency plans may prefer not to invest in better sanitation facilities at the property, while uncertain renters may prefer not to pay the rental premium for better sanitation facilities. Deeper dialogue with landlords of properties with poor quality facilities is needed to understand how landlords' residency plans and security of tenure affect sanitation facility and ongoing maintenance investment decisions. A need to regulate the types of sanitation facilities landlords build and their maintenance is one potential implication. It is unclear why those with uncertain plans have greater access to safe emptying services. This may have to do with security of tenure or other attributes of where they live, given that hygienic emptying service access is largely about location relative to main roads and municipal sludge disposal sites. Those with temporary plans (stays <5 years; 5%) had the lowest access to safe emptying services (18%) and to functional facilities (59%), with the result that none of this group had access to a safe and sustainable functioning system. Temporary and transient residents in Dar's

unplanned communities appear to have the greatest exposure to poor sanitation conditions.

Household income and education effects on access

Nearly all components of safe, sustainable and functional access showed significant income effects (Table A4). Consequently, access to a safe and functionally sustainable sanitation system was 2.6 times greater among Q5 households (19%) compared with those in the two poorest (Q1 and 2) quintiles (7%). Improved facility access, facility functionality, and safe and sustainable system access increased significantly with income quintile. Income effects were less clear on access to a safe and sustainable facility: Q1 and Q5 had similarly high safe and sustainable facility access as a result of higher rates of pit lining and absence of drain pipes compared with the middle quintiles. Income had a limited effect on safe emptying service access, plausible if safe service access depends mainly on public investments in locating and operating municipal fecal sludge waste disposal and treatment facilities, and on upgrading policy actions to improve slum plot access and road networks.

Education was not associated with increasing access to improved or safe and sustainable facilities nor with functionality rates, but significantly and strongly correlated with increasing access to safe emptying services when controlling for income, resulting in a small but significant positive trend in access to a safe and sustainable functioning sanitation system with education. Better educated households may have better information about safe emptying services, may value more highly the benefits of using safe emptying services, or choose to live at plots with vehicle access or in neighborhoods where safe emptying services operate.

Access by location

Safe and sustainable sanitation system access was significantly higher where flooding was not frequent (30%), the water table was not high (41%), and the terrain was sandy (16%), at rates 1.6 to 2.1 times greater than areas with frequent flooding, high water table or non-sandy terrain (Table A4). Functionality was not associated with any tested location characteristics. Hilly areas (13%) were less likely than non-hilly areas to have access to safe emptying

services and to safe and sustainable facilities, but differences were not significant. Kikondoni MC had a significantly lower rate of safe and sustainable functioning sanitation system access (6.4%) than the other two MCs (11 and 14%), traceable directly to significantly lower safe emptying service access (23%) in Kikondoni compared with the other MCs (40%). These results suggest significant spatial disparities in the quality of sanitation services and conditions among Dar's low-income, unplanned sub-wards associated with disparities in access to hygienically safe and sustainable facilities and hygienically safe emptying services, affected in part by geo-hydrologic, topographic and municipal council location.

Trends in safe and sustainable functioning access

The proportion of still-standing facilities built in each decade with an unhygienic waste pit drain pipe for flooding out rose from 15% in the 1950/60s to 32% in the 2000s (linear trend $p = 0.002$), an alarming trend for environmental health and safety. At the same time, a significant upward trend was observed of building facilities with hygienic below-ground lining (38% in 1950/60s, to 71% in 2000s, linear trend $p = 0.001$). These two opposing trends have mixed implications for safe emptying and disposal of fecal waste in study communities. Year-by-year construction trends suggest a very small increase in improved technology and safe and sustainable sanitation system access of 1.3% and 0.7% per year ($R^2 = 0.14$ and 0.20). The slow, incremental improvement in the hygienic safety and sustainability of on-plot sanitation systems being built in low-income, unplanned settlements of Dar is attributed mainly to greater private investment in cement slabs and lined pit designs, but is greatly held back by increasing rates of installation of flood out drain pipes and lack of improvement in access to safe emptying services. Very constrained gains are consistent with JMP-documented progress of about 1% increase per year in urban access to improved sanitation technology from 1990 to 2010 in Tanzania (WHO/UNICEF 2012a).

CONCLUSIONS

This study examined sanitation access and equity in Dar es Salaam looking beyond the current MDG definition of

'improved' to assess the hygienic safety and sustainability of sanitation systems in the low-income, unplanned settlements where 70–80% of Dar's population resides. While it might be argued that hygienic safety and sustainability of sanitation facilities and pit emptying are less important in low density rural areas, they appear to be critical in low-income, urban informal settlements where population densities are rapidly increasing.

We developed and applied a relatively straightforward household survey methodology to collect information on three critical factors: the sanitation facility design, its management and functional state. We then used the information to assess five indicators of system hygienic safety and sustainability and three indicators of system functionality. The approach involved a small number of survey questions, accompanied by a systematic inspection of the sanitation facility and property, which together we estimate would add about 10 minutes per household on average to the conventional set of JMP water, sanitation and hygiene survey questions. Surveyors would need to be trained to conduct the inspection accurately but would not require special skills. In our study, we successfully trained consumer market research enumerators in the technical aspects of the inspection.

As the sector looks to post-2015 goals and targets calling for progressive improvement in the quality of sanitation services to address safe fecal sludge management (WHO/UNICEF 2012b), our methodology offers a starting point to consider in the post-2015 enhancement of the current JMP survey approach, going beyond a simple characterization of technology type, to examine additional factors impacting on the quality and viability of sanitation access.

Applying these new, more rigorous indicators, we found access to adequate sanitation facilities in Dar's unplanned areas to be far lower than current JMP estimates. We also found significant income-associated, educational and spatial disparities in adequate access across low-income, unplanned settlements. Among Dar's informal population, those in the two poorest quintiles, residents with less education, temporary and transient residents, those living in areas with difficult hydro-geologic conditions, and in Kikondoni Municipal Council, were consistently the most vulnerable to poor sanitation conditions. On-plot sanitation facilities shared by multiple low-income households compared with

those used by just one household in unplanned areas of Dar were more likely to be hygienically safe and functionally sustainable, most likely because greater resources can be mobilized from sharing households to invest in a higher quality of sanitation service.

Lack of hygienic pit emptying services and plot inaccessibility in low-income, unplanned areas of Dar leave many poor households who invest in better quality latrine facilities with few good options for preserving the value of their investment, leading an increasing number to install a flood-out drain pipe and resort to unhygienic pit-emptying methods. On the other hand, where residents in unplanned poor areas have access to a hygienic emptying service they appear more willing to upgrade to a safe and sustainable sanitation facility design that enables the use of these services. This suggests that public investments to create widespread access to hygienic emptying services, currently available to only 33% of poor residents in the study areas, could be an effective approach to stimulate greater private investment in and access to safe and sustainable sanitation. As the current MDGs approach their expiry and new goals and targets are discussed (WHO/UNICEF 2012b), these findings may have important implications for defining what constitutes 'adequate' sanitation in urban areas, particularly for poor populations living in high-density informal settlements.

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