Strengthening the delivery of WASH in urban informal settlements

Addressing multiple exposure pathways in urban environments

CRC for
Water Sensitive Cities

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Strengthening the delivery of WASH in urban informal settlements: addressing multiple exposure pathways in urban environments

This paper is the second released by the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) ThinkTank. The ThinkTank's focus is to challenge current thinking about how to create cities that are liveable, resilient, productive and sustainable. We provide information, ideas and advice on how to address the 21st century challenges facing water providers and policy makers, drawing on research and on-ground experience of the CRCWSC and its partners. Our aim is to broker ideas, stimulate policy debate, influence practice and offer creative yet practical solutions that can help accelerate the transition to being water sensitive.

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Executive summary

By 2050, around 70 per cent of the world's population is expected to live in cities and towns—a megatrend known as urbanisation. Urbanisation presents many opportunities to improve the daily lives of people around the world: accelerated economic growth, greater competitiveness, higher average educational attainment, social and political stability, as well as opportunities to introduce modern technologies and infrastructure.

Unfortunately, it is likely that many new urban dwellers will not benefit from these opportunities. Much of this rapid urbanisation is expected to occur in Asia and Africa, where many of these new urban dwellers will live in informal settlements on the edges of towns and cities. At present, close to 1 billion people live in slum conditions, and UN-Habitat (2016) reported that 30 per cent of the urban population lives in informal settlements.

People living in urban informal settlements are among some of the most disadvantaged people in our communities. As a society, we aspire to 'leave no-one behind' and to 'reach first those who are furthest behind'. But, so far, we do not have an appropriate and effective way to deliver some of the most basic human rights for people living in informal settlements: access to clean water and sanitation. This lack of clean water and sanitation, combined with poor drainage and a lack of flood management, means informal settlement populations are often exposed to faecal contamination in the environment via multiple exposure pathways.

Often, the centralised (networked) approaches to providing clean water and sanitation that we usually find in cities and towns are not possible in informal settlements, or it will take many years to deliver them. It may take up to two generations to introduce networked solutions in informal settlements, for example, as cities and towns prioritise access for growing middle classes in the face of limited financial resources. At the same time, non-networked, decentralised or community-based approaches to the delivery of water and sanitation services that have been used in rural areas may not be appropriate either, particularly in the face of the magnified water stressors to which urban populations are exposed. Yet, with continued exposure to these stressors (environmental faecal contamination, flooding and water scarcity), people living in informal settlements experience poor health outcomes (among other things).

This paper is a call to action for everyone involved in ensuring people living in urban informal settlements have access to clean water and sanitation: the water, sanitation and hygiene (WASH) and development community, local governments, urban planners, water and sanitation service providers, community groups and civil society organisations, and development banks and financiers. While ensuring that we continue to promote good hygienic practices and behaviour, we need to strengthen the delivery of water and sanitation services to urban informal settlements, because our experience suggests current approaches are not producing the health and environmental outcomes we desire in the urban 21st century.

One of the major issues affecting urban informal settlements is the lack of sanitation and the consequential multiple faecal contamination pathways, especially when combined with other water management issues. To be effective, safe sanitation must account for site and context-specific priorities and include safe management of both the solids and liquid effluent. With increasing density, the environmental capacity for assimilating faecal contamination falls rapidly, and in the absence of effective containment and treatment, the residential environment becomes contaminated. Poorly treated effluent containing pathogens makes its way into local groundwater supplies, local soils, local waterways and water bodies, including in the immediate environment where children live and play.

This scenario is exacerbated when informal settlements are located in environments constantly influenced by water inundation and floods. Importantly, the sources of contamination come from both within the residential environment, and from external sources, including poorly managed sanitation from surrounding and upstream settlements.

So in leaving no-one behind and reaching first those who are furthest behind, we propose an holistic approach to addressing the multiple faecal contamination pathways in informal settlements to ensure:

- safely managed sanitation
- flood management and mitigation
- improved environmental quality
- multiple fit-for-purpose water sources
- good hygiene behaviours and practices.

The urbanisation megatrend

In 2012, the National Intelligence Council (2012) identified four megatrends that could fundamentally change our world. One of these megatrends is demographic patterns comprising: an ageing population; a shrinking number of youthful states and societies; migration; and of most interest to us, growing urbanisation.

By way of example, world population is forecast to increase by 2.5 billion to 9.7 billion by 2050, and 70 per cent of these people will live in cities and towns (UN-Habitat 2016) (Figure 1). Population growth in Asia and Africa will account for almost 90 per cent of this population increase, predominantly in China, India and Nigeria (UN Department of Economic and Social Affairs 2018).

Unless we radically change how we plan and manage urbanisation, projections indicate many of these new urban dwellers will end up in slums or informal settlements on the edges of towns and cities. UN-Habitat (2016, p. 57) characterises informal settlements as lacking one or more of the following five conditions:

- access to clean water
- access to improved sanitation
- sufficient living area that is not overcrowded
- durable housing
- secure tenure.

Figure 1: Projected urbanisation growth

These conditions clearly violate the right to adequate housing (UN-Habitat and OHCHR 2009). Slum dwellers suffer from inadequate sanitation, infrastructure and services, deficiencies that affect their health and wellbeing and the wider environment. And within this already disadvantaged group, women, girls and vulnerable people often suffer the most from the challenges of living in urban informal settlements.

Our challenge is to improve the outcomes for the people living in informal settlements—and the scale is immense. Today, close to 1 billion people live in slum conditions, and 30 per cent of the urban population lives in informal settlements (UN-Habitat 2016). With 90 per cent of the additional 2.5 billion people projected for the global population living in Asia and Africa, this region is likely to see the fastest growth in informal settlement populations. UN-Habitat (2016) reported that although the proportion of Asian residents living in slums fell between 1990 and 2012, the number of urban slum residents rose by 100 million.

This rapid growth in urban centres generally, and informal settlements specifically, poses many complex and interrelated issues, including resource constraints and degraded environments. At the same time, the world is facing increasing climate uncertainty, which may exacerbate many problems. Cities and towns concentrate and magnify the effects of these issues.

Urban water management and health

Sustainable urban water management is a major issue facing urban informal settlements. More than 2 billion people globally are living in countries with excess water stress, defined as the ratio of total freshwater withdrawn to total renewable freshwater resources above a threshold of 25 per cent. Already, northern Africa and western Asia experience water stress levels above 60 per cent, which indicates the strong probability of future water scarcity (UN Department of Economic and Social Affairs 2016). When water is scarce, drinking water quality deteriorates. Water delivered intermittently is often contaminated with the environmental faecal waste that surrounds leaky water pipes.

The expected rise in urbanisation will likely exacerbate this stress. As these growing urban areas demand more and more water, water scarcity and the associated problems of water quality will also grow. Climate change is also likely to exacerbate this stress, by affecting the frequency and volume of rain.

One of the major issues affecting urban informal settlements is the difficulty in managing faecal contamination in the environment (including greywater, faecal sludge and liquid supernatant) and its relationship to other urban water management challenges of poor drainage, flooding, water scarcity and environmental degradation in these dense settlements.

