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The Sanitation Ladder, What Constitutes an Improved Form of Sanitation?

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Supporting Information

ABSTRACT: This study aimed to assess whether the MDG classifications and JMP sanitation ladder corresponded to hygienic proxies. Latrines were purposefully sampled in urban and rural Tanzania. Three hygienic proxies were measured: *E. coli* on points of hand contact, helminth at point of foot contact, and number of flies. Additionally, samples were collected from comparable surfaces in the household, and a questionnaire on management and use, combined with a visual inspection of the latrine's design was conducted. In total, 341 latrines were sampled. The MDG classifications "improved" vs "unimproved" did not describe the observed differences in *E. coli* concentrations. Disaggregating the data into the JMP sanitation ladder, on average "shared" facilities were the least contaminated: 9.2 vs 17.7 ("improved") and 137 *E. coli*/100 mL ("unimproved") ($p = 0.04$, $p < 0.001$). Logistic regression analysis suggests that both the presence of a slab and sharing a facility is protective against faecal-oral exposure (OR 0.18 95% CI 0.10, 0.34 and OR 0.52, 95% CI 0.29, 0.92). The findings do not support the current assumption that shared facilities of an adequate technology should be classified for MDG purposes as "unimproved".

INTRODUCTION

With over 50 pathogens transmitted in excreta, including those responsible for diarrheal disease, schistosomiasis, and soil transmitted helminth infections, access to adequate sanitation is of key importance to public health. Despite this, in 2000, 42% of the world's population, some 2.6 billion people, lacked access to basic sanitation,[1] and in 2002, sanitation was added to the existing Millennium Development Goal (MDG) target for water, with the aim of halving, "by 2015 the proportion of people without sustainable access to basic sanitation". One decade on, the United Nations estimates that 2.4 billion people still lack access to basic sanitation, and there appears little chance that the MDG sanitation target will be met.[1]

The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) is mandated to monitor progress toward the MDG target. As such, the JMP classifies sanitation facilities as either "improved" or "unimproved" (Figure 1), primarily based on the technology used by the household.[2,3] However, any facility that is shared by more than one household is considered "unimproved" and does not contribute to the MDG target.[2]

Shared facilities were classified as "unimproved" based on the conviction that there is little commitment or incentive for individual users to keep the facility clean or well maintained, and therefore were considered to pose a greater health risk. Furthermore, concerns have been raised around accessibility—particularly at night, or if there is a fee, which might result in some users resorting to unhygienic practices for some of the time.[4] These issues were of particular concern for more vulnerable groups, including women and children.[5] The JMP has been considering raising the threshold for excluding shared facilities from two to five households. However, a strong evidence base for adopting a different threshold for the post-2015 Sustainable Development Goals (SDG) is currently lacking.[2]

Since 2008, the JMP has presented data in a disaggregated format or "sanitation ladder" with ascending "rungs" of service level: open defecation, unimproved, shared, and improved (Figure 1).[2] Moving up the rungs of the ladder is assumed to result in an improvement in the hygienic quality of the facility, and thereby a reduction in health risks for users.[2] However, there is surprisingly little evidence to support this,[6] or what actually constitutes a hygienic latrine. The current definition of improved sanitation does not include anything regarding the actual use, cleanliness, maintenance, or overall quality of the facility. This has led some commentators to suggest that the current figures of people with access to adequate sanitation are significantly overestimated.[7]

In the absence of robust evidence on what constitutes an improved form of sanitation, this study, conducted in two sites in Tanzania, aimed to assess whether the MDG classifications of "improved" and "unimproved" corresponded to hygienic proxies. In addition, using the same proxies, it aimed to assess whether the current hierarchy of service categories, the JMP

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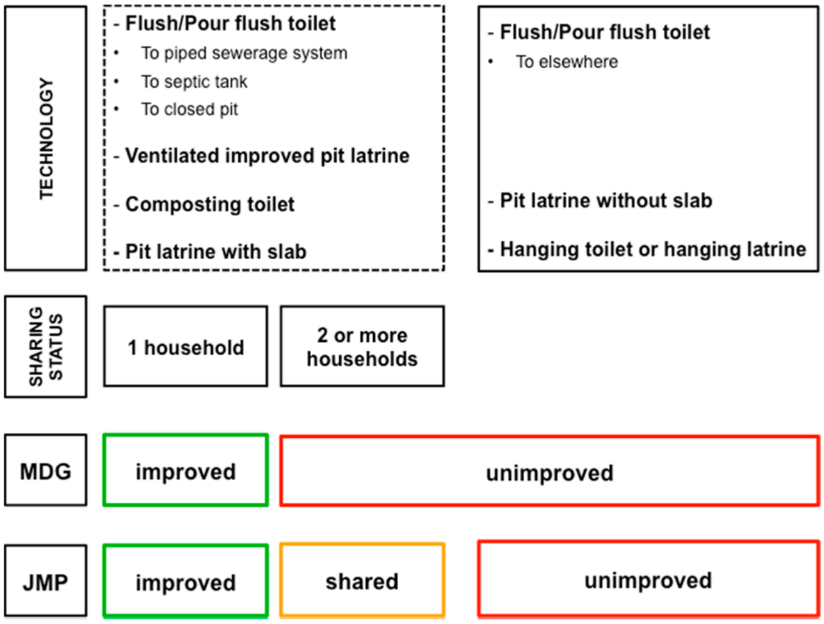

Figure 1. MDG classification system and JMP sanitation ladder. Note: For the MDG classification, all facilities shared between two or more households are considered to be unimproved regardless of technology, whereas for the JMP, sanitation ladder shared facilities of an otherwise acceptable technology are classified separately. In addition, the JMP reports individuals without access to any form of sanitation separately.

sanitation ladder, does indeed offer ascending levels of protection with regard to faecal-oral exposure.

