THE BOSTON CONSULTING GROUP

Working Paper

Urban Sanitation:
Why a portfolio of solutions is needed

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December 2014

Strategic Sanitation researchers and policymakers well recognize the need for portfolio approaches (such as deploying multiple technologies across a region) to sanitation and particularly the need to think beyond sewers as the solution to providing universal access to sanitation in cities. However, this isn't necessarily the view of those who don't spend their time in this field but whose attitudes can influence how sanitation investment decisions are made both in terms of funding level and investment priorities. For instance, many still see sewers as synonymous with sanitation and regard on-site systems such as septic tank based options as inherently less attractive options despite the strong body of evidence that indicates that in many situations on-site systems could be the preferred method. Though perspectives are slowly beginning to change, there is an opportunity to accelerate the acceptance and use of a portfolio of solutions especially among those with key roles in urban planning in the developing world. This document is intended to review the evidence that has led the sanitation research community to move toward the portfolio perspective, and act as a conversation starter to encourage key decision makers to think beyond sewer-based systems to meet the sanitation needs of their constituents. The target audience for this paper includes:

- Elected officials and policymakers influencing sanitation infrastructure decisions;
- Utilities and government agencies responsible for sanitation service provision in developing countries;
- Stakeholders such as NGOs, donors, and multilaterals looking for high-level cost comparisons and an overview of the broad choices available.

The approach of the paper is to outline the key differentiating factors and full cost (up-front and ongoing) for different sanitation solutions, which are widely implemented at scale to emphasize the need for a portfolio approach during sanitation planning. The paper will also describe the need for other sources of innovation in sanitation.

Abstract

The face of our cities is changing. Never before have more people on the planet lived in cities rather than in rural areas. In 2010, 50.5 percent of the world's population lived in urban areas and as we move to the middle of this century, the figure could reach 70 percent. Forecasters predict that the global urban population will reach 5.2 billion people in 2050, from a base of 2.6 billion in 2010. Africa alone is expected to gain around 25 million new urban dwellers per year, while Asia is predicted to add close to

35 million new urban residents per year through 2050. In both cases, most of the growth will occur in mid-sized cities.[1] The speed and magnitude of such urbanization in developing countries presents a significant challenge for local governments to adequately plan for and meet the needs of their populations. Developing countries will need to respond to this process of urbanization much faster than developed countries did in the past, and it will require a new way of thinking about urban planning. In this article, we discuss approaches to providing one of the essential services: sanitation.

With millions of people living in such close proximity in cities, it is essential to actively manage sanitation to prevent the spread of disease and environmental pollution. In the densest urban centers where populations soar to well over 30,000 people per square kilometer and high-rise buildings housing thousands of people are common, conventional sewerage is currently the only way to effectively manage such large volumes of human waste. However, most of the projected population growth is not anticipated to be in these types of formal dense urban centers but rather in the less dense areas surrounding the city centers and in informal settlements.[2,3,4] In these areas, choosing the appropriate sanitation approach becomes less straightforward and a range of solutions will be needed. Differences in population density, water usage and availability, soil type, water-table level, availability of capital, ability to pay, and uncertainty about growth patterns will strongly influence whether sewers remain the optimal solution or whether other approaches such as on-site sanitation (e.g., septic tank based systems, etc.) become better options. What is clear is that the health, economic, and environmental benefits of providing effective and efficient sanitation is essential. Those cities and countries that address sanitation most effectively will advance their success relative to those that fail to address the challenge. Innovation in the technologies and business models that support different sanitation solutions will also be needed to ensure that the portfolio of options offers a set of robust and cost-effective solutions with sufficient flexibility to tackle challenging and dynamic situations.

1 Introduction

The challenge of identifying and implementing suitable urban sanitation systems has been with us since the first cities emerged in Mesopotamia nearly 6,000 years ago. An adult human being generates an average of 250 grams of feces and one liter of urine each day.[5] The sheer volume of human waste that the world's cities must safely collect, treat, and dispose of every day to serve the 2.6 billion urban dwellers makes the provision of sanitation a complex and expensive challenge.

Yet it is a challenge that must be addressed. Water-borne diseases extract a tremendous toll on society, with over 1.5 million child-deaths occurring each year from diarrheal diseases alone.[6] It is estimated that 88 percent of all diarrheal deaths can be attributed to a combination of a lack of access to safe sanitation, unsafe drinking water, and inadequate availability of water for hygiene.[7] Productivity is also affected. The World Bank's Water and Sanitation Program estimates that a lack of proper sanitation reduces the GDP of 18 African countries by an average of 1 to 2.5 percent or a sum of approximately $5.5 billion each year.[8] As a result, sanitation investment can be very cost effective. The World Health Organization (WHO) estimates that every dollar invested in sanitation provides a return to society of nine dollars. All these reasons make the provision of sanitation an essential element of any country's public health and economic strategy.

In addition to health and economic improvements, the arguments in favor of providing universal access to sanitation include security for vulnerable populations--especially women and children–and preservation of human dignity. In recent years, there has been a strong push to recognize the right to sanitation as a basic human right. In 2010, the United Nations General Assembly passed a resolution explicitly recognizing the human right to water and sanitation and acknowledging that clean drinking water and sanitation are essential to the realization of all human rights.[9] Prior to the UN action, and since, a number of countries and states including South Africa, Uruguay, Honduras, Algeria, Bangladesh, Kenya, and Sri Lanka have recognized the right to sanitation in their national constitutions.[10,11] Last, the environmental benefits of the proper treatment of human waste cannot be overstated, when you consider the significant contamination of rivers and lakes by untreated sewage.

As governments look to provide sanitation, sewers are often the first thought. The first modern sewer system was built in London in the mid-19th century, in response to the deadly cholera epidemics of the 1840s and the "Great Stink" of 1858.[12] Since then, sewer-based sanitation systems have come to be regarded in many quarters as the gold standard for urban sanitation. For many, large centralized sewer-based networks have in fact become synonymous with urban sanitation. Other potential options such as septic tank-based on-site sanitation are often viewed as less sophisticated methods that are more suitable for rural applications or, at best, as stopgap measures while decision makers find the means to extend sewer networks.

The challenge is that even today, sewer-based sanitation is only available for a small portion of the total urban population in many areas (Figure 1). These systems struggle to operate effectively with blocked lines and inoperable treatment plants. As the urbanization trend continues, governments will need to find sanitation solutions that are effective, sustainable, and affordable, to address the needs of those people who are un-served or underserved today, as well as new city dwellers.

Figure 1. Percent of urban population in select countries served by sewer-based systems in 2012

Country	No. of urban dwellers served by sewer-based solutions* *(Millions)*	% of urban dwellers served by sewer-based solutions*
Bangladesh	9.2	22%
Ethiopia	0.4	2%
Ghana	0.5	4%
India	109.1	28%
Kenya	3.3	34%
Nigeria	9.1	11%
Senegal	1.0	19%

*Source: United Nations' Joint Monitoring Program (*improved solutions only)*

In this paper, we argue that a nuanced look at different options for the long-term provision of sanitation is required. Attempting to address the needs of rapidly urbanizing societies through sewer systems alone is neither optimal nor cost-effective and will handicap governments in their attempts to provide sanitation services for their urban residents. Urban planners, policymakers, and funding agencies need to tap a broader portfolio of sanitation options or face crippling investment and maintenance costs and a constant struggle to keep pace with growth. A broad portfolio of solutions must be explored and the relative merits of each option considered in light of specific local conditions and development forecasts. An approach tailored to local requirements and driven by local support for investing in a broad array of sanitation efforts is needed to make tangible and sustainable progress in providing sanitation for the projected 5.2 billion urban dwellers over the next 40 years. We propose a simple framework that uses the relative tradeoffs of sewer-based systems versus on-site systems (in particular septic tanks) along specific dimensions to determine under which conditions one is likely to be a more suitable solution than the other. We also underline the need for technological innovation in a field that has seen surprisingly little advancement over the last two centuries. Still, no technical solution can be effective without a study of the non-technical considerations such as the accompanying business models which are critical to success.