The importance of water and sanitation

Poor access to clean water, and poor wastewater management can lead to poor population health outcomes:

- Open defecation increases the risk of coming into contact with human waste, which in turn can cause diseases such as cholera, typhoid, hepatitis, polio, schistosomiasis, trachoma, diarrhoea, worm infection and undernutrition.
- Diarrhoeal disease remains the second leading cause of death for children globally. In 2016, diarrhoea accounted for 8 per cent of child deaths among under-fives globally (United Nations Inter-agency Group for Child Mortality Estimation 2017). Close to 600,000 children under 5 years of age die of diarrhoea each year.
- Some studies have linked poor sanitation to early childhood stunting and delayed mental and physical development, both of which can have significant lifelong effects (Merchant et al. 2003). Gastrointestinal infection and the secondary effects of intestinal inflammation (such as stunted growth and poor cognition) are prevalent among children in informal settlements.

Some estimates suggest that already more than 700 million urban residents do not have access to improved sanitation globally, including 80 million who defecate openly (Andersson et al. 2016). Many of these people are urban migrants who move to informal, peri urban areas. These informal settlements exacerbate the inextricably linked challenges of sanitation, water provision, environmental degradation and public health. As a result, the urban poor, and particularly children, are disproportionately affected by poor sanitation and/or access to clean water, which reinforces existing processes of inequitable urban development.

Unarguably, better sanitation improves dignity and safety. It may also provide broader human health benefits, although it is important to consider the multiple pathways for faecal–oral transmission that can affect human health. Recognising these connections between sanitation, clean water and health, the 193 nation signatories to Agenda 2030 at the United National Sustainable Development Summit in September 2015 expressed a strong commitment to ensuring access to basic human rights, including access to clean water and sanitation. Indeed, universal access to clean water and sanitation is one of the Sustainable Development Goals (SDGs) agreed in 2015: SDG 6. SDG 6 is also closely linked with other SDGs. For example, SDG 6 progress improves health (SDG 3), social justice (SDG 16) and productivity (SDG 8), as well as environmental protection and restoration goals embodied in SDG 14 (life below water) and SDG 15 (life on land).

In urban informal settlements, SDG 6 is also intrinsically linked to issues related to sustainable cities (SDG 11) and the New Urban Agenda (NUA). In line with SDG 11 to 'make cities and human settlements inclusive, safe, resilient, and sustainable', the NUA recognises business as usual to address urban informal settlements will not produce the outcomes required. The NUA calls for stronger and more integrated urban governance, urban and territorial planning and design, and effective financing frameworks to promote inclusive urbanisation and upgrade informal settlements in an integrated manner.

Leave no-one behind

One of the key aspirations of the SDG agenda is to 'leave no-one behind' and to 'reach first those who are furthest behind'.

In terms of delivering water and sanitation in dense urban environments, the traditional approach has been to strive for a networked water and sewerage solution, but the centralised (networked) approaches usually found in cities and towns are not likely to be implemented in urban informal settlements (World Bank 2017). For example, in the 150 years since the London sewer construction was completed, this technical approach has not trickled down to the informal settlements in low income countries. This outcome reflects the significant economic, legal and political barriers associated with introducing centralised approaches in informal settlements.

In many cases the financial investments required are significantly beyond the capacity of governments to generate politically. For example, Latin America and the Caribbean would need to invest more than US$33 billion to increase the coverage of wastewater treatment to 64 per cent by 2030 (Mejía et al. 2012). Informal settlements are often characterised by absentee landlords, disputes over land tenure, uncertain tax and service revenue, migration and conflicting municipal development priorities—all barriers to infrastructural development. These factors contribute to an overall lack of agency and political power.

Given these barriers to servicing those furthest behind, alternative interventions are needed to improve water and sanitation in these settings. Delivering water and sanitation beyond the centralised network also requires important behaviour change components for interventions to be successful. This approach is known collectively as the delivery of water, sanitation and hygiene (WASH).

WASH and health

The health benefits of improved sanitation and water supply have long been recognised. In the absence of city-scale water supply and sanitation networks, many approaches have been developed that aim to deliver similar health outcomes using alternative, typically decentralised approaches. The delivery of water supply and sanitation must be done in conjunction with the delivery of improved hygiene practices.

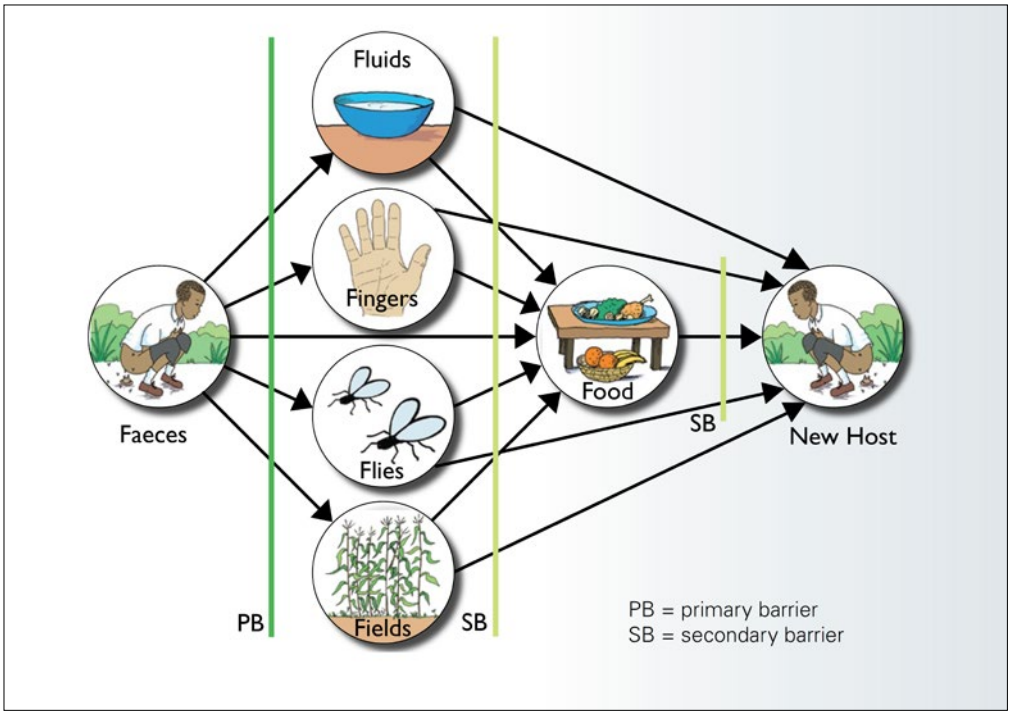
Conceptually, conventional approaches to the delivery of WASH in rural settings aim to limit faecal–oral transmission via three main barriers (Figure 2):

- **Eliminating open defecation, containing faeces and reducing contact during defecation,** typically by providing a toilet and promoting handwashing, which may be considered primary barriers. Treatment is not required for in situ sanitation when the excreta is safely contained and given adequate time to compost. However, a toilet by itself is not sufficient if the effluent is not safely managed and leaks, or is prematurely emptied into the local or downstream residential environment. Bernstein (2002) found 90 per cent of public wastewater in low income countries was discharged untreated into the environment. This finding is particularly problematic for residents of informal settlements, who lack the infrastructure to move this contamination out of their local neighbourhood.

- **Providing safe water, which is a secondary barrier.** Safe water activities can range from digging wells, to providing chlorination tablets, to accessing a reticulated water supply network.

- **Encouraging good hygiene practice, which can be both a primary barrier (handwashing after defecation) and a secondary barrier (handwashing before handling food, for example)**. In its broadest sense, hygiene refers to the cleanliness of the whole environment. That is, it includes practices to protect the quality of the environment (solid waste management, prevention of groundwater contamination etc.), as well as personal hygiene habits such as handwashing.

Figure 2: Key WASH barriers to reduce faecal–oral transmission in rural settings



Source: UNICEF 2011.

