Preprint:
Mills, F., Foster, T., Kome, A. et al. (2024) How safe is safely managed on-site sanitation? What we need to know beyond global monitoring. [Preprint - Research Square]

https://doi.org/10.21203/rs.3.rs-3693108/v1

How safe is safely managed on-site sanitation? What we need to know beyond global monitoring

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Article

Keywords:

Posted Date: January 15th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3693108/v1

Additional Declarations: There is a conflict of interest Co-author Juliet Willetts is a guest editor of this special issue. Other guest editors Rick Johnston and Tom Slaymaker were involved in discussions on this manuscript to confirm details of global monitoring were accurately explained.

Version of Record: A version of this preprint was published at npj Clean Water on July 7th, 2024. See the published version at https://doi.org/10.1038/s41545-024-00353-2.

Abstract

Halfway through the Sustainable Development Goal (SDG) period, there has been little research on the criteria for monitoring safely managed sanitation under SDG target 6.2. For reporting against SDGs, global indicators are necessarily limited and exclude many safety aspects from a public and environmental health perspective. Primary survey data from 31,784 households in seven countries in Asia and Africa were analysed, comparing estimates of safely managed on-site sanitation based on global indicators with five complementary indicators of safety: animal access to excreta, flooding and overflow, groundwater contamination, emptying frequency, and the safety of emptying. Application of additional criteria reduced the population with safely managed sanitation by 0.4-38% for specific indicators, with the largest impact due to the risk of groundwater contamination, animal access, and containments overdue for emptying. Combining these indicators across the service chain, excluding transport and treatment, found three-quarters of on-site systems currently assessed as safely managed with global indicators were considered unsafe based on complementary indicators. A more comprehensive assessment of safety of on-site sanitation can be achieved through these indicators, which could be integrated into national monitoring systems and used to inform sanitation investments that address local health related risks.

Introduction

Inadequate sanitation is associated with numerous and varied health risks.[1] There are multiple sources of faecal environmental contamination from inadequate sanitation systems and multiple pathways for exposure.[2,3] The presence of a toilet is therefore an insufficient measure to indicate whether positive health outcomes are likely to be achieved by sanitation improvements,[4] hence various authors critiqued the Millenium Development Goal target, expressed solely in terms of access to toilets.[5] The Sustainable Development Goal (SDG) target 6.2 of safely managed sanitation services aims to address these limitations by considering the management of excreta from the toilet to final treatment and disposal.[6] The Joint Monitoring Programme (JMP) led the development of global indicators and standardised core questions to enable consistent and practical classification of sanitation services for national and global monitoring (see Table 3).[7] However, these indicators do not cover all aspects of safety, such as those outlined in WHO guidelines on sanitation and health.[1] The guidelines suggest countries agreeing to the SDG framework should routinely monitor and report on the global indicators, as a minimum, and suggest these are complemented by more nuanced and contextual regional and national indicators. The JMP proposed some expanded indicators, but these focus on expanded definitions of toilet access, for example privacy of toilet use, and include limited expanded indicators related to the safety of containment, emptying and disposal.[7] Safely managed sanitation as defined for global monitoring, while a significant improvement in monitoring access to improved toilets, should not be assumed to indicate a service level that protects against many key faecal transmission pathways. Since what doesn't get measured doesn't get managed,[8,9] relying on global indicators to prioritise investment may result in sanitation improvements that do not address critical health risks.

Despite debate and research on other aspects of SDG 6.2, there has been little assessment of the indicators for safely managed sanitation services nor exploration of the complementary indicators that could address the gaps. Numerous publications have critiqued and suggested improvements to the classification of shared toilets as limited sanitation,[10] the monitoring of progress of lower service levels,[11] the means of implementation targets,[12] and explored alternatives for monitoring safely managed water services.[13] However, there has been little discussion on the formation and scope of the indicators for safely managed sanitation services. The opinion piece by Rose et al. defined safe sanitation through a communal social lens as based on the “social construct that lies at the intersection of knowledge, societal engagement, and controls”. This paper highlighted the role of the community in monitoring but did not review the indicators for safely managed sanitation or propose alternative indicators relevant to their definition.[14] Beard et al. highlighted the challenges to assessing on-site systems and the need for revised categories for improved sanitation facilities, yet they did not review indicators related to safe management across the service chain.[15] One paper proposed complementary indicators for safely managed sanitation services for national monitoring in Austria.[16] This provided valuable insights for a high-income 100% sewer context yet was less applicable for low- and middle-income countries with predominantly on-site sanitation.

National and subnational decision-makers should not rely on global monitoring alone to inform investment. Globally defined indicators for water and sanitation may not adequately capture the national realities and challenges faced by individual countries or best suit the needs of individual countries to assess progress towards national goals.[16,17]. Beard et al. argued that for urban sanitation, global monitoring efforts do not provide a clear picture of the challenge of managing excreta at the city scale and that the current indicators have a limited ability to inform policy and action.[15] This paper does not intend to critique the objective and approach of the SDGs or indicators used for global monitoring but to highlight that these indicators are just one way to define a “safely managed sanitation service”. Indeed, the 2030 Agenda for Sustainable Development recommends that global indicators be complemented by indicators at the regional and national levels, which will be developed by Member States.[18] The Guidelines on Sanitation and Health also suggest more indicators are needed at the utility and sub-national levels to inform local programmes and actions.[1] Although the number of countries able to report against safely managed sanitation has increased, significant data gaps remain, particularly regarding on-site sanitation,[19] making it an opportune time to inform the scope and approach to monitoring sanitation.

Beyond those currently assessed by the global indicators, there are a range of additional exposure pathways associated with inadequate sanitation systems and their management. Animal access to uncovered or inadequately protected faeces can transmit excreta and pathogens to people, surfaces and food, especially in dense settings or places where animals and humans are in close proximity.[20,21,22] Inadequate subsoil treatment of leachate from unsealed on-site sanitation can contaminate groundwater supplies used for drinking water, with contamination risk influenced by toilet and containment type, soil type, groundwater level and proximity to wells.[23] Exposure to faecal pathogens can also derive from poor operation and management of sanitation. Infrequent emptying of on-site sanitation is associated with an increased likelihood of overflowing, malfunction or reduced performance and was also reported to lead to unsafe emptying practices such as entering the pit to remove hardened sludge or informal emptying practices such as wash out, putting both the workers and public at risk of exposure.[2,24] The health risks sanitation workers face during emptying have been increasingly recognised, including direct exposure to faecal pathogens and risks from working in confined spaces.[25,26]

While environmental sampling and detailed health exposure studies and models have improved our understanding of health risks, household surveys can assess potential exposure pathways at a larger scale and lower cost. Several tools, models and detailed research studies have developed methods to investigate critical faecal exposure pathways.[21,27–29] While they have been valuable in demonstrating the high concentration of pathogens in the environment and need to consider multiple exposure pathways, they typically require high skills or equipment and can be difficult to conduct at scale. Household questionnaires, while limited in simple questions and self-reporting, benefit from capturing sanitation data at scale for relatively low cost when included in broader surveys. Assessment of indicators of pathogen exposure pathways cannot ensure that a system provides 100% protection against human contact with excreta; however, it can point to common failures in sanitation systems that increase the risk of exposure to prioritise improvements or further in-depth investigation. There remains an opportunity to expand household monitoring to better assess and prioritise potential exposure pathways at a larger scale than the field-based exposure assessments.

Recognising that global monitoring is necessarily limited for simplicity and comparability, this paper proposes complementary indicators that could be incorporated into household monitoring to provide a more comprehensive assessment of on-site sanitation focusing on faecal exposure pathways. While research on other aspects of SDG 6.2 led to debate and refinement of indicators (e.g. shared sanitation) for the assessment of safely managed services, as noted above, previous research identified the need for complementary indicators yet did not suggest potential indicators relevant to low- and middle-income countries. SNV, an international non-government organisation, conducted baseline monitoring between 2018–2019 in 34 urban and rural districts across seven countries to inform and monitor progress of their sanitation programs. Trained enumerators conducted surveys of 31,784 households, which included global core questions and supplementary questions related to additional exposure pathways as well as qualitative assessments of service provision. The data from health-related household questions were assessed to compare five complementary indicators with the equivalent global sub-indicators for improved, contained and emptied on-site sanitation. This research evaluated the extent to which consideration of critical exposure pathways reduced the proportion of systems classified as safely managed on-site sanitation and analysed the contexts or conditions in which different indicators may be more or less important. National sanitation monitoring systems continue to be updated to improve reporting against the SDGs and could incorporate these locally relevant complementary indicators to enhance understanding of local health risks and inform sanitation investments.