■ METHODS

In the period from January 2012 to August 2012, facilities classified as improved, shared, and unimproved were sampled in urban and rural Tanzania. For each facility, a questionnaire on management and use was filled out, combined with a visual inspection of the latrine's design. In addition, key contact points in the latrine and household were sampled for the presence and concentrations of *E. coli*. Soil samples were collected and analyzed for the presence of helminth eggs, and in each latrine flytraps were left for a 24-h period.

Study Area. An urban and rural study site was selected in Tanzania: Temeke the largest unplanned and unserviced district of Dar es Salaam where the majority of households rely on pit latrines and septic tanks of varying quality as their main form of sanitation;[8] and the rural villages around Ifakara in the Morogoro region of southwest Tanzania, where it is estimated that less than 15% of the population have access to improved sanitation and simple pit latrines are the main form of sanitation.[9]

Sample Size and Sampling Approach. Sample size calculations were estimated using data from a pilot study carried out in the summer of 2011.[10] On the basis of an assumed 0.5 log difference in means, a 95% confidence interval and 80% power a minimum total sample size of 360 latrines was calculated. On the basis of the assumption that there would be a higher level of sharing in the urban site compared to the rural site, we aimed to sample twice as many latrines in urban areas. Latrines were selected purposefully, in order to ensure a wide range of latrine types corresponding to the JMP classification and facility categories.

Data Collection. *Household and Latrine Assessment.* The household survey was conducted in Kiswahili with an adult resident of the household. Information was collected on the demographics of the latrine users, maintenance issues and potential confounding factors such as place of child defecation, and animal ownership.

Researchers visited each latrine to record information on the quality and upkeep of the facility, for example: specific features (e.g., materials used for construction); and condition (e.g., completeness of the superstructure); and how full was the pit of the latrine.

Sample Collection and Analysis. Three potential routes of environmental transmission of faecal pathogens related to sanitation were assessed: hand contact with contaminated latrine surfaces, estimated by the presence and concentration of *E. coli*; helminth infection arising from foot-contact with or ingestion of contaminated soil; and mechanical transmission of faecal pathogens by flies. In addition, in order to enable us to identify whether a latrine posed an increased risk to users compared to their surrounding environment, samples were collected from comparable surfaces within the household compound.

Pathogens on point of hand-contact were estimated using a surface swipe swab method as described previously,[11−13] and detailed in the Supporting Information (SI). Samples were taken from three high frequency contact surfaces within the latrine superstructure (door handle and two points of potential hand contact while seated/squatted in the facility), and from similar surfaces within the household (door handles, light switches, and kitchen tops) . An attempt was made to sample 10 cm^2 at each contact point; however, especially at door handles, this was often not possible, and as a result *E. coli* are reported as per 100 mL of solution. *E. coli* was enumerated using direct filtration with a commercial media: *m*-coliblue24 (HACH, Loveland, U.S.A.).

Where feasible, a composite sample of roughly 30 g of surface soil was taken from around the circumference of the drop hole, at points where it was thought an individual would place their feet. A second composite sample was collected from all areas within the household compound (defined as the area between the latrine and house) where everyday activities

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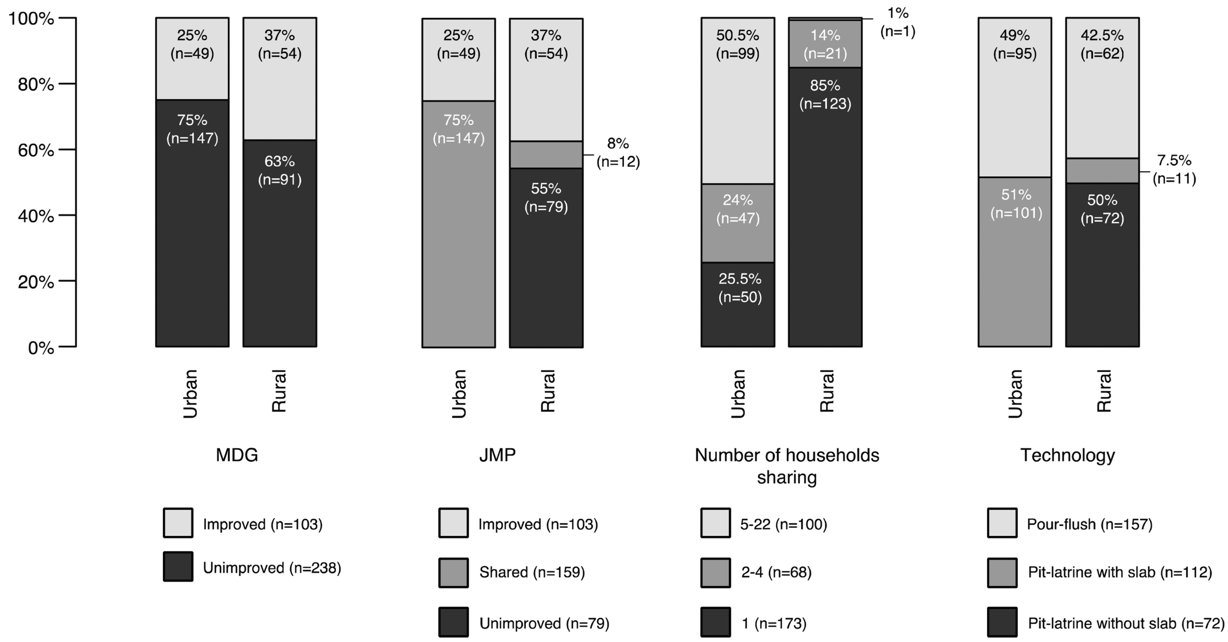

Figure 2. Difference in distribution of latrine characteristics between urban and rural regions.