Because adequate sanitation is a primary protective barrier to faecal–oral disease transmission, investing in sanitation can be expected to significantly reduce illness. Freeman et al. (2017) found access to sanitation protected people against illnesses such as diarrhoea, soil-transmitted helminth infections, trachoma and schistosomiasis.

Similarly, Wolf et al. (2018) found interventions to improve drinking water, sanitation and hygiene can reduce the risk of diarrhoeal disease. Spears (2013) found even if households do not have basic sanitation, eliminating open defecation in the community can still improve health outcomes.

Indeed, there have been some improvements in access to clean water and sanitation, although the corresponding health improvement is less well defined. There is growing recognition that Wagner & Lanoix's (1958) well-recognised f–diagram does not reflect the complexity of faecal contamination and disease transmission pathways, particularly in urban settings (WHO 2005, Mills 2018, Mitchel 2016).

The efficacy of WASH

Empirical evidence shows the efficacy of non-networked WASH interventions is highly varied. Some studies found interventions were effective in reducing diarrhoea, while others reported no effect. Some suggested interventions delivered in isolation were not effective, while others found no difference if interventions were combined.

It is generally accepted, based on a large body of existing knowledge, that WASH interventions result in a reduction in the burden of disease (Clasen et al. 2010 and Clasen et al. 2015, for example). However, many studies have questioned the links between specific WASH interventions and improved health outcomes. Clasen et al. (2014) examined the effectiveness of a sanitation program in India, for example, and found no evidence that providing latrines reduced exposure to faecal contamination, or prevented diarrhoea, soil-transmitted helminth infection or child malnutrition. Similarly, Boisson et al. (2013) assessed the effect of household water treatment (via freely distributed water chlorination tablets) on diarrhoea among children under 5 years of age. This study found no evidence that the intervention prevented diarrhoea, either among children under 5 years of age, or among all members of the study population. Another study, Sinharoy et al. (2017), investigated the efficacy of programs to promote healthy behaviours in Rwanda, such as latrine use and handwashing. This study found the interventions had no effect on caregiver-reported diarrhoea in children younger than 5 years of age. The program also had no effect on faecal contamination of household drinking water.

By contrast, an extensive and rigorous study by Luby et al. (2018) found evidence that WASH interventions reduced the incidence of caregiver-reported diarrhoea in children in rural Bangladesh. That same study found combining interventions was no more effective in reducing diarrhoea, than focused single interventions. But, while Luby et al. (2018) recorded lower incidence of caregiver-reported diarrhoea, the study did not find evidence that interventions improved child growth outcomes. The linear growth of children who received a WASH intervention, either in isolation or in combination, was no different from that of children who did not receive an intervention. Instead, the study found only children who received nutritional supplements in addition to WASH interventions recorded small growth benefits.

Cumming & Curtis (2018) also reported on trials that found WASH interventions had no effect on linear child growth. While acknowledging the context for these studies, Cumming & Curtis (2018) concluded that business as usual in the WASH sector may not be enough to significantly improve child growth, because it focuses on basic sanitation rather than safely managed sanitation. Similarly, Null et al. (2018) in the WASH Benefits Kenya trial found no improvements to childhood diarrhoea and little to no improvement to child linear growth. They proposed a range of explanations for this, including that sanitation interventions alone might not be sufficient to protect against exposure to faecal contamination in the environment that originates from other pathogen exposure pathways within the community.

The observed variations in the efficacy of WASH may be attributed to a combination of factors, ranging from poor implementation or uptake of interventions that are potentially effective, to inappropriate interventions that had little potential for eliminating exposure. Many of these variations, whether individual elements are applied in isolation or in combination, highlight the importance of context specificity when applying WASH interventions.

Vulnerable communities are exposed to multiple social and biophysical faecal-oral transmission pathways. Their relative significance is context-specific and, as such, therefore ensuring successful interventions to disrupt the faecal-oral pathway requires rigorous site analysis to design a fit-for-purpose strategy. Depending on the mapped sources of contamination and the faecal-oral transmission pathways, and an assessment of their relative significance and interplay, intervention strategies may be targeted at individual intervention activity in some instances; in other cases, a combination of activities may be necessary to address multiple priority pathways.

Importantly, mapping faecal contamination and faecal–oral transmission pathways provides a snapshot in time. The relative significance of the transmission pathways could change from year to year, which may affect both the interventions required, and whether they are applied in isolation or in combination.

In addition, in urban informal settlements, the complex interplay of multiple faecal-oral transmission pathways is further exacerbated with the increased significance of exposure to biophysical environmental contamination.

WASH in urban informal settlements

Most urban informal settlements are poorly serviced for sanitation and clean water.

Equally, drainage and flood protection are often limited or non-existent, providing multiple additional pathways for external contamination of the local environment. Further, water scarcity often results in households using poor quality water for many domestic uses, including cooking, bathing and washing dishes.

The urban sanitation challenge

Faecal–oral diseases occur regularly when parasites, bacteria or viruses found in the faeces are transmitted through contact with contaminated soil and water. In many cases, attempts to alleviate the problems facing informal settlements are done by adapting non-networked sanitation interventions usually applied in rural settings to urban environments, often without assessing environmental biophysical or hydrological characteristics that may exacerbate faecal contamination of the residential environment. Common examples of non-networked sanitation solutions adapted for urban informal settlements include pit latrines, cesspits and septic tanks.

In rural areas, population densities are lower and the environment has more capacity to assimilate the waste stream discharged to it, which makes these sanitation interventions suitable. With increasing population density, however, the environmental capacity for assimilating the faecal discharges reduces rapidly, increasing the contamination of the immediate residential environment and hence the risk of exposing residents to pathogens.

Successful use of septic tanks to safely manage sewage relies on carefully matching septic density to the soil's capacity for assimilating the waste stream from these tanks (Box 1). In urban informal settlements, this precondition is significantly exceeded, which results in soil and groundwater contamination. The US Environmental Protection Agency designated areas with septic tank densities of greater than 104 systems per square kilometre as regions of potential groundwater contamination (Yates 1985). The dwelling density typical of informal settlements in Suva, Fiji, for example—where most dwellings have a rudimentary septic tank—is approximately 1700 dwellings per square kilometre, an order of magnitude greater than the nominated threshold.

Box 1: Using septic tanks in informal settlements

A septic tank is a chamber (usually underground) for collecting domestic wastewater and is where primary treatment starts. The tank must store collected wastewater for an adequate amount of time, to allow solids and floating scum to separate, and for anaerobic breakdown to initiate. The wastewater is then discharged to a secondary treatment area, typically an infiltration field or soak pit. Here, effluent is slowly dispersed into surrounding soils where naturally occurring soil microbes further reduce concentrations of pathogens and nutrients.

For this process to be effective, the soil type must support a suitable infiltration rate (for example, it cannot be clay) and there must be sufficient space to disperse all effluent without causing ponding and boggy conditions. Often, these conditions are not present in urban settlements. First, there is insufficient space for infiltration fields or soak pits. Second, soils are often inadequate, so effluent does not infiltrate to a sufficient depth. Rather, it forms channels and flow paths through the top soil layer towards the nearest receiving water body and waterway. That is, poorly treated wastewater discharges directly to local waterways.

In addition, the density of septic tanks in urban informal settlements often exceeds the capacity of the local soils to assimilate pollutants.