2 Potential Urban Sanitation Solutions

The basic technologies defined for different urban sanitation options have not changed significantly in the past several decades and relatively few potential solutions have been used at scale. Four of these represent the dominant set of urban sanitation solutions used today:

Centralized conventional sewer-based systems: Designed to rapidly transport large volumes of human waste using a network of pipes from large areas of dense human habitation to centralized wastewater treatment plants (WWTPs), where the water and waste can be treated before being discharged back into the environment. They require relatively high water availability to function effectively.

Decentralized simplified sewer-based systems: Designed to serve smaller neighborhood-sized areas. They use shallowly buried, smaller diameter pipes than conventional sewers as well as smaller WWTPs. These systems have seen significant application in Latin America, especially in Brazil where these are referred to as "condominial sewers".

On-site septic tanks: Designed to be used by a single household or shared among small numbers of households. The septic tank is meant to allow for settling of solids and treatment of the effluent, which is usually allowed to leach into the ground using a leach field or a soak-away. The solids collected in the tank must be pumped out when the tank fills up and ideally treated at a fecal-sludge treatment plant. When properly designed and regularly de-sludged, septic tanks are a relatively low-cost solution with limited environmental impact. The two main challenges are ensuring that the removed sludge is properly treated and not simply discharged into the environment and leaching safety where population densities are high.

On-site pit latrines: Latrines (dry and pour-flush) consist of a hole dug in the ground below a toilet superstructure. In many countries, latrines are the predominant rural sanitation option; however, they are still used in urban areas as well due to their overall simplicity and low cost. Latrine pits are usually unlined and can leach significant quantities of nitrogenous compounds and pathogens into the soil, potentially contaminating groundwater. The risk of groundwater contamination is significantly worse for latrines than it is for septic tanks.[13] As a result, latrines are unlikely to be a sustainable, long-term sanitation solution in urban areas given the density of inhabitants, especially in those areas that use groundwater for drinking.

On-site systems (pits and septic tanks) were the predominant sanitation option in European cities until the middle of the 19th century when the first modern sewer systems emerged. Even today, on-site sanitation systems that rely on septic tanks and vacuum trucks are prevalent in rural and peri-urban regions of Europe, North America, and Japan. In the past, manual emptying of the septic tanks and pit latrines was the only option available to a household when its tank filled up. Today, however, mechanical methods of collecting and transporting waste are common.

Other options: A number of other sanitation options such as Ecosan/Composting toilets and Urine Diverting Dry Toilets (UDDT) are sometimes mentioned as potential large-scale solutions especially when these are coupled with innovative, collection-based business models. Such solutions can be an attractive option as they do not require water (and, in fact, discourage the use of water), can be low cost, and enable recovery of nutrients for reuse. A significant number of these toilets exist in rural and peri-urban areas across many countries. However, these options have not yet been demonstrated to be effective on a large scale for densely populated urban applications, though work is underway to do so. There is also a delicate balance in maintaining these business models which often rely on resource recovery (such as fertilizer generation) schemes to help offset the cost of collecting the waste. As yet, it is unclear if these collection schemes can be self-sustaining.

Other technologies are in the early stages of product development, such as those being developed under the Bill & Melinda Gates Foundation's "Reinvent the Toilet" challenge. These solutions promise to be self-contained, on-site systems that can treat waste, remove pathogens, and create valuable byproducts through the recovery of nutrients, energy, and water from human waste. Most of these technologies are still being developed and will require several years to be fully tested and ready for large-scale implementation.

It should be noted that in addition to innovation in the type of sanitation options available, resource recovery is an important area of investigation. Resource recovery innovators are looking to maximize the value that can be extracted from fecal matter and urine through recovery of water, energy, and/or nutrients. Existing resource recovery is largely achieved through the creation of fertilizer, however, new options such as the creation of biochar, biogas, and biodiesel are being explored. A number of approaches are being researched and piloted. Valuable-product recovery has the potential to subsidize sanitization services. We will not address this area in this report, but it should be monitored and considered as part of integrated solution development.

In this paper, we focus our analysis on the three sanitation options that are currently best placed for large-scale urban implementation:

- ***Centralized sewers***
- ***Simplified sewers***
- ***Septic tank-based on-site sanitation***

These solutions have large-scale examples of implementation in many countries all over the world. They can provide broadly equivalent service quality for users and could be implemented with sufficient safeguards to prevent significant environmental pollution to groundwater and surface water. While this is a relatively short list, it will be supplemented as innovative solutions mature and as many regions pilot more novel approaches as part of their portfolio strategy.

3 Sanitation System Costs

The three different types of sanitation systems compared here can be implemented for a wide spectrum of population sizes. Therefore, it is helpful to use capital and operating costs on a per person basis to compare the cost-effectiveness of different sanitation options. The numbers shown were extracted from a combination of available literature sources (such as IRC WashCost analysis and World Bank and Asian Development Bank project reports; see references for a full list of sources), interviews with leading sanitation experts and BCG analysis conducted as part of a larger study on Fecal Sludge Management for the Bill & Melinda Gates Foundation. This investigation was focused on estimating the cost of sanitation provision in developing country settings only and as such developed world economics were excluded from the analysis.

The level and type of waste treatment can affect capital and operating costs, especially for sewer-based systems, which have a broad range of potential treatment options. For the sake of comparison, we have assumed secondary treatment using an activated sludge process for sewer-based sanitation systems. Figure 2 provides a summary of the per capita capital and operating costs for the three different sanitation solutions under investigation. Local factors such as interest rates can have a significant impact on the operating cost of any system. We have not included interest rate differences in our comparison of costs.

Figure 2: Comparison of capital and operating costs of different sanitation system options

Type of sanitation option	Capital costs ($/person)		Annual operating costs ($/person/yr)
	Projected costs assuming all targeted customers connect	Actual costs based on actual connections to network	
Centralized conventional sewer-based system	130 – 330	220 - 940	12 – 28
Decentralized simplified sewer-based system	105 – 155	105 - 155	4 – 10
On-site septic tank-based system	70 – 360	70 – 360	4 – 12

Source: Sanitation cost case studies, IRC WashCost, BCG analysis
Note: For simplified sewerage and on-site septic tank-based sanitation, small scale ensures that close to 100 percent of targeted customers connect to the network.

3.1 Capital Costs

The data presented in this section are based on literature reviews of case studies which investigated and measured the capital and operating costs for developing world installations of conventional sewer projects, simplified sewer projects, and on-site sanitation solutions based on septic tanks. Ranges generated from the synthesis of the case study findings were then pressure-tested with experts.