Results

As background to the results for the complementary indicators, Figure 1 presents the overall access to improved sanitation for the 21 urban cities and 13 rural districts. Most households used improved on-site sanitation systems (79% average across countries), which are facilities that aim to hygienically separate excreta from human contact. A small number of households in African cities used improved toilets connected to sewers (1%) and on average across countries 10% practised open defecation, predominately in rural Laos. The JMP classifies shared improved toilets as “limited sanitation”, which were used by an average 17% of urban respondents and 6% rural respondents. This resulted in 65% and 71% of respondents in urban and rural areas reported accessing at least basic sanitation (Table S7). While only ‘at least basic’ sanitation can be considered as ‘safely managed’ sanitation services, in this paper the analysis of each indicator considered all improved sanitation facilities, as both shared and private facilities contribute to faecal environmental contamination (Berendes et al., 2018). The contextual factors included typology of improved sanitation facilities, of which 89% of households in rural areas reported the use of a pit (i.e. direct pit, off-set pit, two sequential pits, double off-set pit, composting) and 11% reported the use of a tank (septic tank, holding tank, communal septic tank) (see Table S2). In urban areas, the use of tanks and pits was equally reported across the whole sample, although this varied between countries.

Containments had been in use for an average of 8.6 years in urban areas and 5.8 years in rural areas. Of improved on-site systems, 6% had previously been emptied in rural areas and 22% in urban areas.

Improved facilities: Animal access to excreta

Moving beyond the high-level assessment of facility type, data was analysed to assess whether facilities classified as improved were still at risk of animal access to excreta, which can result in mechanical transmission of pathogens from animals to humans. On average across all countries 81% of respondents reported using an improved sanitation facility, yet 14% of respondents used improved toilets that were accessible to rats and flies. In urban areas the proportion of improved facilities reduced by 18% when assessed for animal access, which was a greater reduction than in rural areas (8%). The reduction varied between countries, ranging from a reduction of 1% in Laos and 2% in urban Nepal to 28% and 29% in Tanzania and Zambia, respectively. The variation between cities or districts within a country was greatest for Bhutan, Bangladesh and Zambia, with the greatest impact (51% reduction) in Zhemgang district, Bhutan. Poor households and dry toilets had a greater risk of animal access than non-poor households or water-based toilets (Table 1).

Containment - Flooding and overflow

The assessment of flooding and groundwater risk first considers the global indicator for containment, which requires that on-site systems do not have an outlet discharging excreta to surface environments. Based on the global definition, on average across countries, 70% of respondents used “contained” on-site sanitation and 9% used uncontained systems. In urban areas, an average 15% of respondents used uncontained systems, although this varied between countries, with Bangladesh having the highest proportion of uncontained (52%) and Zambia the lowest (1%, see Table S1). In rural areas, SNV’s monitoring only assessed the presence of outlets in Nepal where only 4% of improved OSS were uncontained. In urban areas wet toilets, tanks, shallow containments (less than 3m deep) and systems in deeper groundwater were at greater risk of being uncontained (Table 1).

Looking beyond the global indicator, an average 4% of respondents use systems classified as contained in global monitoring yet were reported to flood, leak, or overflow (see methods in Table 3). Despite the small impact, it occurred in all countries except Bhutan and was more common in urban (5%) than rural (3%) areas. Flooding and overflow were reported for another 3% of respondents that were already classified as uncontained with the global indicator. There was some variability between cities or districts within countries, particularly in Bangladesh and rural Nepal, where some districts had up to 15% contained systems reported to flood or overflow while other districts had none. Dry toilets, pits and poor households had a greater risk of reported flooding and overflow (Table 1).

Containment – Groundwater risk

While the global indicator assesses releases from on-site sanitation to surface environments, groundwater contamination from on-site sanitation is a critical exposure pathway in some contexts. A risk matrix based on literature was used to assess potential groundwater contamination risk based on household self-reported containment depth and secondary data on groundwater depth and soil type collected for each sub-district or neighbourhood. Methods are described in Table 3 with further details in supplementary materials. The analysis found an average 38% of the population use systems classified as contained but pose a high risk of contaminating groundwater and ranged from 42% in urban areas to 31% in rural areas, with considerable variation between countries (see Figure 4). The between-city or district variation was also the highest of all complementary indicators, with most countries having areas of low and high risk, indicating the variability of local environmental conditions (see groundwater depth and soil type in Table S5). The exception was Bhutan, where there was no risk in any of the surveyed districts. Recognising that the exposure risk to potentially contaminated groundwater is most relevant to populations using groundwater for drinking, further analysis, beyond SNV's current indicator, considered system posing a risk to groundwater only when 25% or more of the respondents in the district reported using groundwater for drinking. Figure S1 presents the adjusted results, which reduced the proportion of uncontained sanitation due to groundwater risk to an average 27%. This revision had the greatest impact in Tanzania with 83% of respondents with on-site systems at risk to groundwater but only 4% at risk if groundwater use was considered. Urban Nepal and Zambia were also impacted but the reduction in risk was only 5%. Figure S9 presents the city and district data on the use of groundwater for drinking and the proportion of contained on-site systems that posed a high risk to groundwater contamination, clustered by country. The highest risk was found in districts of Bangladesh and Nepal, although the figure also demonstrated substantial within-country variability as other cities in these countries had a low risk.

Overdue emptying – unemptied stored in-situ and emptying within timely threshold

The global indicator for emptying within the assessment of safely managed sanitation considers whether containments were ever emptied. Of all respondents, 10% had improved on-site systems were previously emptied, 1% built a new pit and 64% were never emptied and 3% didn't know, which was considered never emptied for analysis (Table S1). Emptying rates were lowest in Zambia, Bhutan and Laos (1 to 4%) and highest in Bangladesh (32%) (see Figure 7). Emptying was more likely for older systems, wet containments and urban areas (Table 1).

Many types of containments are designed to be regularly emptied so they function as designed or do not overflow, therefore the complementary indicator assessed whether unemptied systems were overdue for emptying by assessing operation compared with a calculated timely emptying threshold. The threshold years operation is calculated based on the number of users, containment size and sludge accumulation, estimated for each containment type and each country (see methods in Table 3 and supplementary materials). Compared with the 67% of respondents that used unemptied improved containment, considered by global monitoring as safely stored in-situ, when years of operation were assessed 21% of the population's unemptied improved containments were overdue for emptying. The largest reductions due to overdue emptying occurred in Indonesia (42%), followed by urban and rural Nepal both with 27% reduction, while Zambia was the least impacted by this complementary indicator (6%, see Figure 6). Within countries the was some variation between cities or districts, particularly in Nepal where reductions ranged from 11% to 44% between cities. Of improved on-site systems that had never been emptied urban areas, wet toilets and non-poor households were at increased risk of being overdue for emptying, highlighting it is not just an affordability issue (Table 1). Of previously emptied systems, only an average 0.4% of improved on-site systems are overdue for re-emptying, with a maximum reduction of 0.8% of systems in Indonesia (Figure S11 presents disaggregated city and district results).

Emptying – Occupational health and safety risks

While 10% of respondents had improved on-site systems previously emptied, only 8% were emptied without someone entering the containment. From Figure 7, the greatest reduction in safe emptying when considering entering was in urban Nepal (5% reduction) and and Bangladesh (4%), with small reductions in Tanzania and Nepal (0-1%), where completely mechanical emptying was more common. Entering was more likely for containments emptied by the household or tenant (24% entered), compared with manually (15%) and mechanical (3%) service providers. Rural areas and wet containments were at greater risk of reported entering to empty, although rural areas were also more likely emptied by users (35%) than in urban areas (6%) (Table 1).