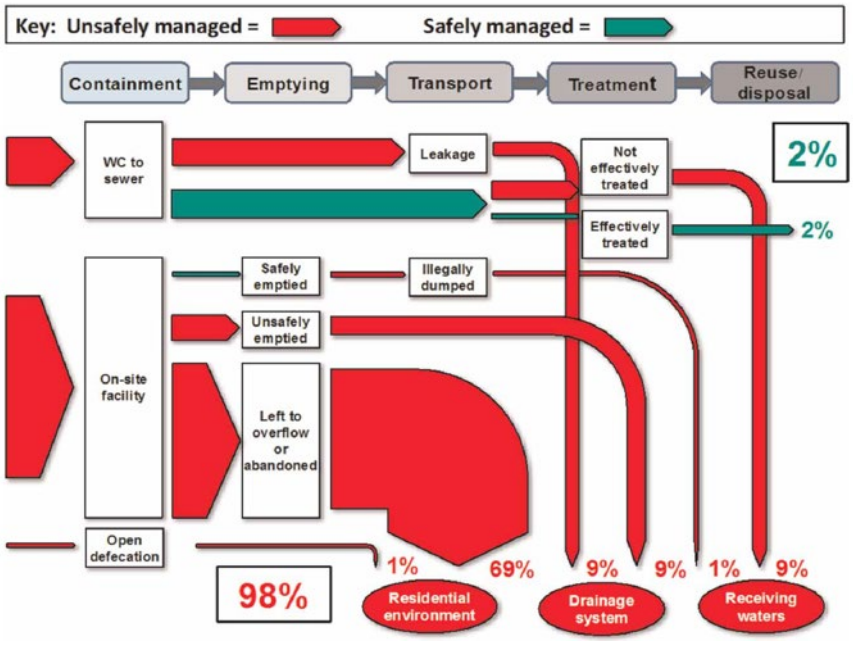
As Cairncross et al. (1996) explained, addressing the source of the pathogen in the domestic domain (that is, by providing sanitation in a house) may not be sufficient, if the source is not also treated in the public domain (such as public spaces, streets and roads, pathways, open fields etc.). The United Nations World Water Assessment Programme (2017) noted that while household level sanitation facilities have improved significantly in the past two decades, many risks to public health remain due to poor containment, leakages during emptying and transport, and ineffective sewage treatment.

Mills et al. (2018) noted the importance of understanding links between faecal waste discharge patterns and potential pathogen exposure pathways to improve urban sanitation decision making. The Pathogen Hazard Diagram (Mitchell et al. 2016) importantly recognises the likely widespread impact of faecal contamination from liquid discharges as a result of poorly constructed and 'leaky' septic tanks in urban settings (for example, Figure 3). The results of a SaniPath study (Robb et al. 2017) in low income urban neighbourhoods in Ghana also highlighted widespread and often high levels of faecal contamination in both public and private domains (and the food supply). The Pathogen Hazard Diagram and SaniPath Tool have been developed specifically to address and assist in identifying the myriad of potential faecal contamination pathways in urban settings.

As noted above, SDG 6 focuses on 'safely managed' water and sanitation; that is, the safe management of both water supply sources and faecal waste (solids and liquid/supernatant). Safely managed wastewater is adequately treated to reduce nutrient and pathogen concentrations to levels that are deemed safe before it is discharged into the environment (World Bank 2012; Mitchell et al. 2016). In non-networked systems, the wastewater (both liquids and solids) should undergo multiple treatment phases to achieve adequate pollutant reduction, but Hutton & Varughese (2016) estimated only 26 per cent of urban and 34 per cent of rural sanitation and wastewater services effectively prevent human contact with excreta along the entire sanitation chain and could therefore be considered safely managed.

Improving water and sanitation is not simply about providing a tap, a toilet and some soap (World Bank 2012)—and improved sanitation is not solely about faecal sludge management. Safely managed sanitation requires properly managing both the liquid supernatant and the solid phases of wastewater. Liquid effluents that are both deliberately and accidently discharged to the environment are largely unnoticed and unmanaged (Mitchell et al. 2016).

Figure 3: An example of a faecal flow pathways diagram in a non-networked sanitation scheme—Dhaka, Bangladesh



Source: Peal et al. 2014.

Sometimes, first steps in a shift away from open defecation are towards solutions that are rudimentary and do not ensure that excreta and effluent are safely managed (Box 2). The benefits of taking steps to move up the 'sanitation ladder' (away from open defecation and towards safely managed sanitation) are acknowledged. Indeed, Freeman et al. (2017) found evidence of health gains moving up the ladder, even to unimproved or basic sanitation.

The costs of safely managed WASH services are three times the costs of basic services for water and sanitation. If unserved populations go straight to receiving safely managed services, without passing through lower level services, the savings are estimated to be in the order of US$1 billion a year (Hutton & Varughese 2016).

Box 2: Common sanitation problems in urban informal settlements

Sanitation services in urban informal settlements aim to reduce faecal contamination in the environment. Many settlements are of high density and located in areas prone to inundation such as along low-lying coastal zones, in areas of high groundwater, or areas subject to frequent flooding. These communities and their living environments are frequently exposed to multiple pathogen contamination pathways. The elimination of open defecation is a priority but providing safe sanitation remains an ongoing challenge. Some of the common physical and engineering challenges in delivering safe sanitation services include the following:

- Septic tanks are not coupled with an adequate infiltration field or soak pit, resulting in inadequately treated effluent being discharged to the surrounding environment, often to local open stormwater drains.
- Septic tanks are coupled with a (sometimes makeshift) infiltration field or soak pit, but in areas of high groundwater or inappropriate soil type.
- Septic tanks are located at densities known to cause significant environmental contamination (Islam et al. 2016).
- Septic tanks and pit latrines are not emptied or replaced as required, making them prone to overspill (Williams & Overbo 2015). For example, fewer than 10 per cent of septic tanks are emptied. Often the overspill is due to deliberate actions, such as breaking a hole in the side of the tank when it is full.
- Shared sanitation facilities can increase the risk of adverse health outcomes (Heijnen et al. 2015) in some cases. Individuals in sharing households are more likely to practise open defecation, and shared facilities are less likely to be functional, less clean, and more likely to have faeces and flies.
- Waste is not collected safely. For example, residents empty latrines and septic tanks by hand, rather than by safe practices such as vacuum trucks (Williams & Overbo 2015).
- Waste that is collected is released directly into drainage systems or open water bodies without treatment (Andersson et al. 2016).
- Often, treatment facilities (if they exist) have been built with support from donor countries, but low and middle income countries have insufficient resources (both financial and technical) to operate and maintain them effectively.

Links to water supply, drainage and flooding

It is common to find instances where onsite sanitation solutions may reduce exposure to faecal-oral transmission for some residents (for example, by installing a pit latrine or a rudimentary septic tank), but the faecal sludge and liquid effluent are not managed safely.

In these cases, faecal contamination is often redistributed within the local environment, or discharged into local waterways, impacting downstream neighbourhoods. That is, there is a perceived reduction of risk of exposure (because now there are basic sanitation services) but, in reality, the risk of exposure is greater because the untreated faecal sludge and effluent are discharged directly into the environment.

In many cases, faecal contamination of the residential environment is influenced by both the solid sludge and the effluent pathways. Poorly treated effluent containing pathogens is discharged into local groundwater supplies, local soils, local waterways and waterbodies. This practice can have a dramatic effect on local water supply sources. It is a scenario commonly seen in Indonesia, for example, where limited water utility coverage means a large proportion of the population use untreated surface water and groundwater as their primary household water supply source (World Bank 2012).