Centralized conventional sewer-based sanitation systems involve significant upfront investment in infrastructure. Projected capital costs for projects in the developing world range from $130 to $330[14] per person, and on average tend to be lower than actual costs after construction. Actual project costs ranged from $180 to $260[15,16,17,18,19] per person if the entire population targeted by the system had connected to it. However, centralized conventional sewer-based systems are often "up-scaled," or designed with the predicted maximum size of the catchment population during the lifetime of the system in mind, since changes and expansions after the initial installation can be quite costly. In addition, many such systems struggle to get households to sign up due to the high one-time cost of connecting to the sewer network as well as additional sewerage tariffs. In some cases, as little as 20 percent or so of the targeted population had connected to the network a few years after the system had become operational. In the event of a lower than expected connection rate, actual capital costs can be as high as $220 to $940 per person served. [15,16,17,18,19]

For a decentralized, simplified, sewer-based system, actual capital costs range from $105 to $155 [15,20,21,22] per person. These systems tend to cost less than conventional systems that serve the same number of people, since their design allows for less expensive materials to be used, and installation requires a less intensive construction process. They are somewhat more flexible and easier to scale up than centralized conventional sewer-based systems. Therefore, they are much less frequently "up-scaled" from the very beginning. These systems also typically involve a higher degree of community participation and consultation that helps drive household connection to the network. As a result, simplified sewer-based systems are much less susceptible to higher per capita costs due to insufficient connection to the network. However, simplified sewers also have drawbacks which limit their uptake. Specifically, the small size of the pipes used to connect households to the central treatment site means that the pipes can easily be blocked and when left to a community to repair are often not fixed in a timely manner leading to system failures.

In addition to connection rates, population density, area topography, and water-table height can significantly change the capital cost of centralized and decentralized sewer-based sanitation systems. Their impact is shown in Figure 3.

Figure 3: Drivers of capital cost for sewer-based sanitation systems

	Factor	*Driver of lower capital cost/person*	*Driver of higher capital cost/person*	*Magnitude of impact*
1	Population density	Higher density	Lower density	High
2	Topography	Sloped, no hills	Flat or very hilly	Moderate
3	Water table height	Deep water table	High water table	Moderate

Population density is the most important driver of per-person capital cost for sewer-based systems. While wastewater treatment facilities exhibit economies of scale, the costs of the network for a given area do not increase significantly as population density rises if the area covered remains the same. In a case study of Natal, Brazil, decentralized simplified sewerage became cost-neutral with on-site septic tank systems at population densities of 16,000 people per square kilometer, while centralized conventional sewerage remained more expensive than on-site septic tank-based systems even at 30,000 people per square kilometer.[23]

Capital costs of sewer-based systems are moderately increased by flat or very hilly topography or a high water table. [24,2526] As indicated in Figure 3, challenging topography can increase the number of pumping stations and/or amount of digging required to ensure the required flow of liquid toward the wastewater treatment plant. A high water table may inhibit laying pipe at the depth required to create sufficient slope, thereby necessitating more pumping stations as well as additional measures to prevent groundwater contamination. It can also leave sewerage vulnerable to infiltration from groundwater, which increases the required system capacity and raises costs accordingly.[27]

On-site septic tank-based systems take a more decentralized approach to sanitation. Capital costs for modern on-site septic tank systems range from $70 to $360[28] per person, with the majority of system costs falling at the low end of this range. A significant portion of this cost is the construction of the septic tank, which is often paid for by the household. The size of the septic tank required has a significant impact on the capital cost of on-site septic tank-based systems. Septic tank size varies based on the size of the household using the tank and the average water usage, as well as the amount of exfiltration from the system, which depends on soil permeability and water table height.

3.2 Operating Costs

The major operating costs for centralized conventional sewer-based sanitation systems are energy costs, personnel costs, and maintenance and repair costs. In developing countries, these costs range from $12 to $28 per person per year over the designed life of the sewer, with energy costs typically comprising a significant portion, especially in flat areas that require considerable pumping. These operating costs do not include annual financing charges, which can soar to 100 percent of the cost of operation. Given that expensive infrastructure loans are almost always required to fund construction, the cost of these loans should be factored in at the local level depending on funding terms.

The key factors that drive operating costs for centralized conventional sewer-based sanitation systems are:

- *Extent of system automation*: More automation tends to lower operating costs, but usually at the expense of raising initial capital costs.
- *Site topography*: Flat sites require more pumping stations to move the sewerage to the WWTP, which results in higher fuel and electricity costs.
- *Treatment type*: Tertiary treatment usage can increase operating costs by 20 to 35 percent when compared with activated sludge processes, while using only primary treatment or waste stabilization ponds can reduce operating costs by 15 to 50 percent and 55 to 60 percent respectively. [29,30,31,32] Selecting limited

treatment options, however, can involve significant environmental tradeoffs in the name of cost reduction.

Simplified sewer-based systems have lower operating costs in the range of $4 to $10 per person, per year as they usually rely on gravity-based flow, and transport waste over shorter distances to decentralized WWTPs. It should be noted that management of many small, decentralized WWTPs can increase the labor cost for large municipalities as more staff is required to manage the larger number of plants.

Annual operating costs for on-site septic tank-based sanitation systems range from $4 to $12 per person. Most of these costs are related to the emptying of septic tanks. Operating costs depend on the following factors:

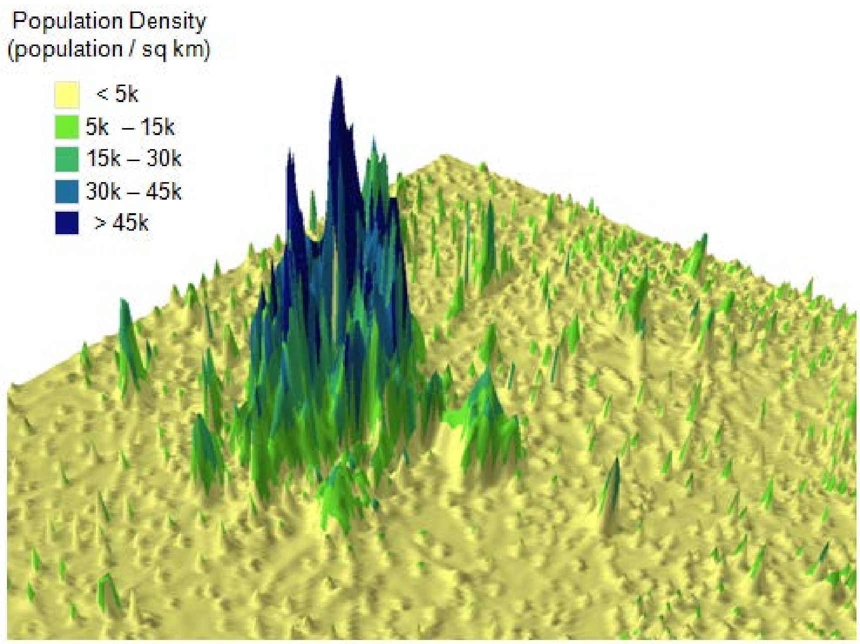
- *Distance to the disposal site:* Longer distances from the household to the sludge treatment or disposal site require greater travel and more fuel consumption.
- *Household tank type:* If located in an area with high water table, construction may require sealed cesspools that do not exfiltrate and must be emptied more frequently.
- *Septic tank size relative to household size:* Smaller volume per person tanks will need to be emptied more frequently and emptying prices are not strictly volumetric.
- *Local pricing:* Cost of available septic tank emptying methods varies depending on local conditions.

It is important to note that the operating costs for septic tank-based systems are most commonly borne directly by the household or landlord and not the municipality as is the case with sewer systems.