The other health and safety indicator was the use of a minimum level of personal protective equipment (PPE), including boots, gloves and a mask. Across all countries, only 3% of respondents used improved OSS that were emptied with adequate PPE. The lowest compliance was in Bangladesh where 32% of impoved on-site systems had been emptied, yet 29% were systems emptied without minmum PPE. The next largest reduction was in Nepal and Tanzania where 6% of respondents used improved containments that were emptied without minimum PPE (Figure 7). Greater PPE compliance was reported for containments emptied by the household than those emptied by service providers, and for manual rather than mixed or fully mechanised emptying, noting this data was self-reported. There was little variation between cities for both indicators, except for Bangladesh only 1-4% of respondents reported systems emptied with adequate PPE despite emptying ranging from 11-44% yet. The risk of inadequate PPE was greater for urban areas and poor households (Table 1).

Influence of context variables on the significance of complementary indicators

Analysis of the associations between contextual factors with the complementary indicators can inform which indicators or exposure pathways may be most important in certain contexts. Table 1 indicate which technological, socio-economic and evnironemntal factors increase the probability of systems failing each indicator. Improved on-site systems in urban areas had a significantly greater risk of flood or overflow, groundwater contamination or being overdue for emptying than those in rural areas, yet entering to empty was a greater risk rural areas. Poorer households were at greater risk of animal access and flooding or overflow yet lower risk of being overdue for emptying or entering during emptying. Areas with shallow groundwater (<5m) faced a greater risk of groundwater contamination, animal access and flooding but a lower risk of being overdue for emptying and entering to empty.   Considering containment type, dry containments and pits were significantly more at risk of animal access and flooding or overflow, whereas wet containments and tanks had a greater risk of entering to empty. Older containments (> 5 years old) had a greater risk of flooding yet a lower risk of animal access.

Table 1. Risk ratio estimates for strength of association between context variables and the complementary indicator.

Context variables (household level)								
Risk ratio[1] [95% CI]		Rural / urban	Poor / not poor	GW <5m / >5m	Dry / Wet containment	Pit / Tank	Age >5yrs / <5yrs	Depth <3m / >3m
Of improved	**Animal access**	**0.86** [0.79-0.93]	**1.74** [1.65-1.84]	**1.22** [1.16-1.28]	**4.84** [4.63-5.05]	**2.18** [2.05-2.31]	**0.79** [0.75-0.83]	1.02 [0.95-1.09]
	Uncontained (global) [2]	*NA*	**1.077** [1.03-1.13]	**0.51** [0.49-0.54]	**0.16** [0.14-0.19]	**0.33** [0.31-0.34]	**1.80** [1.71-1.89]	1.53 [1.46-1.60]
Of contained (global)	**Flood or overflow**	**0.37** [0.31-0.45]	**2.07** [1.86-2.29]	**1.21** [1.09-1.34]	**1.77** [1.57-2.01]	**1.81** [1.59-2.05]	**1.37** [1.23-1.54]	1.08 [0.93-1.25]
	Ground-water risk	**0.48** [0.46-0.5]	**0.92** [0.89-0.95]	**3.95** [3.82-4.08]	**1.1** [1.06-1.14]	**1.26** [1.23-1.3]	1.00 [0.98-1.03]	1.04 [1-1.08]
Of improved	**Emptied (global)**	**0.25** [0.22-0.29]	**1.24** [1.17-1.31]	**1.23** [1.17-1.29]	**0.6** [0.54-0.67]	**1.09** [1.04-1.15]	**5.41** [4.94-5.93]	1.03 [0.96-1.09]
Of improved not emptied	**Overdue for emptying**	**0.61** [0.57-0.66]	**0.66** [0.62-0.71]	**0.89** [0.85-0.94]	**0.47** [0.42-0.53]	**1.07** [1.02-1.12]	**98.04** [71.9-133.6]	**1.09** [1.04-1.15]
Of improved emptied	**Overdue for re-emptying**	**2.74** [1.44-5.2]	**0.24** [0.11-0.51]	**0.6** [0.39-0.93]	0.34 [0.08-1.38]	1.14 [0.75-1.71]	1.88 [0.77-4.6]	**3.81** [2.48-5.83]
	Entered	**1.56** [1.18-2.08]	**0.74** [0.61-0.88]	**0.62** [0.53-0.72]	**0.32** [0.19-0.55]	**0.72** [0.63-0.83]	1.03 [0.8-1.34]	1.03 [0.85-1.25]
	Inadequate PPE	**0.77** [0.7-0.86]	**1.12** [1.09-1.15]	0.97 [0.97-1.02]	1.03 [0.98-1.08]	**1.08** [1.05-1.11]	0.97 [0.93-1.01]	0.99 [0.96-1.02]

Notes: 1 Risk ratios that were significant (Significance 2-sided p>0.05) are in bold

2. Contained of improved was only assessed for urban samples since outlets were not assessed in all rural surveys.

Overall analysis of the difference between global and complementary indicators

Table 2 shows the proportion of households meeting global indicators considering the existing definition used by the JMP for global monitoring of safely managed sanitation (on the left). The columns to the right show the reduction in this proportion when considering additional potential exposure pathways of the complementary indicators, including the overall and country average reduction for each indicator. The complementary indicators resulting in the greatest reduction in the proportion of respondents considered safely managed were the indicator of groundwater risk (38% reduction), followed by unemptied containments overdue for emptying (21%) and animal access (14%). While 10% of households had emptied their on-site system (global indicator), very few of these are overdue for re-emptying; therefore this indicator had the lowest impact (0.4% reduction). Indicators had varied impacts between countries, for example in Bhutan, animal access caused the greatest reduction which may be associated with high use of dry pits, whereas in Laos, considering animal access had a minor impact while the complementary indicators for groundwater risk and overdue for emptying had the largest impact on assessment of safety. Within-country variability was lower than between-country variability for most indicators except groundwater risk, which had equally high variability within countries as between (Table S4).

Table 2. Proportions of respondants meeting global and complementary indicators (I) and the average reduction due to complementary indicators overall and per country (II)

Global and complementary indicators	I) Total respondents assessed as safe for each indicator	II) Reduction in the population considered safe due to complementary exposure pathways (Global % – Complementary %)									
		All countries		Urban					Rural		
		Ave	Std Dev	BGD	IDN	NPL	TZA	ZMB	BTN	LAO	NPL
Improved (global)	81%										
Improved and no animal access	66%	14%	12%	11%	20%	2%	28%	29%	21%	1%	4%
Contained (global)	70%										
Contained and no flooding	66%	4%	2%	6%	3%	5%	5%	4%	0%	3%	7%
Contained and low groundwater risk	32%	38%	24%	34%	24%	31%	83%	39%	0%	38%	57%
Not emptied (global)	67%										
Not emptied and not overdue for emptying	46%	21%	11%	16%	42%	27%	21%	6%	8%	20%	27%
Emptied (global)	10%										
Emptied and not overdue for emptying	9%	0.4%	0.3%	0%	1%	1%	0%	0%	0%	1%	0%
Emptied and didn't enter pit	8%	2%	2%	4%	0%	5%	1%	0%	0%	1%	3%
Emptied and used adequate PPE	3%	7%	9%	29%	3%	6%	6%	1%	1%	2%	7%

While the indicators were presented separately to highlight their individual impact and variation between contexts, safely managed sanitaiton requires cumulative analysis across the service chain as excreta must be managed from containment to treatment. The data allowed for cumulative assessment of safely managed sanitaiton services across the steps of improved, contained, emptied and stored-in situ but a full assessment of safely managed services was not possible since transport and treatment data cannot be collected through household surveys. Each household was assessed whether the sanitation system could be considered safely managed through a) safely stored in-situ or emptied and buried in situ or b) emptied and removed offsite but unknown disposal and treatment. Figure 8 compares the population with access to safely managed onsite sanitatio (excluding transport and treatment) considering the global or complementary indicators for different steps in the sanitation service chain, and differentiates the proportion of safely stored in-situ with those emptied given unsafe transport and treatment could further reduce the emptied estimates. Overall considering global indicators, 60% of respondents accessed safely managed on-site sanitation services up to emptying, although a proportion of the 6% emptied could be unsafe if not adequately transported and treated. The proportion of households meeting global and complementary indicators was 15%, one quarter of the value found using global indicators only. The difference was larger in urban areas, where the assessment with complementary indicators reduced the proportion of households with safely managed to one fifth the estimate with global indicators, while in rural areas it was one third. The largest difference was in Bangladesh and Tanzania, where the proportion of households with safely managed on-site sanitation based on global indicators was 30% and 55% respectively compared with almost zero considering complementary indicators (Figure S4). Laos and rural Nepal had the next largest reduction with the assessment using complementary indicatrs around a tenth of the global estimate, while Bhutan was the least impacted with complementary indicators resulting in an estimate two thirds the estimate with global indicators.