(cooking, washing, and bathing children) were carried out, as identified by householders. Soil temperature, pH and moisture were measured in situ using hand-held meters (HI 99121, HANNA, U.S.A. and Lutron PMS-714). STH ova and larvae were extracted using a combination of sedimentation and flotation as described previously.[9] Details are provided in the SI.

Sticky paper traps (Zeroin, ZER878, STV International Ltd., U.K.) were placed in each latrine for a 24-h period. In order to standardize, wherever possible, traps were hung from the roof of the latrine superstructure approximately half a meter behind the drop-hole. Light readings were taken from within the latrine using a hand-held meter (Testo 540 Luxmeter, Testo, U.K.). Trapped flies were counted and identified to family level; only *calliphoridae* and *muscidae* families are reported, as these are the only two known vectors of both diarrheal diseases and trachoma.[14,15]

Data Analysis. Data were entered into Excel, and all statistical analysis was conducted in R version 2.15.2 (R-FSC, Vienna, Austria). Where there was more than one latrine in a household and use was equal between them, the number of users was divided by the number of latrines. Chi-squared tests were used to examine latrine characteristics by region. Nonparametric methods of analysis, geometric mean/standard deviation, and Poisson regression were used to assess the association between *E. coli*, flies, and helminths concentrations with latrine characteristics. The association between *E. coli* and helminth samples taken from the latrine, and its associated compound was tested using matched Wilcox test. Differences in proportion of negative samples were assessed with chi-squared test.

Logistic regression analysis was used to explore the relationship between the density of *E. coli* within the latrine and the components of the MDG definition; (i) the presence of a slab (pour flush and pit latrines with a slab grouped); and (ii) accessed by no more than one household. *E. coli* density was classified as a binary variable using a cutoff of value of 100 CFU/100 mL, as often used in household drinking water studies to indicate high risk levels.[16] The model controlled for season as it was significant with *E. coli* density, but did not control for additional latrine characteristics or region based on the premises that the JMP does not consider these factors in its definitions. Additional analysis was undertaken, stratifying the results by region to account for colinearity, and separately controlling for those latrine characteristics, which were significantly associated with *E. coli* density. The results of the additional analysis are presented in the SI.

Ethics. The Ifakara Health Institute's (IHI) review board, National Institute for Medical Research (NIMR) in Tanzania, and the LSHTM granted ethical approval for this study (IHI 14-2-10, NIMR 1143, LSHTM 5659). Community meetings were held to introduce the study, and all study participants provided written informed consent.

RESULTS

In total, 341 latrines were sampled (SI Table S1), which was less than planned as fewer latrines with a slab were identified than expected in rural areas. Swabs were successfully collected from all 341 latrine and corresponding household, 78 soil samples were taken from latrine floors and 238 from compound floors, and 320 flytraps were retrieved.

General Characteristics of Latrines. Under the current MDG classification, 70% of sampled latrines would be considered "unimproved". Just over half of all latrines sampled were accessed by a single household. The median number of households sharing was 5.5, up to a maximum of 22 households. The total number of users ranged from 1 to 37, with an average of 7.4 users per latrine.

As demonstrated by Figure 2, there was a significant difference in latrine characteristics between regions. Most notably, pit latrines without a slab were only found in rural areas, while 90% of latrines with a slab and over 86% of all shared facilities were sampled in Dar es Salaam. In general, urban areas had a greater number of users per facility, better levels of education, and more tenancy (SI Table S1).

***E. coli* Concentrations on Points of Hand Contact.** Almost 30% of sampled latrines were free of *E. coli*, while less

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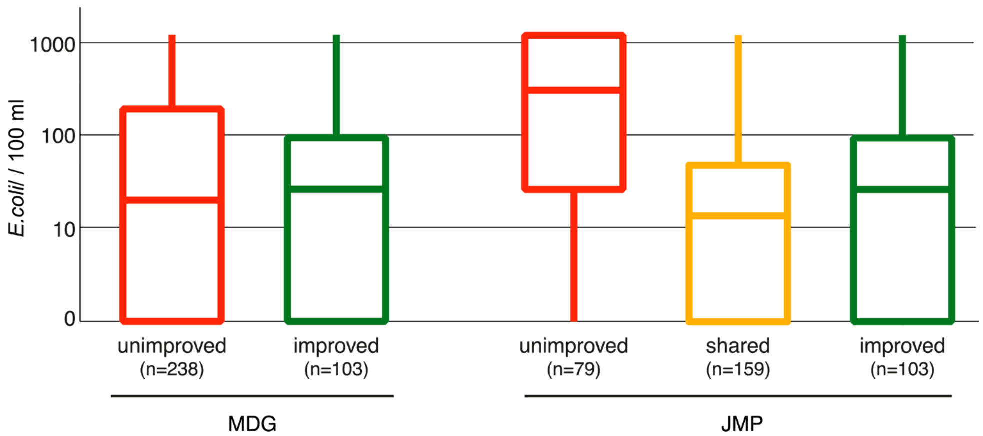

