CITY-WIDE SANITATION: THE URBAN SUSTAINABILITY CHALLENGE

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CITY-WIDE SANITATION: THE URBAN SUSTAINABILITY CHALLENGE

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EDITORIAL
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Editorial: City-Wide Sanitation: The Urban Sustainability Challenge

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Editorial on the Research Topic

City-Wide Sanitation: The Urban Sustainability Challenge

The Sustainable Development Goals (SDGs) adopted in 2015 have led to a paradigm shift in how urban sanitation is managed. Targets 6.2 (safely managed sanitation and hygiene services) and 6.3 (reducing the portion of untreated wastewater) now put the focus on managing the entire sanitation chain, encompassing containment, emptying, transport, treatment, and safe reuse or disposal. This has major implications for urban areas, which are a major contributor of untreated wastewater, creating hotspots for environmental degradation and public health hazards (both within and outside of cities) impairing social and economic productivity.

While national water, sanitation and hygiene (WASH) targets increasingly reflect SDG ambitions, aiming to provide universal coverage and reach higher levels of service, this is proving difficult in the urban context. Recent Joint Monitoring Program (JMP) and Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) reports have underlined uneven progress in sanitation coverage, with progress disproportionally benefiting the wealthy, leaving the urban poor unserved (JMP 2019 update). According to the Joint Monitoring Programme, the gap between the richest and poorest has been reduced in 52 countries but increased in 22 countries—mostly countries emerging from conflict (UNICEF/WHO, 2019, p. 34).

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THE URBAN CHALLENGE

Most cities in low and middle-income countries are growing bigger and denser, with vast underserved informal and peri-urban settlements. To achieve the SDG "urban" goals and provide a citywide solution to sanitation, a more integrated and inclusive approach is needed to cover all urban areas. This novel concept supports a blended approach that includes a menu of solutions such as onsite sanitation systems with fecal sludge management (FSM), decentralized or small-scale systems for areas too far from existing sewers or too dense for household solutions and, where this makes sense, piped sewers (e.g., central business districts). Total sanitation coverage for cities in low and middle-income countries will need to comprise a mix of different contextualized solutions. This special edition of Frontiers in Environmental Science provides a deeper insight into the institutional, technological, and socio-economic challenges of the new urban sanitation paradigm.

Equitable services for all urban dwellers are at the core of citywide inclusive sanitation (CWIS). While the exact definition of CWIS is still evolving, the guiding principles first published in 2016 (Citywide Inclusive Sanitation: A Call to Action: https://citywideinclusivesanitation.com/) have since gathered momentum with development partners, governments and service providers in many countries. CWIS thinking rests on four principles: (i) Prioritize the human right of citizens to sanitation—equitable and accessible for all; (ii) Deliver safe management along the whole sanitation service chain, from the toilet to safe treatment and reuse; (iii)

Integrate sanitation in urban planning and renewal, providing liveable and sanitary environments; and (iv) Commit to working in partnership to deliver citywide inclusive sanitation, including formal and informal partners.

While CWIS is still an evolving framework for informing urban sanitation investment programming, Citywide Inclusive Sanitation has already started to shape programming and investments from development banks and major sector actors.

This special Research Topic of Frontiers in Environmental Science is the first collection of academic contributions that seek to conceptualize and frame the new citywide inclusive sanitation paradigm for urban sanitation in low- and middle income countries. We seek to critically evaluate existing alternative approaches to urban sanitation, introducing new city-wide equitable sanitation concepts and solutions. In the 13 papers selected for this special edition, we provide a historical perspective on the emergence of this new approach, a definition of the main features and pillars of CWIS and we provide insights for some of the menu options that make citywide sanitation an actionable and implementable approach for the rapidly urbanizing global South. The special edition is structured in four parts: Part 1 provides an overview of the conceptual framework of citywide inclusive sanitation and defines key CWIS concepts and principles. Papers in Part 2 introduce methods and applied approaches that can help disentangle the complexities of citywide sanitation. Part 3 provides insights on fecal sludge management approaches to safely empty, transport, treat and dispose of or re-use fecal sludge. Finally, Part 4 addresses the role non-conventional small-scale or decentralized sanitation can play in providing equitable access to sustainable sanitation services.

(i) CWIS Concept

Citywide inclusive sanitation as a concept is being continuously refined through on-going debate, practice and implementation. The growing body of programmes and investments informed by the approach already provides opportunity for reflection. In addition, emerging analyses point to ways that the approach could be sharpened to address key urban sustainability issues, including public health, climate change and economic performance.

Two policy briefs provide insight into the CWIS concepts and principles employed by two significant funders of urban sanitation, with a common narrative on the need for radical change from "business as usual." Schrecongost et al. review the genesis of CWIS and lay out core outcomes of the required public service delivery system, namely equity, safety, and sustainability across all areas of a city, not just for sewered areas. They assert that this system must demonstrate three functions: a responsible authority with a clear, inclusive mandate for service delivery; a mechanism to ensure accountability for performance against this mandate; and processes for managing and planning resourcing including financing, assets and human resource. In their contribution, Gambrill et al. also assert that conventional sewerage and wastewater treatment should not be considered the only option and that a range of solutions—both on-site and sewered, centralized or decentralized—must be tailored to the realities of growing cities. The authors point out the need for changed mindsets amongst governments, development agencies and consultants, evolution of engineering curricula to include non-conventional solutions and a rethink on the way sanitation infrastructure is funded.

In their contribution, Mills et al. examine contamination, climate change and costs as three factors that require increased attention to reach key outcomes integral to inclusive citywide sanitation, namely public health, sustainability and economic performance. The authors provide available evidence on these three areas, including fecal contamination risks associated with onsite, decentralized and centralized systems in urban living environments, integration of climate change impacts such as flooding into sanitation planning, and use of cost effectiveness analysis against consistent service objectives to support improved comparison of the mix of sanitation options likely to be appropriate to different contexts across a city.

ii) Methods

Citywide inclusive sanitation as a novel approach to urban sanitation requires an array of new tools and methods to provide answers for planning and programming non-conventional sanitation solutions.

The paper by Narayan et al. investigates if social network analysis (SNA) provide a viable approach that can deal with the complexity of the set of stakeholders involved in the governance of Water, Sanitation and Hygiene (WASH) and the diversity of their interests. The SNA is applied to study the governance of decentralized wastewater treatment in four cities of India). The results corroborate key differences between mega and secondary cities in terms of institutions, community engagement and the overall sanitation situation. These findings are relevant if we are to confront the politics and institutional blockages that prevent the provision of safely managed sanitation for all.

Peal et al. describe a methodology for rapid analysis of excreta flows in urban areas using so called excreta or shit-flow diagrams (SFDs), a methodology that has gained popularity in the last few years. The authors provide the first comprehensive analysis of SFDs conducted in 39 cities with a population of 72 million and provide an insight into the main sources of unsafely managed excreta. The study helps understand sanitation failures at supra-city level, ranging from non-contained fecal sludge in urban areas to wastewater that is delivered to treatment but not properly treated. The paper provides evidence of the urgent need for improved management and monitoring of urban sanitation in cities around the world.

In their contribution on "Sanitation Cityscapes," Scott and Cotton provide a new conceptual framework for citywide urban sanitation that embeds sanitation within wider urban governance. Urban systems are not linear, and the Cityscape provides a conceptual framing of how sanitation services are located with respect to urban residents' demand, tenure, neighborhood typologies (the living environment), the ways services are delivered (the service delivery environment), and the ability of the city to deliver basic services (the enabling environment). They propose 16 core indicators to describe any given sanitation service delivery context using data drawn from an application of the framework in an Ethiopian town.

Mtika and Tilley raise a number of pertinent issues regarding sanitation planning in a small town in Malawi, adopting the Community-Led Urban Environmental Sanitation (CLUES) approach. The 2-year field research revealed that the high turnover of government staff affected institutional knowledge retention, acceptance and continuity and ultimately the potential to engage in a successful planning exercise. Because baseline data was outdated or non-existent, data collection activities consumed unexpected amounts of time. Most importantly, stakeholder participation was limited and relied on participation and transportation payments, which have become a permanent feature of "community development" in many African countries. They therefore propose a simplified version, making use of available data and followed only by small towns with a functioning planning department, adequate tax collection, organized community groups and a budget for final implementation.

iii) Fecal Sludge Management (FSM)

In embracing onsite systems as part of the technology mix, finding solutions to safely empty, transport, treat and dispose of or re-use fecal sludge (FS) is an significant priority.

Russel et al. argue that Container-Based Sanitation (CBS) is now established as a new type of improved sanitation system for poor urban areas that provides a sustainable service for the entire sanitation service chain. The authors outline the main challenges that need to be resolved in order for CBS to reach maturity and scale, including official recognition by local authorities and utilities, improved regulation and innovative financing.

Mehta et al. report on the experience with scheduled desludging of onsite containment in urban India, which sees FSM as a regular service similar to municipal solid waste collection. The paper provides an account of emerging experience with the design and implementation of scheduled desludging to achieve social and environmental benefits in two Indian cities.

McConville et al. present a structured three-step approach for comparing nutrient-recovery FS treatment systems against a wide range of sustainability criteria covering five dimensions: (i) health, (ii) financial, (iii) social, (iv) technical, and (v) institutional. The authors apply the approach in the context of selecting the most appropriate and acceptable nutrient-recovery options for upgrading a FS treatment system in Kampala, Uganda. Used in this way, the approach provides decision-making support for both short-term and long-term investments with a view to deliver citywide inclusive sanitation based on locally specific prerequisites.

iv) Decentralized Sanitation

Bridging gaps between household scale and city scale, decentralized solutions hold significant promise, however their governance, regulation and management poses new challenges, explored in these three contributions.

Reymond et al. investigate the governance arrangements necessary for the successful scaling up of small-scale wastewater treatment plants (SSTPs) in low and middle-income countries, along the whole project cycle, from technology selection to operation and maintenance. Based on the analysis of the scaling up process in India, the study sought to understand why many SSTPs underperformed and identify the required governance arrangements for such systems to fulfill their potential in terms of urban sanitation coverage and water reuse, and their role in citywide inclusive sanitation. The paper explores the concept of a "hybrid governance approach" that blends hierarchical, market, and network governance to foster market regulation and stakeholder coordination and promotes the need for dedicated units at state and city scale to manage distributed systems.

Also with a focus on governance and management, Willetts et al. report on research in Indonesia, where more than 20,000 community-scale systems have been built in low-income urban communities. The study investigated the potential of a co-management approach between city governments and communities, to overcome the current struggles faced by communities unable to cope with the technical, social and financial management of these systems. The proposed co-management approach assists city governments fulfill their legal mandate for ensuring services, and is an important advance given the increasing trend of community-scale systems in low and middle- income countries.

Tackling the critical area of regulation, Schellenberg et al. focus on wastewater discharge standards in India with a view to how these influence the place of innovative, decentralized, ecologically sound solutions, including those that enable re-use. Drawing on examples from other emerging economies and in Western Europe, the paper looks at how revised policy and regulatory approaches could benefit the fertile technology landscape in India, providing new opportunities for creative approaches to urban sanitation.

A FINAL NOTE

These 13 contributions together provide a way forward to tackle the impasse faced in many low- and middle-income country cities in improving urban sanitation services. Central to this, is the acceptance of urban sanitation as a public good that requires governance structures and investments that ensure services for all parts of a city and to all people. Within this, innovation and sustainable solutions can emerge, including at household, decentralized and centralized scales, with an eye to meeting the impending impacts of climate change, facilitating re-use of precious resources including water and nutrients, and, in line with sanitation's core objective, protecting public health.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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POLICY AND PRACTICE REVIEWS
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Citywide Inclusive Sanitation Through Scheduled Desludging Services: Emerging Experience From India

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The focus of Swachh Bharat Mission (Clean India Mission) was to build toilets to make India open defecation free. While India has succeeded in achieving this goal, to move toward "safely managed sanitation" as per target 6.2 of the Sustainable Development Goals, it is necessary to ensure that all fecal waste is safely collected and treated. The common practice for desludging of septic tanks is "demand-based desludging" rather than a regular service. Such practices have adverse social and environmental impacts. To overcome these shortcomings, scheduled desludging is advocated. This paper first reviews the need for regular desludging of septic tanks. It then outlines the emerging experience of design and implementation of scheduled desludging for inclusive, equitable, and sustainable sanitation to achieve social and environmental benefits in two Indian cities. In these cities, a performance-linked annuity payment framework is used to engage a private desludging enterprise. Payment is met through a sanitation tax and transfer from the general property taxes. It outlines the benefits of scheduled desludging in Indian cities and argues that it is critical to achieve improved sanitation.

Keywords: scheduled desludging, India, business models, fecal sludge management, inclusive, citywide, sanitation, private sector participation

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INTRODUCTION

In August 2014, the Government of India launched the Swachh Bharat Mission that aimed to make India open defecation free. Since its launch, nearly six million toilets have been built in cities across India and 83% of cities have become open defecation free (Swachh Bharat Mission, 2019). The challenge now in India is to move beyond toilet construction and ensure safely managed sanitation to meet the sanitation target of Sustainable Development Goal 6 (SDG−6.2). There are lessons from Bangladesh, which was open defecation free in 2015, yet sanitation challenges remained. "The Bangladesh experience has shown that declaring thousands of villages as 100 percent or open defecation free (ODF) is just the beginning of this success story… a lot more needs to be done" (Hanchett and Akhter, 2015, p. 24). Similarly, provision of toilets in Jakarta without adequate attention to the entire sanitation service chain did not improve sanitary conditions. "Although the percentage of residents in Jakarta with access to improved sanitation facilities has reached 87% (2% to sewer systems, 85% to septic tanks), the rivers in the city have become natural sewers" (Japan International Cooperation Agency [JICA], 2012, as quoted in Hashimoto, 2019, p. 2).

In India, of 4,700 cities, only 400 cities have sewerage networks that are connected to treatment plants. "Smaller cities and towns have found it extremely difficult to extend sewerage services, in part because they rarely have enough water, uninterrupted power supply, skilled staff, capital, or planning capacity" (Narayanan et al., 2017, p. 228). These small cities, of populations <100,000, are fully dependent on onsite sanitation systems. In these cities, toilets are usually connected to septic tanks. The design, construction, and maintenance of septic tanks is, typically, the responsibility of households. There are two problems in having safely managed sanitation with this system. First, the septic tanks are not desludged regularly. Irregular and delayed desludging affects the effective functioning of septic tanks. Secondly, emptying charges are high and the poor and low-income households avoid using toilets so that their tanks are not filled up. Further, when the tanks overflow, the septage seeps into the ground and mixes with drinking water sources. This has negative environmental impacts on groundwater and surface water, and eventually on the health of local populations.

This paper is based on the experience of scheduled desludging in the two cities of Wai and Sinnar in Maharashtra (India). Wai has a population of 43,000; Sinnar of 80,000. In Wai, scheduled desludging operations have been going on for nearly a year; in Sinnar, for five months. It is for the first time in India that an effort to desludge septic tanks regularly, as a public service, has been initiated. The paper describes the experience of implementing scheduled desludging services in these two cities. It also reviews various service models for desludging in Asia. The paper also argues that scheduled desludging is inclusive, equitable, and a sustainable fecal sludge management (FSM) practice.

NEED FOR REGULAR DESLUDGING OF SEPTIC TANKS

A septic tank is designed as a preliminary treatment unit where the settled solids are anaerobically digested. The liquid portion or effluent from septic tanks overflows to soak pits or soakaway fields. "The effluent although clarified to a large extent, will still contain appreciable amount of dissolved and suspended putrescible organic solids and pathogens" [Central Public Health and Environmental Engineering Organisation (CPHEEO), 2013, p. 9–18]. The Central Public Health and Environmental Engineering Organization guidelines recommend that the settled solids from a septic tank need to be desludged on a regular basis for it to function well. It suggests that "yearly desludging of septic tank is desirable, but if it is not feasible or economical, then septic tanks should be cleaned at least once in 2–3 years, provided the tank is not overloaded due to use by more than the number of persons for which it is designed" [Central Public Health and Environmental Engineering Organisation (CPHEEO), 2013, p. 9–22].

Studies have suggested that a desludging frequency of <1 year disrupts the biological process and results in lower digestion rates. For example, "anything from 2 to 5 years is required for the biological processes to develop fully within a septic tank and allow the system to operate properly" (Gill et al., 2016, p. 2). "A higher desludging frequency which is more than designed period, results in substantial portion of solids escaping with effluent" [Central Public Health and Environmental Engineering Organisation (CPHEEO), 2013, p. 9–18]. "These unemptied systems can continue to operate for much longer than designed (some systems have been used for more than 20 years without being emptied) but no longer function as septic systems. When eventually such tanks are emptied, the heavily solidified sludge is difficult to pump out or must be removed manually" (SNV, 2019, p. 8).

"In the United States, where 25% of the population uses a septic tank, the Environmental Protection Agency recommends sludge pump-outs every 4 years, but the final decision is left to the users [Environmental Protection Agency (EPA), 1999, as quoted in Hashimoto, 2019, p. 4]. The United States Agency for International Development (USAID, 2010) indicates that in a regularly desludged system, sludge fills less than one-third of the tank. The swiss Federal Institute of Aquatic Science and Technology (EAWAG) recommends desludging a septic tank every 2–5 years (Swiss Federal Institute of Aquatic Science and Technology (EAWAG), 2008). In Japan, desludging once a year is a legal obligation for household packaged aerated wastewater treatment plants (PAWTPs, or Johkasou in Japanese) users" (Hashimoto, 2019).

The results of a field study conducted on septic tanks in Ireland, and states that "a desludging frequency of 3 years is optimal for septic tank systems over 3.5 m^3, depending on household occupancy. Beyond 5 years, however, the sludge volume in some systems had exceeded the recommended volume limit, and so an upper limit of desludging within at least a 5-year period is essential" (Gill et al., 2016, p. 31).

Many countries have their own standards for desludging frequency of septic tanks. A review across countries in **Table 1** suggests that the norm for regular desludging ranges from 2 to 5 years. The two important factors that determine septic tank desludging frequency are number of users and size of septic tanks. Smaller sized septic tank will require frequent desludging as compared to larger sized septic tanks. Similarly, more users mean a higher septage accumulation rate and higher desludging frequency.

In all the countries referred to in **Table 1**, the primary responsibility is of the household to get the septic tank inspected and desludged. However, this is not the case in India and other developing countries. It is usually the responsibility of local governments to inspect septic tanks. Some local governments in India do provide desludging services for a fee, but only when they are called upon to do so. In many cities, it is the unregulated private desludgers who provide this service. The desludgers are called only when there is backflow from the tank to toilets or the tank is overflowing and the neighbors complain. Under these circumstances, the desludgers often charge high user fees (US$40–70). In the absence of any fecal sludge treatment plant nearby, the desludged septage is let out in water bodies or on open grounds or is used on farms without treatment.

TABLE 1 | Standards for frequency of septic tank desludging.

	Country	Septic tank desludging frequency	Agency setting the norm
1	India	2–3 years	Central Public Health and Environmental Engineering Organisation (CPHEEO), 2013
2	USA	Every 3 years	Environmental Protection Agency (EPA) (2005), A Homeowner's Guide to Septic Systems
3	Australia	Every 5 years	Department of Health, Australian Government, 2010
4	Ireland	5 years or depending on the septic tank capacity and the number of people living in the house	The Water Services (Amendment) Act 2012
5	Malaysia	Every 2 years	MS 1228 on Design of sewerage system [Standards and Industrial Research Institute of Malaysia (SIRIM), 1991; Span, 2009]
6	Philippines	Inspected at least once a year and be cleaned when the bottom of the scum mat is within 7.50 cm (3 inches) of the bottom of the outlet device	Sewage Collection And Disposal, Excreta Disposal And Drainage Of The Code On Sanitation Of The Philippines (P.D. 856.) (Department of Health, Manila, Philippines, 1995)
7	Canada	Inspect the system every 3–5 years and pump out the solids and scum when required	Ontario Septic Smart-Understanding Your Home's Septic System; Canadian Environmental Protection Act (R.R.O, 1990), Reg. 358: sewage systems (Last amendment: O. Reg. 244/09.) (R.R.O, 1990; WHO, n.d.)

SCHEDULED DESLUDGING—EXPERIENCE FROM TWO CITIES IN INDIA

Scheduled desludging represents a planned effort to ensure regular desludging. In this, every property is covered along a defined route and the property occupiers are informed in advance about desludging. The local governments of Wai and Sinnar in India decided to introduce a scheduled desludging through a public private partnership (PPP) arrangement and built fecal sludge treatment plants. Scheduled desludging in the two cities is provided as a municipal service to all properties. This makes it inclusive as all properties in the city receive the service. This includes both residential and non-residential properties. Low income households and those staying in slums are also being able to receive the service.

Scheduled Desludging Through Public Private Partnership

The desludging service is provided in these cities as per a planned schedule to cover all residential and non-residential properties over a 3-year cycle. For this, the city area has been divided into three zones and each zone is planned to be covered in a year. Desludging is done by a private company that has entered into a performance-linked annuity contract with the local governments. The payment to the private provider is made by the local government against the targeted performance. A "sanitation tax" is added to each property tax bill to cover the payments made by local government to the desludging company.

Performance-Based Payment Contract

A "performance-based" contract for desludging was developed for these two cities. Payments under this contract are made against the number of septic tanks emptied and safe discharge at the designated treatment site. The key clauses in the contract enforce high performance standards and safety compliance at the time of desludging septic tanks, requirement of safety gear for workers, quality of suction trucks, cleaning up of spillage, etc. This contract is a service level agreement which protects the interests of all parties—private sector, city governments, and citizens. It has helped the local government to receive good quality regular desludging services for all the properties. While the private service providers make investments in trucks, they get a fixed business and assurance of monthly payments against number of septic tanks emptied.

The private service provider in each city was competitively selected through a standard government e-tender process. In both cities, the bid price for desludging a tank was one-third of the charges levied for demand desludging. The total annual contract value was only 1.8% of total annual revenue expenditure of local governments. It was thus possible to fund this activity through local budgets, but both cities decided to levy a "sanitation tax" to fund this activity.

The risk of late payment by local governments was raised by several private service providers in pre-bid meetings. To mitigate this, an escrow account mechanism—a tripartite agreement between the local government, private sector, and a local bank—was introduced. The local government is required to keep 3 months of contract payment as a reserve fund to safeguard against risk of payment. **Figure 1** depicts the performance-linked annuity model for scheduled desludging services implemented in Wai and Sinnar.

Financing Scheduled Emptying Through a Sanitation Tax

For financing the scheduled desludging services, both cities have levied a sanitation tax. The sanitation tax is part of overall property tax which is paid annually by property owners to local governments for various services. This allows the tax to be more equitable as those with larger and better properties pay a higher property tax. This will also make the desludging service more affordable for the low income groups. The sanitation tax ensures that adequate funds are available for annuity payments to the private service provider. The amount collected from sanitation tax is sufficient to cover annuity payments for scheduled desludging in Sinnar city, while local government in Wai has to allocate both sanitation tax and some transfer from property tax for financing the scheduled desludging service. The local government of Wai is planning to increase the sanitation tax incrementally over the years. The introduction of sanitation tax and scheduled desludging services were welcomed by the

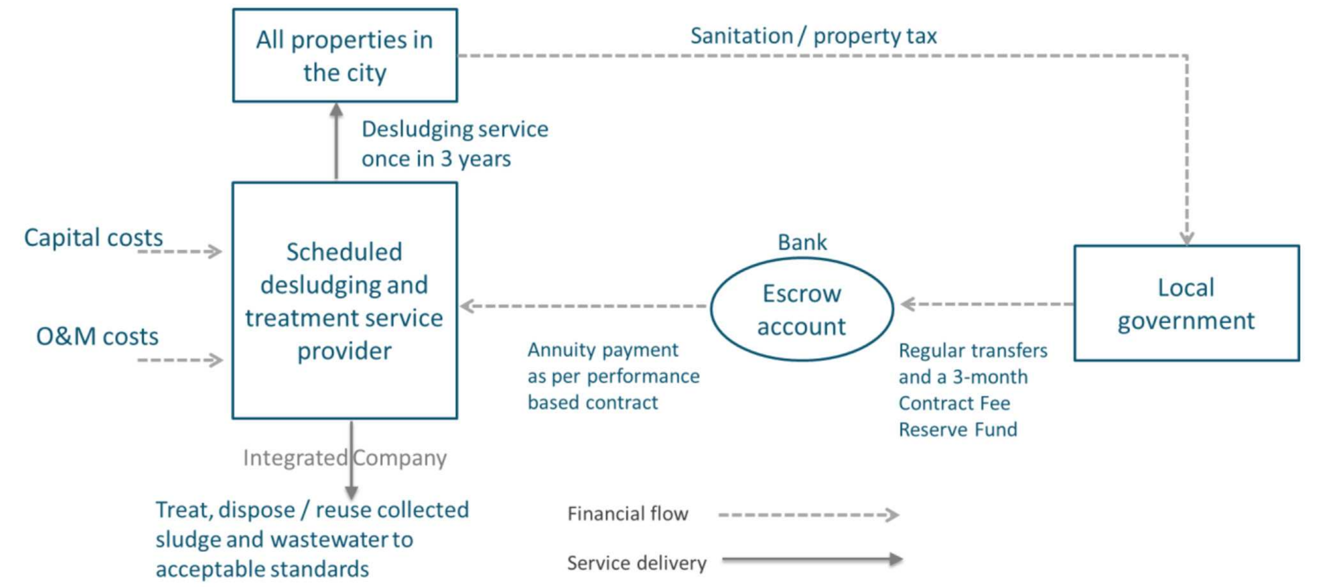

FIGURE 1 | Performance-based Annuity Model for Scheduled Emptying. Source: CWAS, CEPT University.

households of both cities. This was because, as they did not have to pay any money at the time of actual desludging, it was considered as a regular and "free service" provided by the local government.