Discussion

The reduction in the combined estimate of safely managed on-site sanitation from 60% using global indicators to 15% with complementary indicators was a stark finding and demonstrates that while the SDG global indicator 6.2.1a ‘use of safely managed sanitation services’ is an improvement on basic access to toilets, several faecal exposure risks remain unassessed. However, the individual indicators are critical to inform decisions on where and what to improve. The reduction from each complementary indicator compared to the global indicator ranged from 0.4% to 38% of the population, highlighting that some of the proposed indicators had little impact, whereas others can significantly change whether a system should be perceived as truly safe, even if it does meet the global criteria for ‘safely managed’. The indicator on groundwater risk had the largest impact, with 38% of systems classified as contained with the global indicator assessed as a high risk for contaminating groundwater. Considering only areas where groundwater was used for drinking, this reduced to 27%. Overdue emptying and animal access had the next greatest impact, reducing the proportion assessed as safely managed by 22% and 14%, respectively. Although the indicator of flooding had a low average impact, given that increasing flood risk was the most commonly reported impact on sanitation from climate change,[23] monitoring climate-related hazards may be increasingly needed. The average obscures local findings, with up to 15% of otherwise contained systems impacted by flooding and overflow in some cities of Bangladesh and Nepal. Given that only 10% of improved systems had ever been emptied, it was not surprising that the complementary indicators on emptying had the lower overall impact but as a proportion of the emptied systems these risks remain important.

Assessing the individual indicators, rather than the overall combined estimate, was also important given the variability of risks between and within-countries. In many countries sanitation decisions and investment occur at a sub-national scale, therefore data should be disaggregated to the level needed to inform these decisions.[15,32] Data and risk assessments at a local scale were also emphasised by citywide inclusive sanitation (CWIS) planning and WHO’s sanitation safety planning.[33,34] The impact of the complementary indicators varied both between and within countries which indicated that many risks were context-specific and that global or national assumptions about the priority aspects of safely managed sanitation were unlikely to apply to all sub-national contexts (see disaggregated findings in supplementary materials). Indicators with the greatest between-country variation were groundwater risk, which was high in Tanzania (83% reduction) and zero in Bhutan, and use of adequate PPE during emptying, which was most impactful in Bangladesh but low in other countries where emptying rates were also low. Within country variation was most evident for groundwater risk, highlighting that decisions on groundwater risk from on-site sanitation are unlikely to be globally or nationally applicable but may be very important in some contexts.

Resources for monitoring sanitation are often limited, therefore this research can inform which contexts specific indicators may be more critical. There remain concerns that monitoring is expensive and diverts funds from already sparse resources for implementation, and debates whether indicators are selected and used to inform decisions.[17,35] Others argue that the limited resources further emphasise the need for careful indicator selection and sufficient data to support decision-making.[16,17] The analysis of risk ratios found some contextual factors had a risk ratio as expected, such as older on-site systems facing greater risk of being overdue for emptying. In contrast, other ratios were less predictable, such as tanks and wet containments at higher risk of being entered to empty or that poor households were at lower risk of being overdue for emptying. While it may be challenging to decide what indicators will be critical before data collection, this analysis, along with existing background information could be used, or indicator selection could be informed by small pilots or guided by national priorities.

The indicators and methods presented in this paper are not perfect, yet they show a tested way forward to improve monitoring of OSS that can potentially be integrated into household surveys or routine monitoring systems. At the same time, they bring attention to definitions and remaining risk in the global assessment of safely managed sanitation services. Previous research has highlighted the role of development partners in supporting monitoring improvements, yet there was still a lack of tested methods, indicators and recommendations that were directly usable by national governments, who often require testing of new approaches before uptake.[35,36] Further research could improve complementary indicators, such as refining the indicators on groundwater risk or timely emptying with locally relevant data rather than global assumptions, and further evidence on the relationship between infrequent emptying and groundwater contamination on faecal exposure in different contexts. Research has shown that provision of PPE alone is insufficient to protect public health and also difficult to assess use,[28] therefore indicators for sanitation workers health and safety may be selected based on local issues or service objectives, with some examples provided in SNV's outcome indicators.[37] Lastly, while we discuss health risks, it is also important to recognise that these indicators assess the hazards and there remains limited research on the exposure and illness to sanitation related hazards; therefore direct health benefits cannot be guaranteed from achieving these indicators.[38] Nevertheless, investments that address these hazards will progressively reduce pathogens in the environment and contribute towards improved public and environmental health.

The study does not intend to be an exhaustive analysis of all possible indicators for sanitation and instead focuses on household survey questions relevant to reducing health risks. A limitation of this scope was the exclusion of health risks associated with the transport, treatment, and final disposal, which cannot accurately be assessed from household surveys.[39] The global indicators for transport and treatment are the "proportion delivered" and whether "excreta from on-site sanitation receives solid and liquid treatment". Complementary indicators could also be developed for these steps, for example, public health risks associated with excreta spilled during transport. Other drivers for sanitaiton investment, such the environment, finance, equity, service viability, household preferences, etc., could also benefit from development of complementary indicators. Lastly, although the sampling was not nationally (or globally) representative, it presents the diversity of contexts and findings from tested indicators that can be further tested and refined in other contexts.

Despite being halfway through the SDG period, there has been little discussion about the monitoring and definition of safely managed on-site sanitation. This paper shows that, in many cases, on-site sanitation systems may be unsafe, even if classified as 'safely managed' using global indicators and definitions. This is largely because the currently available national data used for global monitoring can't assess all significant exposure pathways. While SDG monitoring created a valuable shift in attention beyond the toilet, national and local monitoring systems need to go beyond the SDG global indicators and integrate additional indicators which enable a more comprehensive assessment of health risks associated with sanitation services. This research further supports the argument for adding indicators to national household surveys to improve understanding at the local level and provides pre-tested indicators relevant to on-site sanitaiton in low- and middle-income country contexts that can be directly integrated into national and sub-national monitoring systems. This paper aims to ignite further debate and research into which complementary indicators for safely managed sanitation are critical to assess faecal exposure pathways prevalent in different contexts, and to inform further refinements of the proposed data collection and analysis methods. As many countries continue to update monitoring methods to address SDG data gaps, these indicators have both immediate applications, while the results can be used in the future to develop even stronger global monitoring systems and inform the post-2030 objectives.

Methods

Data collection through household surveys was designed and implemented by SNV, a not-for-profit international development organisation that works on water, energy and agriculture in 26 countries in Asia and Africa. This paper draws upon the work of their WASH programmes, where they support local governments to improve sanitation services through urban and rural sanitation and hygiene programs. These indicators were included in their standardised performance monitoring framework,[40] initially developed in 2010, which also includes other aspects not analysed in this paper, such as off-site sanitation, hygiene and solid waste, and outcomes indicators on service delivery capacities and performance. SNV performance monitoring framework uses ladders for each step of the service chain that combines multiple sub-indicators of functionality, sustainability and risk. This paper presents the sub-indicators separately for clarity and ease of applying the indicators to other monitoring frameworks.