Figure 3. *E. coli* concentrations (Median) at point of hand contact in latrines classified based on (a) MDG classification and (b) JMP sanitation ladder. Note: The lines of the box-and-whisker plot represent, from the bottom: the minimum value, the lower quartile, the median value, the upper quartile and the maximum value. For MDG "improved" and "unimproved", and JMP "shared" and "improved" the lower value and lower quartile are the same as the data is highly positively skewed. The difference between the upper and lower quartile (between the outer lines of the box) represents the Inter Quartile Range.

than 10% had more than (over 1000 *E. coli*/100 mL. The geometric mean concentration of *E. coli* on points of hand contact within the latrine was 21 *E. coli*/100 mL. Samples collected from household surfaces had significantly lower concentrations; on average 6.1 *E. coli*/100 mL ($p < 0.001$). 55% of latrines were more contaminated than their household, and for 22% there was no difference between toilet and compound; there was no correlation between the levels of contamination in the latrine and the associated household (p = 0.21)

No significant difference in *E. coli* concentrations was observed between latrines classified according to the MDG categories ("improved" and "unimproved") (Figure 3a). When latrine classification was split according to the JMP sanitation ladder categories ("improved", "shared" and "unimproved") "unimproved" were the most contaminated on average; *E. coli* concentrations were over 7 and 14 times greater than for "improved" and "shared" facilities, respectively (137 vs 18 and 9 *E. coli*/100 mL, $p < 0.001$) (Figure 3b). Shared facilities were significantly less contaminated than improved facilities (9 vs 18 *E. coli*/100 mL, $p = 0.04$). Furthermore, the data showed that as the number of households and number of users sharing a facility increased the concentration of *E. coli* within the facility decreased (Table 1). Latrines without a slab were the most contaminated; more than 90% of latrines without a slab were positive for *E. coli* compared to less than 60% of latrines with a slab and less than 70% of pour flush latrines. There was weak evidence of a significant difference in *E. coli* concentration between pour flush latrines and pit latrines with a slab (p = 0.06).

Rural latrines had on average 7.5 times greater concentrations of *E. coli* at point of hand contact than urban latrines (67 vs 8.9 *E. coli*/100 mL, $p < 0.001$), though urban/rural was highly correlated with latrine technology; controlling for urban/rural the difference in *E. coli* concentrations in pit latrines with a slab and pour flush facilities was no longer significant ($p = 0.1$); while the difference in *E. coli* concentration between pit latrines with and without a slab remained highly significant ($p < 0.01$).

Levels of contamination appeared to decrease as the "quality" and "condition" of the latrine structure improved. Latrines built of mud, palm, grass or plastic had significantly higher concentrations of *E. coli* than those built of bricks, or with a corrugated iron roofs, while a properly constructed wall (bricks) reduced contamination by more than four times. A smaller drop-hole (less than 20 cm), and higher levels of the household head's education were also associated with cleaner latrines. Neither ownership of a latrine, nor the presence of children under the age of five in the household appeared to have an impact on the density of *E. coli* within the latrine (Table 1).

Results for the logistic regression model, which included the components of the MDG definition controlled for season are presented in Table 2. The presence of a slab appears to be protective—the odds of a latrine with a slab (including pour flush) being highly contaminated with *E. coli* (greater than 100 *E. coli*/100 mL) was more than 80% lower than without a slab ($p < 0.001$)—while having private access is not—the odds of a shared latrine being highly contaminated was almost 50% lower than private latrines ($p = 0.002$).

Running the regression analysis with the number of households sharing modeled as a continuous variable provides weak evidence that as the number of households increased the odds of a latrine being highly contaminated decreased (OR 0.90, 95% CI 0.81, 1.00). Region was colinear with both presence of a slab and sharing status. When stratified by region sharing status is nonsignificant (SI Table S2).

Helminth Eggs in Soil. A total of 335 soil samples were collected; 78 from around the drop hole of latrines, and 257 within household compounds. Soil samples from latrines were collected from 74 unimproved pit latrines; for five pit latrines without a slab the earth was too hard to take a sample, the additional four samples were collected from latrines with a broken slab. Of the collected samples, 40% were free of helminth ova, while 6.5% contained more than one ova/g (Table 3). The helminth concentrations in a latrine ranged from 0 to 15 ova/g, with a geometric mean of 0.20 ova/g (sd 0.53). Hookworm larvae were recovered most frequently (51% of positive samples), followed by, hookworm ova (21%) and *Ascaris* spp. ova (16%). All latrines with a broken slab (n = 4) were positive for helminths, with an average of 0.34 ova/g of soil.

Of samples taken from the household compound, 44% were free of helminths, while 3% contained more than 1 ova/g. Total helminth concentrations ranged from 0 to 7.8 ova/g; with a

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Table 1. Geometric Mean Concentration of *E. coli* Found at Points of Hand Contact within the Latrine, By Key Characteristic