Awareness Activities

To ensure successful implementation of the scheduled desludging plan, local government officials, and leaders also carried out awareness activities to sensitize their residents about the importance of regular emptying and treatment of septage. This involved promotional campaigns through local media as well as door-to-door outreach programs to inform households about the plan and its benefits. The awareness material covered important aspects such as need of septic tank emptying, details of the local government scheme, how the citizens should be ready, and what to expect during the process of desludging, etc. Along with local government, the private service provider was also responsible for carrying out awareness activities. Such activities were strategically planned for zones where scheduled desludging is ongoing. Local leaders and citizen representatives were involved in awareness activities to ensure their commitment and citizens' acceptance for the successful implementation of the sanitation plan. As a result, residents have embraced the scheduled desludging service and are prepared when the desludger arrives at their doorstep as per the schedule.

Provision for Emergency Services and Apartments

Despite the availability of scheduled desludging, there is always a need for "emergency" desludging from other areas which have not been covered by the service so far. For emergency cleaning, property owners have to first inform the local government instead of calling the private operator directly. The local government inspects and verifies these requests before asking private operators for desludging. About 20% of desludging is done in response to emergency requests. One key issue in the performance contract concerns the number of properties served by a single septic tank, as the payment is made per septic tank serviced. In Sinnar, this has been addressed by making adjustments in the contract to account for this in case of apartment properties.

Monitoring Quality of Groundwater and Rivers

It is expected that regular desludging services will eventually improve the quality of both river water and groundwater. For assessing this, water quality monitoring has been initiated. The water quality monitoring regime was prepared to identify sample locations, parameters to be tested, and sampling procedure for collecting the samples. This was based on the guidelines provided by the Central Pollution Control Board and the Maharashtra State Pollution Control Board. A study was conducted to test the quality of effluent flowing in drains, groundwater, and river water quality at the start of implementing the scheduled desludging. These tests will be repeated every year for the next 3 years to track improvement in water quality. The authors hope to report results of these tests in the near future.

Result of Scheduled Desludging Services in Wai and Sinnar, India

In Wai, over the year, 1,500 properties received desludging services and over 4.8 million liters of septage was delivered and treated at the fecal sludge treatment plant. Nearly 95% of the households and property owners have welcomed scheduled desludging service. In Sinnar, in 5 months of operations, 686 properties received desludging services and over 2.85 million liters of septage was delivered and treated at the fecal sludge treatment plant. The acceptance rate in Sinnar was 80%. The few who did not accept the service in both cities were the ones whose tanks had been desludged recently.

The scheduled desludging program initially faced some challenges. The residents were informed 2 days prior of their turn of desludging and were asked to keep their septic tank cover open on the day of desludging. But many septic tanks did not have a proper access cover or were sealed in such a way that it was difficult for the households to open it. This resulted in delays in desludging and affected operational efficiency. To overcome this challenge, the local government appointed a mason who would go along with the desludging operator and help open the seal as well as close it after desludging. This has helped in increasing operational efficiency. The other challenge was the lack of a proper repair service during breakdown of desludging vehicles. The pump stopped functioning when the septage was too thick. The desludger has replaced the suction pump in Wai with a higher capacity and it functions well now. But major breakdowns of desludging vehicles were repaired at the desludgers' head office, nearly 70 km away. This meant that desludging operations had to be curtailed for a day or two.

Three months prior to the introduction of scheduled desludging, awareness campaigns were launched in both cities. As a result of these campaigns, residents from all over the city started demanding desludging services. So the campaign had to be redesigned and launched only in the zone that was designated for desludging.

These initial challenges have meant that the desludger has to work harder to achieve the monthly targets set in the contract. The contract terms have also been revised to take into account the unforeseen delays in desludging operations. The "model" contract for scheduled desludging has also been revised accordingly, so that other cities in India that are planning for scheduled desludging can use this revised contract.

POTENTIAL BENEFITS OF SCHEDULED DESLUDGING IN INDIAN CITIES

Regular desludging is recommended by several countries for the safe and proper functioning of septic tanks. The emerging experience of scheduled desludging in these two Indian cities suggests several benefits including safe, inclusive, and affordable sanitation systems. In addition, the desludging charge is covered through sanitation tax linked to property tax. Thus, households do not pay any fee directly to the desludger. Such a scheduled emptying service has high acceptance and can help achieve a number of benefits.

Achieves the Norms Through Regular Desludging

Service performance information from five states in India covering more than 900 cities suggests that septic tanks are not desludged regularly (https://www.pas.org.in). Detailed surveys were conducted in the two cities of Wai and Sinnar before the implementation of scheduled desludging, to understand the baseline situation (household size, size of septic tank, connection of septic tank outflow, accessibility of septic tanks from roads, when desludged last, payment for desludging, etc.), and develop an implementation plan. These surveys suggested an average desludging frequency of around 10 years in Wai and Sinnar. With the implementation of scheduled desludging in these cities, desludging is planned for once in 3 years for all septic tanks.

Reduces High Prices of Desludging

Demand-based desludging practices are often hard to regulate and result in high prices for desludging, especially for the poor and in small towns. In Maharashtra, where such data are available through, prices range from INR 3,000 to 5,000 (US$40–70 per trip). Households generally pay these high charges as a "distress price" as they have no other recourse. These high charges also indirectly affect the sustainability of an open defecation free city situation, as some household members may choose to defecate in the open so that the tank does not become full. Desludging charges are generally higher in smaller cities and in areas outside the local government boundaries. This is often the case as the private desludgers are usually based in large cities, where they have better business. In smaller towns, their travel costs are added to those for providing services, resulting in higher prices. As a consequence, in some small cities, a high fee of INR 7,000 (US$100) per trip is charged. Instead, when scheduled desludging was introduced in Wai and Sinnar, the desludgers charged INR 800 (US$12). Thus, scheduled desludging has reduced the charge by nearly one-third. It is important to note that for a private enterprise, there are fixed costs related to overhead and office establishment which decrease by increasing the volume (for example, number of tanks that are emptied). Under a scheduled emptying regime, the market size in terms of number of septic tanks to be emptied every day is known. Private enterprises use their trucks optimally by proper route planning and reduce their operational costs significantly.

Removes the Need for Manual Labor

Lack of regular desludging also has adverse social impacts as the need for manual labor increases with the hardening of sludge inside septic tanks and pits. In India, manual scavenging is a criminal offense under the Prohibition of Employment as Manual Scavengers and their Rehabilitation Act of 2013. It prohibits use of insanitary latrines, and employment and engagement of manual labor for cleaning of sewers and septic tanks. However, despite this, a large number of manual workers are employed for this work. A government survey has identified 54,130 people engaged in this job as of July 2019 (Sen, 2019) and more than 600 workers have died while cleaning septic tanks and sewers across the India as reported by the National Commission for Safai Karamcharis [NDTV (New Delhi Television), 2018]. Regular desludging in these two cities of Maharashtra has eliminated the need for manual workers.

Improves Environmental and Public Health Impacts

Irregular and delayed desludging can also result in increased chances of accidental overflows of fecal matter from septic tanks to open drains. In addition, overflow of supernatant with pathogens leads to groundwater and surface water pollution and other adverse environmental impacts. A study by Gretsch et al. (2016) conducted in four low-income neighborhoods in Accra, Ghana, showed high levels of fecal contamination in open drains.

The authors carried out a study of open drains in cities in Maharashtra, including Wai and Sinnar. Tests of drain water in Wai showed BOD levels of 346 mg/l and fecal coliform levels of >1,600 MPN/100 ml. In other cities, the open drains, where supernatant from septic tanks and gray water mixes, showed fecal coliform levels of >1,600 MPN/100 ml. This drain water goes to the river, thus affecting the quality of the river water. At the downstream end of the river, fecal coliform is >1,000 MPN/100 ml. Groundwater is also affected due to overflows from septic tanks. Ninety-five percent of the samples in these cities showed fecal coliforms levels ranging from 100 to 900 MPN/100 ml.

In contrast, initial results from the zones of two cities where scheduled desludging has been initiated, show that fecal coliform in open drains is below 100 MPN/100 ml. However, we cannot yet establish that there is a direct impact on the health of people in these two cities.

"Linking sanitation services and health impacts is complex" (Mills et al., 2017, p. 2). It is expected that improved sanitation services through regular desludging and proper treatment of fecal sludge will have positive health impacts. However, impact on public health is always difficult to measure and attribute directly to improved sanitation. "While the magnitude of direct health impacts is uncertain, it is generally accepted that inadequate sanitation and exposure to fecal pathogens affect health, and there is growing evidence that the burden of disease may be higher due to long term effects of environmental enteropathy and stunting" (Mills et al., 2017, p. 2).

Links With Local Taxes Rather Than With User Charges

Sanitation is a public good and most public goods are partially funded through taxation. In this vein, scheduled desludging in these two cities is provided as a service by the city government, and is linked to sanitation/property tax. This practice is adopted in other countries as well. Robbins et al. (2012) suggests that in the Philippines, except for Dumaguete, which charges a small user fee, other cities have either a flat tax linked to property tax or a surcharge on water fees. One advantage of this approach is that no user charge/fee has to be paid at the time of emptying. This makes it attractive for property owners to avail of desludging services when their turn comes. This is evident from experiences from India and the Philippines where there is a good response to emptying, because users of the service perceive this as a public service like garbage collection, paid through taxes. In contrast, in Malaysia and Indonesia, which relied on user charges to be paid during desludging, the response to scheduled emptying has been poor (See CEPT University, 2019b).

SERVICE MODELS FOR FSM USING SCHEDULED DESLUDGING

In the case of sanitation, and particularly FSM, it is important to recognize that sanitation is, foremost, a public service. For example, the new World Health Organization's Guidelines for Sanitation and Health suggest to "define sanitation at sub-national level as a basic service for which local government is responsible and accountable" [World Health Organization (WHO), 2018. p. 21]. So instead of the usual "business model," it is treated as a "service model" in this paper.

A service model is defined as model for a public service and outlines the manner in which a service is structured financed, and management arrangements made for its delivery. Appropriate service models are needed to ensure that these services are provided in a sustainable manner, and the related institutional and financing arrangements need to fit within the prevailing regulatory regimes.

Experience in Scheduled Desludging in Asia

Scheduled desludging has been initiated in several Asian counties including the Philippines, Malaysia, Vietnam, Indonesia, and India. The experience varies across these and provides some key lessons.

The Philippines

FSM activities were initiated in the context of the National Sewerage and Septage Management Plan in 2012. It provided up to 40% of costs of sewerage or septage management programs of local cities and municipalities. Robbins et al. (2012) provide details of the approaches used in different cities where scheduled regulated desludging is being successfully implemented—Dumaguete, San Fernando, Baliwag, Metro Manila, and others.

In both Dumaguete and Baliwag, desludging services are provided jointly by city local governments and water districts. The city water districts are responsible for investing in trucks' capital and operational cost, while local government operates and maintains treatment plants. The scheduled desludging service follows a cleaning cycle of 5 years and households pay the desludging charges as part of their monthly water bill, at tariff of PHP 2.00 (US$0.05) per cubic meter of water consumed. The local ordinance developed in Dumaguete serves as a good model for scheduled desludging by establishing clear septage management policies and institutional arrangements. It involved establishing clear standards for septic tank size, desludging frequency, septage treatment, user fees and penalties, and monitoring mechanisms. Furthermore, in Dumaguete, a City Septage Management Authority was established, comprising representatives from the local environmental, health, water, engineering, legal, and financial departments. This has ensured smooth functioning of the program and promotes inter-agency coordination. In Metro Manila the private sector provider, through a PPP for water and sanitation, provides fecal sludge management services in areas not served by sewerage. For this, an environmental fee is charged at 20 percent of the water bill.

Malaysia

Between 1993 and 2013, the government nationalized sewerage services and provided regulated septic tank desludging services through a private concession to Indah Water Konsortium (Indah Waters, 2019). It was responsible for the scheduled desludging program and there was good uptake from 2005 to 2007. This program faced some challenges post-liberalization as there was weak enforcement of septage management policies. The scheduled desludging was not provided as a regular service, and the regulatory agencies did not fine households that failed to do scheduled desludging as per the law (Narayana, 2017). A key reason for the poor sustainability of the program in Malaysia was also the direct user charges that households had to pay, which reduced demand. On the other hand, low collection meant inadequate funding for regular operations. Malaysia now plans to reintroduce scheduled desludging services, learning from the examples of the Philippines and India.

Indonesia

The Government of Indonesia has taken up a program to introduce scheduled desludging in 69 cities across the country. This model is based on requisitions from customers following an intensive awareness campaign. A mobile app is used for households to request desludging services; they need to register on the online platform and inform about their desludging period. Based on this, a scheduled service is provided either by local government or a private service provider. A dashboard is prepared to monitor the activities of the desludging vehicles. Foort (2018) points out that early and strong commitment of city leadership is needed. The program started with user charges where a cost recovery tariff is used to "cover all direct operational cost of collection, treatment, and direct management" (p. 4). However, Foort (2018) suggests that there is a realization that the "most efficient billing is a for a water utility to combine with the monthly water bill. If that is not possible, it might be possible to combine with property tax" (p. 10).

Vietnam

Scheduled desludging practice was introduced in Hai Phong. The service was provided by the Hai Phong Sewerage and Drainage Company. The desludging interval was 5–6 years for household septic tanks and 1–2 years for apartment buildings. In Hai Phong, scheduled desludging service for communities was free of charge. The government has increased wastewater fee as 15% of the water fee in Hai Phong city as compared to 10% in other cities. The private firm was allowed to use the entire wastewater fee to recover expenses of scheduled desludging service. However, it was observed that business was incurring losses and part of the expenses had to be paid from the city's budget. "The main reasons of loss as stated are high annualized depreciation costs, and limited number of trips per truck per day which is much less than break-even point as per their financial analysis" [Institute of Environmental Science and Engineering (IESE), 2011, p. 119]. The company planned to continue scheduled desludging services with further increased wastewater tariff and through sale of compost from treatment systems to make its fecal sludge management business sustainable.

Thailand

Private sector-led integrated FSM services to a cluster of settlements have been adopted in Rayong District in Thailand. Thongthawil Service Co. Ltd. provides septage desludging and treatment services in two municipalities and eight subdistrict organizations. The same private firm operates both desludging and treatment services for a group of nearby cities. Annual license fees are collected from the private sector for providing desludging and treatment service. This model offers the option for funding both conveyance and treatment from households through surcharges as a bundled price. An integrated model combining desludging and treatment is a promising model offering high efficiencies, convenience, and easier contracting, with the same player responsible for operations across the value chain.

Leh, India

The Leh Development Authority, in the Ladakh region of the state of Jammu and Kashmir in India[1], initiated scheduled desludging integrated services with Blue Water, a private company. It entered into a 5-year contract wherein Blue Water will design, finance, build, and operate the fecal sludge treatment plant on the land provided by the Authority. It will also operate desludging trucks provided by the Authority. In this arrangement, the Leh Authority collects user fees, and 90% of fees are given to the private operator after the service is delivered. This fee covers operational costs and a part of the capital costs for the treatment plant. Differential fees are charged to households and commercial properties of hotels and guesthouses. Through this model, it becomes possible to cross-subsidize services for poor households.

Five Emerging Service/Business Models

These examples clearly reflect the strong potential and applicability of scheduled desludging models in varied contexts across several Asian countries. Some of the benefits of a scheduled desludging model are improved performance of septic tanks, equitable, and affordable payments by households as part of their monthly water bill, and ensured income for private service providers. Experiences in Dumaguete (the Philippines) and Malaysia also suggest the need for careful design and creating user awareness. It is also important to design scheduled desludging models that are financially viable to ensure sustainable services in the long run. Where it is difficult to fully finance scheduled desludging services through taxes or surcharge of water bills, it will have to be partly financed by local governments.

Based on the various examples from Asia reviewed above, and drawing on CEPT University (2019a,b) data, **Table 2**

[1]Since October 31, 2019, Leh and the erstwhile state of Jammu and Kashmir are separate Union Territories.

TABLE 2 | Service/Business Models for Scheduled Desludging.

Model description	Benefits	Need to address	Applicability	Cases
1. Scheduled Desludging—PPP Annuity Model: Private service provider brings trucks and operates through a performance-based contract to carry out scheduled desludging on predetermined schedule set by local government. Fees as per the bid are paid to private operators per septic tank emptied. The city collects a sanitation tax or a surcharge on water to cover the payment of fees	Reduces the capex burden for local governments; results in higher service levels; guaranteed fees result in competitive bid prices	Significant information, entertainment and communications (IEC) needed to convince households for desludging; proper monitoring of private sector activities	Presence and willingness of private sector to invest in trucks and capex, and take on contracts; local government has capacity to monitor operations	Wai and Sinnar, Maharashtra, India; Dumaguete, Baliwag, Maynilad and Manila, Philippines
2. Scheduled Desludging—Private Sector Partnership (PSP) Annuity Model: The only difference from the above model is that private service provider leases or operates local/state government trucks and carries out desludging operations on a performance-based contract. Fees determined as per the bid	Government capex may incentivize more and smaller private providers to participate	Proper monitoring of private sector activities; possible lack of maintenance of trucks by private operator	Private sector presence, but low capacity to invest, while local/state government has financial and monitoring capacity	Hai Phong, Vietnam; Odisha; Gevrai, Maharashtra, India
3. Scheduled Desludging on Requisition: Regular desludging service is provided to only those households that request regular desludging on the household register on the online platform; the private operator then informs households about their regular desludging period and provides service	Can be explored as a potential model for transition from on-demand to scheduled desludging	Focus on IEC to generate buy-in by household/property owner	Applicable in areas where there is considerable variations across properties in containment sizes in a given city	Indonesia
4. PPP/PSP-based Integrated Model with Treatment and Scheduled Desludging: The same private firm operates both desludging and treatment services in the city. The treatment facility may be funded by the government or by private sector fully or partially. The trucks are funded by the private firm. Recovery could be from the government (PPP contract) or from desludging charges. Desludging charges from households are the source of opex funding for collection, transport, and treatment. Charges are collected directly by the operator (user charges), or indirectly through the government (FSM taxes), which then pays the operator	Integrated models offer efficiencies, convenience, and easier contracting, with the same private provider	Dependency on a single player: compounds risk of non-performance; and crowds out existing smaller players	There are private players with capacity to manage both treatment and desludging operations	Leh, Jammu and Kashmir, India
5. PPP/PSP-based Clustered Integrated Model with Treatment and Scheduled Desludging: As above, except that the same private firm operates both desludging and treatment services for a group of nearby cities	Cluster approach and co-treatment can provide efficiencies in treatment facilities	Cooperation among cities; efficient road connections	As above, but where the nearby cities are willing to come together for a cluster approach; or where a private provider has the capacity to work with several nearby cities	Thailand (Thongthawil Service Co. Ltd.)

Sources: Based on the Landscape studies for Fecal Sludge and Septage (FSSM) Financing and Business Models across four states by CEPT University (2019a,b) (pp. 68–78, 110–118).

describes five models for scheduled desludging. While scheduled desludging is viewed as a public service, the service models recognize the important role of private sector providers in service delivery. Based on experiences from Leh (India) and Thailand, an integrated model that combines services for desludging and treatment by the same service provider is also possible. This model can also be relevant for combining services in rural and urban areas through a cluster-based model. It is also recognized that for larger metro areas, two or three private operators can be appointed using any of these models to serve different areas or zones. This service model can be applicable for all metros or large cities across India.

WAY FORWARD

The paper has highlighted the experience of two cities in India where a scheduled desludging model is practiced. It clearly reflects that scheduled desludging is needed to ensure proper functioning of septic tanks. Scheduled desludging fees as sanitation tax and linked to property tax or water bills are more acceptable to households. This also helps achieve equitable service by including the poor and low-income settlements; helps in cost optimization and thereby reduces payment burden; improves health and safety practices by removing the need for manual cleaning; and achieves positive environmental impacts.

Given the multiple benefits of scheduled desludging services in the Indian context identified above, and the positive experience from the initiative in two cities, it is now being considered by other cities and states in India. The Government of India has recognized the importance of regular cleaning and has recommended desludging of septic tanks at 2-year intervals. Its national FSM policy envisages "Scheduled emptying of septic tanks or other containment systems at an interval of 2–3 years as recommended by the Central Public Health and Environmental Engineering Organization" (Government of India, 2017). This is also critical to ensure universal access to safely managed sanitation services in urban India by 2030.

However, it is also important to note that implementation of scheduled desludging practices require local government commitment, multiple stakeholder involvement and coordination, a focus on awareness activities, strong monitoring systems, and the availability of a treatment facility of adequate capacity. Scheduled desludging practices are also envisaged to lower costs and have positive impacts on public health and environment.

More detailed studies across service models in different counties are needed to identify key practices and develop standard operating procedures, as well as to assess the environmental and health impacts.

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MM, DM, and UY contributed to the research topic City-Wide Sanitation: The Urban Sustainability Challenge and contributed to the research and wrote the manuscript.

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Taking Container-Based Sanitation to Scale: Opportunities and Challenges

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Container-Based Sanitation (CBS) has rapidly progressed from its inception less than a decade ago to its recent classification as a type of improved sanitation facility by the Joint Monitoring Programme. CBS in many ways represents a sustainable service, as it addresses the entire sanitation service chain; offers a variety of service-based business models; and is affordable to people living in marginalized and informal urban settlements. At the same time, CBS services which have been operating for a number of years have grown relatively slowly. Taking CBS to scale will require solving several diverse challenges, particularly the need for government mandates; regulation; and innovative financing. This paper presents the collective views of some of the world's leading CBS practitioners in an effort to summarize the potential, research gaps, and major challenges to scaling CBS.

Keywords: container-based sanitation, sustainable sanitation system, scale-up, safely managed sanitation, urban sanitation, innovative financing, government regulation, improved sanitation services

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INTRODUCTION

Sustainable Development Goal (SDG) target 6.2 aims to provide "access to adequate and equie sanitation and hygiene for all and an end to open defecation." The objective's indicator is based on the proportion of the population using safely managed sanitation, rather than obtaining access to a basic toilet. Thus, government agencies and municipalities need to upgrade ∼4.5 billion people globally to safely managed sanitation services by 2030 (JMP)[1]. This monumental task falls primarily upon low-income countries and rapidly growing informal urban settlements, which often have large populations coupled with small implementation budgets. Choosing the most sustainable methods and infrastructure for providing sanitation services to all remains a vexing challenge (Whittington et al., 2008, 2012; Jeuland et al., 2013).

SDG target 6.2 is more demanding than the Millennium Development Goal targets. Nevertheless, it provides an impetus to pursue more effective approaches that can serve the entire sanitation value chain. One such example has been the rapid development of container-based sanitation (CBS). CBS consists of an end-to-end service in which toilets collect excreta in sealable, removable containers (also called cartridges). The containers are regularly collected and transported to treatment facilities when full. Since 2010, modern CBS iterations have rapidly evolved into a viable, low-cost sanitation option, particularly in low-income urban settlements where demand for sanitation services is high and on-site sanitation and sewerage are not feasible or cost-effective (O'Keefe et al., 2015; Russel et al., 2015; Tilmans et al., 2015; Nyoka et al., 2017). While transporting waste in containers is not a new concept, doing so in a cost effective, safe and

[1] JMP. (2017). "Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines."

desirable manor has been a significant improvement over previous systems (Nilsson, 2006; Letema et al., 2014).

CBS services have been provided by social enterprises or NGOs, and several city utilities (such as Cape Town and Manila) are adopting CBS as part of their approach to citywide inclusive sanitation (CWIS). Revenues come from customer service fees and the sale of waste treatment by-products, including compost; protein (for animal feed); and energy (Preneta et al., 2013; Foote et al., 2017). It is important to note that CBS service are not cost recovering currently and some amount of philanthropic or public financing is still necessary.

In 2018, the JMP formally recognized CBS as a type of improved sanitation facility[2]. The CBS full value chain approach follows the SDG definition for "safely managed" household sanitation (6.2), even in disaster and humanitarian emergency conditions.

However, as noted in a 2019 World Bank report, despite having been operational for a number of years, most CBS services are still operating in relatively early stage development[3]. This slow growth can primarily be attributed to the serious challenges of operating a utility service focused on the urban poor in the absence of an enabling environment supported by government mandates and regulation.

DISCUSSION OF CBS SERVICE POTENTIAL

CBS has several attributes that enable it to complement the existing suite of sanitation solutions to provide a robust citywide sanitation portfolio.

Flexible, Adaptable, and Modular

CBS has typically been used where it is infeasible or inappropriate to install sewerage systems, such as in densely populated urban neighborhoods, informal settlements, displaced person camps, or areas with high water tables or risk of frequent flooding (O'Keefe et al., 2015; Russel et al., 2015; Greenland et al., 2016; Nyoka et al., 2017).

Traditional sewerage systems require significant up-front capital investment and reliable water and energy supplies to function (Haller et al., 2007; Hutton, 2008; Massoud et al., 2009). Simplified sewers which have been successfully implemented for lower costs than traditional sewers in Brazil and Pakistan also need reliable water supplies (Mara and Alabaster, 2008). Highly professionalized, well-resourced utilities are also required to operate and maintain traditional sewers. Installing sewers may additionally be politically challenging, and can confer legitimacy on squatter settlements, disrupting the integrity of property laws (McFarlane, 2008; Scott et al., 2013; Meeks, 2018). Waterborne sewerage alone is thus unlikely to achieve SDG target 6.2, and calls are increasing for the use of more non-networked options (Mara and Evans, 2018).

[2] JMP. (2018). "Core questions on drinking water, sanitation and hygiene for household surveys: 2018 update."

[3] WB. (2019). "Evaluating the Potential of Container-Based Sanitation."

In contrast, CBS toilets have a lower capital burden, require less water and energy to operate, and require limited infrastructure or installation, allowing users continuous service even after a move (**Figure 1**). In addition, CBS has the potential to be deployed in new areas and quickly scaled to match refugee, emergency, or disaster response needs (Nyoka et al., 2017).

Due to the relatively nascent nature of CBS, operators have typically had to act as designers, developers and builders, all while trying to meet health and safety standards for the entire sanitation value chain. However, the individual modules of the CBS value chain could be plugged into existing CWIS systems to strengthen overall sanitation service delivery. For example, Sanivation treatment plants accept both CBS and pit latrine waste, Sanergy integrates organic solid waste into its treatment process, and Clean Team disposes of waste at government treatment facilities.