Data collection

In partnership with local governments, SNV conducted baseline monitoring between 2018 and 2019 in 18 urban and 13 rural districts across seven countries in Asia and Africa. In three Bangladesh cities (Jhenaidah, Khulna and Kushtia), the baseline survey included slightly different indicators; therefore the mid-term data collected in 2019 was used in this analysis for consistency. The standardised survey tools were translated into local languages and implemented with mobile phone-based technology (AKVO Flow). Enumerators were either local government staff or hired enumerators, managed and trained by SNV staff. A multi-stage sampling method was adopted, with the primary sampling unit of wards and districts from the programme locations previously determined by the national government. The proportion method for sample size was used to determine district/ward sample size, assuming a 5% level of significance and 2-3% margin of error. The secondary sampling unit (SSU) was country-specific, for example in Indonesia it was village (*Kelurahan*), which were randomly selected, and samples were distributed proportionally to the village population. In areas where there were administrative units below the SSU (i.e. neighbourhoods), further random sampling was done and each selected neighbourhood was allocated an equal number of households to be surveyed. Systematic sampling was used to identify the household within each neighbourhood or village. Sample size and details of each city or district are provided in Table S5.

Complementary indicator data collection and analysis

The indicators and data collection approaches were developed for SNV's global sanitation and hygiene monitoring framework for their multi-year urban and rural sanitation and hygiene programmes. The indicators were selected to go beyond the global indicators (see Table 3), recognising that monitoring smaller incremental changes allowed for greater learning and pathways for sanitation service improvements. SNV assessed 40 complementary impact indicators, including a range of behavioural elements (e.g. functionality, use, maintenance), hygiene, and health and safety, as well as outcome indicators to assess service provision qualitatively. The indicators analysed in this paper were a selection of the most relevant impact indicators to assess health risks along the sanitation service chain from toilet to emptying. Table 3 presents the data collection methods, predominately household questionnaires but also enumerator observation and secondary data for the groundwater risk assessment. Further details of the analysis of groundwater risk and timely emptying are presented in the supplementary material.

Data analysis

The objective of the data analysis was to quantify the extent to which the complementary indicators changed the assessment of safely managed sanitation, compared with the current global indicators, as defined by the JMP. The data were first analysed to determine the respondents with at least improved sanitation (as defined in Table 3 and presented in Figure 1). The complementary indicator analysis was only conducted for households with improved sanitation facilities. While safely managed sanitation is only assessed for basic facilities (improved facilities that are not shared), this would have substantially reduced the complementary indicator analysis from Africa, where sharing was high, and the health risks assessed are equally relevant to both shared and not shared facilities. The indicators were presented for each step and then combined along the chain until the emptying step, as safety of transport and treatment cannot be determined from household monitoring, which was the scope of this research. Cumulative assessment was possible for each respondent due to the availability of a single dataset that included multiple indicators, which is often not the case for global monitoring data which typically relies on ratios for cumulative assessment. Good quality data management and analysis is necessary to enable this type of analysis which can also permit disaggregated analysis considering inequalities and gender.

The relative risk of the complementary indicators being assessed as safe or unsafe due to different contextual variables was analysed using SPSS v28.0. The variables included rural vs. urban, poor (lowest two wealth quintiles) vs. not poor, groundwater depth less vs. more than 5m, dry containments vs. wet (pour or cistern flush), pits (all types) vs. tanks (septic, holding tank), toilet age more vs. less than 5 years old, containment depth less vs. greater than 5m. This analysis does not propose a correlation between indicators and variables since other factors may influence but aims to inform which contexts the indicators may be more critical to monitor.

The results were presented per country and with the overall country average rather than total responses, given that sample sizes varied between countries. Data disaggregated at the city or district level are presented in supplementary materials. References to country findings were representative of the cities or districts assessed (see Table S5) and were not nationally representative.

Table 3. Comparison of global and complementary indicators and methods for data collection for complementary indicators [7]

JMP global indicators	Complementary indicators	Question	Method and analysis
Improved toilet facilities[a] include flush/pour flush toilets connected to piped sewer systems, septic tanks or pit latrines; pit latrines with slabs; and composting toilets.	**Animal access to excreta:** Rats and flies cannot enter and exit the toilet or containment	Can rats access the faeces in any way? If not, does the toilet pan or slab allow flies to enter and exit the pit?	Where possible this was observed and if not it was asked to the respondent. Rat access was assessed by observation of the type of pit structure, with hanging latrines and pits without a slab allowing rat access, as well as pits without covers or water seals not funcioning. For fly access, observation of the toilet water seal, pan cover and covering or mesh on vents.
Contained: On-site sanitation facilities that do not overflow or discharge excreta directly to the surface environment[b]	**Flooding and overflow**[c]**:** Pit or tank does not flood, overflow or leak	Does the toilet flood at any time of the year?[2] Does the pit or toilet leak, overflow or flood at any time of the year? If so, how often does it leak or overflow?	As these indicators were considered to go beyond the global indicators, the analysis was only for systems classified as contained based on global indicators. The global indicator for contained is assessed by the core questions “Is there an effluent outlet?” and “Where does the effluent go?”, with systems classified as uncontained if there is an effluent outlet discharging to surface environments (i.e. streets, open fields, drains, streams and other waterways).[1] For flooding, the respondent asked whether the plinth of the toilet flooded or was submerged as a result of flooding in the area. For overflow and leaking, the respondent was asked whether the contents of the toilet or pit overflowed or leaked, as a result of the quality or functioning of the containment. Only responses where the overflow was reported to happen more than once were considered uncontained.
	Groundwater risk: Low risk to groundwater from subsurface leaching of pits or tanks	Household questionnaire: How deep is the toilet pit below the surface? What is the main water source for drinking in this household? Non-household survey data: What is the predominate soil type? What is the typical depth of groundwater?	As for the above indicator of flooding and overflow, groundwater risk was only assessed for systems classified as contained according to the global indicator. Soil type and groundwater depth for each neighbourhood or sub-district were sourced from secondary data (government maps and databases) and interviews with government environmental staff, well drillers and local leaders. A matrix assessing the groundwater risk based on soil type and infiltration depth (British Geological Society, 2001) was used to assess the potential risk (see Table S7). The infiltration depth was calculated as the difference of the groundwater depth from the secondary data (using the upper limit of the range) and containment depth from household self-reported depth, limited to a maximum of 10m as deeper estimates were considered unrealistic (see Table S8). If the result of the matrix was high risk, the system was considered not safely contained. The analysis also assessed the

			proportion of city or district using groundwater sources (all types of wells, bores and springs) for drinking water supply, although this was not included in the complementary indicator.
Disposed in-situ: Improved on-site sanitation facilities that are contained, not emptied and stored on-site	**Timely emptying:** Unemptied pits or tanks, age below timely emptying threshold	Where do the faeces go after the toilet (i.e. pit, tank, drain)*?* How old is your toilet (pit/tank)? Has the pit or tank ever been emptied? When was the last time the pit or tank was emptied? (if emptied)	The timely emptying threshold was the calculated number of years of operation after which the containment was expected to be full of sludge and require emptying. Given containments are different sizes and fill up at different rates which vary with context, national estimates of timely emptying thresholds were calculated for different containment categories (single and double pit latrines, single and double composting latrines and septic tanks). The threshold was calculated from existing national data or rapid assessments of the average containment volume, number of users and sludge accumulation rates based on literature. For containments that have never been emptied, to be considered safely treated and stored in situ the age of the toilet must be less than the timely emptying threshold, allocated based on country and containment type. For emptied systems, the time since previous emptying must be less than the threshold to be considered safely emptied. Pits that were covered when full and a new one built were considered safe, as per the global indicators. Further details of the assumptions and methods are provided in supplementary material Table S9 and Table S10.
Emptied: Improved on-site sanitation storage facilities with containments (septic tanks or latrines) which have ever been emptied.	**Timely re-emptying:** Years since pits or tanks were emptied within timely emptying threshold		
	Emptying health and safety risks: Emptying of containments does not pose a health and safety risk to workers or the public	To empty the pit, did someone need to enter the pit? Did you observe any of the following safter measures during emptying? (use of boots, gloves and a mask)	For containments reported as previously emptied, the first question assessed whether someone entered the pit or tank to empty. This was asked separately from the PPE question due to the high risk of this behaviour. The second question was a multiple-response question, asking whether the respondent observed any of the health and safety practices related to protective equipment, of which all three were required to be considered safe, while a response of some or none was considered unsafe.