4 Considerations for Selecting Sanitation Solutions

There is a great deal of variation in conditions between, as well as within, cities, which can influence the selection of the most appropriate sanitation solution. A perfect example of this is population density – a characteristic that is sometimes used to define cities. The average population density in New Delhi is around 29,000 people per square kilometer; however, a closer look within the city shows that there is a wide range of variability--from areas averaging over 45,000 people per square kilometer to areas with fewer than 15,000 people per square kilometer (Figure 4).

Figure 4. Population density in different parts of New Delhi, India



Source: LandScan 2010, BCG analysis

As urban areas are diverse and complex entities, a suitable sanitation option for a particular location within a city will depend on a number of locally specific factors.

In sections 4.1 through 4.4 we lay out the characteristics that can influence sanitation solution selection in four groups: population characteristics, physical characteristics, political/economic characteristics, and urban planning considerations.

4.1 Population Characteristics

- **Density** – At high population density (over 30,000 people per square kilometer), centralized sewer-based systems are currently the most suitable and practical option given their ability to quickly and efficiently move large volumes of waste away from crowded areas when sufficient water is available. At high densities, the capital and operating costs of sewers can be distributed over a large number of people, which lowers the per capita cost significantly. This is not to say that the cost of sewers is low in this case, just that it is the scenario under which sewers are most effective. Simplified sewer-based systems can also be well-suited to small, high-density areas, especially in places with flat topography, space for a small decentralized WWTP, and narrow streets that limit heavy vehicle access.[33]

In segments of cities with medium (15,000 to 30,000 people per square kilometer) and low (fewer than 15,000 people per square kilometer) densities, the choice between centralized sewer-based systems and decentralized as well as on-site septic tank-based systems becomes less clear, especially where water availability could be an issue. Carefully weighing the benefits and tradeoffs of different solutions at medium and low densities then becomes the priority. Take, for example, the decision of whether to implement a centralized sewer-based sanitation solution at a medium population density. Given the same land area, there are fewer people over whom to distribute the capital costs for the pipe infrastructure at medium densities than at high densities; this is most important for the capital cost of the sewer-pipe network, as its length is more a function of land area than the number of people served. It is also in this context that per capita costs are more sensitive to the number of households that eventually connect to the system.

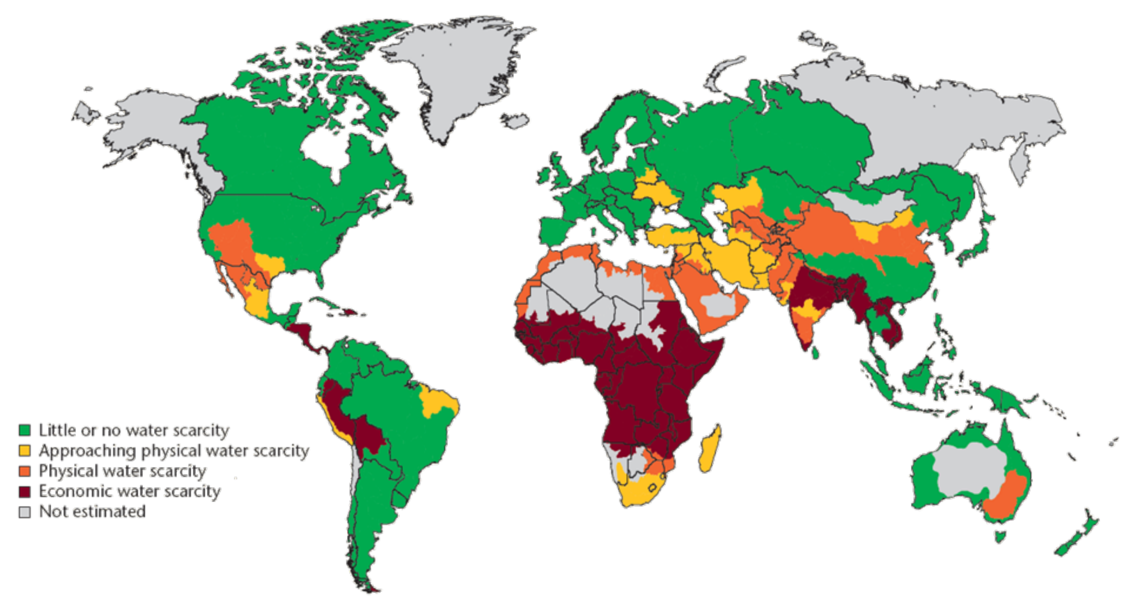
Another example is the choice between on-site septic tank-based systems and simplified sewer-based systems. It is below 30,000 people per square kilometer where, depending on soil type and household water usage, on-site sanitation solutions start to become feasible. Capital costs for on-site systems are not heavily affected by population density. In this case, as population density increases from low levels, there is likely to be a point at which simplified sewerage becomes less costly than on-site septic tank-based systems. However, there is also a point at which on-site septic tank-based systems become technically or environmentally unfeasible due to ground saturation; it is case-specific whether the cost or feasibility effect takes precedence.

- **Water use** – Sewer-based systems, first implemented in cities situated on the banks of large rivers and popularized in countries with significant rainfall, such as the United Kingdom, were designed to use large volumes of water to transport waste over long distances. A minimum of 50 liters of water per person per day[34] is required for sewers to function effectively, with 80 to 100 liters being better for flow in conventionally sized systems. In many countries, this is more than the per capita water availability, making sewer-based sanitation a challenge to implement and run effectively without expanding piped water services. On-site septic tank-based sanitation systems, in contrast, do not use water as a conveyance mechanism to deliver waste to a treatment facility. With these systems, water use can be limited to the extent required to use flush or pour-flush toilets.

4.2 Physical characteristics

- **Water Availability** – While some cities have readily available sources of water nearby, other cities must transport water over long distances (400 kilometers) to reach the city waterworks. Considering how water will be sourced to support urban expansion is important when deciding which type of sanitation solution might be right for a given location. Additionally, climate change is expected to cause changes in rainfall and water availability in many areas. Reduced rainfall and droughts in certain areas will likely accelerate the onset of water scarcity driven by other trends such as groundwater over-drafting and over-allocation of surface water. While domestic water consumption may take precedence over other uses, resulting in a reapportionment of water in some areas, in others, this may not be possible. The suitability of sanitation solutions that require large volumes of water, such as conventional sewerage, will need to be considered carefully in areas where water is already scarce or which are at risk of shortages. Lastly, it is important to consider the total system cost of transporting clean water over great distances for use in carrying away waste, as this cost may be too great for some locations to bear. Below, Figure 5 shows the state of water scarcity globally.

Figure 5. Global Trends in water scarcity



Source: International Water Management Institute, Comprehensive Assessment of Water Management in Agriculture, 2007

- **<u>Soil permeability</u>** – On-site septic tanks systems depend on soil-permeability to reduce the volume of waste that needs to be removed. In areas with less permeable soils, the capacity of water to exfiltrate from the septic tank is limited, and this leads to waterlogging of soil, and septic tanks that fill up quickly. Waterlogged soil hurts the effectiveness of septic tanks and limits the number of well-functioning tanks that can be put into a given area before ground capacity is overwhelmed. Quick-filling tanks have a significant impact on the cost of operating an on-site septic tank-based system, given the need to empty more frequently. When water exfiltration is unacceptable, watertight cesspools can be used as an on-site solution, but operational costs are generally high due to frequent emptying needs. Sewer-based systems are not affected by soil permeability, though soil type can increase pipe-laying costs if bedrock is common.