This scenario is further exacerbated when the settlements are located in environments constantly influenced by water inundation and floods. In many informal settlements, daily tidal inundation and frequent storm flood inundation continually redistribute faecal contamination from receiving waters back into the residential environment. Importantly, the sources of contamination come from both within the residential environment, and from external sources, including poorly managed sanitation from upstream settlements.

Creating fit-for-purpose urban WASH

Safely managed sanitation (solids, liquids and greywater), improved drainage and flood management, diversification of water supplies.

Reducing exposure to faecal contamination will improve community health. Understanding the social-biophysical context, and prioritising interventions towards critical faecal contamination pathways, can be expected to yield more cost effective outcomes.

In the absence of a rigorous assessment of sources and pathways of faecal contamination in the urban environment, and understanding how their relative significance may change over time, an integrated effort that combines the different elements of urban water management to increase the chance of success in improving health outcomes is conceptually appealing.

Context-specific social and biophysical factors will affect the efficacy of urban water management interventions:

- The social factors include cultural practices, behaviours and awareness, for example.
- The biophysical factors affecting faecal contamination pathways range from population and housing density, soil characteristics, water and waste management practices, tidal inundation and contamination from upstream activities.

That is, context is complex, and this complexity is magnified in urban settings and exacerbated by the megatrends of urbanisation and climate change. Mapping and understanding the relative significance of faecal contamination pathways is fundamental to formulating a fit-for-purpose urban water and sanitation strategy. Nevertheless, further research and field-based trials are needed to fully understand the context specificity, relative significance and interplay between the multiple faecal contamination pathways and the role of other urban water stressors.

In the interim, and as research efforts embark on attaining more conclusive evidence, a precautionary principle approach is suggested that adopts an holistic approach to developing urban interventions to deliver WASH, one that pays due regard to the expected heightened influence of environmental contamination. This holistic approach would include a combination of interventions that also account for context-specific social and biophysical factors at a range of scales—from individual behavioural, to the household and the residential environment scale.

The National Resources Defence Council (2014) also advocates this approach. We consider such an approach has the greatest chance of reducing exposure to environmental pathogens and delivering the desired health outcomes.

In dense urban settings, an approach is suggested that prioritises addressing the multiple contamination pathways by:

1. **Reducing direct contact to faecal contamination,** including through the provision of toilets and hygiene practices, and physical barriers such as raised pathways to reduce direct contact with contaminated flood waters and poor drainage.

2. **Reducing exposure to faecal contamination generated by residents within the target community,** by adequately treating wastewater before discharge. This includes safely managing wastewater (both liquids and solids and greywater), and protecting local groundwater resources and downstream environments and communities.

3. **Reducing exposure from external environments, including improved catchment scale water management,** the provision of safely managed wastewater upstream and/or physical barriers to reduce inflows of contaminated drainage and flood waters from upstream communities.

Ideally, this fit-for-purpose approach will encompass (to varying degrees reflecting their relative importance) the following initiatives:

- safely managed sanitation
- flood management and mitigation
- improved environmental quality
- multiple fit-for-purpose water sources
- good hygiene behaviours and practices.

Safely managed sanitation

As outlined, providing safe sanitation in urban informal settlements involves ensuring wastewater is collected and transported safely, so it can be treated and safely discharged into the receiving environment.

Fundamental to safely managed sanitation in informal settlements is treatment at source; that is, it is inappropriate to simply discharge sewage effluent to impact downstream communities. While the opportunity for harvesting the water, nutrients and other resources is now being realised in high income countries, the highest priority in urban informal settlements is to introduce a level of onsite treatment to reduce the community's exposure to faecal contamination when the effluent is discharged into the receiving environment. Low cost technology, such as constructed wetlands, may provide rudimentary treatment to achieve this objective.

Recent advances in integrating nature-based solutions for water into the built environment provide exemplars for highly modular constructed wetland systems that can be readily incorporated into public spaces and building design within high density urban environments. Ideally, the effluent could be used as a resource for horticulture and agriculture production and so support the local economy.

Flood management and mitigation

Multiple design principles can improve drainage and flood management and therefore reduce the regular re-contamination of low lying informal settlements. Often, this contamination comes from both within the settlement and from upstream sources.

Mitigation options include:

- an effective network of drains and, for flat sites, sub-surface drainage, to prevent contaminated water ponding after a flood event
- designated flood pathways
- low level flood barriers, to reduce the frequency of inflow of flood water from adjoining waterways or tidal inflows.

Landscape features used for sewage treatment (for example, constructed wetlands) may also serve as barriers, to limit external inflows of contaminated flood water. Similarly, flood detention systems could also improve the quality of stormwater runoff from the site, to improve the environmental quality of local receiving waters or to enable the treated stormwater to be used as an additional water resource for the community.

Improved environmental water quality

Many inhabitants use the nearby water environment for bathing or recreation. In many cases, this is also the receiving environment for sewage and sewerage effluent from the settlement in question as well as from upstream settlements. Opportunities to improve the environmental water quality will depend on the size of the catchment of these waterways. For large waterways, it is unrealistic to treat the large volume of water involved; a more appropriate solution may be to isolate a designated section of the waterway for community recreation and bathing. In this instance, the catchment of this waterbody must principally be within the settlement boundary, so onsite stormwater quality improvement works can improve environmental water quality.

Again, nature-based solutions such as stormwater wetlands, bioswales and biofiltration systems have demonstrated efficacy at improving stormwater quality.

In some cities, these nature-based solutions have been retrofitted into the built environment to operate as 'dialysis machines' and maintain the water quality of waterbodies within the cities. This same principle could be used in maintaining the water quality of a designed waterbody used by inhabitants of urban informal settlements for their recreation and bathing.

Diverse and fit-for-purpose water sources

Many cities in the developed world are investing in harnessing the water resources within their municipal boundaries. These sources of water include rainwater, stormwater, groundwater and recycled water. The same principles can be adopted to build greater resilience in water supply in urban informal settlements, by promoting multiple fit-for-purpose sources of water.