Reducing Water Usage

The use of water to convey waste creates interdependency between the SDG sanitation target (6.2) the SDG water target (6.1). However, it is impractical in many regions to expect water availability and infrastructure to be able to support the implementation of sanitation in addition to providing basic water access. Instead of water, CBS uses dry cover material (sawdust, charcoal powder or unused by-products of agricultural production) or polymer film (e.g., Loowatt) for "flushing[4]". Water savings using dry or minimal-water systems like CBS as compared to water-flush systems can vary from 6 m^3/person to 25 m^3/person annually, depending on waste separating techniques (Andersson, 2016). Such water saving solutions are becoming more crucial as global cities struggle with the increasing likelihood of water shortages (Muller, 2018).

Combating Climate Change

Sanitation is a significant contributor of greenhouse gas emissions (GHG), producing ∼2–6% of global anthropogenic methane (Saunois et al., 2016). As urban populations grow, the use of rudimentary sanitation systems like pit latrines, septic tanks, and waste settling ponds will increase sanitation-related GHG emissions, potentially undermining efforts to slow climate change (Reid et al., 2014; Ryals et al., 2019). Thus, increased access to sanitation could be linked to increased GHG emissions, unless the prevailing sanitation paradigm shifts to climate-positive sanitation solutions.

A recent study in Haiti found the CBS system there produced less net GHG emissions compared to both waste stabilization ponds and illegal dumping (Ryals et al., 2019). Furthermore, depending on the resource recapture and reuse technology employed during treatment, CBS, unlike other sanitation systems, could contribute to carbon sequestration (Ryals and Silver, 2013; Paustian et al., 2016). CBS toilets produce less diluted or decomposed waste, which is ideal for reuse because it has not been mixed with graywater in sewers or stored in a pit for extended periods of time. As a result, fecal waste from CBS systems often produces higher quality reuse

[4] Dry cover material acts as a visual barrier, smell reducer, and desiccant.

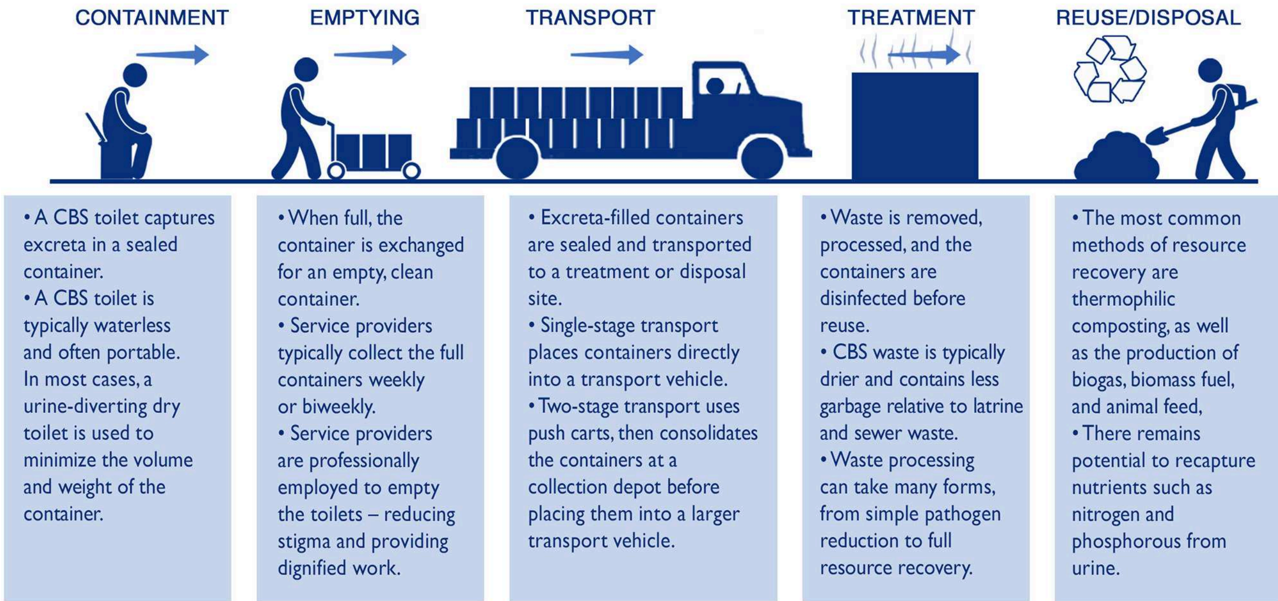

FIGURE 1 | CBS sanitation value chain.

products like biomass and biogas fuels, fertilizer, or animal feed. Hence, CBS could allow for simultaneous progress toward increasing global sanitation access and reducing sanitation-related GHG emissions.

Hygienically Safe

CBS services encompass the full sanitation value chain, and therefore meets the requirement for safely managed sanitation according to the WHO. Assuming feces are properly handled throughout the service chain, including treatment and safe disposal/reuse, CBS is likely to be an effective solution for limiting the spread of fecal contamination within household and community environments (Preneta et al., 2013; Russel et al., 2015; Foote et al., 2017; Mackinnon et al., 2018; Bischel et al., 2019).

Protecting Women and Girls

Two recent reports from the Bill and Melinda Gates Foundation on gender and sanitation noted that in-home CBS services provide women and girls with a private, safe space to use the toilet and manage menstruation and pregnancy[5]. By contrast, open defecation and public sanitation options expose women and girls to high risks of violence and harassment as they travel to defecation locations, often at night (Pommells et al., 2018; Sclar et al., 2018). CBS could contribute to multi-sector approaches to eradicate this type of violence and harassment.

Affordable and Cost Effective

There has been widespread optimism around the potential for CBS providers to be financially self-sustaining given their business-focused approach[6]. A 2018 EY report found that Clean Team in Ghana was able to achieve positive gross margins, a significant step toward self-sufficiency[7]. However, whilst positive gross margins are possible, this could come at the expense of affordable user fees, thus defeating the goal of universal coverage at the city level[8]. Currently, CBS provider user fees in Ghana, Haiti, and Peru range from 3.21 to 12.00 USD per household per month (these fees are between 1.2 and 2.5% of a household income, assuming one adult in the household is earning the annual gross national income). Both a 2017 Copenhagen Consensus Center report and the 2019 World Bank report note that CBS is an affordable and likely cost-effective method of expanding services to marginalized communities[9]. However, the principal pathway to achieving scale is likely to be through government-backed contracts which guarantee service providers revenue and reduce risk.

DISCUSSION OF KEY CHALLENGES FOR CBS

Enabling Environment

Gaining government buy-in at national and local/district levels is essential to extending CBS into unserved areas. However, challenges remain in persuading governments and the wider sanitation sector that CBS is a viable alternative to sewerage.

While CBS has gained official recognition in the 2016 Kenya Environmental Sanitation and Hygiene Strategic Framework as a

[5]BMGF. (2018). "Gender and the Sanitation Value Chain: A Review of the Evidence" and "Case Studies in Gender Integration: Sanitation Product and Service Delivery in Kenya."

[6]EY and WSUP. (2017). "The World Can't Wait for Sewers."

[7]EY. (2018). "Global Leaders in Household Container-Based Sanitation Services."

[8]Combined WASH expenditures below 5% of household income are generally considered affordable.

[9]Sklar and Faustin. (2017). "Pit Latrines or Container Based Toilets?"

safe and cost-effective alternative to sewers and on-site sanitation systems, most countries have yet to take any official stance (van Welie et al., 2019). This is often due to a lack of regulation or restrictive regulation based on outdated definitions of what comprises "safe" sanitation (Peal et al., 2014; O'Keefe et al., 2015).

In an effort to improve the enabling environment, the Container-Based Sanitation Alliance (CBSA) was formed in 2016 and became a legal entity in 2019[10]. The CBSA seeks to standardize CBS through research and advocacy. Each CBSA member seeks to build a policy environment in their respective countries that is conducive to the provision of CBS services. For example, CBSA members are working together with local government partners to conduct World Health Organization (WHO) Sanitation Safety Planning (SSP)[11], which is a modular risk assessment process used to understand and mitigate health-related hazards for each link of the sanitation chain. There is a need to foster conducive policy frameworks and regulation for waste reuse, as well as the development of markets for reuse byproducts.

Financial

There is a significant investment hurdle to ensure a CBS service can start and grow. The unit economics of sanitation and, in particular, the fees that customers can pay (assuming ∼2-3% of household budgets) means the economics are difficult. Additionally, there are few examples of full value chain sanitation services in low-income markets and thus few examples of how to pay for such services. More research is therefore needed to compare the costs and benefits of CBS to traditional options and to understand the magnitude of cost savings gained through increasing service densities and economies of scale.

A new CBS service requires capital expenditures on treatment systems, conveyance equipment (i.e. trucks and carts), and toilets. These expenditures can be very expensive and difficult for any single organization to cover on their own. Additionally, by committing to addressing the full sanitation value chain, CBS providers may have higher operational cost as compared to pit emptying services. However, CBS providers are demonstrating that the use of novel treatment technologies which are safe, efficient, and can facilitate resource recovery ultimately make CBS more cost effective. Thus, leveraging public, philanthropic, and private funds to get CBS services running at scale can lead to greater return on investment in terms of public goods (public health and environmental quality) as well as private goods (privacy, cleanliness, and social status) than traditional options in dense urban settlements.

At an operational level, access to capital and longer-term financing mechanisms to scale up CBS services is often lacking (O'Keefe et al., 2015). CBS implementers are working to develop blended finance models for ensuring that there is sustainable financing in place from a mixture of earned revenues and public sector funding. Like all sanitation options, ongoing public support will be required. This may be through public-private partnership models or other government support such as land leases, tax reductions, access to lower-cost capital, carbon credits, or electricity supply.

Management and Staffing

Some CBS service providers have faced challenges to hire, train and manage their workforces. In some contexts, local recruitment, and retention of high capacity staff can be challenging, as team members must be interested in working in a low-margin and historically stigmatized sector. Similarly, there can be a lack of fecal sludge experts as education typically focuses on traditional sewerage and wastewater treatment plant operations. Thus, incentivizing the creation of university programs that include training in a variety of sanitation technologies, in similar ways to the Gates Foundation-funded MSc at IHE Delft would be very helpful. Furthermore, governments could provide incentives to encourage qualified professionals to continuing working in nascent sanitation services that currently do not provide the economic security of more established sanitation jobs.

Building a More Complete Solution

A toilet must be attractive and aspirational to customers, easy to use, durable, and simple to install. It also needs to be attractive to governments and utilities, and meet the needs of their constituents (i.e., politically and culturally acceptable). The toilet user interface can largely be classified by defecation position and anal cleansing preferences (**Figure 2**). Currently, the majority of CBS toilets are designed for sitters and wipers. Wash water is a particularly important challenge in a dry CBS system, thus more research and design work are needed in washer dominated locations.

Currently, not all CBS services collect urine, as it represents a high added cost due to its weight and volume. While infiltration or urine and graywater may be an acceptable short-term solution, large scale infiltration of urine could lead to elevated nitrate and nitrite levels, as well as pharmaceutical contamination in groundwater (Templeton et al., 2015; Larsen et al., 2016). In places where water tables are high or infiltration is slow, there could be significant standing water and contamination issues. There has been substantial research by the VUNA project among others on urine resource recovery, but these technologies have not been integrated into CBS services (Simha and Ganesapillai, 2017; Hyun et al., 2019; Nagy et al., 2019)[12]. Applied research that achieves a value-add proposition for integrating urine and graywater solutions in CBS services is an area of great interest.

Additionally, more research is need into the impacts CBS services have on access equality and inclusion. Given the potential to positively impact the lives of women and girls, their needs should be at the forefront of future research and design work.

[10]Founder members of the CBSA include Clean Team (Ghana), Loowatt (Madagascar), Sanergy and Sanivation (Kenya), SOIL (Haiti) and X-Runner (Peru). Additional CBSA members and affiliates: Sanitation First (India) and Mosan (Guatemala). Additional CBS organizations: Fundación Sumaj Huasi (Bolivia) and Non-Water Sanitation (India).

[11]WHO. (2016). "Sanitation Safety Planning."

[12]The VUNA project was a collaboration of EAWAG and municipality of eThekwini in South Africa (https://www.eawag.ch/en/department/eng/projects/vuna/).

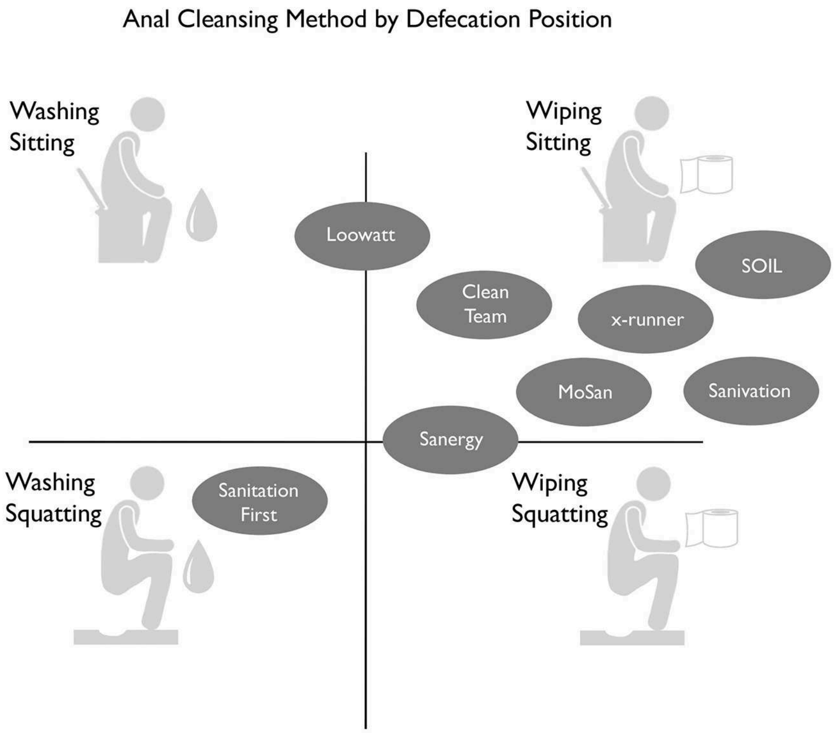

FIGURE 2 | CBS toilet user interfaces.

Logistics

CBS providers have been developing digital systems to support and strengthen service delivery as well as improve the customer experience through better logistics management (Saul and Gebauer, 2018). To aid in this digital transformation, CBSA members have been collaborating on a shared IT platform (VeriSan) for the management of service provision, but continued innovation will be an ongoing necessity.

Transportation needs to be developed in context, especially where there may be poor road infrastructure, high housing density or difficult topography. Several CBS providers use a two-stage model: door-to-door collection of containers with push carts or small motorized vehicles; use of transfer stations for temporary storage; and employing larger trucks for secondary delivery of containers to waste treatment facilities. Transport distance between households and treatment facilities is a key cost driver, and exploring innovative methods for route optimization is an ongoing and needed area of research.

Finally, maintaining hygienic safety throughout the sanitation value chain is essential. Future work that monitors potential contamination failure points and the magnitude of the associated risk in comparison to traditional sanitation options is important for improving the safety of CBS.

CONCLUSION

CBS has the potential to reach un- and under-served urban communities with sustainable, high quality, cost-effective services that can yield multiple economic, health and environmental returns. However, wider sector buy-in and financing is required—this will help shift the prevailing paradigm to a broader understanding of the suite of sanitation options necessary for achieving inclusive citywide sanitation. There is a need to encourage sanitation and public health ministries and policy makers to include CBS among their sanitation policy options and to structure financing (e.g., targeted investment and tariffs, payment by results mechanisms, etc.) and public-private partnerships to support the expansion of CBS services.

With cities expanding at unprecedented rates and the number of people living in informal urban settlements expected to double by 2030, it is critical that new sanitation technologies and services like CBS be studied and made available to governments and unserved communities[13].

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KR, KH, MR, DA, AF, SK, and RB contributed the concept and identification of the perspectives presented. KR wrote the first draft of the manuscript. All authors contributed to manuscript revision and have both read and approved of the submitted version.

[13] UN-Habitat. (2010). "The Challenge of Slums."

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METHODS
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Social Network Analysis for Water, Sanitation, and Hygiene (WASH): Application in Governance of Decentralized Wastewater Treatment in India Using a Novel Validation Methodology

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Social network analysis (SNA) is a versatile and increasingly popular methodological tool to understand structures of relationships between actors involved in governance situations. Given the complexity of the set of stakeholders involved in the governance of Water, Sanitation and Hygiene (WASH) and the diversity of their interests, this article proposes SNA to the WASH sector. The use of SNA as an appropriate diagnostic tool for planning Citywide Inclusive Sanitation is explored. Missing data is a major problem for SNA in the studies of governance situations, especially in low- and middle-income countries. Therefore, a novel validation methodology for incomplete SNA data, relying on information from internal and external experts is proposed. SNA and the validation method is then applied to study the governance of decentralized wastewater treatment in four cities of India. The results corroborate key differences between mega and secondary cities in terms of institutions, community engagement and overall sanitation situation including aspects of decentralized wastewater treatment plants, based on the city types.

Keywords: social network analysis, validation methodology, decentralized wastewater treatment, mega and secondary cities, citywide inclusive sanitation

INTRODUCTION

Social Network Analysis (SNA) is a method of detecting and interpreting structures and patterns of connections between actors who may be individuals, collectives or institutions (Scott, 2017). SNA is a versatile tool for different applications due to its graphical representation, structural intuition and systematic data interpretation (Freeman, 2004; Borgatti and Ofem, 2010). It has been increasingly used in a variety of fields from political science (Fischer and Sciarini, 2016; Victor et al., 2016), business marketing (Iacobucci, 1996), social psychology (Pearson and Michell, 2000) to public health (Valente et al., 2008), and environmental governance (Bodin and Crona, 2009; Bodin, 2017). More substantively, SNA is designed to deal with data on relations among entities, and thus data that describes interconnected phenomena, and consists of non-interdependent observations.

TABLE 1 | Contextualized explanation of relevant SNA concepts for the WASH sector.

SNA concept	Relevant interpretation in sanitation governance
Density	Indicates how closely actors within a network are connected to each other. Calculated as the number of observed network connections over the maximum number of network connections that could exist (if all actors are connected to all other actors). Useful mostly for comparing networks.
Centrality	Centrality indicates the degree to which an actor is embedded in the network. For example, high centrality refers to actors able to collect and transmit information and coordinate with other actors (Scott, 2017). Several centrality measures exist (Freeman, 1979); the most prominent ones are degree centrality (number of connections an actor has), closeness centrality (average path length to all other actors in the networks), and betweenness centrality (actor lying on shortest path between two other actors in the networks). Useful mostly to identify important or powerful actors in the network.
Core and periphery	Indicates the degree to which a network has a core-periphery structure, and whether actors belong to one or the other. The core is defined as a set of densely interlinked actors, which is positioned in the center of the whole network, whereas actors in the periphery are more loosely connected to the center, and not among each other (Borgatti and Everett, 1999). Useful to identify a power structure in the network, and identify marginalized actors.
Centralization	The degree to which centralities in the network are distributed equally or unequally among actors in the network (Freeman, 1979). High centralization exists if there is one very central actor with all other actors being much less central. Useful to identify power structure and hierarchies.
Cliques	Subgroup of actors within the network that is densely connected. Useful to identify fragmentation of the network, or coalitions of actors, etc. (Bron and Kerbosch, 1973).

Whenever a researcher believes that relations among entities are crucial for understanding a given phenomenon, SNA can provide important insights (see **Table 1**)[1].

Governance in water, sanitation and hygiene (WASH) for development, especially in urban sanitation, is complex and commonly involves a number of stakeholders interacting across administrative levels, sectors and demographics (Strande et al., 2014). For instance, political economy studies of WASH and related urban services in Asian low- and middle-income countries, have revealed that the complexity of governance combined with weak institutions are a detriment to urban service delivery (Boex et al., 2020). In such a context, SNA can be used to describe and analyze the polycentricity of governance and institutions relevant for economic development. Furthermore, SNA has been related to (e.g., Ostrom, 2009) crucial concepts of polycentric governance (by assessing the complex patterns of different actors participating in a diversity of parallel decision-making bodies, e.g., Lubell, 2013), and social-ecological systems (by assessing how governance networks of actors are related to underlying ecological networks, e.g., Bodin, 2017). The use of SNA for such contexts can thus take the potentially important structure of relations[2] among different actors into account, and could offer a different and possibly more appropriate perspective as compared to more conventional stakeholder analysis methods, which are often employed in WASH research and practice. The importance of SNA in understanding the complex adaptive systems existent in WASH for development has been indicated by Neely (2013) to answer the questions of *why* and *how* to ensure sustainability of community WASH interventions.

More specifically, SNA has several key advantages for the analysis of complex governance situations. First, SNA can help in identifying and interpreting specific roles of given actors in the governance network including gatekeeper or broker roles (Bodin and Crona, 2009; Ingold and Varone, 2012; Ingold, 2014). These actors can be crucial for the diffusion of information and best practices, or the elaboration of compromise solutions in governance networks. Second, a graphical representation of the SNA, a network graph (or sociogram) provides intuitive visual insights of the interactions between actors and allows for identification of key and marginalized players, and therefore could facilitate more equitable stakeholder involvement. Such information could pave the way for effective stakeholder engagement, taking into account formal, and informal networks, and reveal possibilities to build on existing social structures and points of interventions that improve success in WASH governance. For example, using SNA for identifying collaborative social networks for better water resource governance in the *Mkindo* catchment, Tanzania (Stein et al., 2011). A deeper understanding of stakeholder relations can increase the likelihood of collective action resulting in higher success of interventions (Prell et al., 2009). The use of SNA for identifying key characteristics of stakeholder networks that support institutional development has been shown in the service delivery of rural water supply in several low- and middle-income countries (McNicholl et al., 2017). Third, the very process of SNA data gathering has positive effects on the participation of stakeholders and the building of relationships with them (Jami and Walsh, 2014), while also increasing their awareness of other actors in the network. This is particularly useful in planning for the paradigm shift in urban sanitation that is Citywide Inclusive Sanitation (CWIS), which is based on equity in sanitation service delivery, combined use of diverse sanitation systems, and safe management of fecal waste along the entire sanitation value chain (Lüthi and Narayan, 2018).

Despite the potential benefits of SNA for research in the WASH sector, there has been a preference for stakeholder analysis over SNA, especially in urban sanitation studies (Reed et al., 2009; Lüthi et al., 2011; Reymond, 2014; Myers, 2016). Stakeholder analysis has been criticized for lack of consistency, halved perspectives, and for being in want of accounting informal relations (Hermans, 2005; Reed et al., 2009). Stakeholder analysis is purely qualitative and relies solely on interviews, focus

[1]**Table 1** adapted from Prell et al. (2009). For further SNA concepts, see Prell et al. (2009), Wasserman and Faust (1994), and Scott (2017). **Table 1** provides five relevant SNA concepts for WASH, of which first three are focused in the results and discussion sections.

[2]In this article, the words relations/connections between actors/stakeholders are used interchangeably. "Connections between actors" is often used to describe SNA specific points and "relations between stakeholders" to describe case specifics.

group discussions, and snowball sampling to identify stakeholder interest and influence (Reed et al., 2009). SNA, on the other hand, can be both quantitative or qualitative, and allows for a more mixed methods approach (Edwards, 2010). Studies advocate combining SNA and stakeholder analysis to produce fine-grained insights in water infrastructure planning, because this would improve rigor and offer complimentary perspectives that would help to create a more complete situational diagnosis of stakeholder interest and interactions (Lienert et al., 2013). Other studies have promoted this view in natural resource governance and participatory planning (Paletto et al., 2015; Yamaki, 2017).

One important disadvantage of conventional SNA methodology and related data gathering through surveys or interviews (Wasserman and Faust, 1994) are problems in data collection similar to most other key informant methodologies. SNA requires reliable data to draw strong inferences from the analysis of the networks. This presents the need for a systematic validation procedure, which could mitigate the issues that arise with unreliable data, especially from research in low- and middle-income countries[3], where data quality and availability is a consistent issue (Becker et al., 2012). Since most WASH research is carried out in similar settings, an appropriate validation procedure is even more relevant.

Decentralized wastewater treatment systems in India have witnessed an exponential increase in their uptake across the country in the last decade. This was prompted by an 2006 amendment to the environmental clearance laws that mandated that large buildings (built up area above 20,000 m^2) treat sewage *in situ*. An estimated 20,000 small-scale Sewage Treatment Plants (STP), serving between 10 and 1,000 households, are currently in operation using various technologies (Ulrich et al., 2019). A majority of them are found in cities, both mega and secondary. However, due to the lack of a clear policy framework and jurisdictional overlap between governing agencies at various levels, the performance and sustainability of such small-scale sanitation systems (SSS)[4] are affected (Chandragiri et al., 2019). Sustainable long-term operation of such SSS require effective governance (Ross et al., 2014). Understanding the governance of SSS can also help inform future policies for their planning, implementation and long-term monitoring. Such a study can also help the understanding of the nuanced differences between mega and secondary cities in India, which have inherent differences in institutional set up, urbanization, citizen engagement, decentralized wastewater treatment, and sanitation at large.

Therefore, the combined aim of this paper is to: (i) propose SNA as a useful tool for WASH research and practice, (ii) introduce a novel validation methodology for SNA, and (iii) explore the differences in sanitation governance between mega and secondary cities in India, using SNA as a tool. In doing so, this paper presents the first research carrying out social network analysis research for urban sanitation settings.