	N	GeoMean *E. coli* /100 mL (sd)	*p*-value	% free of *E. coli*	χ^2 *p*-value
location					
latrine	341	21.4 (10.8)	<0.001	30	<0.001
household	341	6.1 (8.2)		48	
MDG					
unimproved	238	23.3 (11.4)	0.37	29	0.8
improved	103	17.7 (9.4)		31	
JMP					
unimproved	79	137.1 (10.5)		11.4	<0.001
shared	159	9.2 (7.0)	<0.001	37.7	
improved	103	17.7 (9.4)	<0.001	31.1	
number of households sharing					
1	173	44 (12)		22	0.01
2−4	68	12 (9.9)	<0.001	40	
5−22	100	8.5 (9.0)	<0.001	36	
technology					
pit w/o slab	72	154 (9.0)		8	<0.001
pit with slab	112	7.6 (6.5)	<0.001	42	
pour flush	157	17 (9.5)	<0.001	31	
region					
urban	196	8.9(6.6)	<0.001	38	<0.001
rural	145	67 (12)		19	
season					
wet	146	10 (6.6)	<0.001	43	<0.001
dry	195	37 (12)		19	
ownership					
tenant	37	11(6.3)	0.12	30	1.00
owner	301	23 (11)		30	
household head education					
none	25	72 (9.1)		12	0.02
primary	251	23(11)	0.03	29	
higher	63	9.0 (8.7)	<0.001	41	
number of users					
1−5	105	38 (14)		25	0.52
6−10	143	21 (10)	0.07	31	
11−15	42	15 (9.1)	0.05	31	
>15	50	8.1 (5.6)	<0.001	36	
number of users under five					
0	107	24(11)		27	0.57
1	119	27(13)	0.72	29	
>1	114	14 (8.7)	0.13	33	
wall material					
other	69	147 (9.6)	<0.001	34	<0.001
brick	272	13 (8.6)		10	
entry to latrine					
open	80	21 (11)		31	0.19
curtain	96	52 (14)	0.02	23	
door	161	12 (7.3)	0.09	34	
roof material					
none	137	12 (9.0)		37	<0.001
grass and leaves	52	211 (8.5)	<0.001	8	
corrugated iron	152	16 (8.5)	0.30	30	
diameter drophole					
>20 cm	22	83 (9.7)		0.9	0.05
<20 cm	139	19 (11)	0.009	31	

geometric mean of 0.13 ova/g (sd = 0.31). Hookworm larvae were most frequently recovered (52%), followed by *Ascaris* spp. ova (14%) and hookworm ova (14%). There was no correlation between the helminth concentrations in the soil around the latrine and the soil in the corresponding household compound.

For soil samples taken from the household compound, no significant difference in contamination was found between the different rungs of the sanitation ladder, nor between rural and urban areas (Table 3). Significantly more compound samples were positive during the rainy season as compared to the dry

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Table 2. Multiple Logistic Regression Model for Low vs High *E. coli* Contamination at Points of Hand Contact within the Latrine and Elements of the MDG Definition

	odds[a]	95% CI	Z	p-value
slab present[a,b]	0.18	0.10, 0.34	−5.50	<0.001
shared	0.52	0.29, 0.92	−2.25	0.002
dry season	2.06	1.19, 3.56	2.59	0.01

[a]Base value for the odds ratio; unimproved facilities, without a slab, privately accessed, wet season. [b]Slab present includes both pit latrines with a slab and pour flush facilities.

season (74% vs 43%, $p < 0.001$). No significant association was found between soil temperature, pH or moisture content, and the presence or concentration of helminth ova.

Fly Collections. Flytraps were retrieved from 320 latrines, 21 went missing or were found on the floor of the latrine, and therefore were not included in analysis. The reason most frequently cited by a household for a missing trap was; removal by a child. Of the collected traps, only 6% were completely free of flies. The most frequently caught species was *Psychodidae* spp., which was present on 271 traps. Looking only at those species that are known disease vectors, *Calliphidora* spp. (total catch, 222) and *Musca* spp. (total catch 899), were trapped on just over half (54%) of all traps. The total number of *Calliphidora* spp. and/or *Musca* spp. caught on a single trap ranged from 0 to 123, with a geometric mean of 1.1 flies/trap. Only 71 (22%) of traps had more than two flies/trap, and only three (0.9%) traps collected more than a 100 flies/trap. Table 4 shows the number of flies by technology, access status, and by urban and rural, with all showing a strong association with the number of flies caught. A borderline nonsignificant negative correlation (−0.11) was found between the number of flies collected and the light intensity in the latrine; with more flies collected in darker latrines ($p = 0.06$).

DISCUSSION

For more than a decade, the JMP has monitored progress toward the MDG for sanitation, using a simple classification system of "unimproved" or "improved". However, the evidence base for the current classification system has not been comprehensively explored, and with discussions underway for a new water and sanitation goal as part of the SDG framework, it is critical that the next generation of classification benchmarks is evidence-based.

Table 3. Geometric Mean Concentration of STH Ova and Larvae Per Gram of Soil Collected from Household Compounds, By Key Household Characteristics

	n	GeoMean STH/g (sd)	p-value	% negative	χ^2 p-value
location					
compound	257	0.13(0.31)	0.66	44	0.90
drop hole latrine	78	0.20(0.53)		40	
MDG					
unimproved	186	0.12 (0.22)	0.38	45	0.84
improved	71	0.17 (0.47)		42	
JMP					
unimproved	76	0.09 (0.22)		46	0.89
shared	110	0.14 (0.22)	0.08	44	
improved	71	0.17 (0.47)	0.09	42	
technology					
pit w/o slab	69	0.07 (0.11)		46	0.74
pit with slab	79	0.15 (0.34)	0.10	41	
pour flush	109	0.16 (0.36)	0.09	44	
number of households					
1	138	0.13 (0.38)		46	0.07
2−4	50	0.14 (0.19)	0.09	30	
5−22	69	0.12 (0.22)	0.97	51	
region					
urban	117	0.16 (0.32)	0.02	41	0.45
rural	140	0.11 (0.29)		46	
season					
wet	108	0.24 (0.45)	<0.001	26	<0.001
dry	149	0.06 (0.13)		57	
number of users under five					
0	84	0.12 (0.31)		40	0.65
1	84	0.17 (0.40)	0.51	48	
>1	88	0.11 (0.20)	0.82	44	
place of child defecation					
latrine	129	0.11 (0.20)	0.12	49	0.25
compound	43	0.22 (0.54)		37	
household head education					
none	19	0.17 (0.65)		58	0.42
primary	194	0.13 (0.29)	0.36	42	
higher	42	0.11 (0.20)	0.60	45	