Good hygiene behaviour

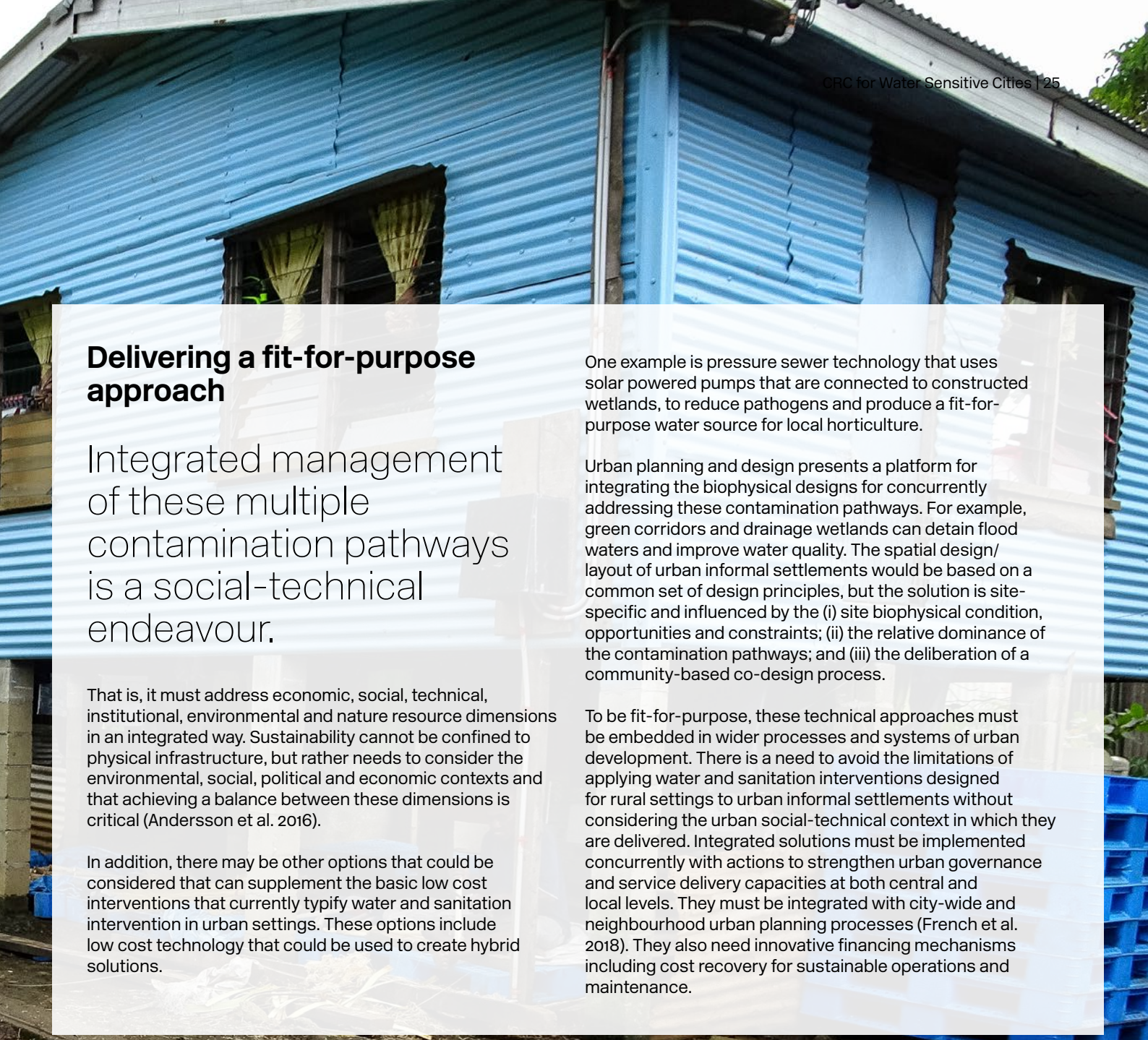
Hygiene behaviour change programs have an important role in addressing the multiple exposure pathways for faecal contamination. Poor hygiene can be a key transmission pathway for disease. Good hygiene practices to reduce these exposure pathways include handwashing with soap, safe water storage, good food handling practices, and solid waste management.

Studies have shown that handwashing with soap can reduce the risk of diarrhoeal disease by 20–40 per cent (Freeman et al. 2014). Handwashing before food preparation can also reduce incidents of secondary transmission from one person to the next. Previous studies have suggested that promoting hand hygiene may be one of the most cost-effective means of reducing the global burden of disease (Cairncross & Valdmanis 2006).

Behaviour change programs may also accompany new infrastructure, to ensure proper use and maintenance into the future. Installing a toilet or hand basin, for example, is effective only if they are used and maintained appropriately.

A co-design approach can enhance the efficacy of behaviour change elements of an intervention. Co-design relies on meaningful participation of residents and other stakeholders in the design process.

The participatory approach engages individuals in identifying key exposure pathways. It also builds capacity and educates key stakeholders (including residents) about the different risk factors for exposure within the local environment. In addition, ensuring each stakeholder understands the reasons for a particular intervention increases the likelihood that infrastructure will be used and maintained as predicted. It also engages local stakeholders in selecting infrastructure solutions, ensuring they are suitable for the local context and culture (International Initiative for Impact Evaluation 2017). At the same time, stakeholders receive educational materials to ensure that key exposure pathways are agreed on and to guide the selection of infrastructure solutions.



Delivering a fit-for-purpose approach

Integrated management of these multiple contamination pathways is a social-technical endeavour.

That is, it must address economic, social, technical, institutional, environmental and nature resource dimensions in an integrated way. Sustainability cannot be confined to physical infrastructure, but rather needs to consider the environmental, social, political and economic contexts and that achieving a balance between these dimensions is critical (Andersson et al. 2016).

In addition, there may be other options that could be considered that can supplement the basic low cost interventions that currently typify water and sanitation intervention in urban settings. These options include low cost technology that could be used to create hybrid solutions.

One example is pressure sewer technology that uses solar powered pumps that are connected to constructed wetlands, to reduce pathogens and produce a fit-for-purpose water source for local horticulture.

Urban planning and design presents a platform for integrating the biophysical designs for concurrently addressing these contamination pathways. For example, green corridors and drainage wetlands can detain flood waters and improve water quality. The spatial design/layout of urban informal settlements would be based on a common set of design principles, but the solution is site-specific and influenced by the (i) site biophysical condition, opportunities and constraints; (ii) the relative dominance of the contamination pathways; and (iii) the deliberation of a community-based co-design process.

To be fit-for-purpose, these technical approaches must be embedded in wider processes and systems of urban development. There is a need to avoid the limitations of applying water and sanitation interventions designed for rural settings to urban informal settlements without considering the urban social-technical context in which they are delivered. Integrated solutions must be implemented concurrently with actions to strengthen urban governance and service delivery capacities at both central and local levels. They must be integrated with city-wide and neighbourhood urban planning processes (French et al. 2018). They also need innovative financing mechanisms including cost recovery for sustainable operations and maintenance.

The call to action

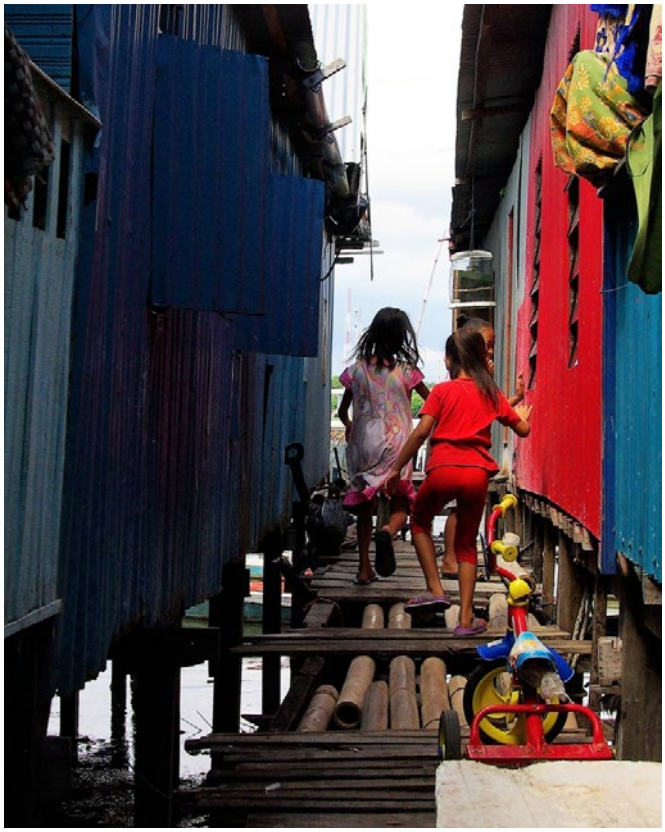
Delivering effective WASH programs to urban settlements is necessarily different and more complex.