METHODS

Social Network Analysis and Low Response Rates

The goal in the first stage was to gather SNA data on the governance networks in four Indian cities based on interviews and surveys. This type of data gathering in the field is well established for SNA and has been previously used as a systematic method to describe and analyze the governance network between multiple stakeholders in areas such as the water sector (Lienert et al., 2013; Angst, 2018), natural resources governance (Bodin and Crona, 2009), climate governance (Ingold and Fischer, 2014), energy governance (Fischer, 2015), policies for reducing emissions (Brockhaus et al., 2014), and planning (Dempwolf and Lyles, 2012; Gerber et al., 2013). In this initial attempt, the relevant actors responsible for the SSS present in the four Indian cities (Chennai, Bangalore, Mysore and Coimbatore) were identified through informal expert contacts and document analysis (a set of about 15–20 actors per case, e.g., national, state and city level public administrations, international organizations, relevant boards, and associations, etc. An overview of actors appears in **Table 2**). Individual representatives of the relevant organizations were then contacted by email and phone in order to interview them or have them fill out a written survey with the same content. For example, in order to assess the relevant network relations among actors, the survey/interview protocol asked actor A to "check, on a pre-defined list of all relevant actors – all those actors with which actor A regularly exchanged technical information on sanitation issues within the last 10 years."

A common problem with gathering network data directly from the stakeholders themselves is low response rates, as with any other interview and survey data gathering. In the present case, the interview and survey response rates on average were <40% (with a maximum of 50% in Bangalore and a minimum of 27% in Coimbatore). Common reasons for non-response are that individuals do not feel competent to answer the questions, are not interested in filling surveys, do not have time, do not want information about their organization to appear in studies, etc. These reasons were mentioned by actors in this specific case, but they correspond to common reasons for non-response in survey and interview-based research. Overall, while low response rates is a common problem specific to social science research in low- and middle-income countries such as India, it is also an issue in many studies of this nature elsewhere, including SNA research in the United States, for example (Lubell et al., 2017).

Low response rates lead to incomplete data. Data can be incomplete with respect to actors that are missing, or, more frequently, with respect to relations between the actors that are missing. Concerning the latter, survey and interview data gathering in the context of SNA always has two potential sources of information for the relations between two actors, that is, from one or the other actor. While this can mitigate issues of

[3]For recent applications of SNA on questions of governance in low- and middle-income countries, see e.g., Brockhaus et al. (2014), Andriamihaja et al. (2019), Fischer et al. (2019), Gorris et al. (2019).

[4]In order to be consistent in terminology, for all the interviews, "small scale sanitation systems" were used to refer to decentralized STPs that serve between 10 and 1,000 households.

TABLE 2 | List of actors identified in the first step for Karnataka and Tamil Nadu. See **Figure 1**.

Level	Organization	Abbreviation
National	Bureau of Indian standards	BIS
	Central Pollution Control Board	CPCB
	Central Public Health and Environmental Engineering Organization	CPHEEO
	Ministry of Skill Development and Entrepreneurship	MSDE
	Ministry of Water Resources, River Development and Ganga Rejuvenation	MWR
State	City Managers' Association	CMA
	Directorate/Commissionerate of Municipal Administration	DCMA
	Department of Environment and Forest	DoEF
	Lake Development Authority	LDA
	State Environmental Impact Assessment Authority	SEIAA
	State Housing Board	SHB
	State Pollution Control Board	SPCB
	State Urban Development Department	SUDD
	State Urban Infrastructure Development and Finance Corporation	SUIDFC
	State Water Supply and Sewerage Board	SWSSB
City	City Municipal Corporation	
	City Water Supply and Drainage Board	CWSDB
	Divisional Pollution Control Board	DPCB
	Urban Development Authority	
International Development Organizations /NGOs	Asian Development Bank	ADB
	Center for Policy Research	CPR
	German International Cooperation	GIZ
	Indian Green Building Council	IGBC
	National Institute of Urban Affairs	NIUA
	World Bank	
Private Players	Architects	
	Buyers of treated wastewater	
	Consultants	
	MEP Consultants	
	STP Designers/Manufacturers	
	O&M service providers	

low response rates (if actor A indicates a relation to actor B, but information from actor B is missing, the researcher still has partial information on that relation), missing data in SNA can still be problematic for several reasons. Most importantly, incomplete network data can lead to unreliable estimates of network-level statistics, given that network-level statistics are based on the structure of the entire network (Burt, 1987). For example, centrality is a popular network measure used to identify the most important actors in a governance network (**Table 1**). Centrality measures can be incorrect due to missing data, or if parts of the networks are missing or disconnected from each other (Costenbader and Valente, 2003). More substantively, the analysis of incomplete network data might lead to the erroneous identification of important actors through wrong or unstable centrality indices. It can further lead to inaccurate density measures (see **Table 1**), if the percentage of missing data differs between the networks to be compared.

Validation Methodology

In order to increase the validity of the data gathered on the four cities in India, a validation methodology was developed. The objective of the process was to validate an existing, incomplete network, using available expertise from informants who have high knowledge of the case and the relationships the actors share within the network. This process of eliciting expert judgements has been previously used for WASH studies in low- and middle-income countries where data is often not readily available and knowledge from experts was found to be invaluable (Montangero and Belevi, 2007). Similar practices have been employed, albeit scarcely, to elicit network data for social network analysis. Carley and Krackhardt (1996) involved a third person within the network to comment on connections between dyadic relations, the equivalent of an "insider." Here, the cognitive inconsistency between non-symmetric and non-reciprocated relations between actors were studied, using such insiders. Orenstein and Phillips (1978) used press reporters to give information about political actors' relations, a case which used members completely outside of the network, an "outsider." As mentioned by Dorelan et al. (1989), it is important for these outsiders to be in the margins of the study group and yet remain knowledgeable.

Insiders bring in detailed information about relations between actors based on their direct experience and a perspective only available to them. Similarly, outsiders are beneficial due to their ability to view the entire network without direct involvement and, therefore, without egocentric biases (Dorelan et al., 1989). Using these two established types of informants, insiders and outsiders, simultaneously, allows for an additional level of confirmation to be obtained regarding network data between actors, while also reducing any possible perception biases.

In order to improve data reliability, a seven-step validation procedure has been proposed below. This procedure is based on network graphs that are visualizations of the social network. Most importantly, these visualizations include nodes (also called vertices) to represent the actors in the governance networks and ties (also called links or edges) to represent relations between the actors. Colors and sizes of nodes and ties can be used to represent attributes of these elements. For example, different colors can be used to represent different types of actors, and tie size can be used to represent the intensity of a relation. The steps of the validation procedure are grouped as desk based steps (1–3), field based steps (4–6) and reconciliation steps (7).

1. Usage of existing incomplete or desk based network graph

   The initial network graph stems from an incomplete social network analysis, with either missing actors or missing information on relations between actors. The incompleteness can be either due to low response rates in interviews or surveys, or to the fact that it was a purely desk based study, which needs validation from the field to bring it closer to the reality of the different types of relations among actors.

2. Expert identification

   This could either be carried out from a Power-Interest matrix, choosing actors with high interest (Quadrant-1 & 4 in **Figure 1**)[5] or who could be chosen from case knowledge. 10–20% percent of the number of actors in the entire network graph, depending on its size, could feature as experts. It is preferable to keep this percentage low, otherwise there is a risk of carrying out an elaborate conventional SNA procedure of interviewing most actors, again with problems of missing responses. It also helps target the most valuable experts and ease the reconciliation (Step 7).

3. Insider–Outsider selection

   An equal number of insiders and outsiders (defined as above) have to be selected from the experts. Those actors positioned in the core of the network graph with high centrality are classified as insiders and those actors who are either in the periphery of the previous network graph or who do not feature as an actor at all, and yet have high interest and/or knowledge about the context of the social network, will be classified as expert outsiders.

4. Discussion based on a simplified unconnected version

   A simple version of the network graph, where actors are arranged randomly with equal sizes and without color codes or connections between them, is presented to each expert (insider and outsider). This ensures that there is only basic inference on the part of the actors, possible from the representation, and does not create any biases. In order to deal with the first basic issue, concerning missing data in the SNA (missing actors), it is verified that all important actors are featured, and that no non-important actor is included. If not, the suggested actors are added or deleted (for example: Divisional PCB is removed as mentioned in **Figure 2**).

5. Simplified version to make connections

   Post the actor verification on step 4, the perceived relations between them are requested from the expert in order to deal with the second missing data issue in the SNA, that is, missing relations among actors. Types of connections vary by case; in governance, typical connections include information exchange (technical and administrative), collaboration, line reporting, etc. (Victor et al., 2016). These connections could be formal only, or informal only, or both- as required by the network graph. Initially, the obvious connections are marked, and then the less visible connections, such as informal or inter-sector connections are made (for example: International Organizations and Private Companies in **Figure 2**). This exercise might take some time, and often requires prompt questions.

6. Existing network graph for representation questions

   Post the simplified unconnected version, the original non-validated network graph is presented to the expert, and representative questions are discussed. The expert is then invited to verify which actors are central or peripheral actors, which connections are present or not, and whether the size and positions of all actors are right, according to his view (note that the position of the actor usually represents its centrality, and the size can represent different types of information, in this case Eigenvector centrality). Additionally, any weak, non-existent or irrelevant connections are marked to be removed (for example: a weak connection between the Central Pollution Control Board and International Organizations was marked for removal in **Figure 3**. Similarly connections between urban development authority and divisional pollution control board, and state funding corporation and pollution control board were also suggested to be removed)[6].

7. Data reconciliation

   Based on all the data collected from the above steps 1–6, the corresponding binary adjacency matrix is filled as 1 or 0–the pair of actors being connected or not connected, respectively. When there are conflicting responses for the same connection from various sources, the reconciliation for the relation is carried out based on the following (see example in text further below):

   (i) Data from the previous network graph;
   (ii) Weightage of expertise of insiders and outsiders;
   (iii) Documental evidence found;
   (iv) Justification provided during the interview;
   (v) Substantial case knowledge.

Validation of the Network Graph

For the validation procedure proposed in this paper, four key stakeholders were chosen for each of the four cities and, a total of 16 validation interviews were carried out (**Table 3**). For reasons of potential research fatigue (Clark, 2008), all the stakeholders chosen were new and had not been interviewed for the previous social network analysis. This was possible, since these actors were not part of the earlier SNA interviews (due to poor selection, unavailability or inaccessibility at that point of time), which resulted in analysis being incomplete in the first place. In addition, certain experts, who were retired or switched careers, yet still had significant knowledge were included in the validation study.

Discussion on Validation Methodology

While such a validation method allows for the gathering of additional data to complement incomplete networks and thus provides an improvement over incomplete survey- or

[5]As part of the study, a stakeholder analysis with a power interest matrix, was carried out for the above cases (**Figure 1**) (Chandragiri et al., 2019). The power interest matrix classifies the stakeholders identified according to the power they hold and their interest in the decision making process on all aspects of decentralized wastewater treatment plants in each of these cities (Reymond, 2014). "Power" (vertical dimension) refers to the ability of an actor to make decisions and to influence the system, independently of its formal role. "Interest" (horizontal dimension) refers to their involvement in the sector, based on their responsibility (Ackermann and Eden, 2011).

[6]Note that additional important information on network relations among actors could be the direction of the relation (directed or undirected, depending on the type of relation) or the weight of the relation (vs. only the presence and absence of the relation). In this study, pre-validated networks are directed, and due to the nature of information exchanged, the validation process yielded undirected networks.

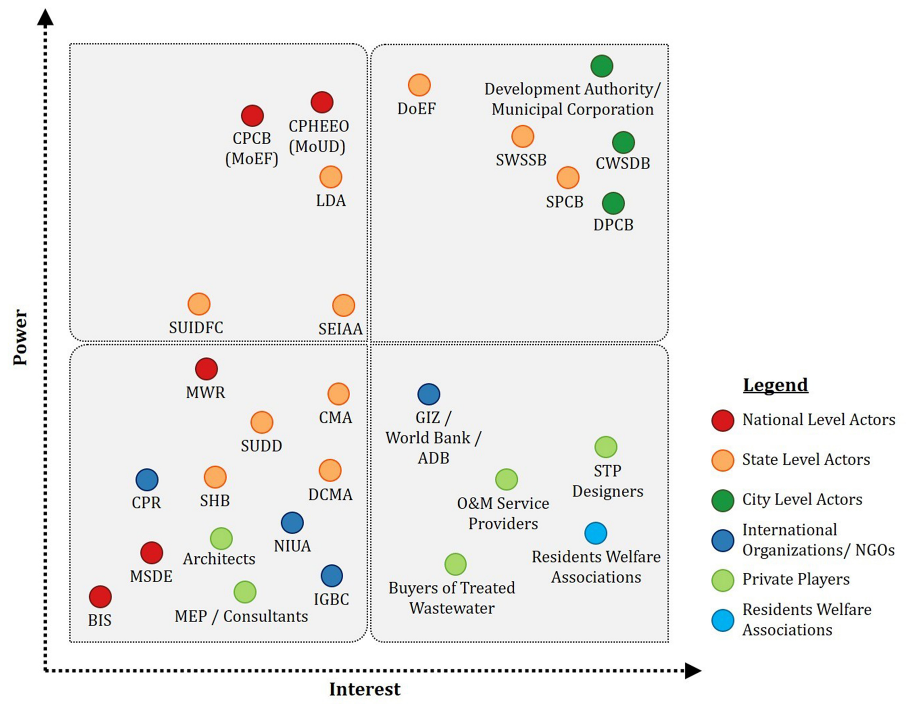

FIGURE 1 | Power-interest matrix of potential stakeholders involved in small-scale sanitation governance at the local level. Refer to **Table 2** for abbreviations. Color coding is followed in all other network graphs presented below.

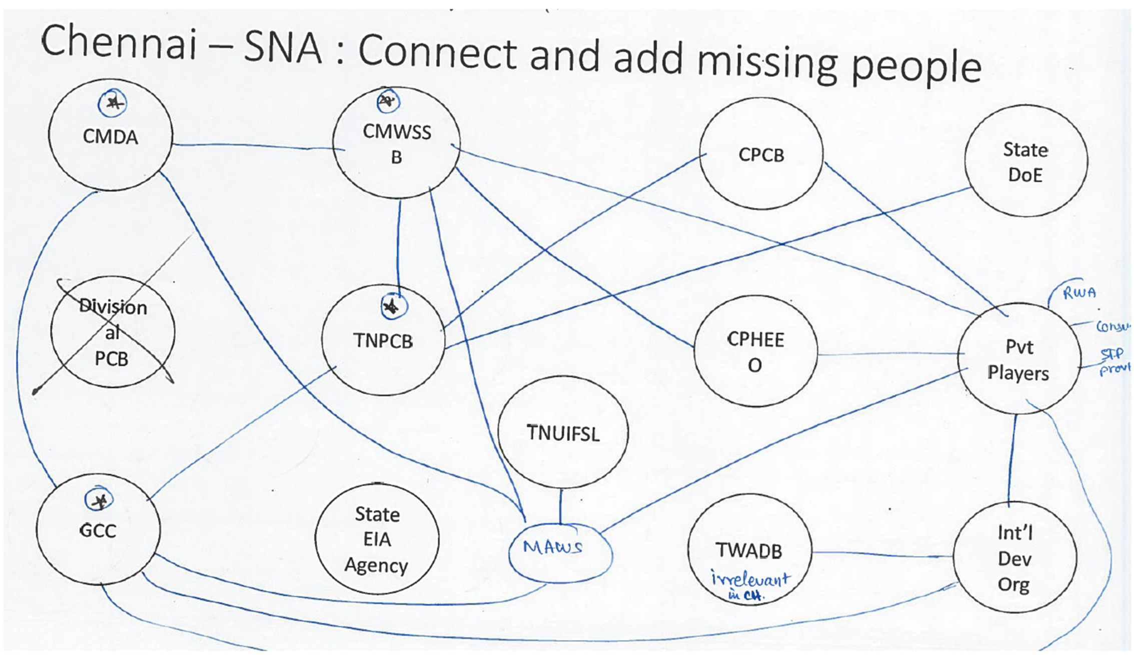

FIGURE 2 | Representation of the discussion based on the simplified version mentioned in Steps 4 and 5 of the validation procedure.

desk-based studies, there are obviously some challenging issues as well. Below, four such challenges and their mitigation are discussed.

Firstly, knowledge biases, exercise preferences and effective priming are concerns for the format of the validation methodology. The order of steps 5 and 6 were found to be

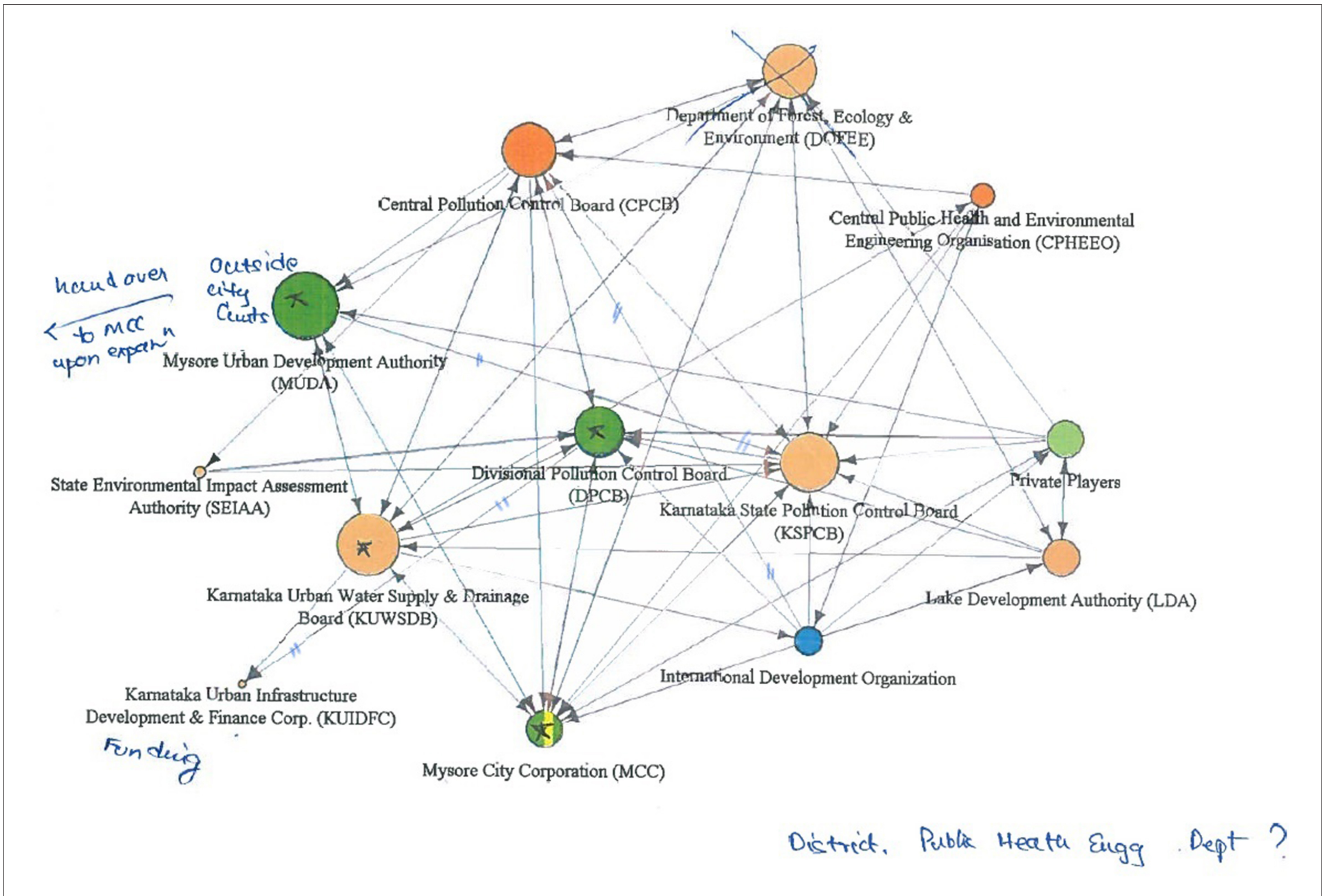

FIGURE 3 | Representation of the discussion based on the initial version of the network graph mentioned in Step 6 of the validation procedure.

critical in drawing out major connections in the expert's opinions without biasing. This sequence also ensured that the actors are primed for a more visually complex, information dense and influential network graph. Through the combined usage of time consuming step 5 and visually intimidating step 6, experts who had a preference for one step over the other were also catered to. Experts are often senior and time pressed; therefore, the process had to be time effective and flexible. Therefore, this two-pronged approach reduces the amount of information lost due to temporal and methodological leaks.

Secondly, clarity in criteria for connections is important to establish at the beginning. Interpretation of the requirements of an existent connection varies depending on experts, and has to explicitly clarified. These assumptions could result in inaccurate connections (for example: are solely funding agencies of decentralized STP projects involved in governance, even if they have no responsibility apart from their financial contributions?). There is the possibility that large biases could emerge from the experts as well (for example: private sector experts tend to focus on their importance, while government players tend to downplay the former's importance (see Fischer and Sciarini, 2015). Both aforementioned concerns, could be mitigated by objectively administering the interview with clarity on the relational requirements and minimizing information spill to prevent biases.

Thirdly, prompting is frequently employed in order to maximize the information elicited from the experts, especially in circumstances where inherent knowledge or previous connections are to be challenged. This could potentially lead to interview frustration or bias (Bowling, 2005). At a certain point when all major connections are explored, to bring out inconspicuous connections, prompting is found to be necessary. The researchers must have a considerable amount of prior case in order to carefully prompt when required. For example in step 5, the connection between private company and the pollution control board, in several cases required prompting to be considered for either connecting or not.

Finally, conflicting information leads to difficulties in reconciliation. Since the validation methodology relies on fewer respondents, albeit experts, it requires care to bring in diverse perspectives. Otherwise, the SNA could risk becoming skewed through purposeful sampling (Patton, 1990). The validation procedure finally rests on the systematic reconciliation of conflicting data points. This is carried out qualitatively and involves the judgement of the researcher, which, yet again, places the requisite of prior substantive case knowledge on the

TABLE 3 | Key Informants interviewed for validation with their expertise levels and interview codes.

Code	Affiliation	Actor	Expertise	City
C1	Academia	Outsider	High	Chennai
C2	NGO	Outsider	Low	Chennai
C3	City Government	Insider	Intermediate	Chennai
C4	State Government	Insider	High	Chennai
B1	NGO	Outsider	High	Bangalore
B2	Private Company	Insider	Intermediate	Bangalore
B3	Utility	Insider	Intermediate	Bangalore
B4	Academia	Outsider	Low	Bangalore
K1	Private Player	Outsider	High	Coimbatore
K2	Academia	Outsider	Low	Coimbatore
K3	State Government	Insider	High	Coimbatore
K4	City Government	Insider	High	Coimbatore
M1	Academia	Outsider	Intermediate	Mysore
M2	City Government	Insider	High	Mysore
M3	State Government	Insider	High	Mysore
M4	NGO	Outsider	Intermediate	Mysore

researcher. Since the method itself is a mix of qualitative data collection and quantitative data analysis, these limitations are inherent and require careful consideration while selecting experts and being systematic during the reconciliation. However, such limitations are prevalent in most qualitative methods (Taylor et al., 2015), including conventional social network analysis (Scott, 2017). The reconciliation procedure becomes crucial when the experts give varying and frequently conflicting network data. Therefore, systematic assessment of the data needs to be carried out, based on expertise weightage, documental evidence, substantive case knowledge, and justification provided during the interviews. For example, when C3 and C4 (**Table 3**) had conflicting views on one specific connection between the city corporation and state pollution control board, C4's view was withstanding since C4 earlier held the positions at both city and state levels. Additionally, C4's justification proved to be more convincing with references to policy documents.

In the results section, we present and compare the governance of decentralized wastewater treatment in four cities based on the data received from the different steps of the data collection, including the validation procedure. Since the goal is to describe governance networks and compare different cases, SNA as a standalone method lacks context to interpret the network graphs and needs to be used in conjunction with other research methods, especially qualitative methods to gain deeper understanding of the situation and prevent simplistic conclusions on the stakeholder interactions (Prell et al., 2009; Edwards, 2010). Therefore, this validated network data was used in compliment with two workshops and 76 in-depth qualitative key informant interviews, which provided the background and context on urban wastewater management in India, for the selected mega and secondary cities, and the differences between them were explored (see results section). In addition, the institutional and performance analysis of the specific small-scale sanitation systems in the four cities was available to provide additional perspectives relevant to this analysis (Ulrich et al., 2019). The validated data was processed using the user friendly SNA specific open source software *Gephi* (Bastian et al., 2009), and represented using *Force Atlas* configuration without any manual manipulation.

RESULTS

In this section, four main results regarding the use of SNA for our case study are presented. Firstly, the comparison of the pre-validated SNA with the validated SNA, and the major modifications made from the validation exercise are given. Secondly, a detailed illustration of using SNA to understand governance of decentralized wastewater treatment in one particular city–Chennai, is made. Thirdly, the differences between mega and secondary cities in terms of sanitation are presented, and then SNA results are discussed in relation to few of these key differences.

Comparing Pre-validated SNA With Validated SNA

The initial procedure yielded an incomplete network, based on which pre-validated network graphs were created for the four cities of Chennai, Bangalore, Mysore and Coimbatore (**Figures 4A–D**). Similarly, network graphs were created using the validated network data for the same cities (**Figures 5A–D**). The five major differences that are clearly visible are discussed below—actor influence, removal of irrelevant actors, addition of important actors, centralities of actors and densities of overall network.

In the interviews, it was unanimously stated that certain actors had a much bigger role in implementation than others who only had soft powers to influence policies. Actors were then broadly classified as implementing actors and influencing actors. For example, comparing **Figures 4B**, **5B**, the Central Pollution Control Board (CPCB) and the Central Public Health and Environmental Engineering Organization (CPHEEO) are influencing actors, while Bangalore's Water Utility (BWSSB) and Resident Welfare Associations (RWAs) are implementing actors. It is important to note that the aforementioned influencing actors are at the national level, while implementing actors are at local level. CPCB sets effluent standards while CPHEEO develops engineering manuals, and both are strong influencers in designing SSS for all contexts. Whereas, BWSSB and RWAs are actors that are directly involved in the building, operation and maintenance of SSS. Although these influencing and implementing actors could have been visually marked differently in their node[7] characteristics, the validated network graph clearly makes the distinction through their position in the core or periphery (**Table 1**), and their node sizes that represent their centrality measures.

[7]Nodes are representation of actors within the network graph. Their color, size and position are important visual characteristics that define them. Other statistics, such as various centralities for each of the nodes, can also be calculated (Scott, 2017).