- **<u>Water table height</u>** – On-site sanitation systems that use septic tanks as well as large sewer-based systems are more expensive to implement in areas with a high water table. Under these conditions, trenches fill up with water during construction and this can often slow down construction and increase costs. For on-site systems, a high water table also means that watertight cesspools are required. As mentioned above, these fill up more quickly than traditional septic tanks and therefore need to be emptied more frequently, resulting in higher operating costs. In areas where the water table is close to the septic tank (or a sewer pipe that is leaking), there is a significant potential for contamination of groundwater if the systems are not properly constructed and managed. This can be a major public health hazard in places where groundwater is used as the source of drinking water.

- **<u>Rainfall</u>** – Areas with high and/or irregular, but heavy, rainfall need drainage to quickly carry water away from local populations. Sewer-based systems can be very good at handling large volumes of water. In some cases they could potentially provide drainage in places where it is not possible to build a separate storm-water network. However, combined sewage and storm-water systems can experience large fluctuations in flow during storms. The system must be able to treat the entire volume in order to avoid large-scale environmental pollution if a wastewater treatment plant becomes overwhelmed. Here again, climate change's impact on rainfall can present a challenge for planners as the likelihood of extreme weather events such as floods is expected to increase over time.

4.3 Political/Economic Considerations

- **Access to capital** – Centralized sewer-based systems require large amounts of capital for up-front investment. Most of this burden falls on the utility, typically government financed. Tariff structures in most countries often struggle to cover ongoing operations and maintenance costs, let alone build a corpus for the inevitable infrastructure replacement that will be required in the future. Additionally, tariff structures can, if not designed properly, place a disproportionate amount of the burden on the lowest income households. Often there is relatively low willingness and, in many cases, ability, to pay for sanitation. The potential political fallout from tariff increases for sanitation can be a powerful deterrent to increasing tariffs. In many cases, sanitation must be funded via water provision tariffs or general tax revenues. Where this is not feasible, international lenders, such as the World Bank, the Asian Development Bank, and the African Development Bank, have sometimes stepped in to fill the void by offering loans with preferential terms. These lenders have in the past had a clear preference for larger centralized infrastructure projects, which are easier to lend to and oversee than on-site sanitation solutions, which is generally more fragmented and complex. Still, international funding sources are not great enough to finance the solution to the world's sanitation problem and this is likely to be especially true as urbanization rates and demand for sewers grows. No matter the solution selected, local municipalities must increase consumer buy-in and support for sanitation and the tariffs required to finance it.

  On-site septic tank based sanitation systems are cheaper to install and operate (*Capital cost*: $70 to $360 versus $220 to $950 for centralized conventional sewer-based systems; *Operating cost*: $4 to $12 for on-site septic tank-based systems versus $12 to $28 for centralized conventional sewer-based systems). They also have a very different buyer dynamic because households share a larger portion of the capital costs (approximately 70 percent), as well operating costs (approximately 90 percent) than they do under centralized sewer-based systems. They typically also scale relatively directly with the number of users – unlike conventional sewers where some investment may need to lead population need for sanitation due to up-scaling. Where the tax base is not sufficient to raise capital internally and funding from international sources is unavailable or insufficient, on-site sanitation can become an attractive solution given its low cost compared to centralized sewerage options. Effective on-site sanitation models are still likely to require capital investment to build local treatment facilities, and clearly, central ongoing operating costs remain in the form of regulation of septic tank installation and service suppliers.

- **Ability to regulate, monitor, and influence** – There is a tendency in sanitation to gravitate toward large centralized systems because these are often easier for local authorities to regulate, monitor, and influence. There are a few large actors to monitor with clearly defined formal roles and responsibilities. It is easier to assess the impact and performance of centralized systems, as they normally have well-laid-out metrics and boundaries. Further, the technically skilled personnel in charge of sanitation efforts are typically engineers trained in sewer systems. By contrast, on-site systems largely operate in the private, and frequently informal, sector. They have a large number of dispersed actors whose interests are not always aligned with those of government. It is more difficult to regulate and monitor sanitation conditions with on-site sanitation solutions to ensure they are functioning properly under these circumstances. In addition, there are often strong incentives for misuse since households that allow septic tanks to release into the environment may not need expensive emptying services, and emptying services that dump illegally will likely drive shorter distances, saving fuel and avoiding dumping fees. Normally, management of such systems is dependent more on an understanding of business operations and incentives than on the engineering capabilities of sanitation professionals. In the past, this has made governments and utilities more comfortable with centralized sewers than with decentralized or on-site systems, but we are now seeing many examples where governments and utilities tackle these issues directly and design supporting environmental factors.

- **Track record and perception** – Centralized sewer-based systems have a relatively long track record in a large number of countries and are the prevalent option in cities in the developed world. They are generally perceived as the "gold standard" for urban sanitation provision. It is not uncommon for people to be less familiar with decentralized options, as these have relatively fewer examples of large-scale implementation in urban areas and they aren't as much of a focus for many engineers trained in sanitation management. This is starting to change. However, on-site sanitation must still battle a perception of being less sophisticated and more suitable for rural environments than urban ones.

- **Involvement of private enterprises** – On-site septic tank-based systems are, by design, much more decentralized and amenable to private enterprise participation than sewer-based systems. Government support is still required to fund fecal sludge treatment plants, to regulate the sector to prevent illegal dumping, and to better enable poorer households to access services. Nevertheless, the smaller price tag of capital investments for on-site sanitation means that households or landlords can invest in septic tanks themselves and meet sanitation needs. Lastly, the potential for a viable emptying business to support on-site sanitation attracts small entrepreneurs to the field in a manner that sewer-based systems cannot. There are numerous models of private sector engagement. For instance, within the Philippines there are cities with fully government-supplied fecal sludge servicing, fully private-sector-operated systems, and hybrid models where government still manages the treatment plants.

- **Community engagement** – The choice of system deployed is likely to be highly dependent on the local societal context and the priority of sanitation relative to other uses of funds. Effective sanitation requires community support at every point to ensure success. Without engagement on the benefits of proper waste treatment, illegal dumping–both by household and service supplier–will inevitably continue, since this is the least costly method of waste disposal. To ensure willingness to pay connection fees and the operating costs of sewer or fecal sludge management services, demand for the service must be created. Some condominial sewer systems may also require community support to manage blockage issues that arise and ensure equipment is properly maintained.

4.4 Urban Planning Considerations

- **Time to solution implementation** – Larger-scale infrastructure projects are inherently time-intensive given their size, and when compared to individual household-level solutions such as on-site sanitation, can take much longer to build. For example, a new, conventional sanitary sewer system being built in a populated area is likely to take between two and six years to complete, depending on size and complexity. Simplified sewer-based systems can be somewhat shorter, taking about two to four years from design to operation. Depending on project complexity, the design phase can range from nine months to two years with some projects starting construction in the later stages of the design phase in an effort to compress the timeline.

  The construction period is the most variable phase of the sewer-based sanitation system timeline. Challenges such as very hilly topography, high population density, highly variable city structure, rocky soil, contract disputes, and a high water table can increase the construction timeframe. Mountainous topography can necessitate tunneling through hills, while a high water table requires extra environmental protection measures when laying pipe.