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Table 4. Geometric Mean Number of Filth Flies (Musca and Blow Flies) Collected, By Key Household Characteristics

	n	GeoMean flies/trap (sd)	p-value	% traps free of flies	χ^2 p-value
MDG					
unimproved	223	1.3 (1.6)	0.003	40	0.004
improved	97	0.69 (1.5)		59	
JMP					
unimproved	76	0.71 (1.1)		54	<0.001
shared	147	1.7 (1.7)	<0.001	33	
improved	97	0.69 (1.5)	0.93	59	
technology					
pit w/o slab	69	0.69 (1.2)		57	0.002
pit with slab	106	2.0 (2.1)	<0.001	32	
pour flush	145	0.79 (1.2)	0.69	51	
number of households sharing					
1	166	0.70(1.3)		57	<0.001
2−4	64	1.3 (2.0)	0.008	47	
5−22	90	1.9(1.5)	<0.001	26	
region					
urban	181	1.7(1.9)	<0.001	34	<0.001
rural	139	0.51 (0.91)		61	
season					
wet	137	1.3 (2.0)	0.13	46	1.0
dry	183	0.98 (1.2)		46	
wall material					
other	68	0.75 (1.2)	0.05	54	0.15
brick	252	1.21 (1.7)		44	
entry to latrine					
open	75	1.72 (1.75)		36	0.002
curtain	92	0.52 (0.92)	<0.001	61	
door	149	1.17 (1.67)	0.09	43	
roof material					
none	125	2.46 (2.13)		26	<0.001
grass and leaves	50	0.40 (0.90)	<0.001	70	
corrugated iron	145	0.58 (0.80)	<0.001	54	

The MDG Classification—Improved vs Unimproved Technologies. This study found evidence that the concentration of *E. coli* at points of hand contact within the latrine significantly decreased moving-up the sanitation ladder, from a pit latrine without a slab to an improved technology. In addition, the majority of pit latrines without a slab were found to be contaminated with STH. These two results suggest that the current JMP classification is valid with regard to the importance of a latrine slab.

In contrast to *E. coli* density, the number of flies caught was lowest in pit latrines without a slab. However, differences in fly density are likely to be a reflection of urban/rural differences rather than an underlying difference between latrine technologies. Significantly more flies were trapped in urban than rural latrines, possibly as a result of the presence/absence of a roof, which was strongly associated with both region and fly density. This result would confirm previous findings in Tanzania that latrines without a roof generate significantly more flies than those with a roof.[17]

The results of univariate analysis of *E. coli* provide some suggestive evidence that the "quality" of the latrine is associated with the level of faecal contamination. Those surfaces that are easier to clean, and less hospitable to the growth of pathogens, such as slab, wall, door, and roof material were significantly less contaminated compared to those made of poorer quality materials. Furthermore, although only a limited number of soil samples were taken from the latrine floor of pit latrines with a broken slab, all were found to be positive for STH. These two results suggest that the current JMP classification is valid with regard to the importance of a latrine slab, although the presence of STH samples taken from the latrine floor of pits with broken slab, although limited in number, indicates the importance of importance of good upkeep in order to prevent infection.

This study found no evidence that shared facilities were more contaminated with *E. coli* than privately accessed facilities. In fact, the regression model provides weak evidence that increasing the number of households is actually protective. This result suggests that, potentially, the underlying assumption that there is little commitment or incentive for users to keep a shared facility clean, does not hold. On the basis of this result, there is no evidence to support the exclusion of shared sanitation even if the threshold was to be raised to more than five households.

More than half of household compounds sampled were positive for STH, though concentrations were low, and viability of ova was not tested. A possible explanation for this could be ongoing practices of open defecation, especially by infants. In this survey, and reported in many other instances, children were observed or reported not to use sanitation facilities,[18,19] as well as exiting the latrine for anal cleansing, effectively circumnavigating the beneficial effect of having access to a latrine. This practice could potentially explain why STH concentrations in compound samples were higher in urban areas than those in the rural areas; a greater number of children under the age of five

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were living in these households, and compounds in urban areas are expected to be smaller, and as a result children might roam around less in urban areas. Finally, latrines in rural areas are unlikely to be emptied, as sufficient space will allow for a newly constructed latrine, while in Dar es Salaam, space is at a premium, latrines need to be emptied. Manual emptying is a messy process, and could contaminate both household compound, and local neighborhood. Areas for sampling were chosen where household members spent large periods of time; the results provide a snapshot into the risk of STH transmission from cooking and washing areas rather than the risk across the compound, and therefore do not necessarily apply to all household members, in particular children.

While these results suggest that in Tanzania sharing a latrine does not limit its protective effect with regard to faecal-oral exposure, there are, of course, other social mechanisms that may render a shared facility unsafe, such as risk of violence or discrimination. Adequate sanitation should not only prevent contact with human excreta, but also provide a service that ensures the security and dignity of all members of the household. Future studies should seek to establish the wider impacts that sharing a facility has on users and should be extended to include publicly accessed facilities.