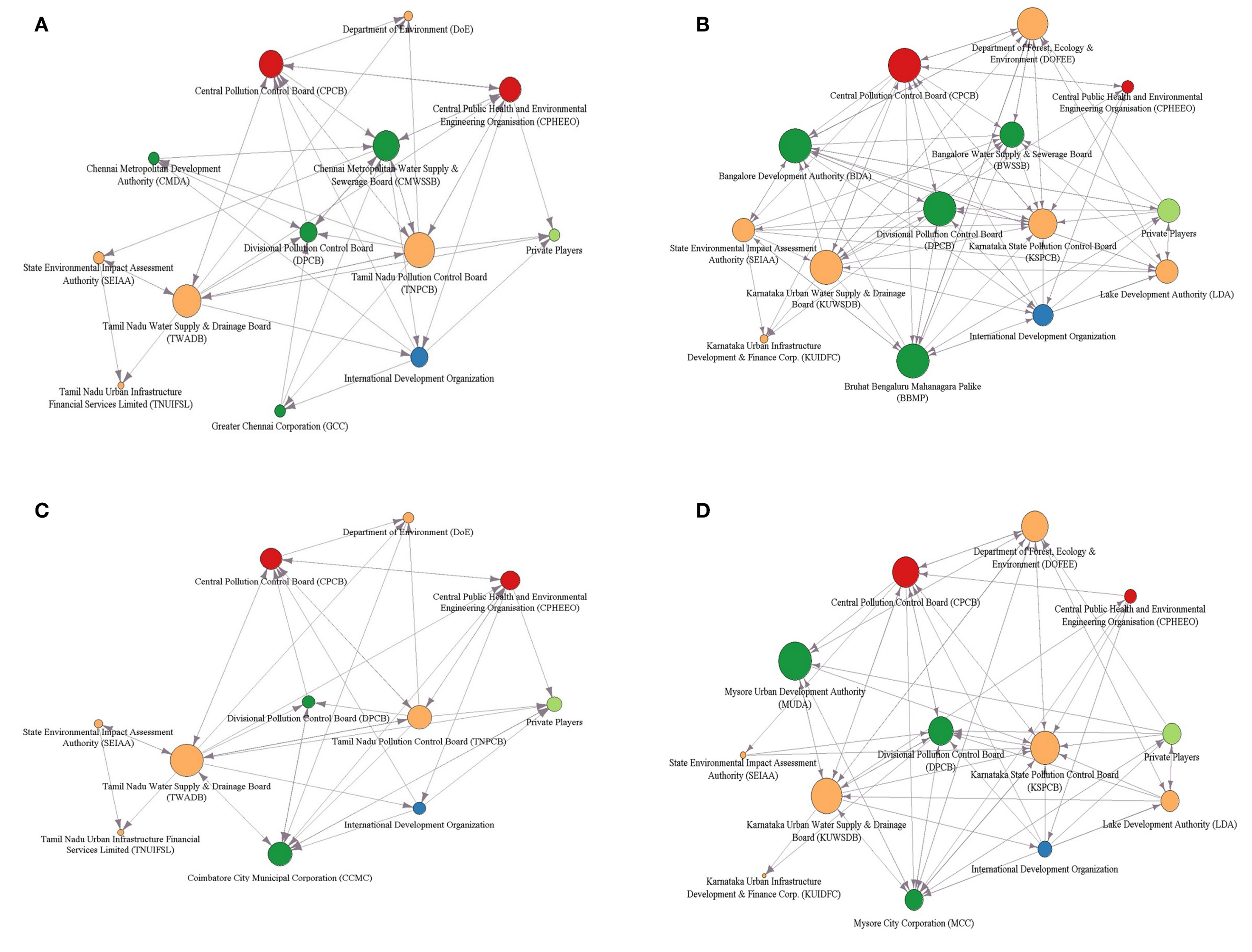

FIGURE 4 | Pre-validated network graph of actors present in **(A)** Chennai, **(B)** Bangalore, **(C)** Coimbatore, and **(D)** Mysore.

Through step 4, the most relevant actors were identified, and unimportant actors were removed. This resulted in changes in the actors present in the network. The main actors removed were the State Environmental Impact Assessment Agency (SEIAA), the Divisional PCB (DPCB), and the Department of Environment (DoE), due to their relative insignificance in the governance of SSS. SEIAA was removed due to the fact that the Impact Assessment Certifications for construction and operation of STPs are within the purview of the respective state pollution control boards (CPCB, 2016). DPCB is a department within the state PCB and, therefore, does not require explicit mention. DoE as a department does not directly play any role apart from being the state level agency that the PCB reports to.

Additions were made to the social network, as certain actors were found to play a directly influencing or implementing role in SSS for these cities. In **Figure 5A**, Chennai River Restoration Trust (CRRT), a special purpose vehicle (an independent legal entity with a specific goal, which in this case has the mandate of the rejuvenation of urban water bodies in Chennai) was found to be engaged in the setting up of SSS and also in coordinating with other actors for SSS's wider establishment, and was therefore, added. Similarly, the node Private Players (**Figures 4A–D**), was meant to represent RWAs, NGOs, private STP companies, and consultants. Since the adjacency matrix of their relationship with other actors varied highly, they were split into two groups (**Figures 5A–D**). Further, the main agency that directed all municipal governance including water and sanitation was the Municipal Administration and Water Supply (MAWS) in the state of Tamil Nadu, and the Directorate of Municipal Administration (DMA) in the state of Karnataka. These agencies were found to play a bigger role in the smaller cities with respect to SSS.

Overall, the centralities of actors changed with modification in the network data. The most central agency is no longer the PCB, but the utility (CMWSSB/BWSSB) in the mega cities of Chennai and Bangalore while the municipal corporation (CMC/MCC) became the most central actor in the secondary cities of Coimbatore and Mysore, with the parastatal water supply and drainage board (TWAD/KUWSDB) playing a bigger role in the latter two.

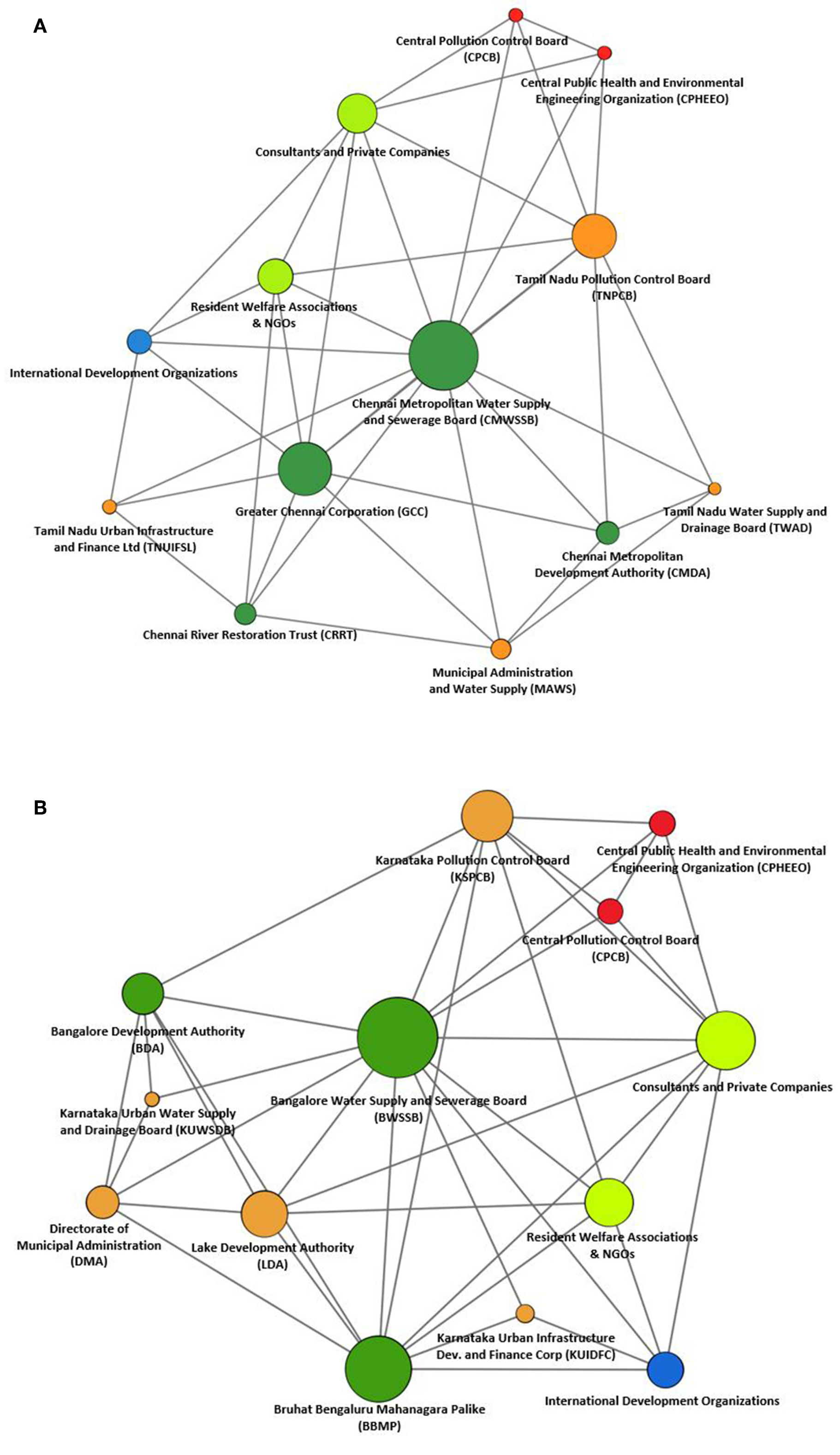

FIGURE 5 | Continued

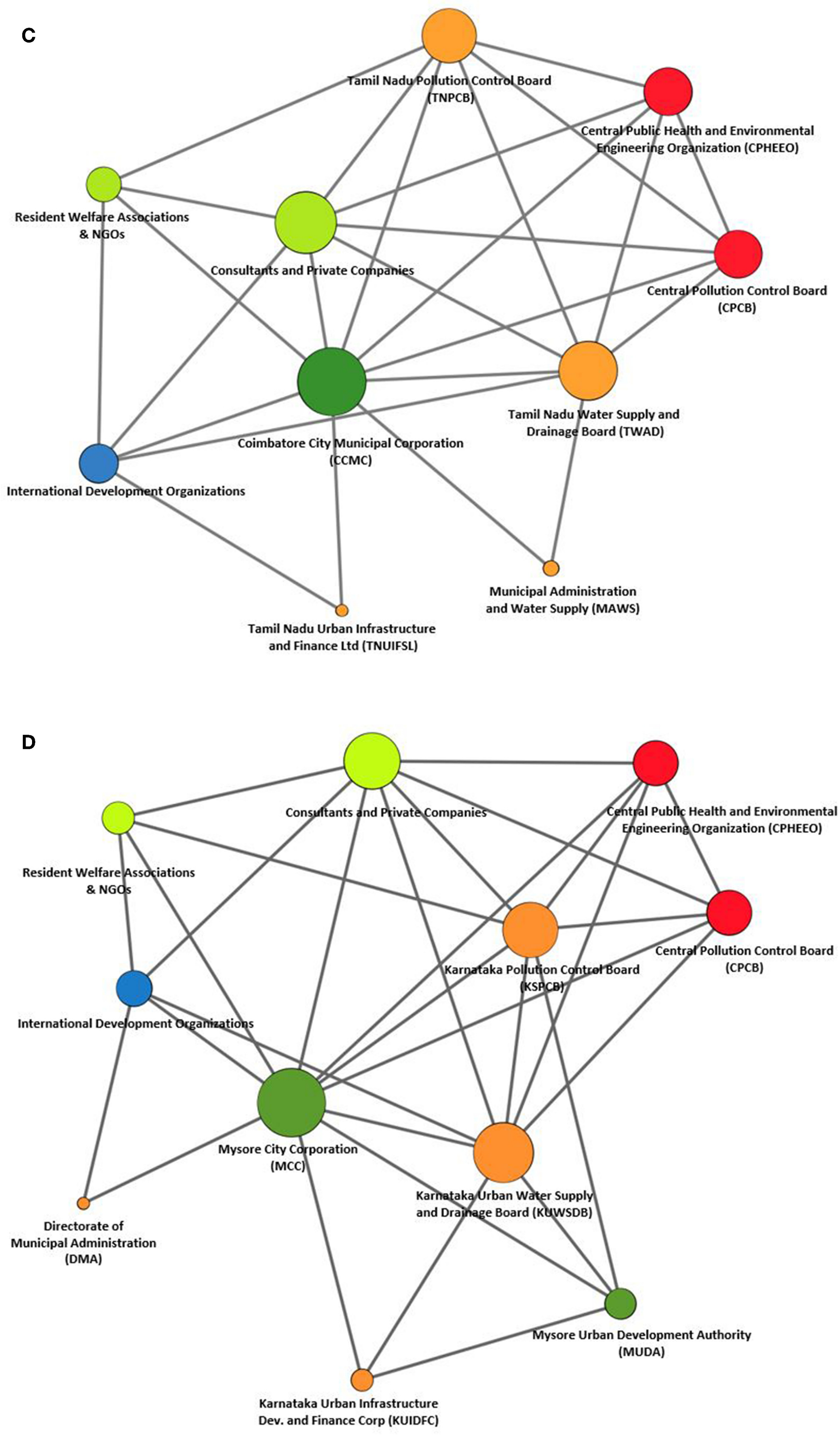

FIGURE 5 | Validated network graph of actors present in **(A)** Chennai, **(B)** Bangalore, **(C)** Coimbatore, and **(D)** Mysore.

TABLE 4 | Network densities for the respective cities before and after validation.

City	Density from initial SNA	Density in validated SNA
Chennai	0.28	0.50
Bangalore	0.36	0.52
Coimbatore	0.30	0.58
Mysore	0.41	0.55

TABLE 5 | Centrality measures of different actors in Chennai.

Actor	Degree centrality	Betweeness centrality
CMWSSB	12	20.25
GCC	9	6.17
TNPCB	8	5.25
Consultants and private companies	7	2.58
Resident welfare associations and NGOs	6	1.17
MAWS	5	1.08
CMDA	5	0.5
CRRT	5	0.92
International development organizations	5	0.58
CPCB	4	0
CPHEEO	4	0
TWADB	4	0.25
TNUIFSL	4	0.25

The densities of the networks of the four cities have also changed to reflect a more uniform network density across the four cases (**Table 4**). This is a result of the changes in the overall number of actors and the changes in the individual relations of each actor. The higher values are due to the elimination of irrelevant actors who earlier had minimum connections, thereby increasing the overall network density.

Using SNA to Understand Governance of Decentralized Wastewater Treatment

In order to illustrate the usage of SNA for insights into the governance of decentralized wastewater treatment, the case of Chennai is taken as an example (**Figure 5A**). There are a total of 13 key actors involved in the city's SSS. The network overview characteristics, such as network density and average path length provide basic insight into the network graph. A density of 0.50 indicates quite strong connections, as half of the actors are directly connected with each other. The network diameter of 2 shows that the longest distance between two nodes positioned afar is 2, and for them to have contact there is one actor in between. The average path length of 1.5 corroborates this by suggesting that on an average, any two actors are connected through one and a half other actors. These network characteristics are particularly useful when comparing networks, but are more difficult to interpret by themselves. For example, we can state that a network in one city is denser than in another city, but it is hard to judge whether the network is dense, *per se*, as this depends very much on the type of network (type of context, types of nodes, types of ties, etc.).

All actors either perform the roles of implementing or influencing agencies and, as mentioned before, this is not explicitly labeled, but the size of the nodes and their positions form a core and periphery structure (**Table 1**) which indicates whether the actors are implementing or influencing. In the case of Chennai, the Utility (CMWSSB), the municipal corporation (GCC), State PCB (TNPCB), Consultants & Private Companies, and RWAs & NGOs are directly involved in the process of commissioning, licensing, building, operating, and maintaining SSS. Therefore, they are clearly seen to be implementing agencies, while all the others remain only as influencing agencies since they only have indirect involvement in the process, such as financing, setting standards for discharge and performance, providing expertise, advocating or simply approving SSS projects.

The centralities of these actors offer more detail in terms of how much power they have within the network. This also translates to how much influence they have in governance within this context. Among the many different centralities (**Table 1**), degree centrality and betweenness centrality are the most relevant in the present case, as they offer simple measures of an actor's influence within the network. Together, they offer a complimentary set of perspectives i.e., degree centrality represents the simple number of connections an actor has—and thus the actor's potential to serve as a hub. Whereas, betweeness centrality represents the extent to which an actor is placed on a path between other actors. The latter shows the power an actor has in controlling information exchange between other actors, and how the network will get disrupted if that actor is removed. **Table 5** provides the values of centralities for all actors involved in SSS governance in Chennai. For example, CMWSSB as the most central actor has connections to all other 12 actors, whereas four actors are connected to only a third of the network (degree centralities of 4). The betweenness centralities are more complicated to interpret directly from the measure, but suggest a clear hierarchy in terms of the actors able to connect other actors within the network. While both centrality measures offer theoretically informed complementary perspectives, they are also highly correlated, suggesting that actors cumulate different aspects of centralities and related potential for influence, etc.

Based on the centralities, actors and their most suitable functions can be identified. For information diffusion, the actor with the highest centrality measures (both degree and betweeness) is CMWSSB. They are best placed to inform all actors of policy changes, standard settings, and best practices. For, the role of monitoring, a governmental agency requires a high centrality and to be within the core of the network, yet independent enough that it is not easily influenced by virtue of its connections to other actors. In this case, CMWSSB, GCC and TNPCB are relevant agencies for monitoring the performance of SSS in Chennai. TNPCB has already been constitutionally mandated to monitor all sewage treatment discharges, according to the Water Act of 1974. A recent notification from the National Ministry of Forests and Environment has delegated the power of ensuring compliance with environmental standards, to the urban local bodies such as GCC (Chandragiri et al., 2019). In reality, there is little clarity on these institutional mandates for the long-term monitoring of SSS and each of these agencies have their own limitations in terms of jurisdictional reach and capacity (Chandragiri et al., 2019). Therefore, purely looking at the SNA, CMWSSB is the most central actor with the highest betweeness centrality by far; it has access to most of the other actors involved in SSS. In addition, CMWSSB is an independent agency and works toward overall sanitation provision for the city; it is best suited to perform the role of monitoring individual SSS. Further, since CMWSSB themselves are required to report to TNPCB about their own treatment performance, TNPCB could be the ultimate custodian of the monitoring database and capable of performing the final verification audits of SSS performances. This function is suitable to their limited organizational capacity.

In the planning process of CWIS projects, it is important to involve all stakeholders present (Narayan and Luthi, 2019). In this particular case of governance of SSS, actors, such as CRRT, who advocate for SSS and for the restoration of urban water bodies in the city, are often not included in the planning. Similarly, CMDA who is responsible for zoning and approval of all construction plans including those of SSS, does not even feature in conventional stakeholder analysis for the same reason. This is also evident from the lack of connections between international organizations involved in SSS projects and CRRT/CMDA. Such agencies can be powerful allies when forming coalitions to create policy shifts or simply to help support the planning of SSS in CWIS projects.

SNA can also inform about many other aspects of WASH research and practice, such as the important role of consultants and private companies in setting up SSS as seen by their betweeness centrality, or the limited connections international organizations have with state and national level actors in SSS governance (visible in the network graphs in **Figures 5A–D**). These all have a direct effect on the governance of this sector. These are all deeper insights which other methods such as stakeholder analysis, often fall short in bringing to light.

Comparing Small Scale Sanitation in Mega and Secondary Cities

Although there is no standardized definition for the boundary of a city, the administrative jurisdiction, built up area and degree of economic and social interconnectedness together provide a delineation of what is a city. Mega cities are, however, clearly defined as urban agglomerations with a population more than ten million (UN DESA, 2016). Secondary cities are more complicated to describe, as they are contextually defined in terms of population, functionality, connectivity and hierarchy. However, at large, these are cities with a population that is between 10 and 50% of the largest city in the country, and contribute significantly to the regional and subnational economies (Roberts, 2014).

In India, cities are classifiede under several systems by the revenue departments, census agencies, central ministry of urban development and individual state governments (Nandi and Gamkhar, 2013). At the national level, the Class system and Tier system are popular and they classify cities by population and economic contribution. They are however, inconsistent with international terminology and vary even between each other. Therefore, in our analysis henceforth, international definitions are followed. Mega cities are 10 million above in population and secondary cities are ones with a population of at least one million, and feature among the top five in the economic hierarchy of the state.

Therefore, Chennai and Bangalore with populations of 10–11 million each feature as mega cities, whereas Coimbatore and Mysore with populations of 1–3 million each (UN DESA, 2016) and by virtue of their positions in the respective state hierarchy, feature as secondary cities. The reason for choosing to study these four cities is multi-fold. Among the five mega cities in India, Chennai and Bangalore were most comparable by size and demography. The states of Tamil Nadu and Karnataka to which they belong, respectively, have dedicated and progressive sanitation policies. Hence, within the two states, the respective secondary cities of Coimbatore and Mysore were chosen due to high data availability from past projects. Therefore, by reducing inherent variability, the key differences with respect to sanitation could be better focused.

In the sanitation sector, especially within India, the differences between rural and urban contexts (O'Reilly and Louiss, 2014; Chaudhuri and Roy, 2017) and the characteristics of small towns have been previously explored (Sundaravadivel and Vigneswaran, 2001; Singh et al., 2015). However, there has been no study to date of the differences between mega and secondary cities in the WASH context. There are considerable differences in their institutional set up, funding availability, community engagement, urbanization and presence of SSS (**Table 6**) that are worth exploring[8]. These differences are important in planning for CWIS, which aims to contextually determine sustainable sanitation interventions (Lüthi and Narayan, 2018). Since the governance landscape, business ecosystem, stakeholder involvement and local knowledge vary significantly between these two types of cities, accounting for these differences in the planning and design stage of sanitation systems, especially in SSS, augers well for their success and sustainability.

Relating SNA Measures to the Differences Identified

The network graphs (**Figures 5A–D**) and their related measures (**Table 1**) that result from the SNA can be usefully related to some of the differences between mega and secondary cities with respect to sanitation, particularly SSS (**Table 6**). Other differences, however, are beyond the scope of SNA. The discussion below focuses on three key differences that relate to SNA.

Firstly, the differences in the institutional set up are visibly seen, as the number of actors involved, and their respective positions in the network graph vary. Sanitation in mega cities is governed by a dedicated utility, while sanitation in secondary cities is often governed within the municipal

[8]Although most of the differentiating characteristics of mega and secondary cities mentioned, including institutions and community engagement, are common across all of India, there could well be unique factors in each city that create outliers in their sanitation situations. Additionally, the differences explored here only have limited extrapolation outside the sub-continent.

TABLE 6 | Key differences between Mega Cities and Secondary Cities of India in overall sanitation as summarized from qualitative interviews and workshops.

Aspect	Mega cities	Secondary cities
1. Institutional set up	• Dedicated Utilities for Water and Sanitation. • No role for parastatal Water agency (TWADB/KUWSDB) • Little role for municipal corporation	• No dedicated Utility • Subset of Municipal Corporation • Major role for parastatal agency in planning and designing sanitation systems
2. Funding availability and cycles	• High municipal fund generation • Higher state budget allocation • Relatively fast funding cycle due to proximity to decision makers; but slowed down due to interdepartmental coordination requirements	• Low municipal fund generation • Relatively low state budget allocation • Slower funding cycles due to distance from the power center. But fewer agencies to coordinate for fund release
3. Community engagement	• High number of RWAs and NGOs • Low direct engagement with citizens • Fact attributed due to higher migrated population	• Lower number of RWAs and NGOs • Better engagement with citizens • Fact attributed due to closer relationship between people and local government
4. Decentralization of STPs	• Higher number of SSS • Stricter city by-laws present • More number of large buildings required to treat sewage *in situ* • Pockets of unsewered areas needing SSS on site • More SSS private companies present • More water reuse incentive	• Low number of SSS • Fewer large scale complexes • Sewer aspirational, so SSS not considered a long term option • Fewer SSS private companies • Lower water reuse incentive
5. Overall sanitation situation	• Lower overall safe management of fecal waste Based on Shit Flow Diagrams – 50–60% (Eawag, 2019) • Lower national ranking in cleanliness survey: Swachh Survekshan 2019. Chennai – 61, Bangalore – 194	• Higher overall safe management of fecal waste Based on Shit Flow Diagrams – 70–80% (Eawag, 2019) • Higher national ranking in cleanliness survey: Swachh Survekshan 2019. Mysore – 3, Coimbatore – 40

corporation itself. This is clearly seen through the central actors in the network graphs (**Figures 5A–D**), where the utilities of Chennai and Bangalore (CMWSSB/BWSSB) assume the central positions, whereas in Mysore and Coimbatore, they are replaced by the municipal corporations (MCC/CMC), along with a larger role for the parastatal agencies (TWAD/KUWSDB). Similarly, due to the limited capacity available for SSS planning in secondary cities (Chandragiri et al., 2019), consultants and private companies end up playing a larger role (see **Figures 5C,D**).

Secondly, community engagement is another key difference between mega and secondary cities. In the former, there are a higher number of non-governmental organizations (NGOs) and resident welfare associations (RWAs) reported; yet, the quality of engagement with the citizens is relatively lower when compared to the secondary cities. One plausible explanation from experts for this, is the higher amount of migrants venturing into mega cities for job opportunities, who have a significantly lesser connection with the governance of the cities, when compared to the residents who have spent a majority of their lives in secondary cities, and the latter have a greater motivation for better governance and infrastructure. Studies have suggested that the sense of belonging among migrants toward a new city, their past experiences, and the broader narrative in place, affect their involvement in urban governance (McDuie-Ra, 2012; Scholten et al., 2017; Wessendorf, 2017). This aspect is not clearly deductible from the present network graphs, since the quality of the relations were not accounted for in this analysis. Nevertheless, SNA as a tool has the scope to do such an analysis and can represent the quality of relations though the thickness or shades of color in the connections.