Conversely, with on-site sanitation solutions, because construction typically focuses on the individual household level, planning is simple and quick, taking as little as a day or two. This is followed by roughly a week of construction, depending on materials used, soil conditions, and weather. Still, proper operation of on-site septic tank-based solutions implemented by households requires supporting infrastructure and policy, which can take time to establish:

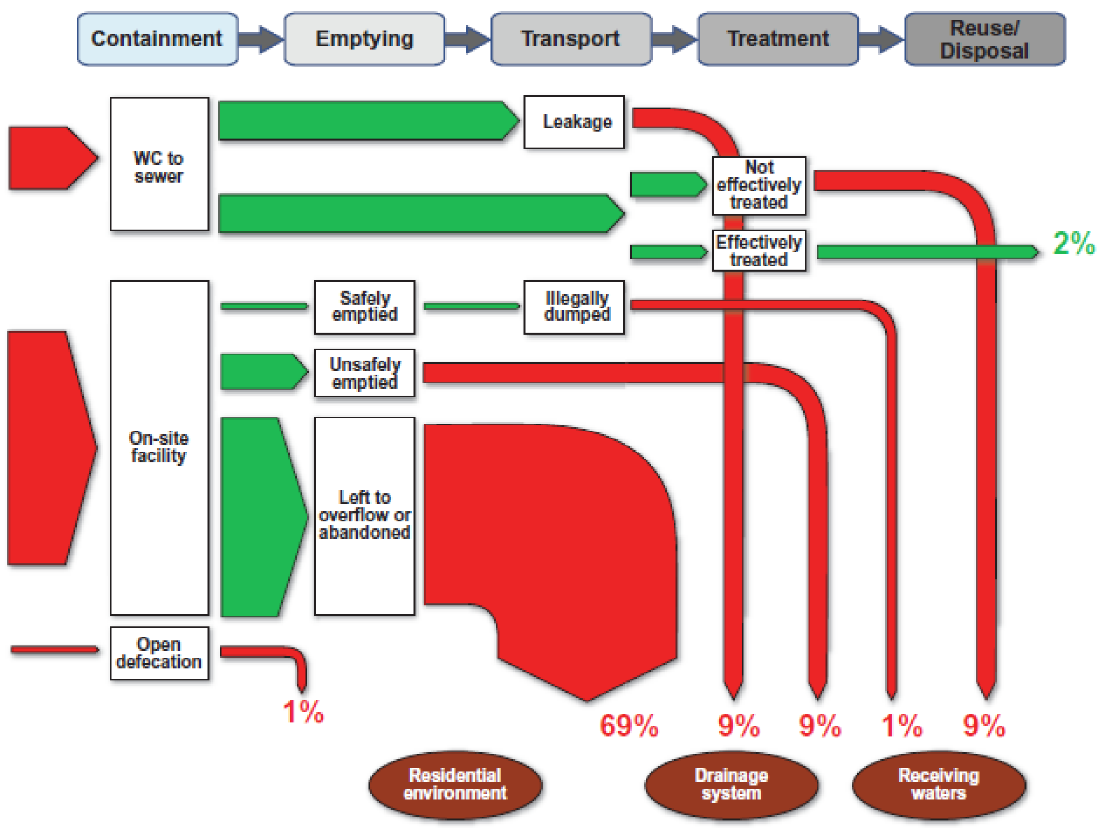
- A clear legal framework that mandates planned emptying
- Clear guidance on where septic tanks can be built and infiltration rates
- Planning and building the needed fecal sludge treatment plants
- Setting up or supporting the utility or businesses for emptying
- Regulations and oversight for the proper management of emptiers

- **Scalability** – Sewer-based systems are designed to reach their planned capacity close to the end of their lifetimes. The cost per capita of sewers will decrease over time as the number of connections increases. This makes sewers more difficult to introduce initially given their oversized nature and high cost. Decentralized and on-site sanitation systems are much more adaptable to the scale of the current population they serve, due to their decentralized nature and modular approach to infrastructure. Decentralized solutions are also much more adaptable to the rapid and potentially unplanned growth expected in many cities across the world over the next 40 years. This unplanned growth is expected to take the form of lower density urban sprawl, making flexibility and scalability important considerations in sanitation planning. If sewers are to be used, this type of sprawl makes predicting population characteristics difficult and the task of planning and sizing large infrastructure investments with long design lives extremely complicated.

- **Environmental impact** – Today, no sanitation solution has zero environmental impact. Each system has issues and risks. The best a local government can do is work to mitigate the risks for each system to prevent as much environmental contamination as possible. As an example, on-site sanitation systems can lead to groundwater contamination as leachate from septic tanks interacts with groundwater. This may be an issue in high-density settlements that use shallow groundwater as their primary source of drinking water. Levels of contamination can increase if proper maintenance and desludging of septic tanks is not executed. In areas where there is no available safe and legal dumping site or fecal sludge treatment plant, extracted sludge can also pose an environmental hazard when dumped.

Release of untreated sludge and resulting environmental damage can also be an issue with sewer-based systems. If sewerage systems are not properly operated and maintained, the potential for large-scale water-body contamination is high. If sewer systems also collect rainwater, wastewater treatment sites can become overwhelmed during storms and discharge significant amounts of untreated sewerage into the environment. It has been estimated that sewer-based systems have leakage of up to 5 to 15 percent between the household and the treatment plant. Additionally, work by the Water and Sanitation Program has shown that a significant percentage (overall 58% is not properly treated, but in some cases 0%, Figure 6) from of the waste being brought to WWTPs in major cities is not properly treated.[35]

Figure 6. Fecal Waste Flows in Dhaka, Bangladesh highlight poor treatment levels



Source: WSP

5. Need for Innovation in Sanitation

The set of sanitation solutions that is currently available to decision makers for implementation on a large scale is limited, and there are inherent constraints with each available option. Sewer-based systems require large upfront investments and significant quantities of water to operate effectively, and they consume large amounts of energy transporting and treating waste. Centralized systems are on average less flexible in dealing with rapid and unpredictable population growth and fast-changing sanitation needs. Septic tank-based on-site systems can be difficult to regulate and monitor effectively and, if not properly designed and properly emptied, are a potential source of groundwater contamination. They also require sludge to eventually be collected, transported, and treated – an expensive exercise fraught with potential pitfalls that may cause environmental contamination and severe impacts on public health if not managed effectively.

Historically, urban sanitation solutions have not seen significant innovation relative to other fields and the sector has been ripe for paradigm-changing technical innovations targeted at different parts of the sanitation value chain:

Customer interface → Collection → Conveyance → Treatment → Disposal or Reuse

A broad array of sanitation solutions is currently in the process of development and scale-up. For instance, several new dry toilet options mimic the look of a porcelain seat or squat toilet and rely on frequent collection of waste in easily sealable cartridge-like storage units. Many of these products rely on urine diversion to separate urine and feces to facilitate easier downstream processing/resource recovery, which can be an important part of the overall business model. These systems are potentially attractive in locations where labor is relatively cheap and density of households is high. Uniloo in Ghana and Sanergy in Kenya are two examples of this approach.

The toilets being developed under the Bill & Melinda Gates Foundation's "Reinvent the Toilet" challenge go one step further by attempting to compress the sanitation value chain into a single piece of on-site infrastructure that would serve as a self-sustaining, end-to-end solution. The toilet would collect the feces and urine, remove pathogens, and convert human waste into valuable energy, fertilizer, and safe, usable water. If successful, the Reinvented Toilet would eliminate the need for long-distance transportation of human waste and the accompanying energy requirements. The current challenge is to make all this possible in a culturally appropriate, compact, and robust manner at an affordable price (final target is $0.01/person/day) across a variety of different operating conditions, user practices, and expectations.