Notes:a) **Basic sanitation** includes improved facilities that are not shared with other households. Indicators on transport and treatment not shown.

b) This question was relevant for both pits and tanks however, in SNV's monitoring framework it was not included in rural areas of Bhutan or Laos as pre-testing indicated this practice did not occur in rural areas.

c) Note this relates to a recently updated core question that will be monitored in UNICEF's household surveys (MICS7) to assess releases of excreta to the surface through overflow, floods or containment collapse.[41]

Declarations

Data availability

The data that support the findings of this study are available on reasonable request from the corresponding author. The data are not publicly available due to them containing information that could compromise research participant privacy.

Author contributions

FM, JW, RM and AK contributed to the initial conceptualisation of the work. GH, RM, AN and AK designed and managed SNV's data collection and AN collated and cleaned the datasets. FM analysed the data for this paper with support from TF, JW and BE. FM composed the manuscript drafts and all authors provided comments and revisions to the drafts. All authors approve of the submitted manuscript.

Acknowledgements

This paper was developed as part of ISF-UTS and SNV's learning partnership. We would like to thank FCDO, DGIS, DFAT and the Gates Foundation for financial support of SNV's WASH programmes through which this baseline data was collected between 2018-2019. The funder played no role in study design, data collection, analysis and interpretation of data, or the writing of this manuscript. We also thank SNV's WASH country leaders and teams involved in the data collection and government partners that supported this. Special thanks to Jamie Bartram, Tom Slaymaker and Rick Johnston who were consulted or reviewed drafts of this paper.

Competing interests

Authors FM, RM, AK, TF, BE, GH and AN declare no financial or non-financial competing interests. Author JW serves as a guest editor of this journal and had no role in the peer-review or decision to publish this manuscript.

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Figures

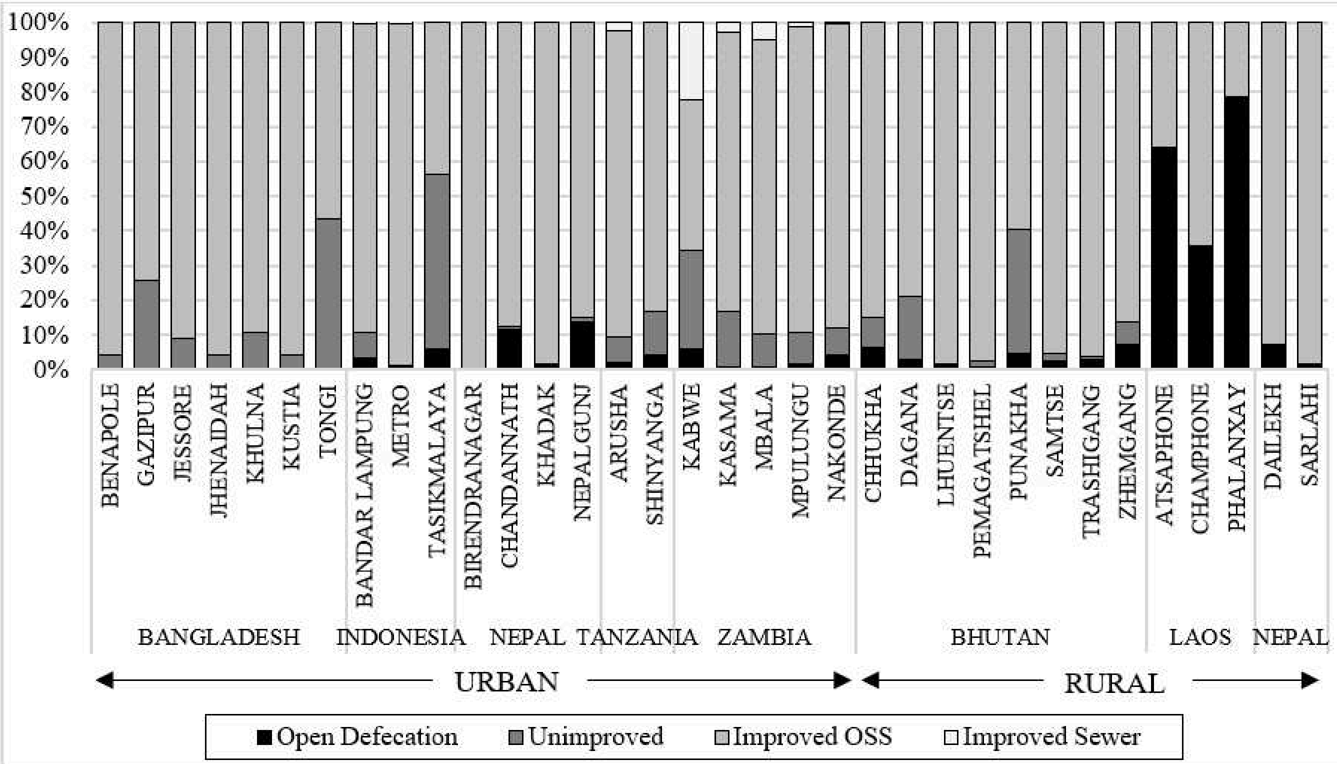

Figure 1

Household access to sanitation by category of facility, as defined by the JMP standard indicator set for 21 urban and 13 rural districts of seven countries based on data collected by SNV in 2018-2019. Complementary indicators were only analysed for the improved santiation facilities.

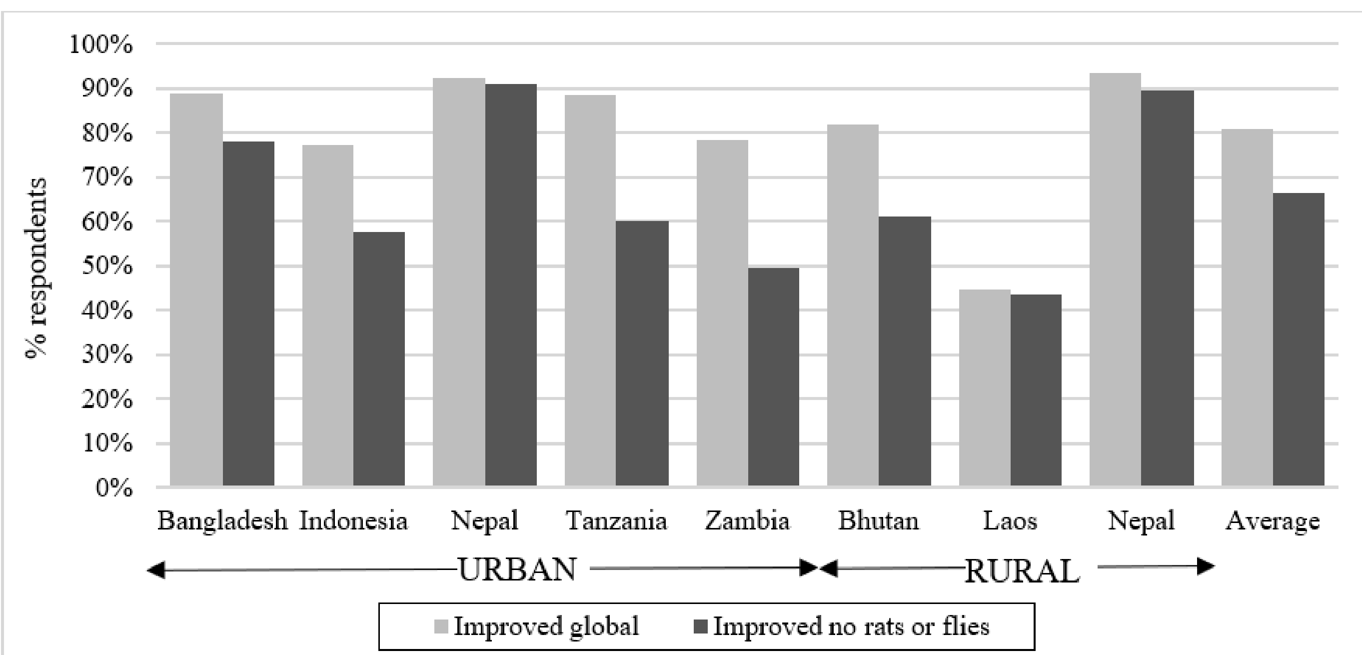

Figure 2

Proportion of households with access to improved sanitation considering the global indicator compared with the complemetnary indicator that considers toilets that are improved and not accessilbe to animals. Reduction in improved when considering animals greatest for Indonesia, Tanzania, Zambia and Bhutan compared with Nepal and Tanzania, which also had the lowest proportion of dry or composting pits.