Thirdly, the overall sanitation situation in the two secondary cities have been found to be considerably better than that of the two mega cities, as seen in the results of the "Fecal Waste Flow Diagram" (also called "SFD") assessments (Eawag, 2019). The national level survey on cleanliness, which includes fecal waste and solid waste management, have placed Mysore and Coimbatore in the top 50, whereas, Chennai and Bangalore are 61 and 194 (MoHUA, 2019). However, Chennai, along with Bangalore, consistently ranked above 100 in the past editions. The SNA for these four cities can contribute to the explanation of this diagnostic. Mega cities have issues regarding coordination and overlapping jurisdictions, which the network graphs have visually revealed with multiple actors (Utility, Municipal Corporation, Pollution Control Board and City Development Authority) involved in SSS governance and implementation, yet having limited connections between them. This causes issues in sanitation governance and leads to slower funding cycles even though the proximity to power centers is closer in mega cities. The overall graph density further gives an insight into relatively poorly connected actors in mega cites compared to marginally better secondary cites (**Table 4**).

DISCUSSION

The above results indicate that SNA could bring out useful information and new perspectives for WASH governance that other methods miss out. SNA can also corroborate key qualitative evidence, while allowing for a systematic comparison of the governance networks in different cities.

The validation method itself goes beyond the WASH sector and can be applied in any situation where the reliability of network data is low. The validation methodology proposed in this paper is particularly useful when data reliability is low due to poor response rates; it helps validate incomplete and desk based SNAs, which was found to be the case in the initial attempt of carrying out a conventional SNA.

The results also reveal that a simple SNA, such as the present case, has limitations in terms of the differentiating factors that could be analyzed between mega and secondary cities. Yet, this limitation can be significantly overcome. There is scope for SNA as a tool to get more complex, and to account for the quality, strength and formality of connections by weighing the relationship and representing them using thickness, patterns and color shades of edges connecting nodes (e.g., Brandes and Wagner, 2004).

The reconciliation procedure in the validation methodology relies on the researcher having inherent case knowledge and places emphasis on their judgement. Albeit systematic, the replicability of results is uncertain, as in any other qualitative method. Since the reconciled data is a binary matrix of relations, there is high risk of low replicability. This can be mitigated if the reconciliation is based on statistical measures of centrality or simply Bayesian, which then could be represented as weighted edges. The size of nodes, which currently represents centrality, could also be altered to represent other factors, such as perceived importance, size of organization, power, interest, or any other factors the research would benefit in representing.

It is important to use SNA in tandem with other methods to derive relevant conclusions that are complimentary. SNA as a standalone method risks being simplistic with little context sensitivity. Depending on the research question, SNA in compliment with stakeholder analysis, qualitative interviews, focus group discussions, stakeholder workshops, discourse analysis, etc., could deliver deeper insights. This has been shown throughout the results, which uses contextual information from qualitative interviews and document analysis to strengthen various arguments, such as the larger role of the private sector in driving SSS in secondary cities. Furthermore, additional useful questions could be asked based on the network data, and involving more advanced statistical tools. For example, Exponential Random Graph Models (ERGMs) (Cranmer et al., 2016; Fischer and Sciarini, 2016) and similar models allow for inferences on the factors associated with network ties between two actors. Relying on such methods could for example reveal whether actors exchange information mainly due to their ideological similarity, or due to being part of the same institutional arena. Based on such results, concrete measure could be taken to strengthen network relations among a given set of actors in the entire network.

Therefore, SNA has the potential to be a powerful tool in the WASH sector, especially when planning for Citywide Inclusive Sanitation (CWIS), which involves participation of all stakeholders, in order to provide equitable and context appropriate solutions. Therefore, the results of an SNA, along with a stakeholder analysis, adds value to the initial step of planning—a diagnostic study of sanitation governance in the select city. SNA as a process is just as valuable as the results, since it allows for the identification of marginalized stakeholders who are part of the sanitation governance, by not just the researcher, but also the survey participants themselves (Valente et al., 2015; Hauck et al., 2016). SNA as a process, proposed in this paper, is enriching for the participants as well, since it uses techniques of knowledge co-production which engages the local actors in social learning (see Schröter et al., 2018). Such a tool is important in the urban WASH sector, especially in low and middle-income countries, such as India, where the complexity of stakeholders involved is immense. This could help the planning for CWIS become inclusive even at the local level closest to implementation. It could identify actors who could potentially act as policy entrepreneurs or form advocacy coalitions to bring about policy shifts (Ingold, 2011).

The differences in mega and secondary cities that are presented also significantly help in planning for SSS in particular. Lack of monitoring leads to poor operation and maintenance, which then leads to poor performance of systems, and ultimately results in failure of SSS, as proved in India (Davis et al., 2019; Ulrich et al., 2019). The present SNA has been shown to identify the actors who are best suited to carry out the long-term monitoring of SSS. Although WASH governance is not rigid and can be adaptable (Rosenqvist, 2018; Chandragiri et al., 2019), based on an actor's position and connections, their functional potential could be explored to identify which actors are best placed to perform certain functions—central actors for information diffusion and overall influence, and peripheral actors for support functions, presence of cliques for collaboration etc. Such nuanced and visual information will be a useful addition, when seeking to strengthen governance, by using stakeholder participation tools in local scale systems such as *The Governance Spectrum* and *Role play Scenarios* (Mitchell and Ross, 2016) or form the basis for action research using participatory design games as used in the study of governance of community-managed sanitation services in Indonesia (Rosenqvist, 2018).

Further research is necessary to understand the limits of using SNA for the WASH sector, and of the validation methodology presented. The proof concept tested in this article has <15 actors in each of the four cities. The feasibility of the usage and validation could be tested for larger networks, where the nodes are not institutional actors but individual actors, in cases directly involving implementation of CWIS interventions.

CONCLUSION

The paper proposes SNA as a useful tool for the WASH sector, especially in planning for CWIS. It provides deeper insight into the stakeholders involved in governance situations, such as decentralized wastewater treatment. Apart from visually representing the actors and the exchange of information between the connections, SNA has been shown to be used for comparing contextual differences between different cases, such as SSS governance in mega and secondary cities.

The validation procedure helps to overcome the problem of low response rates in the gathering of network data, which results in incomplete SNA and leads to unreliable network graphs and centralities. The problem of incomplete or desk based SNA, which is frequently present in research in the WASH sector of low- and middle-income countries can be overcome through the use of the proposed validation methodology. The novel use of the combination of insiders and outsiders with expert knowledge, balances the biases and widens the perspective of the SNA.

The proof of this concept is tested in four mega and secondary cities in India—Chennai, Bangalore, Coimbatore and Mysore, for the context of the governance of decentralized wastewater treatment. Using Chennai as an example, the use of SNA to show fine grained insights, such as overall network densities, actor centralities, and functional suitability of actors to perform monitoring has been illustrated. This, combined with the inferences from qualitative analyses, shows that the SNA can corroborate few key differences between mega and secondary cities with respect to SSS governance, their institutions, community engagement, funding availability and the overall sanitation situation. These differences are important considerations to be discussed when planning and designing CWIS projects for such cities.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

According to Eawag Ethical Review of Projects involving human subjects, this was deemed minimal risk. All participatory data collected was through verbal consent and fully anonymised.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Environmental Sanitation Planning: Feasibility of the CLUES Framework in a Malawian Small Town

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Small towns are growing in size and number, but compared to the big cities that fuel economies, or rural areas that feed nations, small towns are generally less prioritized by governments and donors, both because they appear less immediately troublesome and because they defy easy classification. As such, growth has largely been unplanned for and remains unregulated, which means that responsible governments lack the commensurate tax base and political might to plan for and aquire the services they need to handle the changes that they face. For exactly these reasons, the Community-Led Urban Environmental Sanitation (CLUES) tool was developed to assist small towns with the planning and implementation of environmental sanitation infrastructure and services but we found no documented cases of it being used or evaluated. The goals of this work were to first, document the information obtained from the CLUES process as a case study for the condition of environmental sanitation in a small town in Malawi; and secondly, to evaluate the technical, political, and financial feasibility of the CLUES manual in a Malawian context. As facilitators, we guided the community and government through each of the 7 CLUES steps over the course of 2 years to understand the actual demands of the guidelines from the perspective of the user. Once the process was completed, we were able to critically reflect on our stated objectives and present those results here. The results of the process revealed that water quality was good (no measured *E. coli* at 45 water points) as was access to a sanitation facility, though water quantity was insufficient and fecal sludge management and solid waste collection required Council attention. However, because baseline data were outdated or non-existent, the data collection activities required to determine the status consumed unexpected amounts of time, and the results were, because of internal movement and politics, difficult to disseminate and leverage. Most importantly, stakeholder participation was limited and relied on participation and transportation payments, which have become a permanent feature of community development in Malawi. Following the CLUES process was expensive, time consuming and politically fraught; it is unlikely that any small town in Malawi would be able to follow the process as outlined. A simplified version, conducted by an in-house planning department should focus on identifying gaps, needs, and priorities, as a way of not only addressing environmental sanitation issues, but as a way to kick-start better data collection and management that can underscore long-term planning activities.

Keywords: planning, small-town, sanitation, rural, urban, urbanization, Malawi, Africa

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INTRODUCTION

Urbanization is occurring rapidly; it is estimated that 60 million people move to urban areas annually (CWIS, 2018) and most of the growth is in informal settlements and slums (Water Aid, 2016). Although the population in Africa and Asia is predominantly rural (50 and 58%, respectively), more people will be living in urban areas by 2030 (Ikwuyatum, 2016). It is estimated that globally, city populations will increase by 50%, from 4 to 6 billion between 2016 and 2045 (Tayler, 2018). The rural-urban shift has brought increased economic growth (Ikwuyatum, 2016) but employment opportunities are increasingly difficult to come across as is land for housing or urban agriculture. With an increasing number of residents, cities struggle to provide public services, especially when the tax base does not grow accordingly (Awumbila, 2017). However, urbanization does not just affect big cities: knowing that many cities have reached their capacity to take newcomers, young migrants are diversifying their destinations and as a result, small towns are expected to double in size and number within 15 years, and double again within 30 years (Caplan and Harvey, 2010).

Small towns are broadly defined as small urban settlements or secondary towns (Sandec-Eawag, 2017). There is no universal definition for small towns because the population threshold used in different countries is not consistent (Roberts, 2014) but generally ranges between 1,000 and 50,000 inhabitants (Owusu, 2005; Wessels, 2012; Roberts, 2014). Alternative definitions frame small towns from an economic-development perspective: “small district hubs that have potential to become economic drivers of activity and services to rural areas” (Thomas and Alvestegui, 2015). Regardless of definition, central governments generally prioritize small towns less than large urban centers, as they have fewer constituents, and therefore less political power. On the other hand, and unlike growing cities, they are opportunities to demonstrate tangible change, as they have not developed beyond the point at which major infrastructure or planning changes are no longer possible.

Despite global efforts to increase the availability of improved water and sanitation for all, only 24% of the sub-Saharan population has access to safely managed water, i.e., individuals have a water facility accessible on the premises, water is available when needed (at least 12 h/day), and water supplied is free from contamination, i.e., fecal and chemical contamination (World Health Organization and UNICEF, 2017). Fecally-contaminated water is often associated with diarrhea, which is especially dangerous for children and those with weakened immune systems (Nguyen et al., 2017). Similarly for sanitation, 72% of the sub-Saharan population lacks even basic sanitation (World Health Organization and UNICEF, 2017), though access is not uniform between rural (26%) urban (34%) areas (Hutton and Varughese, 2016). During the 1980s most Water, Sanitation and Hygiene (WASH) services were focused on rural areas, and then in the 1990s, the focus shifted to urban areas, where small towns started to received investments in piped water supply infrastructure. However, funding for operation, maintenance, and the eventual expansion did not follow (Mugabi and Njiru, 2005).

WASH services in small towns are largely neglected by government officials due to a lack of capacity, weak institutional frameworks defined by unclear responsibilities among stakeholders, inadequate financial resources, and a lack of feasible sanitation solutions (Thomas and Alvestegui, 2015). Specifically, most technology-driven solutions are usually not feasible or affordable due to high poverty rates among dwellers and a small tax base collected by local authorities (Thomas and Alvestegui, 2015; Humphreys et al., 2018). Despite the evidence that poor people are willing to pay for improved water and sanitation services, most continue to use unregulated private services since system managers are often unable to recover the costs related to providing new or rehabilitated systems (Mugabi and Njiru, 2005). Further complicating provision is the fact that small towns are typically unplanned, and have mixed urban and rural attributes (Mugabi and Njiru, 2005). For example, centralized water and wastewater infrastructure is normally managed by city councils and/or utilities in cities, with little responsibility for the customer, while in rural areas, sanitation (usually pit latrines) are managed by the household. Small towns are increasingly required to provide city-like services, but to a population with rural-like infrastructure, making management difficult, and potentially fragmented. Furthermore, the incomplete transfer of power to local organizations, a lack of transparency and accountability, and encroachment of power by the local elite negatively affect the equitable distribution of water resources (Richards and Syallow, 2018).

Planning has been described as “deciding between various options for the future and then acting to see that they are implemented” (Kvarnström and McConville, 2007). More specifically, Municipal Sanitation Plans, Water and Sanitation Strategy Plans, or City Sanitation (Master) Plans (CSPs) assist with citywide sanitation development by incorporating visions, missions, and goals and strategies (Wafler, 2018). The challenge however, is that funding for sanitation plans is rarely incorporated into national budgets, and as small towns lack the tax base to self-support these activities (Water Aid, 2016). Because there is often an overlap in several departments with different vested interests, coordination becomes cumbersome (Water Aid, 2016). It is exactly for this reason that methodical, clear planning approaches are required to help planners jointly identify problems, targets, and timelines.

Various sanitation planning frameworks have been developed to address the needs of different users in the urban world: Open Planning of Sanitation Systems, which was recommended by the EcoSanRes Programme in 2004 (Kvarnström and McConville, 2007); the Household-Centered Environmental Sanitation (HCES), developed by the Swiss Federal Institute of Aquatic Science and Technology (Eawag) in 2005; Sanitation 21, developed by the International Water Association (IWA) in 2006 (Kvarnström and McConville, 2007); and the Strategic Sanitation Approach (Wright, 1997). It is difficult to adequately assess the effectiveness of these tools, or their relative applicability to small towns, given the near lack of documented case studies. Peal et al. (2010) assessed the state of documented planning cases, and we have found no additional information since.

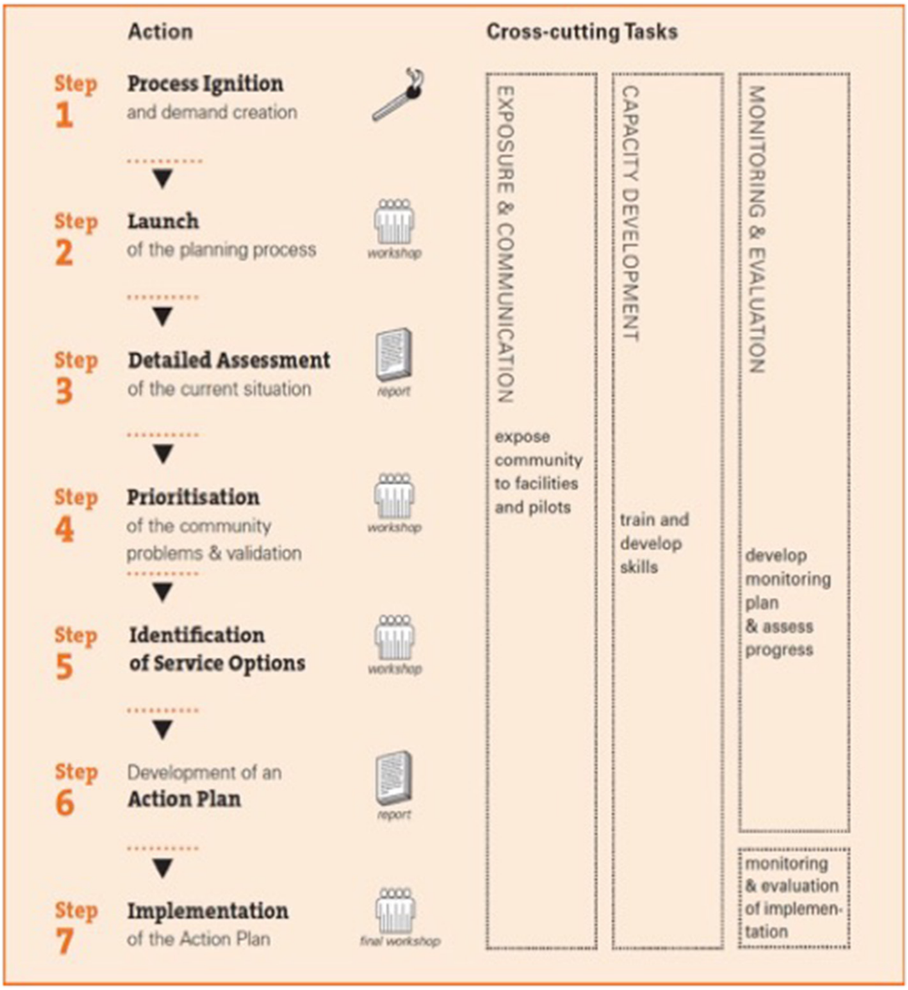

FIGURE 1 | The 7 planning steps of CLUES (Source: Lüthi et al., 2011).

Uniquely, the Community Led Urban Environmental Sanitation (CLUES) approach was developed specifically for the planning and implementation of environmental sanitation infrastructure and services in low-income small towns (Lüthi et al., 2011). **Figure 1** summarizes the 7 planning steps of CLUES.

Along with studies underway in Nepal and Bolivia this is one of the first cases of a sanitation planning approach for a small town that we know to be documented.

In Malawi there are 4 city councils: one for each of the major cities in the country (Lilongwe, Blantyre, Zomba, and Mzuzu), and two municipal councils for what could be called "small towns" (Luchenza and Kasungu) (Luchenza City Council, 2013; OECD, 2016). Luchenza municipality is in the southern region of Malawi and shares boundaries with Thyolo district to the west and south, Mulanje district to the east and Chiradzulu to the north (Luchenza City Council, 2013). In 2019, Luchenza municipality had an approximate total population of 12,600 (National Statistics Office, 2019).

Inadequate access to safe water, sanitation and practical hygiene services are some of the key challenges faced by, and identified previously by the Luchenza Council. All wards have mixed housing densities which is attributed to a failure to adhere to the housing plan, control of land by chiefs, laxity in development control, and poor staffing levels (Luchenza City Council, 2013).

Using Luchenza as a case study, the goals of this work were to first, document the information obtained from the CLUES process as a case study for the condition of environmental sanitation in a small town in Malawi; and secondly, to evaluate the technical, political, and financial feasibility of the CLUES manual in a Malawian context.

METHODS

Setting

The 2-year study was conducted in Luchenza municipality in southern Malawi (**Figure 2**) and covered all 8 wards of Luchenza: Lolo, Thundu, Sambagalu, Kapiri, Luchenza, Namadzi, Mapanga, and Namisonga.

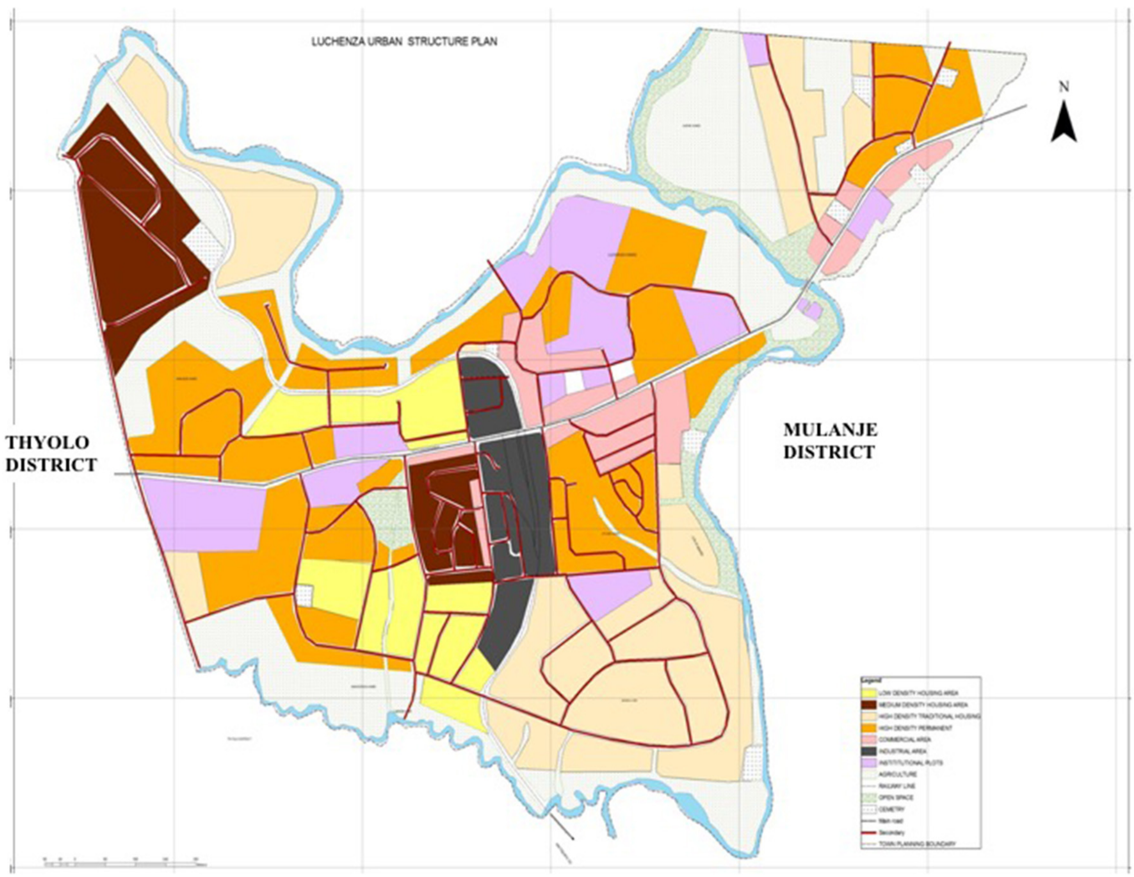

FIGURE 2 | Map of Luchenza.

The Luchenza Municipal Council is a statutory body set up under the Local Government Act 1998 Cap. 22:02. The local council is mandated to pass by-laws, mobilize resources for development, maintain peace and security, and promote infrastructure, economic, and social development through the formulation, approval and implementation of the programs and projects. The Chief Executive Officer (CEO) is the head of the Council and is assisted by directors of council departments. The Urban Executive Committee (UEC) is the technical advisory body to the Municipal Council. It is composed of all government line ministries, statutory corporations and non-governmental organizations working in the district (Luchenza City Council, 2013).

Traditional leaders, who inherit power through lineage, still retain significant influence on the politics in Malawi despite the fact that they exist outside of the democratic system. The traditional leader hierarchy (from highest to lowest power): Traditional Authority Group Village Heads (GVHs), Village Heads (VHs), and village chiefs. Each of the GVHs has a councilor (Luchenza City Council, 2013). The Council structure is presented in **Figure 3**.

The town was selected based on its size, population growth, typically complex political structure, and expressed interest on the part of the Council.

CLUES Participants

All environmental sanitation stakeholders that we could identify were included in the CLUES process: community members, municipal council departments, municipal cleaners, traditional leaders, councilors, ward committees, neighborhood committees, Community Based Organizations (CBOs), and business owners. For the data collection in Step 3 (elaborated below), we randomly selected 280 households (35 households/ward). The in-depth interviews were administered to the Director of Health, the Chair of Health and Environment, 2 municipal cleaners, 1 water point committee representative, and 1 public toilet committee representative. The Director of Health is responsible for overseeing all health and sanitation issues in Luchenza e.g., inspecting food premises for expired goods. Water point committees in Luchenza are responsible for collecting water fees from users, and managing the city-run public toilets.

CLUES Implementation

The CLUES process is comprised of 7 planning steps and is summarized in **Figure 1**.

Steps 1 and 2

Though we attempted to follow the process and written directions as closely as possible during the implementation some

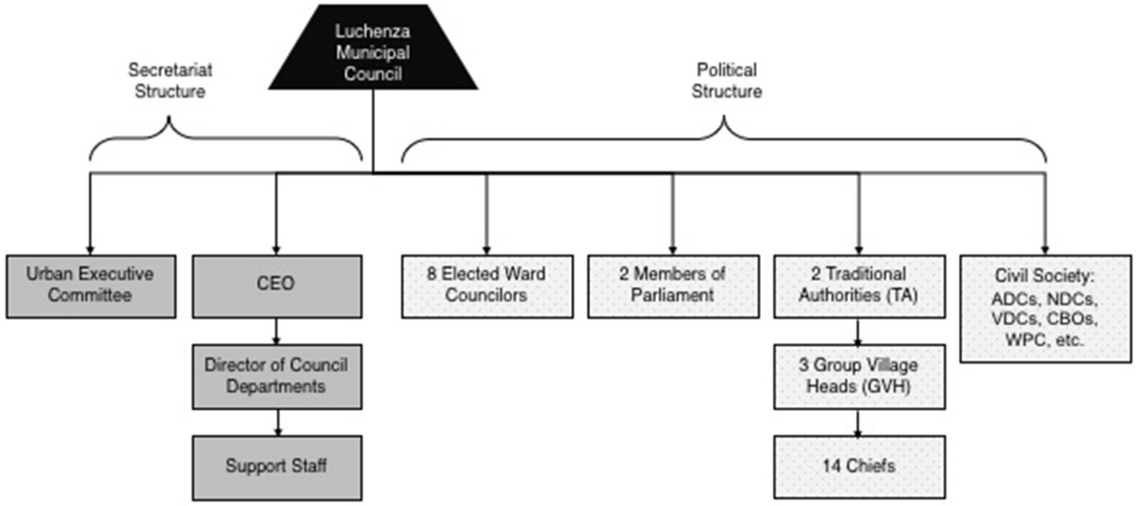

FIGURE 3 | Luchenza Council structure.

changes were made. The first and second planning steps ("Process ignition and demand creation" and "Launch of the planning process," respectively) were merged as the outcomes were deemed to be relatively similar (informing and exciting the community), and as a way to save money on workshops, especially early in the process. In this fused step, environmental sanitation stakeholders were identified using a "snow-balling approach" starting from the council. The main focus was to identify the stakeholders, understand the type of work they were doing with regard to environmental sanitation, and to identify some of the challenges they faced during their work. We met with all department heads through informal meetings and then started going further into communities to identify community stakeholders. Apart from department heads, we met the supervisor for municipal cleaners, 5 CBOs, 2 builders (contractors), 1 plumber, and 6 residents who helped us identify more stakeholders.