Since the emphasis of most current sanitation systems is on the collection, treatment, and disposal of human waste, significant efforts are being made to enable cheaper collection and conveyance of waste from on-site systems. The Bill & Melinda Gates Foundation as well as a number of country-level innovations in vacuum truck construction and semi-mechanical emptying technologies (such as Gulper) are underway and are examples of attempts to tackle the challenge of having to empty and transport large quantities of human waste from septic tanks and pit latrines.

In the current sanitation paradigm, excreta and urine are treated as waste and the objective is to first remove waste from human contact and then remove pathogens and potentially harmful compounds (as well as nutrients that might lead to eutrophication – the response of ecosystem to the addition of substances such as nitrates and phosphates from sewage which can result in algal blooms or the depletion of oxygen in the water which can negatively affect animal life) as cost-effectively as possible before dumping cleaned water back into the waterways and solids into landfills. In many cases, this requires large amounts of land or sophisticated, energy-intensive electromechanical processes that are expensive to operate and maintain. A significant amount of research is being conducted on harnessing the potential value of sewage and septage (solid and liquid waste from septic tanks) through the generation of biogas, biodiesel, fertilizer, and biochar that can be used as a soil amendment. Attempts are also being made to cost-effectively dewater sludge to use the treated water for irrigation and non-potable domestic use. The challenge for all these resource recovery efforts is to create solutions that can recover economically the resources at locations close to their intended use. Solutions must be flexible to adapt to varying waste streams and must generate products in sufficient quantity and with consistent quality to find a regular and viable market. The major challenge with these approaches is that the systems often require a significant input of energy to extract and access the energy or nutrients contained within the sewerage or septage.

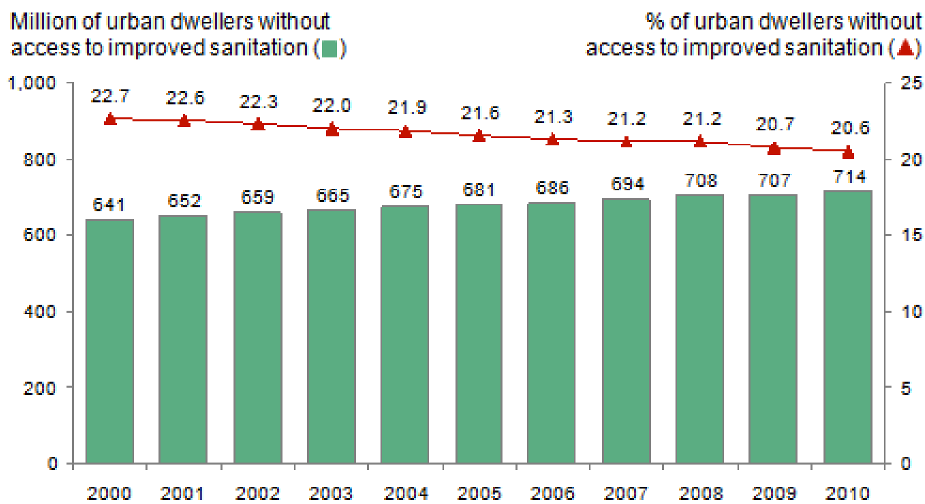
Addressing the sanitation needs of urban populations requires more than just the development of new technological solutions. It also requires addressing a fundamental challenge that exists in the system today. In many instances, sanitation providers struggle to collect sufficient revenues from consumers to cover the cost of operations. This limits both the coverage and quality of service that can be delivered. To address this market-failure in sanitation, efforts are required to both lower sanitation service costs and increase the revenue that can be generated from providing sanitation.

First, innovators need to step in and help to develop new, efficient approaches across the value chain, focused on infrastructure and technology, as well as new services or business models to deploy these and existing technologies. New technologies must be viewed within the context of the overall business and operating model in which they will operate, and be required to demonstrate their effectiveness at scale. As an example, to help lower service costs, new customer-sourcing models could be instituted, such as prepayment of emptying fees for septic tanks through water/utility bills. This approach would make it easier to cluster the emptying of household septic tanks and pits which, in turn, allows operators to plan their emptying schedules more efficiently, and maximizes the use of expensive equipment. A second lever to lower the cost of sanitation for the consumer can be to increase the level of competition in the sanitation marketplace through private sector involvement. Governments will typically still need to provide regulatory oversight and a clear legal framework to encourage private sector participation while protecting the consumer and the environment. A third lever is to increase the demand for improved sanitation by consumers and households. Until there is a strong push by the people to improve their sanitary conditions, it will be difficult to drive major changes forward.

5 Looking ahead

The first decade of the 21st century saw a concerted effort by countries all over the world to move toward achieving the Millennium Development Goals. The target of reducing the number of people without access to improved sanitation by half by 2015 was ambitious. Progress toward this goal has been slow, and cities in particular have struggled. Due to rapid population growth and migration from rural areas, the number of urban dwellers without access to improved sanitation has increased on an absolute scale from 640 million people in 2000 to 715 million people in 2010. While this has resulted in a modest decrease on a percentage basis from 22.7 percent in 2000 to 20.6 percent in 2010, the improvement has been far from dramatic (Figure 7). While the water MDG was met early, the sanitation goal will not be achieved. Looking forward, sanitation policymakers must find innovative ways to make gains in the face of similar and, in some cases, more pronounced urbanization in the future. The sheer scale of this global challenge is immense and unprecedented in human history.

Figure 7. Trends in the number of urban dwellers without access to improved sanitation



Source: JMP

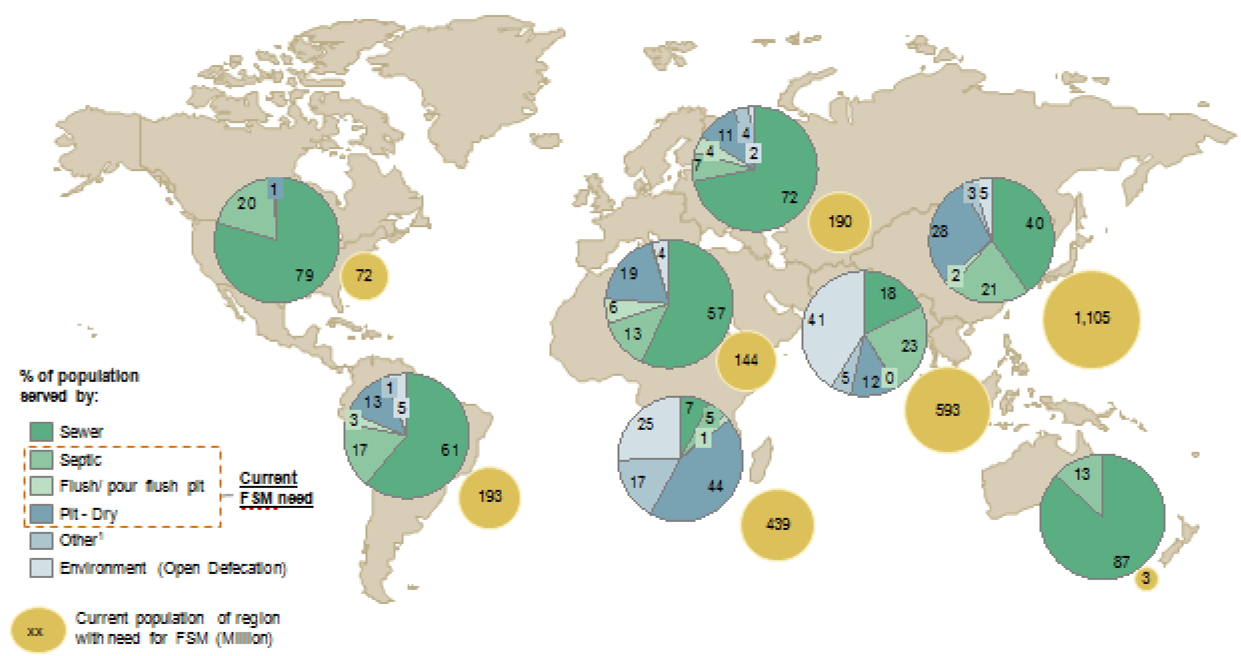
Even if the world were static, no one sanitation solution would work in all situations. Governments all over the world will be contending with increasingly uncertain and unpredictable environments. Sanitation solutions for the coming decades will need to be more adaptable, modular, and scalable to adjust to rapidly changing conditions. Given the projected growth for urban centers, the importance of developing a plan for how to manage sanitation cannot be overstated. A portfolio of different sanitation solutions will be required to meet all these requirements and an increasing focus on more flexible decentralized and on-site systems is likely.