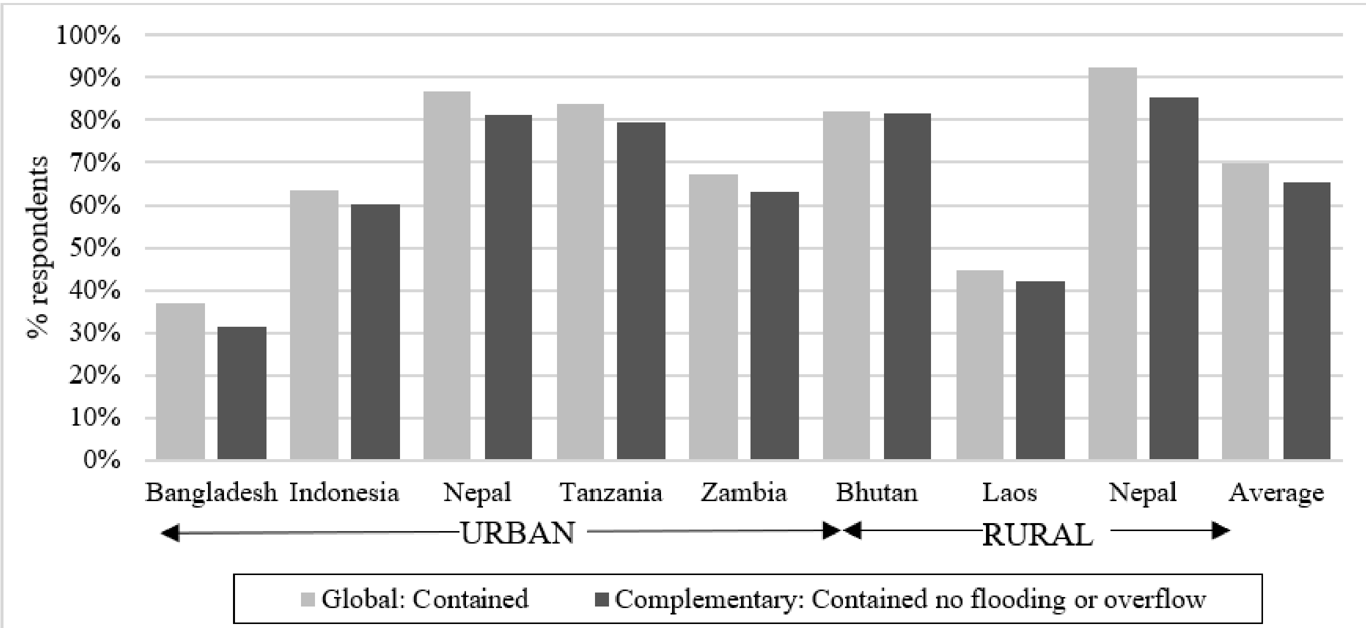

Figure 3

Comparison global indicator of containment with the complementary indicator that considers on-site systems that are contained and were reported to not flood or overflow. On average across all countries the impact of flooding or overflow on contained systems was small yet varied, with Bangladesh most impacted.

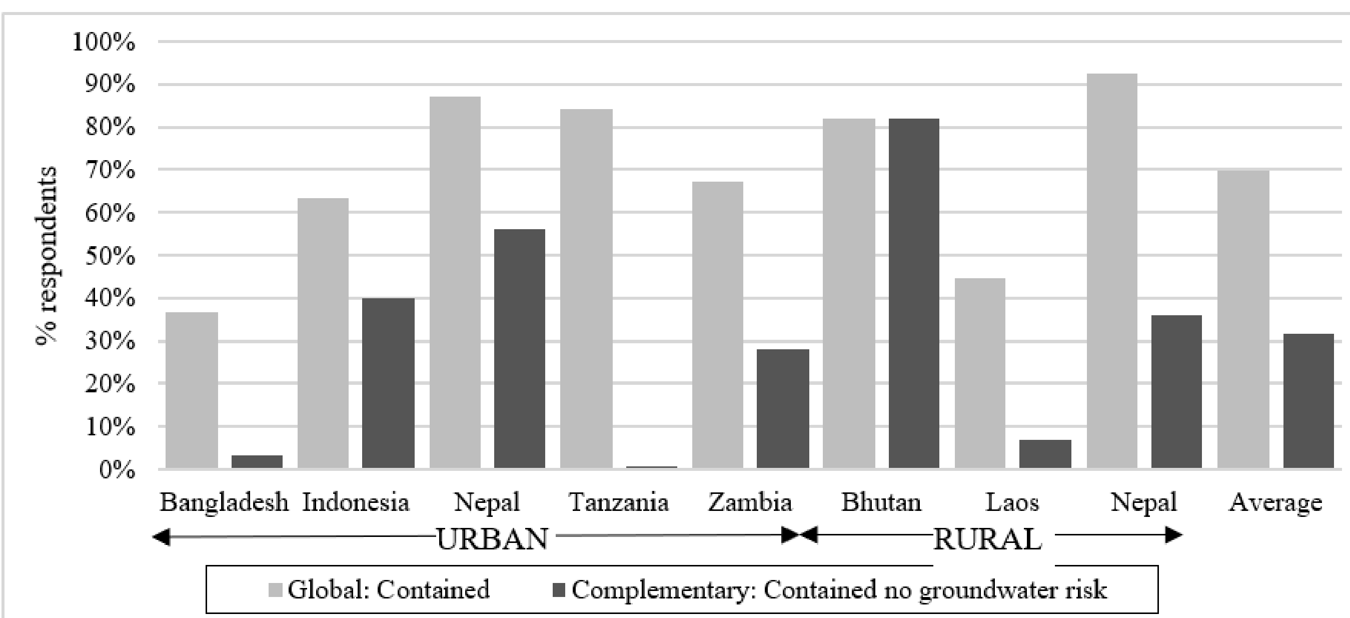

Figure 4

Comparison of global indicator for containment with the complementary indicator that includes on-site systems that are contained and not posing a high risk of groundwater contamination. The complementary indicator reduces the proportion of systems considered contained across most countries, excluding Bhutan where there is a low risk of groundwater contamination considering infiltraiton depth and soil type.