We need to embrace this complexity and avoid over-simplifying the interplay among the many faecal contamination and exposure pathways when designing and implementing WASH programs for these communities. The result of not doing so is the decreasing efficacy of WASH programs with increasing urbanisation.

We aspire to 'leave no-one behind' and to 'reach first those who are furthest behind', yet we continue to struggle to deliver some of the most basic human rights for people living in informal settlements: access to clean water and sanitation. Business as usual—from community scale WASH projects to large expensive centralised systems—will not produce the health and environmental outcomes for urban informal settlements that we need in the 21st century. A fit-for-purpose middle ground between these two approaches may offer hope for the goal of 'leaving no-one behind'.

The megatrend of urbanisation will see a marked increase in urban populations. We argue we should be more prepared for the anticipated growth in demand for services to deliver WASH in urban informal settlements. We must anticipate that population and housing density will significantly increase the influence of environmental faecal contamination in faecal–oral transmission pathways.

Therefore, we must consider carefully how best to approach the delivery of WASH in urban areas. These settlements present unique social, spatial and financial characteristics that require a more integrated approach to deliver solutions at a range of scales.



Site context is a key determinant of an appropriate intervention. Mapping and assessing the relative significance of the multiple faecal contamination pathways is considered essential in developing strategies to deliver water and sanitation services in urban settings. Urban WASH programs must also embed system resilience strategies, to accommodate how the relative importance of these pathways may change over time.

WASH practitioners must strengthen the adaptation of non-networked sanitation approaches for urban informal settlements to respond to the social-biophysical complexities of these environments.

Call to Action#1:

Funding policies, scoping and implementation of WASH programs for urban informal settlements must be adapted to respond to the complex interplay of multiple faecal contamination and exposure pathways, including the significance of environmental faecal contamination. An holistic approach to implementing a combination of interventions that also accounts for context-specific social and biophysical factors at a range of scales should be the underpinning principle for funding policies.

Call to Action#2:

Scoping WASH programs for urban informal settlements must be fit-for-purpose to accommodate the multiple faecal–oral disease transmission pathways, paying particular attention to the expected increase in significance of environmental faecal contamination. Program scoping must be informed by mapping and understanding the relative significance of the multiple faecal contamination and exposure pathways.

A community co-design focus is essential. Strengthening the delivery of water and sanitation services to urban informal settlements can best be achieved through coordinated and integrated actions that deliver:

- safely managed sanitation
- flood management and mitigation
- improved environmental quality
- multiple water sources
- good hygiene behaviours and practices.

Call to Action#3

WASH practitioners and funders must collaborate with the following stakeholders to implement a fit-for-purpose approach to designing and implementing WASH programs for urban informal settlements: local governments, urban planners, water and sanitation service providers, community groups and civil society organisations, and development banks and financiers.

This paper is a call to action, but not only to the WASH and development community. A wider range of stakeholders must be engaged.

References

Andersson, K., Dickin, S. & Rosemarin, A. (2016). 'Towards "sustainable" sanitation: challenges and opportunities in urban areas'. *Sustainability*, 8, p. 1,289.

Bernstein, S. (2002). 'Freshwater and human population: a global perspective'. In: *Human population and freshwater resources: US cases and international perspectives*, by Krchnak, K. (ed). New Haven: Yale University.

Boisson, S., Stevenson, M., Shapiro, L., Kumar, V., Singh, L.P., Ward, D. & Clasen, T. (2013). 'Effect of household-based drinking water chlorination on diarrhoea among children under five in Orissa, India: a double-blind randomised placebo-controlled trial'. *PLoS* Med, 10(8).

Cairncross, S., Blumenthal, U., Kolsky, P., Moraes, L. & Tayeh, A. (1996). 'The public and domestic domains in the transmission of disease'. *Tropical Medicine and International Health*, 1(1), February, pp. 27–34.

Cairncross, S. & Valdmanis, V. (2006). 'Water supply, sanitation and hygiene promotion'. In: *Disease control priorities in developing countries*, by Jamison, D.T., et al. (eds). 2nd edn., Washington DC: World Bank.

Clasen, T.F., Alexander, K.T., Sinclair, D., Boisson, S., Peletz, R., Chang, H.H., Majorin, F.& Cairncross, S. (2015). 'Interventions to improve water quality for preventing diarrhoea', *Cochrane Database of Systematic Reviews*, 10(CD004794).

Clasen, T., Boisson, S., Routray, P., Torondel, B., Bell, M., Cumming, O., Ensink, J., Freeman, M., Jenkins, M., Odagiri, M., Ray, S., Sinha, A., Suar, M. & Schmidt, W.P. (2014). 'Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial'. *The Lancet,* 10 October .

Clasen, T.F., Bostoen, K., Schmidt, W.P., Boisson, S., Fung I.C., Jenkins, M.W., Scott, B., Sugden, S. & Cairncross, S. (2010). 'Interventions to improve disposal of human excreta for preventing diarrhoea', *Cochrane Database of Systematic Reviews*, 6(CD007180).

Cumming, O. & Curtis, V. (2018). 'Implications of WASH benefits trials for water and sanitation'. *The Lancet*, vol. 6, June, pp. e613–4.

Freeman, M.C., Stocks, M.E., Cumming, O., Jeandron, A., Higgins, J.P.T., Wolf, J., Prüss-Ustün, A., Bonjour, S., Hunter, P.R., Fewtrell, L. & Curtis, V. (2014). 'Hygiene and health: systematic review of handwashing practices worldwide and update of health effects'. *Tropical Medicine and International Health*, 19(8), pp. 906–16.

Freeman, M.C., Garn, J.V., Sclar, G.D., Boisson, S., Medlicott, K., Alexander, K.T., Penakalapati, G., Anderson, D., Mahtani, A.G., Grimes, J.E.T., Rehfuess, E.A. & Clasen, T.F. (2017). 'The impact of sanitation on infectious disease and nutritional status: a systematic review and meta-analysis'. *International Journal of Hygiene and Environmental Health*, 220(6), August, pp. 928–49.

French, M., Popal, A., Rahimi, H., Popuri, S. & Turkstra, J. (2018). 'Institutionalising participatory slum upgrading: a case study of urban co-production from Afghanistan, 2002-2-16'. *Environment and Urbanisation* .

Heijnen, M., Routray, P., Torondel, B. & Clasen, T. (2015). 'Shared sanitation versus individual household latrines in urban slums: a cross-sectional study in Orissa, India'. *American Journal of Tropical Medicine and Hygiene*, 93(2), pp. 263–8.

Hutton, G. & Varughese, M. (2016). *The costs of meeting the 2030 Sustainable Development Goal targets on drinking water, sanitation and hygiene: summary report*. Washington DC: World Bank Water and Sanitation Program.

International Initiative for Impact Evaluation. (2017). *Systematic review brief: water, sanitation and hygiene*, available from http://www.3ieimpact.org/media/filer_public/2017/08/29/srs-handwash.pdf.

Islam, M.S., Mahmud, Z.H., Islam, M.S., Saha, G.C., Zahid, A., Ali, A.Z., Hassan, M.Q., Islam, K., Jahan, H., Hossain, Y., Hasan, M.M., Cairncross, S., Carter, R., Luby, S.P., Cravioto, A., Endtz, H.P., Faruque, S.M. & Clemens, J.D. (2016). 'Safe distances between groundwater-based water wells and pit latrines at different hydrogeological conditions in the Ganges Atrai floodplains of Bangladesh'. *Journal of Health, Population and Nutrition*, 35(1), August.