In many situations, a focus on providing improved decentralized and on-site systems will allow governments to keep pace with the tide of urbanization and avoid the high-water requirements, investments, and operating costs associated with conventional sewerage. There are many issues to address; some potentially negative, others potentially positive. Leaking systems and illegal dumping are a huge problem in many areas. Collection services and systems require innovation both in storage and collection technology. Resource recovery could subsidize the costs of sanitation and create attractive commercial endeavors with the potential to support significant sustained employment.

For on-site systems in particular, a variety of operating models will also be needed to successfully implement these sanitation solutions under different local conditions. Such new business models may range from centrally government controlled and operated models, to dispersed private models with government oversight to ensure that the greater public interest is protected. Professionalization and standardization of sanitation services can help to alleviate concerns about the quality of services, public health and safety, and environmental sustainability.

The vast majority of the fecal sludge management (FSM) market is served by private entrepreneurs, and BCG analysis (using information from the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation) shows that 2.7 billion people are in need of FSM services today (Figure 8), and by 2030 this number is predicted rise to as high as 4.9 billion people if current sanitation trends continue. Today, the global market for FSM services is estimated to be between $5 and $7 billion. For such a prevalent need, this may seem small, but the value is driven by the fact that most households only need to have their septic tanks or pits emptied every one to three years, though this varies considerably across individual markets where high water table and smaller tank sizes can drive higher frequencies.

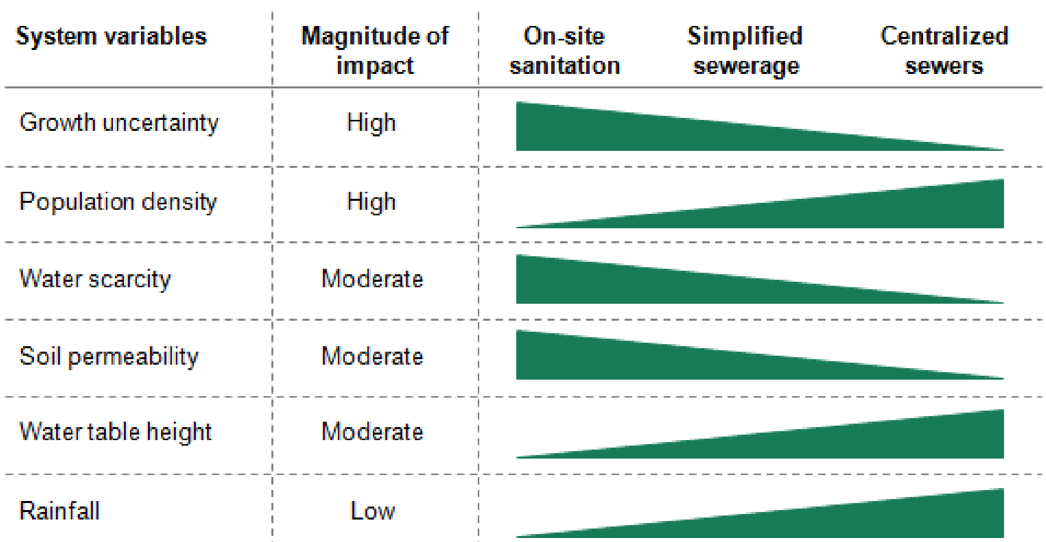
Figure 8. 2.7 billion people worldwide need sludge management today (FSM)



Addressing the sanitation needs of urban populations requires more than just selecting the right sanitation options and developing regulations to reduce environmental dumping. It also requires addressing a fundamental challenge that exists in the system today: In many instances, sanitation providers struggle to collect sufficient revenues from consumers to cover the cost of operations. This limits both the coverage and quality of service that can be delivered. To address this market failure in sanitation, efforts are required to both lower sanitation service costs and increase the revenue that can be generated from providing sanitation.

Each of the different sanitation options discussed in this paper, as well as the many new options currently being developed, will have a role to play in the global sanitation provision effort. We have outlined a simple framework (Figure 9) to indicate how an increase in the value of specific local variables affects the relative attractiveness of different sanitation options (all other factors being equal, an increase in population density makes centralized sewer systems more attractive, while higher uncertainty about future growth pushes the needle in favor of decentralized and on-site systems).

<u>Figure 9</u>. Impact of an increase in the value of different system variables on the relative attractiveness of sanitation options



Some countries are already taking a portfolio approach to sanitation provision for their residents. The Philippines, Malaysia, and Senegal and Burkina Faso, South Africa, are a few examples. In doing so, they are moving away from a primarily sewer-based approach to a more balanced sanitation strategy that incorporates decentralized and on-site systems better suited to local conditions.

In the Philippines, the cities of Manila and San Fernando are deploying a diverse range of sanitation solutions using interesting models of collaboration between government utilities and private service providers (for example, a portion of the water tariff collected by the government utility in San Fernando is used to fund a five-year cycle of septic tank desludging by private operators). In Malaysia, the Indah Water Consortium effectively manages a network of centralized sewer systems and a decentralized sewer-based system, and is also responsible for collection and treatment of septage under a broad sanitation agreement with the government. In Africa, ONAS in Senegal and ONEA in Burkina Faso have taken a lead in using fecal sludge management as an integral part of their urban sanitation strategies. Dakar, Senegal, has combined centralized, decentralized, and on-site systems all operating in different parts of the same city.

The above countries represent a broad range of economic, cultural, and political conditions. However, they all leverage partnerships with the private sector combined with strong sanitation strategies and regulatory support and oversight to create conditions that are conducive to the implementation of a portfolio of diverse sanitation solutions. This portfolio approach has helped them accelerate the provision of sanitation in a flexible, efficient, demand-responsive, and cost-effective manner. We believe now is the time for other cities to follow suit.

Acknowledgements:

We would like to thank the following people for their guidance and input on this paper: Anna Romelyn Almario, Robert Baffrey, Pete Kolsky, Ravikumar Joseph, Catarina Fonseca, Doulaye Kone, Dorai Narayana, Emery Myers, Isabel Blackett, Jelle van Gijn, Julia King, Lindsey Tough, Mai Flor, Max Maurer, Monique Retamal, Sara Rogge, Rosalyn Rush, Suresh Rohilla, and Steve Sugden.

Funding for this paper was provided by the Bill & Melinda Gates Foundation and the Boston Consulting Group.

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