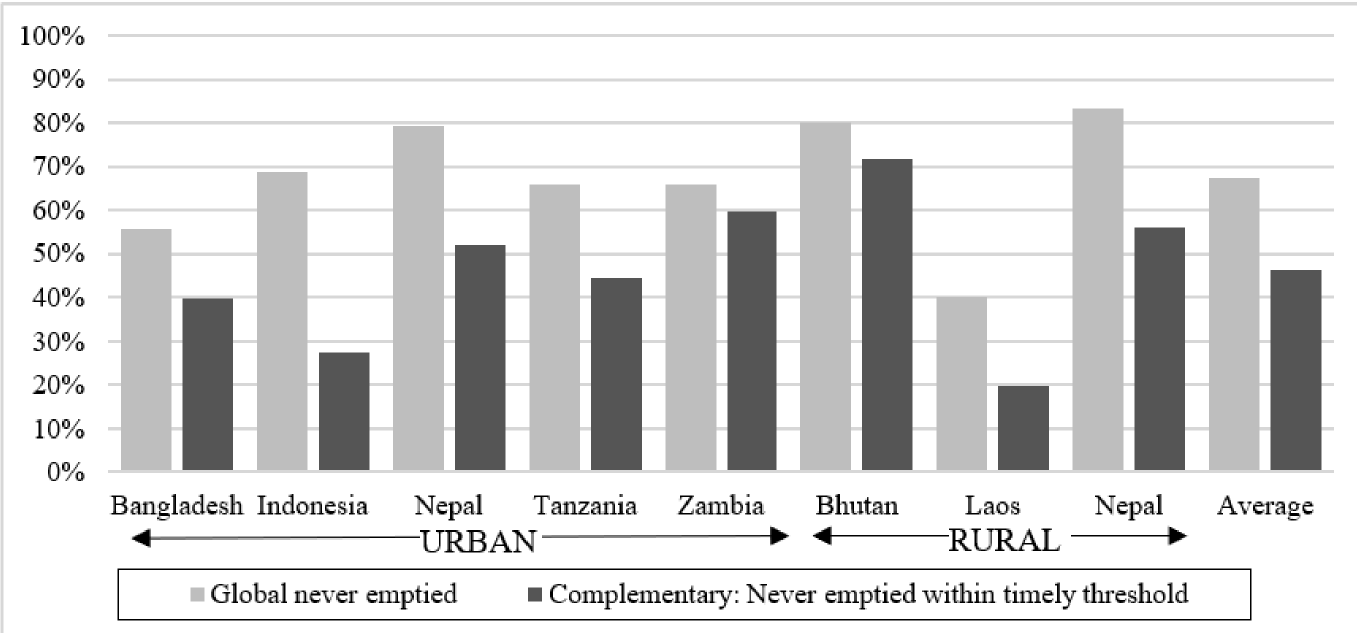

Figure 5

Figure. 6. Comparison of global indicator of households with improved on-site systems that were never emptied with the complementary indicator of improved unemptied systems not overdue for emptying. Contained and not emptied systems are considered safely managed sanitation, however this complementary indicator demonstrates many of these systems are likely full of sludge and at risk of reduced function or overflowing.

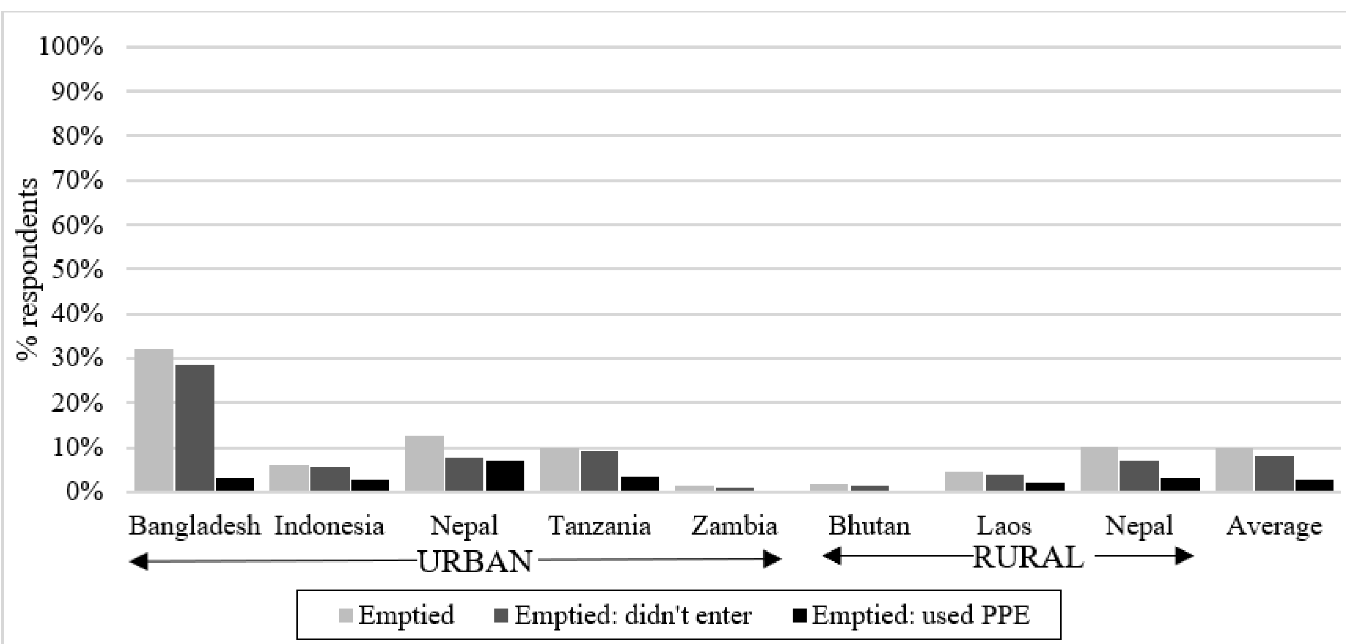

Figure 6

Fig. 7. Comparison ever emptied with those emptied following health and safety practices

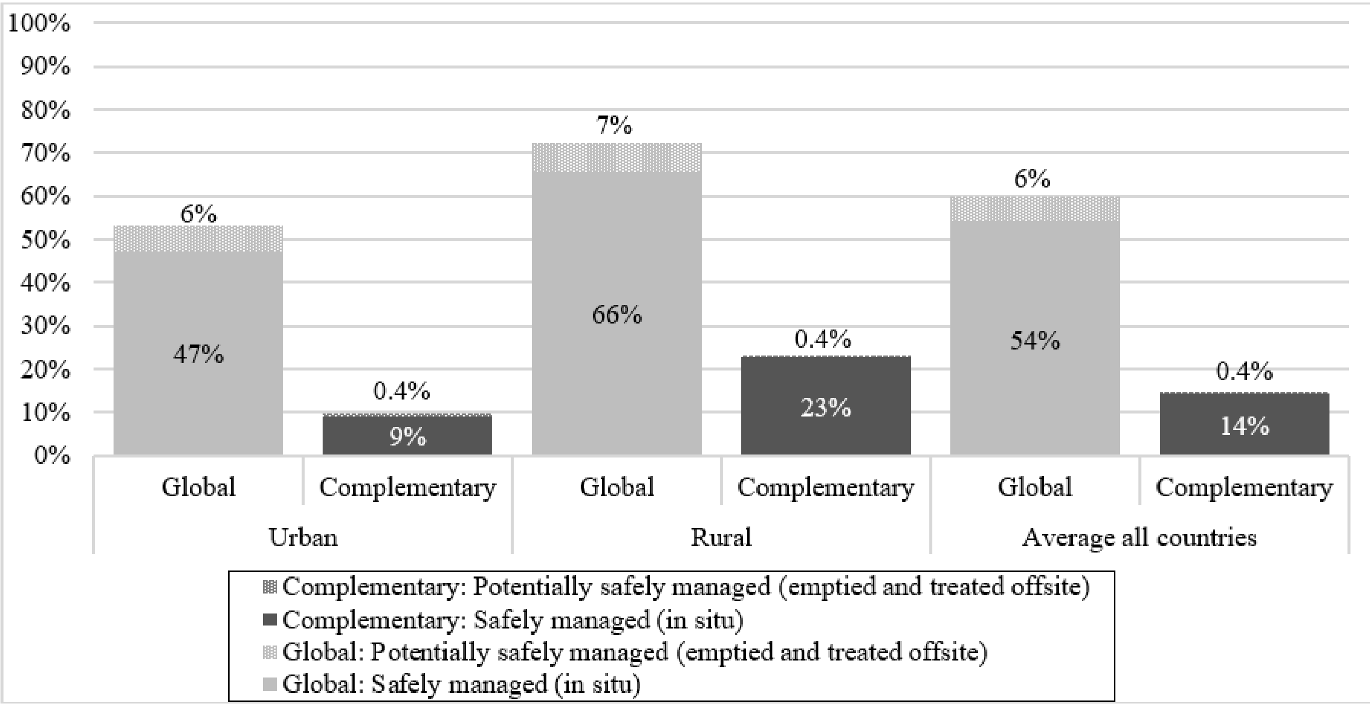

Figure 7

Fig. 8. Comparison cumulative estimate safely managed on-site sanitation (excluding transport and treatment) for the global and complementary indicators disaggregated by those safely stored in-situ and those safely emptied.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarymaterials101023.docx