There were major differences between the urban and rural sites, with generally better access to improved technologies and higher levels of sharing in urban areas. In particular, no pit latrines without a slab were identified in the selected urban neighborhoods. Sharing was found to be more than four times as common in Dar es Salaam, than in the sampled rural areas, a finding that is in line with Tanzania's most recent Demographic and Health Surveys survey.[20] Future studies should increase the study size in order to overcome issues of colinearity, as it would be of interest to explore whether a globally standardized system that allows comparison across countries/regions is adequate: what constitutes adequate sanitation may vary widely by context depending on such factors as population density, climate, or hydro-geology. Potentially, a simple pit latrine without a slab may be adequate for a dispersed low-income rural area, but almost certainly would not be sufficient in a densely populated informal urban settlement.[21]

Health Impact and Study Limitations. *E. coli* is an indicator organism for faecal contamination, representing a large group of faecal bacteria present in both humans and animals. Many will not be pathogenic, while other more pathogenic species, such as enteroviruses, *Cryptosporidium* spp. and *Giardia* spp., can survive longer in the environment than *E. coli*.[15] Therefore, the presence or absence of *E. coli* does not necessarily indicate the presence or absence of pathogenic bacteria. Furthermore, an individual's risk depends on the frequency of latrine visits, as well as the level of immunity to pathogens present. It is therefore difficult to predict the health risks associated with the concentrations of *E. coli* found. However, the observed trend of significantly higher *E. coli* concentrations during the hot summer months corresponds with the peak of diarrhea cases found in Tanzania.[20] The health risks presented by exposure may be mitigated or limited by protective behaviors such as hand washing with soap.

The concentrations of STH found in latrines in this study were low, albeit comparable to those previously found in pit latrines in Tanzania,[9] with on average less than 1 ova, or larvae/g of soil. On the basis of the WHO guideline for the safe use of excreta in agriculture, which states that faecal sludge can be used in agriculture if it contains less than 1 ovum/g,[22] the risk of infection from the sampled pit latrines without a slab is likely to be low, as only five percent of all samples had more than 1 ovum/g. However, household members are in daily and prolonged contact with contaminated soil in their latrines, often without footwear, and consequently run the risk of reinfecting themselves, with higher intensities of STH associated with more severe health impacts.[23]

While the concentrations of both *E. coli* and STH were lower in the household than the latrine, there is some evidence to suggest that some latrines are not preventing the spread of faecal pathogens, or other pathways of contamination, like excreta from domestic animals, such as chickens or dogs, are more dominant. Just under half of all households sampled actually had higher levels of *E. coli* than their corresponding latrine, and it is likely that the results underestimate the level of contamination within the household; walls and doors were chosen to allow for a direct comparison with the latrine data; however, these surfaces are not necessarily the highest frequency contact surfaces; a study conducted in Bagamoyo, Tanzania, found environmental contamination to be pervasive on basins, cups, plates, toys, and brooms, all at concentrations higher than those of the latrine walls in this survey.[24]

The efficacy of the STH soil extraction method used has not been determined, and it is unable to establish the viability of ova. Results could therefore underestimate contamination. However, a cross-sectional study in an urban region of northern Brazil reported that the egg count in stool samples correlated with those in soil samples, implying that soil contamination may be a good proxy for measuring disease at the household level.[25]

A number of observations raised concerns over the efficacy of the sticky traps. First, traps were no longer effective once they had gotten wet; in Dar es Salaam 2 days of rain meant that traps had to be discounted, while in other instances traps had been repositioned, which could have compromised its ability to trap flies. Second, larger fly species, especially *Calliphidora* spp., were able to remove themselves from the trap if their wings were not trapped. Potentially, therefore, sticky traps provide an underestimate of the true number of flies within a latrine. This is supported by the results of a 2013 study conducted around Ifakara, which trapped considerably greater numbers of flies using different trapping methods, 1.1 vs 124.[17]

This study presented the first attempt to empirically assess the validity of the MDG classification with regard to faecal-oral exposure. The findings from this one study/one country do not support the current assumption that shared facilities of an improved technology category renders the facility less safe and therefore "unimproved". Globally, the number of people reliant on shared sanitation has increased from 322 million in 1990 to 783 million in 2012,[1] 500 million of whom live in an urban environment. Without reconsidering shared sanitation, the MDG, and future targets, are unlikely to be met. However, this study does not take account of the wider issues associated with shared sanitation related to privacy, discrimination, and whether women and children are marginalized as reported in other studies. More research is needed to understand whether and how these quantitative measures of exposure translate into disease risk.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Details on the methodology for surface swipe swab method and STH extraction, and a table of results for characteristics of

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sampled latrines by region. This material is available free of charge via the Internet at http://pubs.acs.org/

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Author Contributions

J.L.R.E., O.C., and J.H.J.E. designed the study; J.L.R.E. and B.L. collected and analyzed the data; J.L.R.E., O.C., and J.H.J.E. were involved in writing the paper. All authors have read and approved the final manuscript. J.H.J.E. is the guarantor of the paper.

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REFERENCES

(1) UNICEF, WHO. Progress on drinking water and sanitation. 2014 update. 2014.

(2) UNICEF, WHO. Progress on Sanitation and Drinking Water; 2010 update. *Joint Monitoring Programme for Water Supply and Sanitation*, 2010.

(3) Kvarnström, E.; McConville, J.; Bracken, P.; Johansson, M.; Fogde, M. The sanitation ladder—a need for a revamp? *J. Water Hyg Develop* **2011**, *1* (1), 3−12.

(4) Cairncross, S, Valdmanis, V. Water supply, sanitation and hygiene promotion. In: Jamison, D. T., Breman, J. G., Measham, A. R., Alleyne, G, Claeson, M, Evans, D. B., et al., Eds. *Disease Control Priorities in Developing Countries Washington DC*; The World Bank; 2006; p 771−792.