Once identified, participants (66) were invited to attend a launching workshop which had 3 main activities: a mapping exercise, a tour around the municipality to supplement the mapping exercise, and a capacity building tour at a children's entrepreneurial training village, called Green Malata. The mapping exercise was held to understand the environmental sanitation situation in Luchenza and to give participants a chance to highlight and explain the challenges and problematic areas in their community. Participants were also asked to place stickers on a map to identify "sanitation hot-spots" e.g., broken water points or open defecation prone areas. Afterwards, all participants visited Luchenza's dump site and a road used for open defecation (commonly called "pa umve" to mean "unhygienic"). The aim of visiting these two sites was to make people aware of their existence and location, and also to identify, as a group, poor practices, causes, effects, and ultimately, possible solutions. The aim of visiting Green Malata was to show participants improved methods of solid waste management: paper recycling, composting, and anaerobic digestion (biogas production).

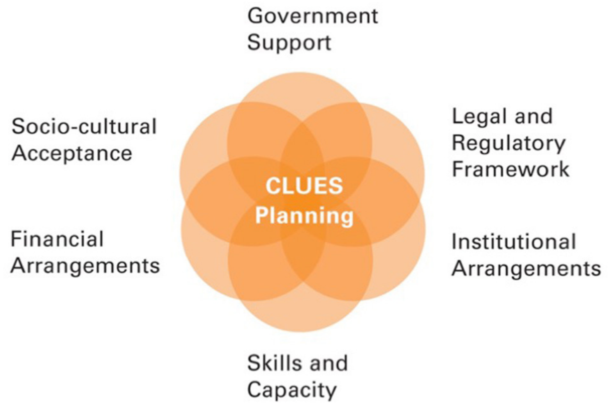

FIGURE 4 | Enabling environment according to CLUES (Source: Lüthi et al., 2011).

After the launching workshop, we conducted a comprehensive literature analysis/assessment of the enabling environment and the output of this exercise was a status assessment report for Luchenza. The enabling environment is a set of interrelated conditions that impact the capacity of actors to engage in development processes in a sustained and effective manner (Thindwa, 2001). In the CLUES framework, aspects of the enabling environment are government support, legal and regulatory framework, institutional arrangements, skills and capacity, financial arrangements, and socio-cultural arrangements. **Figure 4** displays aspects of the enabling environment in the CLUES framework.

The enabling environment for Luchenza was assessed using documents such as by-laws, the Local Government Act, the Public Health Act, and a report on the socio-economic profile of Luchenza. The analysis included information from initial project exercises such as the launching workshop and stakeholder meetings.

The assessment of the enabling environment was disseminated among stakeholders. Eight stakeholder representatives received the status assessment report (output of the assessment of the enabling environment) but no specific feedback about the contents of the document was given in return.

Step 3

The third planning step ("Detailed assessment of the current situation") involved a detailed assessment of the current environmental situation using a cross-sectional, descriptive study which involved a mapping exercise of public water points and public toilets, microbiological water tests at public water points, a household survey, and key informant interviews.

Data from the household survey and mapping exercises were collected electronically using "Kobo Collect" (http://www.kobotoolbox.org). A questionnaire covering the aspects of water supply, stormwater and graywater, sanitation, and solid waste was used to collect data from household respondents to examine current households' practices and performance in environmental sanitation and to determine the factors that contribute to poor environmental sanitation practices in Luchenza. We initially pilot-tested 20 households for validity and the pilot respondents were not included in the main sample.

Open questions were used to collect qualitative data from key informants during interviews to obtain an in-depth understanding of the current service levels.

To determine microbiological water quality, water samples were collected at 45 public water points. The samples were immediately placed in cooler boxes and transported to a laboratory at Chonde Health Centre in Mulanje (the closest laboratory space). Upon arrival at the lab, the water samples were immediately refrigerated and analyzed as rapidly as possible, within 6 h. The samples were analyzed for total coliforms (TC) and *Escherichia coli* (EC) in colony-forming units using a membrane filtration method. The bags that were used to collect water samples were aseptically opened using a flame-treated pair of scissors. A 100 ml water sample was filtered through a 0.45 μm Millipore membrane using a Delaqua filter device. The filters were then placed on Hyserve Compact Dry Plates and incubated at 37 degrees Celsius for 24 h. Thereafter, any colonies formed were counted in colony forming units per 100 ml.

Step 4

Stakeholders in Step 4 ("Prioritization and validation") identified and prioritized environmental sanitation problems through a participatory workshop where the outcomes from planning Step 3 were validated (authenticated). In addition, participants prioritized environmental sanitation problems in Luchenza through a pocket voting exercise, i.e., individuals anonymously ranked their priorities by allocating their votes into different "pockets" (water, sanitation, solid waste, graywater, stormwater).

Steps 5 and 6

Planning Steps 5 and 6 ("Identification of service options"; "Development of an action plan") were also merged because the outcomes were complementary, i.e., putting together an action plan report, and a comprehensive outline of the service options that were recommended to Luchenza municipality.

Data Analysis

Workshop and meeting minutes were recorded throughout the steps and were compiled in reports and disseminated to all stakeholder representatives, ~90 people.

All quantitative data were analyzed using Stata Software Version 11. The raw data from the in-depth interviews and community workshops were analyzed qualitatively. The data were translated into English and transcribed. The written transcripts were grouped into themes and significant statements for each theme were identified and triangulated into the quantitative data to give in-depth analysis.

CLUES Assessment

The secondary goal of implementing the CLUES process (the first goal being the development of a comprehensive environmental sanitation plan) was to critically assess the financial, technical, and social feasibility of the CLUES process, using Luchenza as our case study.

The financial feasibility was assessed by compiling all non-salary costs for the project over its duration. Salary costs were not included as salaries for the two researchers were not dedicated exclusively to this project and we hesitate to estimate what fraction of time was dedicated to this work. More importantly, the salaries would not be representative of the hopefully, local government leader, who would be responsible for leading this type of process in the future.

The technical feasibility was based on our own experiences of reading, understanding, following, and ultimately implementing the CLUES guidelines without any outside guidance. The technical feasibility also included an assessment of the logistics and practical challenges to conducting each CLUES step. We compiled much of this information from our internal and public reports that summarized the challenges, delays and reasons throughout the process.

The social feasibility assessment was based on the continuous feedback we received from participants during the process, the feedback given at the final hand-over meeting to the Council, and our own reflections after the 2 year process was complete.

Ethical Practice

Before launching, permission to conduct the study was sought from the Luchenza Municipal Council and the Thyolo District Health Officer (DHO). The research team met with and proposed the idea to the mayor, the Chief Executive officer (CEO), and the director of administration and they not only agreed to participate in the research, but to host the main researcher at the council office and provide an office space.

We obtained ethical consent (approval 1724) from the National Health Sciences and Research Committee (NHSRC) and permission to conduct the study was obtained from the Luchenza Municipal Council and Thyolo District Health Office. Furthermore, permission to undertake laboratory microbiological water tests at Chonde Health Centre was obtained from the health centre itself and from Mulanje District Health Office. Lastly, we obtained informed consent from all participating subjects.

RESULTS AND DISCUSSION

CLUES Process

Steps 1 and 2

The CLUES process revealed that increased access to improved environmental sanitation services was recognized by the government as important for socio-economic development. However, funding for implementing environmental sanitation activities was inadequate (effectively absent). In other words, the politicians believed in, or at least professed to the importance of improvements, but were unable or unwilling to budget for them.

In terms of the legal and regulatory framework, laws for governing environmental sanitation services were present. However, most Acts were outdated and laws only focused on the elimination of open defecation and basic solid waste management. The most used regulation for health and environment (Public Health Act), had not been updated since the 1960s, when it was created. Furthermore, fecal sludge disposal laws were not indicated/specified in any of the Acts or by-laws reviewed; the responsibility for by-law enforcement was not clearly specified. However, the absence of regulations which mandate exclusively water-based technologies (i.e., septic tanks and/or sewers), represented a window of opportunity for appropriate solutions, and potentially even locally-designed policy.

Luchenza municipality had a clear administrative structure. Both the political and secretariat structures were functional. There was a history of CBOs working together with the council to improve and promote environmental sanitation. For instance, stakeholders reported that the CBOs, Health Surveillance Assistants (HSAs), and Ward Development Committee (WDC) members carried out inspections to check if households had functional or sufficient sanitary facilities but reported that there was a lack of collaboration among different sectors and departments. Conversely, private sector involvement was minimal. The private sector is small, not industrial and largely family run (small shops, repairs and mechanics, agriculture, etc.). Given that most businesses operated with one or two employees, the economic benefit of civil participation was likely insufficient compared to the income generated with a full staff. Not having any private sector representation was a clear detriment to the development of Luchenza given the potential financial contributions, regardless of how small, that could be obtained.

Local knowledge and technical skills in managing environmental sanitation services were found to be lacking especially for solid waste and fecal sludge management. Most people were knowledgeable about sanitation issues, such as latrine construction. However, it was evident that they were not able to afford durable construction materials hence most latrines collapsed in rainy seasons or during floods.

Printed information for the financial status of the municipality was available for previous years, but had not been compiled for recent ones. Additionally, there was no information on how much funding was allocated to environmental sanitation. The lack of money to fund sanitation services was in part due to the debts owed to the municipality (in property tax, though the Council was not able to say how much exactly was owed), and inadequate/unpaid funding from the central government. Given that the average income per household was approximately MK53,900 or 76$USD per month (at the rate of 1$USD = MK707), the opportunity for the Council to increase taxes was limited.

Stakeholders expressed a clear demand for improved sanitation services and were receptive to new ideas: there were a variety of community groups and CBOs that already existed, community champions who were respected, and newly elected leaders who seemed committed. Furthermore, some organizations such as Plan Malawi had success working with community members and were able to reduce open defecation practices. The potential for violence and/or vandalism was an anticipated threat with respect to construction of new sanitation infrastructure but was considered minor.

The enabling environment assessment clearly illustrated some barriers (most prominently a lack of funding), but also pointed to a functioning civil society, an un-enforced, but unrestricted set of policies, and a stable, and clearly structured local government. The decision was made to continue the process despite an imperfect set of conditions.

Step 3

A total of 280 households across all 8 wards of the municipality were recruited in the household survey while 58 public water points were mapped. Findings from the survey are displayed in **Table 1**.

Water

More than 50% of the households in Luchenza identified public boreholes as their main drinking water supply and most users paid for water, i.e., an average of MK210/month for public borehole users, MK8,935/month for piped water to plot users, MK780/month for public tap users, and MK743/month for kiosk users ($USD = approximately 0.3, 12, 1, and 1, respectively). Water fetching took an average of 20 min for borehore users, 20 min for surface water users, 8 min for public tap users, and 7 min for kiosk users. However, the time values reported are based on traveling time only and not on queuing time. Only 5% of the 149 households in Luchenza that used non-piped water practiced water purification at their household, i.e., by chlorination (5 households) and boiling (2 households).

A total of 58 public water points (boreholes, kiosks, and communal taps) were discovered (**Figure 5**), of which 45 were functional. The water tests revealed the complete absence *E. coli* and Total Coliforms. However, these samples were only taken at one point in time and not continuously throughout the various seasons which may affect contamination levels.

Graywater and stormwater

Graywater is any water from the household that is not from the toilet (i.e., shower, sink, etc.); 52% of the households disposed their graywater on the open ground. During the household

TABLE 1 | Selected* environmental indicators across wards.

Ward		Kapiri	Lolo	Luchenza	Mapanga	Namadzi	Namisonga	Sambagalu	Thundu
Sample (*n*)		35	35	36	35	35	35	35	35
House ownership	Own (%)	94	46	14	51	91	86	60	31
	Rented (%)	6	54	36	43	9	14	40	54
Household members (average #)		5	5	6	4	5	5	5	5
Total household earning (MK)		40,774	62,703	62,454	65,133	55,359	35,365	43,935	67,384
Main water source (%)									
	Piped water to yard/plot	17	43	69	46	20	23	57	54
	Public borehole	77	29	31	49	77	74	37	0
	Water kiosk	6	29	0	3	0	0	3	0
Pay for water (% yes)		23	77	97	57	71	94	97	97
Graywater disposal method (%)									
	Open ground	77	57	22	60	60	54	49	34
	Septic tank connected to a toilet	0	11	28	6	3	9	3	31
	Other	6	14	8	23	17	11	20	9
Standing water present (% yes)		69	71	47	77	80	77	60	74
Type of sanitary facility (%)									
	Concrete slab and pit	26	31	28	54	9	34	43	54
	Flush toilet and septic tank	0	6	17	0	0	6	0	11
	Pour flush toilet and septic tank	0	0	6	0	0	0	0	3
	Soil and sticks slab and pit	66	37	11	34	83	51	49	9
Shared sanitary facility (%)		20	20	31	43	51	37	17	46
Solid waste storage (%)									
	Containers (plastic/metal)	0	20	14	6	0	0	9	54
	No storage (direct disposal)	100	80	86	94	100	100	91	46

Not all options for each variable are presented and therefore not all variables total to 100%; full results are presented in the* ***Supplementary Material**.*

survey, we observed that 69% of the households had standing water present on their plot. Municipal drains were blocked with sand, stones, and solid waste which prevented stormwater from flowing freely which may encourage the growth of malaria transmitting mosquitos and other vectors.

Rainwater harvesting was reported by 71% of the households although most households collected the rain water directly from iron sheets and not through a rain water gutter. In addition, most households (29%) reported that it was only a "little" rain water that could replace regular water supply. Flooding was experienced in 9% of the households.

Sanitation

Most households (96%) across all wards had sanitary facilities on their plot. However, 34% of these households reported sharing their sanitary facility(s) with other households, which is not considered as safely managed sanitation (World Health Organization and UNICEF, 2017). Although most houses had sanitary facilities, the most common toilet design was "unimproved" i.e., mud and stick designs with no vent pipes as observed in 44% of the households.

Pit emptying was not a common practice: filled latrines were replaced by new ones. On average, 64% of the households had abandoned sanitary facilities on their plot and the average number of abandoned sanitary facilities per plot was 2. Furthermore, there were no private pit emptiers in Luchenza. The vacuum truck at the council was not in use due to a mechanical issue, but when it was in operation, it dumped sludge at the same dumpsite where the trash was disposed. The inability to empty pits or treat fecal sludge on-site for reuse or disposal means that pits have a higher likelihood of overflowing, causing people to practice open defecation, or emptying the fecal sludge themselves, all of which result in serious human and environmental health risks (Tayler, 2018).

There are 13 public toilets in Luchenza: 4 were built by the Council and cost MK50/use; 3 were built by the community and are free; 1 was built by a local MP and is free; and 4 are privately run and cost MK/use. Three of the 4 toilets built by the council are non-operational, but the privately run facilities are functional, and generally well-maintained.

The sites where community members mostly identified as potential sites for new public toilets in Luchenza were Chonde market, Luchenza market, Luchenza depot, and Luchenza hall.

Solid waste

Direct disposal of solid waste, i.e., disposing it onsite or wherever it was created, but not in a contained pit, was reported in 87% of the households. Composting was reported in 41% of the households across all wards. However, the type of composting that was practiced was "uncontrolled" where organics would be thrown in pits and after some time, applied in fields (i.e., without controlled thermophilic conditions or aeration).

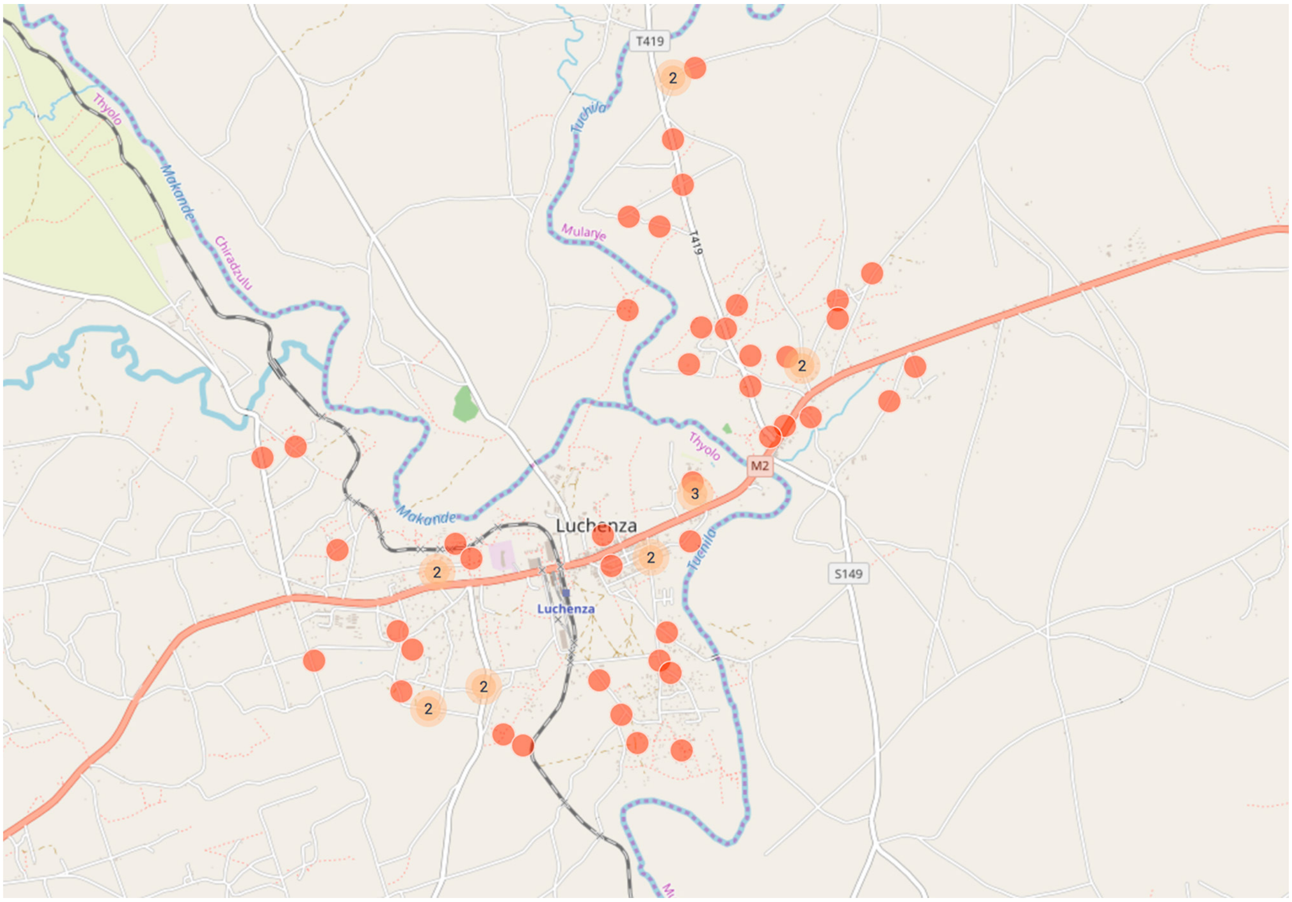

FIGURE 5 | Water points of Luchenza.

There was no waste collection truck in Luchenza. A pick-up truck would sometimes be hired for waste collection, but only for municipal solid waste i.e., in markets and in the trading center, but not household waste.

Step 4

Sixty people attended in the validation workshop, including the mayor and various councilors. The goal of the validation workshop was to have participants validate the results from Step 3 and/or provide corrections, and help to prioritize the problems that were identified. All results presented from the data collection exercise were validated by the community, though refuted by the representative from the Water Board. Through a pocket voting exercise, stakeholders identified water supply as a priority problem in Luchenza especially a shortage of public water points and frequent water outages for piped water. Forty-three percent of the households reported they had water outages of at least 1 day per week and 22% of households reported they had experienced water outages for up to a whole week. Stakeholders at the workshop in Luchenza also reported that they felt they were overcharged for piped water to their plot and that they were getting incorrect bills. Issues related to fecal sludge management and solid waste did not demand as much conversation or attention as those related to water, which became especially heated.

Steps 5 and 6

At planning stages 5 and 6, we developed an environmental sanitation action plan: a guiding document that presents a comprehensive set of steps and recommendations for Luchenza. The contents of the sanitation plan were suggested and validated by the community in Luchenza through a workshop. The action plan addressed all components of environmental sanitation i.e., drinking water, gray- and stormwater, sanitation, fecal sludge, and solid waste, which the community members (both the municipal council and individual households) could adopt to meet their own stated objectives. The plan has short (1 year) and long-term activities, with a maximum number of 8 years. Furthermore, each target has specific roles for community members and the council (secretariat) with approximate costs.

During a third workshop, the researchers also grouped the 79 participants in 8 groups according to their location, i.e., 8 wards of the municipality. Each group had ∼10 members: the ward councilor, ward chiefs, ward committee representatives, neighborhood committee representatives, community members representatives, and some staff from the municipal council and the water board. The aim of having these working groups was to have a community task force to initiate the action plan i.e., through advocacy and community activities. These working groups would also serve as support systems for the communities in implementing the action plan at household level. The groups identified stated their willingness to participate and agreed to meet in their wards to make a plan for implementing the strategy. The Action Plan is provided in the **Supplementary Material**.

Step 7

"Implementation of the Action Plan" should normally be completed by following the strategic plan that was developed and agreed upon in Step 6. However, because the City was unwilling to allocate any funds or time to implementation (and had refused to believe that we would not fund the implementation), we decided on a middle ground: to retrofit a model household with the most crucial facilities recommended in the environmental sanitation action plan. This was not required, or even mentioned in the CLUES guidelines, however we felt compelled to find a way to demonstrate some type of tangible outcome, both to "complete" the process and to appease the council. The aim of the model household was to serve as a reference point for other households, such that they could view the various technologies, learn how they operate and eventually, install some or all of them at their own home. The idea was for the model household to be open to visitors, and available to give technical guidance on how to construct or operate the identified technologies, having been trained by the project team. The model household would also have free brochures to give to the ward committees and/or individuals seeking technical guidance.

The model household was identified during the third workshop where the action plan was validated. The terms for selecting the model household were: willingness to serve as the model household, open to queries and ready to give technical guidance on how to set up the facilities, permanent residency in Luchenza, living on a plot that is not rented, sufficient land on the plot, and easy accessibility. To identify the model household, each of the 8 community working groups formed at the workshop nominated one participant and wrote down the name of the nominee on a piece of paper. The 8 pieces of paper containing names were folded and the project team anonymously picked the name. Very strict protocols like this were always necessary to guarantee transparency and negate any potential for accusations of favoritism.

The model household was equipped with a rain water gutter to harvest rain water, a soak pit and an interceptor tank to drain waste water from the household's cattle enclosure (biggest source of wastewater at the household), a hygienic dishwashing and laundry station, a Fossa Alterna sanitary facility, a hand washing station, a 4 m^2 compost enclosure (made of bamboo) for organic waste, a garbage pit for inorganic waste, and an improved drain connection from the shower room to allow greywater to flow into a soak pit. Work at the model household was done by a contractor from Luchenza. Nevertheless, costs of the model household as depicted in **Table 2** could be significantly reduced with the use of substitute materials such as grass or bamboo instead of bricks and iron sheets. The labor charge could also be removed or reduced as some of the work could be done by household members on their own.

TABLE 2 | Model household expenses (exchange rates were calculated for the month of purchase).

Facility	Cost	Amount (MK)	Amount (USD)
Soak pit	Materials	80,300	111
	Labor	30,000	42
	Total	110,300	153
Rain water gutter	Materials	11,200	15
	Labor	4,000	6
	Total	15,200	21
Dishwashing and laundry station	Materials	24,800	34
	Labor	15,000	21
	Total	39,800	55
Fossa Alterna	Materials	74,900	103
	Labor	45,000	62
	Total	119,900	165
Handwashing station	Materials	2,800	4
	Labor	NA	NA
	Total	2,800	4
Compost pile	Materials	8,000	11
	Labor	7,500	10
	Total	15,500	21
Inorganics garbage pit	Materials	12,750	8
	Labor	7,500	10
	Total	20,250	18
	Grand total	323,750	447

Having completed the work at the model household, all the community working groups for the project were called for a tour, where the house owner (herself a Chief) explained what the facilities were and how they would be used. This event was to give insight and to motivate the groups on activities they could initiate in their own wards. A follow up at 1 month revealed that none of the group members had met; it was not clear if it was because the model household owner had prevented the groups from visiting or if the working groups had simply failed to attend. We were then prompted to organize a composting competition among the group members i.e., for them to motivate households in their wards to set up simple and basic compost piles (1 m^2). Thinking that maybe the whole model household was too overwhelming or amibitious, the idea of the composting competition was to start with one component of the model household and build capacity step-wise. The group with the largest number of piles would receive a money prize (MK50,000 or 138$USD) followed by a runner up (MK50,000 or 70$USD) but no ward could win without a minimum of 20 compost piles. After three more months of repeated follow-ups, only two groups (20 piles in Sambagalu ward and 15 piles in Kapiri ward) managed to make any compost piles. Furthermore, it was only one person in Sambagalu implementing the entire initiative (i.e., not the groups that had been formed). In Kapiri, the compost piles were mostly dry and clearly set up just for the judging.

As a follow-up for the model household during a surprise inspection 4 months later, the household had inorganic waste all over the compound, the compost pile had been removed, the Fossa Alterna was very wet (i.e., dry organics/ash were not being added regularly), and a new bathroom had been constructed inside the house releasing graywater openly on the plot.