Jamison, D.T., Breman, J.G., Measham, A.R., Alleyne, G., Claeson, M., Evans, D.B., Jha, P., Mills, A. & Musgrove, P. (2006). *Disease control priorities in developing countries*. Washington DC: World Bank.

Luby, S.P., Agboatwalla, M., Painter, J., Altaf, A., Billhimer, W., Keswick, B. & Hoekstra, R.M. (2006). 'Combined drinking water treatment and hand washing for diarrhoea prevention, a cluster randomised controlled trial'. *Tropical Medicine and International Health*, 11(4), April, pp. 479–89.

Luby, S.P., Rahman, M., Arnold, B.F., Unicomb, L., Ashraf, S., Winch, P.F., Stewart, C.P., Begum, F., Hussain, F., Benjamin-Chung, J., Leontsini, E., Naser, A.M., Parvez, S.M., Hubbard, A.E., Lin, A., Nazime, F.A., Jannat, K., Ercumen, A., Ram, P.K., Das, K.K., Abedin, J., Clasen, T.F., Dewey, K.G., Fernald, L.C., Null, C., Ahmed, R. & Colford, J.M. (2018). 'Effects of water quality, sanitation, handwashing, and nutritional interventions in diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial'. *The Lancet*, 29 January .

Martin, N.A., Hulland, K.R.S., Dreibelbis, R., Sultana, F. & Winch, P.J. (2018). 'Sustained adoption of water, sanitation and hygiene interventions: systematic review'. *Tropical Medicine and International Health*, 23(2), February, pp. 122–35.

Merchant, A., Jones, C., Kiure, A., Kupka, R., Fitzmaurice, G., Herrera, M. & Fawzi, W.W. (2003). 'Water and sanitation associated with improved child growth'. *European Journal of Clinical Nutrition*, no. 57, pp. 1562–8.

Mills, F., Willetts, J., Petterson, S., Mitchell, C., & Norman, G. (2018). 'Faecal pathogen flows and their public health risks in urban environments: a proposed approach to inform sanitation planning'. *International Journal of Environmental Research and Public Health*, 15(2), p. 181.

Mitchell, C., Abeysuriya, K. & Ross, K. (2016). 'Making pathogen hazards visible: a new heuristic to improve sanitation investment efficacy'. *Waterlines*, 35(2), pp. 163–181.

National Intelligence Council. (2012). *Global trends 2030: alternative worlds*, available at https://globaltrends2030.files.wordpress.com/2012/11/global-trends-2030-november2012.pdf.

National Resources Defence Council. (2014). 'Connecting water, sanitation and hygiene with fresh water conservation and climate resilience: the need to facilitate integration in development assistance'. *Issue brief,* 14–08–B.

Null, C., Stewart, C.P., Pickering, A.J., Dentz, H.N., Arnold, B.F., Arnold, C.D., Benjamin-Chung, J., Clasen, T., Dewey, K.G., Fernald, L.C.H., Hubbard, A.E., Kariger, P., Lin, A., Luby, S.P., Mertens, A., Njenga, S.M., Nyambane, G., Ram, P.K., Colford, J.M. (2018). 'Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial'. *The Lancet Global Health*, 6 (3), pp. 316–329.

Peal, A., Evans, B., Blackett, I., Hawkins, P., & Heymans, C. (2014). 'Faecal sludge management: a comparative analysis of 12 cities'. *Journal of Water, Sanitation and Hygiene for Development*, 4(4), pp. 563–575.

Robb, K., Null, C., Teunis, P., Yakubu, H., Armah, G., & Moe, C.L. (2017). 'Assessment of fecal exposure pathways in low-income urban neighbourhoods in Accra, Ghana: rationale, design, methods, and key findings of the SaniPath Study'. *Am. J. Trop. Med. Hyg* ., 97(4), pp. 1020–1032.

Sinharoy, S., Schmidt, W.P., Wendt, R., Mfura, L., Crossett, E., Grépin, K.A., Jack, W., Rwabufigiri, B.N., Habyrimana, J. & Clasen, T. (2017). 'Effect of community health clubs on child diarrhoea in western Rwanda: cluster-randomised controlled trial'. *The Lancet*, vol. 5, July, pp. e699–709.

Spears, D. (2013). 'How much international variation in child height can sanitation explain?', *Policy research working paper 6351*, Washington DC: World Bank.

United Nations Children's Fund (UNICEF). (2011). *Water, sanitation and hygiene for schoolchildren in emergencies: a guidebook for teachers*. New York: UNICEF.

United Nations Department of Economic and Social Affairs. (2016). *Progress towards the Sustainable Development Goals: report of the Secretary-General*, available from http://www.un.org/ga/search/view_doc.asp?symbol=E/2017/66&Lang=E.

United Nations Department of Economic and Social Affairs. (2018). *2018 revision of world urbanisation prospects*, available from https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html.

United Nations Development Program. (2018). *Goal 6 targets*, available from http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-6-clean-water-and-sanitation/targets/.

UN-Habitat. (2016). *State of the world's cities 2016*, available from http://wcr.unhabitat.org/main-report.

UN-Habitat & Office of the High Commissioner Human Rights. (2009). *The right to adequate housing*, fact sheet 21, available from https://www.ohchr.org/Documents/Publications/FS21_rev_1_Housing_en.pdf.

United Nations Inter-agency Group for Child Mortality Estimation. (2017). *Levels and trends in child mortality: report 2017*. New York: United Nations Children's Fund.

UN-Water. (2018). *Sustainable Development Goal 6: synthesis report on water and sanitation 2018*, available from http://www.unwater.org/publications/highlights-sdg-6-synthesis-report-2018-on-water-and-sanitation-2/.

United Nations World Water Assessment Programme. (2017). *The United Nations World Water Development Report 201*. Wastewater: the untapped resource. Paris: United Nations Educational Scientific and Cultural Organization (UNESCO).

University of Florida. (1987). 'Onsite sewage disposal—influence of system densities on water quality'. *Notes in soil science*, available from https://engineering.purdue.edu/~frankenb/NU-prowd/density.htm.

Wagner, E., Lanoix, J. & World Health Organization. (1958). 'Excreta disposal for rural areas and small communities'. *Monograph Series*, no. 39, p. 187. Geneva: World Health Organization.

Williams, A.R. & Overbo, A. (2015). *Unsafe return of human excreta to the environment: a literature review*. Chapel Hill, North Carolina: The Water Institute at University of North Carolina.

Wolf, J., Hunter, P.R., Freeman, M.C., Cumming, O., Clasen, T., Bartram, J., Higgins, J.P.T., Johnston, R., Medlicott, K., Boisson, S. & Prüss-Ustün, A. (2018). 'Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression'. *Tropical Medicine and International Health*, 23(5), May, pp. 508–25.

World Bank. (2012). *Indonesia water investment roadmap* 2011–2014. Washington DC: World Bank.

World Bank. (2017). *Citywide inclusive sanitation: a call for action*. Washington DC: World Bank.

World Bank Water & Sanitation Program. (2013). *Economics of sanitation initiative*. Washington DC: World Bank.

World Health Organisation. (2005). *Sanitation and hygiene promotion: programming guidance*. Geneva: Water Supply and Sanitation Collaborative Council.

World Health Organization/UNICEF Joint Monitoring Program. (2017). *Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines*. Geneva: World Health Organization/United Nations Children's Fund.

Yates, M.V. (1985). 'Septic tank density and groundwater contamination', *Groundwater*, 23 (5), pp. 586–91.

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