(5) Biran, A.; Jenkins, M. W.; Dabrase, P.; Bhagwat, I. Patterns and determinants of communal latrine usage in urban poverty pockets in Bhopal, India. *Trop Med. Int. Health* **2011 Jul**, *16* (7), 854−862 PubMed PMID: 21414114..

(6) Heijnen, M.; Cumming, O.; Peletz, R.; Chan, G. K.; Brown, J.; Baker, K.; et al. Shared Sanitation versus Individual Household Latrines: A Systematic Review of Health Outcomes. *PLoS One* **2014**, *9* (4), e93300 PubMed PMID: 24743336. Pubmed Central PMCID: 3990518..

(7) DANIDA. *Reaching the MDG target for sanitation in Africa: A call for realism*; Ministry of Foreign Affairs of Denmark: Copenhagen, Denmark, 2010.

(8) WaterAid, Tearfund. Water Reforms and PSP in Dar es Salaam. New Rules, New Roles: Does PSP Benefit the Poor? Dar es Salaam, Tanzania, 2003

(9) Baker, S. M.; Ensink, J. H. J. Helminth transmission in simple pit latrines. *Trans. R. Soc. Trop. Med. Hyg.* **2012 Nov**, *106* (11), 709−710 PubMed PMID: 22939710.

(10) Exley, J. L. R. *Is the Current Classification of Latrines in Developing Countries Compatible with Acceptable Standards of Hygiene?*; London School of Hygiene and Tropical Medicine: London, U.K., 2011.

(11) Berrang, M. E.; Northcutt, J. K. Use of water spray and extended drying time to lower bacterial numbers on soiled flooring from broiler transport coops. *Poultry Sci.* **2005**, *84* (11), 1797−1801 PubMed PMID: 16463980..

(12) Rusin, P.; Orosz-Coughlin, P.; Gerba, C. Reduction of faecal coliform, coliform and heterotrophic plate count bacteria in the household kitchen and bathroom by disinfection with hypochlorite cleaners. *J. Appl. Microbiol.* **1998**, *85* (5), 819−828 PubMed PMID: 9830117. Epub 1998/11/27. eng..

(13) Sinclair, R. G.; Gerba, C. P. Microbial contamination in kitchens and bathrooms of rural Cambodian village households. *Lett. Appl. Microbiol.* **2011 Feb**, *52* (2), 144−149 PubMed PMID: 21198693. Epub 2011/01/05. eng..

(14) Cohen, D.; Green, M.; Block, C.; Slepon, R.; Ambar, R.; Wasserman, S. S.; et al. Reduction of transmission of shigellosis by control of houseflies (*Musca domestica*). *Lancet* **1991**, *337* (8748), 993−997 PubMed PMID: 1673210. Epub 1991/04/27. eng..

(15) Feachem, R.; Bradley, D.; Garelick, H.; Mara, D. D. *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*; John Wiley & Sons: Chichester, U.K., 1983; p 501.

(16) WHO. Guidelines for drinking-water quality, Vol. 1. Recommendations. World Health Organization: Geneva, Switzerland, 1993.

(17) Irish, S.; Aiemjoy, K.; Torondel, B.; Abdelahi, F.; Ensink, J. H. Characteristics of latrines in central Tanzania and their relation to fly catches. *PLoS One* **2013**, *8* (7), e67951 PubMed PMID: 23874475. Pubmed Central PMCID: 3715525..

(18) Majorin, F.; Freeman, M. C.; Barnard, S.; Routray, P.; Boisson, S.; Clasen, T. Child feces disposal practices in rural orissa: a cross sectional study. *PLoS One* **2014**, *9* (2), e89551 PubMed PMID: 24586864. Pubmed Central PMCID: 3930746..

(19) Yeager, B. A.; Huttly, S. R.; Bartolini, R.; Rojas, M.; Lanata, C. F. Defecation practices of young children in a Peruvian shanty town. *Soc. Sci. Med.* **1999 Aug**, *49* (4), 531−41 PubMed PMID: 10414812. Epub 1999/07/22. eng..

(20) National Bureau of Statistics. Macro T. Tanzania I.. *Demographic and Health Survey 2010*, 2011.

(21) Project UMD . Health, Dignity and Development: What will it take? Earthscan: London, 2005.

(22) WHO. WHO guidelines for the safe use of wastewater, excreta and greywater. *IV Excreta and Greywater Use in Agriculture*; WHO: Geneva, Switzerland, 2006.

(23) Brooker, S. Estimating the global distribution and disease burden of intestinal nematode infections: adding up the numbers—a review. *Int. J. Parasitol.* **2010**, *40* (10), 1137−1144 PubMed PMID: 20430032. Pubmed Central PMCID: 3034165. Epub 2010/05/01. eng..

(24) Pickering, A. J.; Julian, T. R.; Marks, S. J.; Mattioli, M. C.; Boehm, A. B.; Schwab, K. J.; et al. Fecal contamination and diarrheal pathogens on surfaces and in soils among Tanzanian households with and without improved sanitation. *Environ. Sci. Technol.* **2012**, *46*, 5736−5743 PubMed PMID: 22545817. Epub 2012/05/02. eng..

(25) Schulz, S.; Kroeger, A. Soil contamination with Ascaris lumbricoides eggs as an indicator of environmental hygiene in urban areas of north-east Brazil. *J. Trop Med. Hyg.* **1992**, *95* (2), 95−103 PubMed PMID: 1560490. Epub 1992/04/01. eng..

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