Post-CLUES Meeting

As a final stage for the project, we had the final meeting with representatives from the council and all ward councilors to report the findings. Though we attempted to highlight the positive results such as the updated data, increased awareness, early adoption of composting, etc., representatives from the council stressed that the implementation had "failed" due to a lack of "motivation" in monetary terms; specifically, they stated that the allowances given during the workshops were insufficient and that it would be hard for people to carry out the work in the working groups for free.

CLUES Evaluation

From the outset of this project, the goal was to evaluate the technical, political and financial feasibility of following the CLUES process in a Malawian small town. Our evaluation is based on our quantitative data, experiences, and critical reflections, especially those that occurred at the end of each step, as we re-read the instructions for the subsequent step and prepared to follow the guidelines, inevitably building upon what we had learned previously.

Technical Feasibility

Technical feasibility in this context, refers to how the easy the CLUES document was to use, and to how easy the steps were to implement.

Availability and usability of recent data

CLUES recommends a round of baseline data collection as one of the initial steps in the planning process: information on population and demography, stakeholders, recent maps, water and sanitation infrastructure (e.g., water points, public toilets), and physical characteristics (e.g., soil type, flooding). However, data availability was a challenge in Luchenza as most data were outdated. In some scenarios, the data were completely non-existent. In addition, Malawi suffers from frequent power outages. In Luchenza, the city council had its power disconnected due to unpaid bills and had to rely on a diesel generator, though because fuel is so expensive, they could only afford to use it for a few hours per day. As a result, digital data are rare (in Luchenza and across the country), and council staff continue to rely on paper-based information. There is no systematic data collection from the council which means that decisions are rarely, if ever made based on recent, robust information. In instances where data are available, it is usually stored away or in a disorganized pile of deteriorating papers that staff are unlikely to use.

As researchers, we had the time, money and motivation to collect necessary information (e.g., photocopying and enlarging maps at professional copiers), but it is unlikely that any application of the CLUES framework by a government body would have a similar luxury (i.e., large-scale copying was done in the major city, Blantyre).

Time

Although the CLUES framework does not specifically state the time required for each step, it recommends 18 months for the entire planning process.

The actual process took 22 months although it could have been shortened. One factor that led to the lengthy approach was the time spent collecting baseline data due to the low population density and the fact that some houses and areas were separated by features such as farms, rivers, and bushes (i.e., enumerators could not rapidly move between homes).

Secondly, the stakeholder analysis/identification was lengthy because of the lack of available information on existing stakeholders and poor coordination among stakeholders (stakeholders not knowing other stakeholders). Furthermore, obtaining consent/ approval from several bodies or individuals to conduct the study and/or execute some activities during the project delayed the planning process. For instance, permissions were requested from Thyolo DHO and the council to conduct the study, and also from Chonde Health Centre and Mulanje DHO to conduct water quality lab analyses at the health centre. Additionally, always notifying respective leaders (chiefs, councilors) before working in their area (i.e., during the household survey and mapping exercises) was a prerequisite which consumed a non-trivial amount of time. Though the "digital revolution" has purportedly come to Africa, official invitations must still be delivered on paper, by hand, for them to carry official status.

Political Feasibility

Government support

The geographical location of Luchenza played a significant role in how the government (both local and central) affected the planning process. As seen in **Figure 2**, Luchenza lies between two district councils (Thyolo and Mulanje) which creates confusion and overlap in management activities. Essentially, we were required to work with the two councils collaboratively e.g., when seeking permissions. When asking for permission to conduct the research (for ethical clearance), we were required to ask for permission from Thyolo District Health Office (DHO) but used one of the health centers in Luchenza for water quality tests, which required permission from the Mulanje DHO because the health center was situated on the "Mulanje side of Luchenza."

On a local government level, there was high staff turnover which affected institutional knowledge, acceptance and continuity. The high turnover was because Luchenza is viewed as a demotion for higher ranking government officials and is an "economic backwater" due to isolation, limited infrastructure and services e.g., electricity, and limited developmental (i.e., corruptable) projects (Caplan and Harvey, 2010). For instance, during the entire period the project was conducted i.e., 2 years, we worked with 3 different CEOs and 2 administrative officers. The high turnover means that there is limited ambition by the senior administration to invest in Luchenza because time spent by staff in Luchenza will be short and the returns, if any, would

TABLE 3 | Cost estimate of CLUES steps in Luchenza (exchange rates were calculated for the month of purchase).

Description	Amount (MK)	USD ($)
Steps 1 and 2–launching workshop and status assessment		
A. Launching workshop		
Purchase of mapping stickers	4,550	
Venue booking	20,000	
Venue toilet cleaning materials	840	
Airtime	12,500	
Assistant allowance	5,000	
Catering (tea break and lunch)	102,300	
Purchase of drinking water (80 bottles)	30,560	
Purchase of 72 drinking bottles (incentives)	65,400	
Printing and photocopying invitation letters, programs, and handouts	8,050	
Purchasing stationery (pens, pencils, A3 plain papers)	37,000	
Workshop tour transport	41,000	
Planning transport	17,800	
Transport allowance for 50 participants	25,000	
Sub-total	370,000	505
B. Status assessment		
Printing, photocopying and binding status assessment reports	16,840	
Sub-total	16,840	23.16
Step total	386,840	532
Step 3–detailed assessment (public water point mapping and water testing, household survey)		
A. Public toilet mapping		
Stationery	8,020	
Airtime (other)	5,900	
Airtime for hotspot internet	6,500	
Transportation	12,000	
Allowance for assistant for data collection	50,000	
Sub-total	82,420	113
B. Household survey		
Airtime (other)	19,450	
Airtime for hotspot internet	47,100	
Transportation	22,500	
Printing, photocopying, and purchasing stationery	15,140	
Assistant allowance	50,000	
Sub-total	154,190	212
C. Water-point mapping		
Airtime (other)	2,200	
Transportation	20,200	
Printing, photocopying, and purchasing stationery	16,566	
Assistant allowance	20,000	
Electrical supply/ appliances for lab	7,650	
Lab security (windows, burglar bars)	41,500	
Sub-total	108,116	149
Step total	344,726	474
Step 4- priorities workshop		
Airtime (other)	3,500	
Transportation	4,000	
Printing, photocopying, and purchasing stationery	15,050	
Venue	20,000	
Catering	101,660	
Assistant allowance	3,000	
Step total	147,210	202
Step 5 and 6–action plan workshop		
Airtime (other)	4,000	
Transportation	12,500	
Printing, photocopying, and purchasing stationery	26,215	
Venue	20,000	
Catering	155,950	
Assistant allowance	13,000	
Transport allowance for 75 participants	75,000	
Step total	306,665	422
Grand Total	1,185,441	1,630

likely go unnoticed by important officials. This scenario is likely true for most small towns across Malawi.

Stakeholder participation

The CLUES framework relies on stakeholder engagement and participation as an important factor throughout all planning steps. However, despite a constant presence, objective reinforcement, and city-backing, stakeholder participation was limited and a significant barrier to success. First, participants required financial motivations ("sitting fees") to attend workshops e.g., transportation allowances (on average MK1,000 per person) and other incentives e.g., food (on average, a meal cost K2,000 per person). Second, participants and council members required constant reminders and follow-ups in the form of telephone calls, printed invitations, and/or home visits. Third, over the course of hours of meetings and discussion, it became clear from the community representatives that any labor or contributions would be the responsibility of the city council, and that the community had only an advisory role. Privately and publicly in meetings, participants felt that if they contributed financially to any sort of infrastructure development, their money wouldn't be put to use (theft from officials). Similarly, some participants were of the general opinion that no matter what, environmental sanitation would not improve in Luchenza; a long history of failed promises and corruption [Malawi is the 120th least corrupt nation out of 175 assessed according to Transparency International (TI) (2019)] had left the community apathetic and doubtful of change.

Institutional Arrangements/Responsibilities

During the assessment of the enabling environment, it appeared as if there was a clear and defined administrative structure at the council. Furthermore, community working groups existed and were seemingly active: ward committees, Neighborhood Development Committees, Area Development Committees, and water point committees. Political leaders (councilors) and traditional leaders (chiefs) were also recognized in formal structures. However, the detailed assessment in Step 3 showed that there were no clearly defined responsibilities of the leaders or groups and the private sector was largely absent from local-decision-making processes. During the second workshop, some participants stressed that it was the duty of elected councilors to solve sanitation problems. Similarly, during the household survey, respondents stated that they were unwilling to raise funds for water points as it was not their duty to do so, but that of their leaders and the council secretariat.

Expectations

Despite numerous statements to the contrary, it is obvious that when the idea of CLUES was presented, individuals in Luchenza imagined that they would receive something, especially in monetary terms. Years of financial and material handouts to residents, along with a deeply embedded culture of government corruption seems to have prevented anyone from believing us when we continually emphasized that we were only helping to compile materials, facilitate discussions, and provide technical backstopping. Perhaps other projects had started in a similar fashion only to be coerced into extra investments by the end? Regardless of precedent, it was clear that no one's expectations were met.

Financial Feasibility

Even without researcher salaries, the CLUES process was expensive and not likely feasible for a small town in Malawi to afford on its own. A large portion of the cost went to incentives, catering, and transport allowances for participants, which may seem lavish but were, as discussed above, essential (**Table 3**). Workshops were useful in that they renewed enthusiasm, reminded the group about the progress and demonstrated the researchers' commitment (especially after the 1-year mark). However, commitments made by the Ward committees and the City Council to follow through on action items were rarely if ever achieved. Workshops were supposed to highlight and then build on the actions taken, but instead, we would accept the myriad of reasons why progress wasn't made and try to push on to the next step, conscious of the allotted timeline.

In terms of Luchenza's own solvency, they obtain minimal funding for WASH facilities and services from the central government and are supported by a small local tax base (Luchenza City Council, 2013). **Table 4** displays the council's revenue source from 2008 to 2013. Assuming an annual income for our time period of $200,000 (a higher than expected value given the trend), the process, excluding labor, transport, and overhead costs (e.g., internet) would represent about 1% of the budget. Considering that minimum wage in Malawi is MK 25,000/month (33$USD) and that the Council could rarely pay its electricity bill for the duration of the exercise, it is unlikely that this expenditure could or would be justified.

The "Other Recurrent Transactions" in **Table 4** encompass Infrastructure Development Funds (IDF) and Sector Funds for Environment. We were unable to obtain official figures, but the city claims to have more than 40% of their tax bills outstanding. Currently, they issue letters and make visits to the offending citizens but do not have the power to freeze bank accounts, directly debit paychecks or take any other types of direct action.

CONCLUSIONS AND RECOMMENDATIONS

Our experience made clear that the CLUES process would likely not be feasible for a local council of a small town in Malawi to conduct. The lack of data, the time required, the financial investment, and the hierarchical culture that is founded on a long history of patronage and traditional chiefdoms, were not conducive to the long-term participatory process. However, Malawi is a special context in that it is exceptionally poor, has one of the lowest electrification rates in Africa, and a history of corruption that has been encouraged and exacerbated by the NGO culture of incentives or "sitting fees." That said, the CLUES process could, with modifications, be adapted and used with success in other countries or contexts.

The enabling environment must be thoroughly assessed prior to launching the project. As researchers, we had a research timeline so did not have the luxury of thoroughly evaluating the enabling environment before selecting Luchenza, and this was a mistake. As with many research projects, we had a fixed budget and deadline for deliverables. Doing a preliminary assessment of the enabling environment of multiple towns would have been the right thing but too time consuming for this study. Had we been adequately aware of the incentive expectation, the limited operating budget, the high turnover of government staff, and the general culture of apathy, we would not have initiated the process in Luchenza. Similarly, the lack of data, computers, maps, and documents cost us a great deal of time and money, and should have instead, signaled that the city was not ready or able to make use of evidence for decision-making.

In terms of the actual guidelines, the launching workshop mentioned in step 2 should be the kick-off event and/or the initial community meeting itself. Launching activities like sanitation marketing, where sanitation products and services would be showcased/sold, should be delayed until community members are more aware of sanitation issues and have a vocabulary and context in which to understand them. Furthermore, we as researchers did not have enough information about the project area before the assessment conducted in Step 3 to showcase or promote specific sanitation products or initiatives. We organized a demonstration trip to a composting facility for the participants to learn about the method and product, but, based on the observed and stated practices later on, the visit was too early and out of context for the participants to truly understand and embrace the technology for their own purposes.

Step 3 consumed the majority of the budget and must be shortened. Again, it would not have been so extensive had there been more available information. Specifically: sub-step 1 (collecting and synthesizing existing information about the

TABLE 4 | Sources of revenue for Luchenza City Council (2013).

Revenue source	2008/09 USD ($)	2009/10 USD ($)	2010/11 USD ($)	2011/12 USD ($)	2012/13 USD ($)
Market fees	25,931	23,401	35,755	50,621	27,409
Property rates	22,330	57,211	66,551	99,838	48,558
Business licenses	7,867	7,533	6,137	15,640	6,448.6
Fees and other charges	82,088	36,004	15,761	34,285	17,071
Other recurrent transactions (ORT)	24,419	26,746	26,056	36,139	19306
Total	162,636	150,894	150,260	236,525	118,792

project area) should be part of the assessment of the enabling environment to determine if there is sufficient information, or sufficient willingness on the part of the host organization to collect and/or obtain it; otherwise, the process should probably be stopped. Data collection activities in this step should be done to supplement or update existing information, but not to generate completely new maps, accounting statements, and demographic surveys.

Finally, and most importantly, for the CLUES process to ever really succeed as a planning tool, it must be led/ implemented by an internal person or institution that is responsible for the project area. As researchers, we were interested in understanding how feasible the process would be so this necessarily biased the results, especially since there was an inherent assumption that minimal effort would be required from the council and that all costs would be covered. Any future use of CLUES should be done by experienced, full-time city planners who have contracts beyond the scope of the planning and implementation phase, to ensure commitment, buy-in and political will. External agencies who wish to support the use of CLUES should instead offer to fund the materials, data acquisition, experts, and other expenses required to complete the process, rather than actively leading it themselves.

The current CLUES document is 102 pages and users have access to 30 downloadable tools (e.g., example surveys, agendas, invitation letters, etc.). A simplified version (e.g., 30 pages) which specifies a few, concrete deliverables would make the document more useable and effective. In its current form the demands feel overwhelming and the process unwieldly. The goal of the guide should be to help users (a) identify what they have in terms of services, funding, and capacity; (b) determine what can be done given the resources available; and (c) prioritize the activities according to constraints.

In this and other contexts, the greatest benefit of using CLUES can come from the process of seeking out and compiling data, even if it is only to recognize that few data exist. Given that so little is known about small towns, concerted efforts should be made to help local governments collect, digitize and disseminate data for their own use, and if deemed feasible, future planning exercises.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the National Health Sciences and Research Committee. Written consent was obtained from all households who participated in the household study.

AUTHOR CONTRIBUTIONS

WM managed the process and collected the primary field data. WM also participated in drafting the manuscript, analyzing the dataset, and writing the final manuscript. ET developed the research concept, supervised the field work, and collaborated on the writing and editing of the manuscript. All authors have read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

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Estimating Safely Managed Sanitation in Urban Areas; Lessons Learned From a Global Implementation of Excreta-Flow Diagrams

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The urban population will rise to 6.7 billion by 2050. The United Nations has committed to provide everyone with safely managed sanitation, but there is limited understanding of the scale of the challenge. This paper describes a methodology for rapid assessment of sanitation in cities including a graphical representation (a shit-flow diagram or SFD) and reports on findings from implementation in 39 cities. The SFD provides high level information for planning purposes covering the entire sanitation system in a city. More than half of the human excreta produced in these cities is not safely managed. The most significant portions of the unsafely managed excreta are: (i) contents of pits and tanks which are not emptied and are overflowing, leaking, or discharging to the surrounding environment (14%); (ii) contents of pits and tanks which are emptied but not delivered to treatment (18%); (iii) fecal sludge and supernatant delivered to treatment but not treated (3%); (iv) wastewater in sewers not delivered to treatment (14%); and (v) wastewater delivered to treatment but not treated (6%). Many cities currently relying on onsite sanitation for safe storage, particularly in Africa, will need new strategies as populations grow. Containment systems that discharge to open drains are common in some Asian cities; these pose a public health risk. Dumping of excreta is widespread and there is a lack of realistic performance data on which estimates of the extent and effectiveness of treatment can be made. The SFD production process can be challenging due to a lack of data and low technical capacity in cities. There is often uncertainty over terminology and over the status of infrastructure. Formalizing definitions for the SFD preparation process was found to be useful in overcoming capacity constraints in cities. The SFD produces a credible snapshot of the sanitation situation in a city. The paper provides evidence of the urgent need for improved management and monitoring of urban sanitation in cities around the world and highlights the role of the SFD as a planning tool.

Keywords: cities, urban sanitation, monitoring, health risk, excreta flow diagram, SFD, shit-flow diagram

INTRODUCTION

The United Nations Millennium Development Goals (MDGs) are widely recognized as having increased attention by key decision makers of the need for investments in sanitation. While the world missed the MDG sanitation target in 2015, nevertheless it is estimated that 1.9 billion people gained access to "improved" sanitation between 1990 and 2015, equivalent to more than 200,000 people every day (Mara and Evans, 2017). High rates of urbanization and the greater ambition of the new Sustainable Development Goals (SDGs) which cover the period from 2015 to 2030 suggest that the challenge for sanitation in the future will be even greater. The urban population will rise to 6.7 billion by 2050 (United Nations Department for Economic and Social Affairs, 2018). In cities and towns, it is increasingly clear that global targets now call for solutions which provide "safely managed sanitation" from the toilet through treatment to the point of disposal or end-use (World Health Organization/United Nations Children's Fund, 2017a).

Urban sanitation requires a high level of technical competency, due to the need for interlinked or networked systems that address both the intensely personal sphere of private sanitation and the management of excreta for public health and environmental protection. Before cities can improve the rate of safe management of sanitation, they must first understand the current situation. This is challenging since services are often provided informally; regulatory control is low and performance data unavailable (Baum et al., 2013; Sato et al., 2013; Williams and Overbo, 2015). The assessment of "safety" is also challenging since it requires an understanding of both hazards in the environment and exposure in affected populations (World Health Organization, 2016; Robb et al., 2017).

Several recent efforts have attempted to fill these gaps. The Performance Assessment System (PAS) developed in India for water supply and sanitation benchmarking (Mehta et al., 2011), AQUASTAT (Food and Agriculture Organization, 2018), and the International Benchmarking Network (IBNET) (2018), all attempt to describe the current status of urban sanitation in large numbers of locations. PAS is comprehensive and widely accepted in parts of India but AQUASTAT and IBNET have both largely failed to encompass systems outside of those provided by large scale utility service providers. Very little reliable data are to be found on overall performance of the mixed and somewhat chaotic sanitation systems, which predominate in rapidly growing low- and middle-income cities with limited management capability or planning control. Sanitation Safety Planning (SSP) assesses risks associated with poor sanitation (World Health Organization, 2016); it was developed by the World Health Organization and builds on their Guidelines for Wastewater Re-use (World Health Organization, 2006). SaniPath is an effort to apply the same approach at a higher resolution at the local level (Robb et al., 2017). However, neither has yet been widely adopted.

Peal et al. (2014a) describe the development of a methodology for assessing urban sanitation service delivery through a service delivery assessment (SDA) scorecard and a fecal waste flow diagram (also known as a shit-flow diagram, SFD, or SFD Graphic). The SDA and SFD Graphic provide an overview of the sanitation situation without recourse to detailed field studies. The SDA facilitates the analysis of a complex situation by breaking down the systems and assessing the individual components according to a series of objective criteria, while the SFD Graphic provides immediate visual cues about where system failures may be occurring, which can be linked back to institutional aspects of service delivery. This work fills the gap between the generalized data in AQUASTAT and IBNET and the more detailed SaniPath approach. The "shit-flow diagram" or SFD approach has had rapid uptake and is now accepted as a tool for focusing political will and technical effort on critical sanitation problems at city level. For example, based on this approach, the World Bank developed the Fecal Sludge Management (FSM) Diagnostics for Service Delivery in Urban Areas tools (Scott et al., 2019) and the International Resource Centre (IRC) developed a Fecal Waste Flow Calculator (IRC, 2018). A similar approach is also used for monitoring target 6.2 of the Sustainable Development Goals—which has as its indicator "the proportion of the population with safely-managed sanitation"—although the definition of safe management used by the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) is not the same as those used to prepare an SFD (World Health Organization/United Nations Children's Fund, 2017b). The 2018 World Health Organization guidelines on sanitation and health also make use of the SFD methodology (World Health Organization, 2018).

This paper describes a standardized methodology that has been developed and used to prepare SFDs. It also reports on the implementation of the approach in 39 cities. The results are used to examine key trends and gaps in both information and implementation relating to urban sanitation globally.

METHODS

The SFD Production Process

Since 2014 the approach described by Peal et al. has been further developed through a project entitled the SFD Promotion Initiative (SFD-PI). The SFD production process has been codified in a manual which is available on the project website (SFD-PI, 2018a). The manual includes a set of standard definitions; the assumptions used to model excreta flows; and lists of recommended data sources on which estimates can be made. It also describes the process of preparing an SFD Report including: approaches to stakeholder consultation; methods for data collection and verification; a list of guidance questions for assessing the service delivery context (**Table 1**); and standard report format. There is also an SFD Graphic Generator tool, which automates drafting of SFD Graphics (SFD-PI, 2018b). The tool produces outputs as portable network graphics (.png), which can be downloaded for use in an SFD Report or for sharing directly with stakeholders.

General Approach to SFD Analysis

SFD analysis uses the "sanitation chain" to ensure that excreta flows are tracked from the point of production (containment), through emptying, transport and treatment, up to the point of

TABLE 1 | Guidance questions for assessing service delivery context (from SFD-PI, 2018a).

Enabling environment to service delivery	Data collected at all stages of the service chain: containment to end-use or disposal
Policy, legislation and regulation	**Policy:** To what extent is provision of sanitation services enabled by appropriate, acknowledged and available policy documents (National/Local or both)?
	Institutional roles: To what extent are the institutional roles and responsibilities for sanitation service delivery clearly Defined and operationalized?
	Service provision: To what extent do the policy, legislative and regulatory framework enable investment and involvement in sanitation services by appropriate service providers (public or private)?
	Standards: To what extent are norms and standards for each part of the sanitation service chain systematically monitored and reported?
Planning	**Targets:** To what extent are there service targets for each part of the sanitation service chain in the city development plan, or a national development plan that is being adopted at the city level?
	Investment: How much was invested in sanitation services in the last investment plan and how much has been incorporated into the next approved investment plan? What has been achieved as a result of the last level of investment (including investing in human resources, Technical Assistance, etc. as well as infrastructure)?
Equity	**Choice:** To what extent is there a range of affordable, appropriate, safe and adaptable technologies for sanitation services available to meet the needs of the urban poor?
	Reducing inequity: To what extent are there plans and measures to ensure sanitation serves all users, and specifically the urban poor?
Outputs	**Quantity/capacity:** Is the capacity of each part of the sanitation service chain growing at the pace required to ensure access to sanitation meets the needs/demands and targets that protects public and environmental health?
	Quality: To what extent are the procedures and processes for monitoring and reporting access to sanitation services applied, to ensure safe and functioning facilities and services through the service chain? Is the quality of the facilities and services sufficient to ensure they protect against risk throughout the service chain?
Expansion	**Demand:** To what extent has government (National or Local) developed any policies and procedures, or planned and undertaken programs to stimulate demand for sanitation services and behaviors by households?
	Sector development: To what extent does the government have ongoing programs and measures to strengthen the role of service providers (public or private) in the provision of sanitation services, in urban or peri-urban areas?
Service outcomes	**Quantity:** To what extent is the excreta generated from onsite and offsite sanitation technologies effectively managed Within each part of the service chain? *(Note: This information is used to generate the SFD Graphic)*

end use/disposal (**Figure 1**). It is based on the idea that excreta flows are either "safe" or "unsafe". "Safety" is assessed in terms of whether the hazard (pathogens in excreta) are likely to enter the environment at each point along the sanitation chain *and* if human exposure to that hazard at that point is also likely to result in a public health risk. To keep the SFD Graphic clear and uncluttered, very few technical terms are displayed; generic terms and color-coded arrows sized proportionally to the population whose excreta follow each pathway are used to describe the sanitation chains and service outcomes. Green arrows represent flows at each step along the chain which are likely to have a "safe" outcome; red arrows represent "unsafely managed" flows.

The analysis is therefore divided up according to the sanitation chain: firstly, an assessment of the containment system and the extent to which excreta are safely "contained" at the point of production and then an assessment of how excreta flow from the point of production through piped networks (e.g., sewerage), or via non-piped networks (e.g., handcarts, vacuum tankers, or trucks), to treatment and end use/disposal.

Standard Definitions of Terms and Variables

Terminology

Terminology used to describe the components of sanitation systems is extensive, varies regionally, and is often inaccurately applied. To ensure consistency, standard definitions of terms and variables were developed based on the most recent literature (Strande et al., 2014; Tilley et al., 2014). A broad distinction is made between onsite sanitation in which excreta (primarily fecal sludge) are collected and stored where they are generated; and offsite sanitation in which excreta are collected and transported away from where they are generated, in the form of sewage or wastewater (SFD-PI, 2018a).

Containment Systems

The "containment system" is the first step in the sanitation chain (see **Figure 1**) and refers to both the toilet and the infrastructure immediately following the toilet. Thus, for offsite systems it refers to the toilet and the connection to a sewer or drain. For onsite systems it refers to the toilet, the pit or tank into which the toilet discharges and any soak pit, sewer, drain, or open ground to which the pit or tank is connected (SFD-PI, 2018a).

Assessing "safe management" at the toilet is challenging and depends on a range of behavioral issues including cleaning of facilities and handwashing. For this reason, the terms "contained" or "not contained" are used rather than "safe" or "unsafe" management for this step. Contained systems are those which are *unlikely to result in pathogen transmission to the user or the general public in the absence of any other adverse behavior*. By contrast systems described as "not contained" result in *an elevated risk of exposure to pathogens in the nearby population irrespective of household habits such as handwashing*.

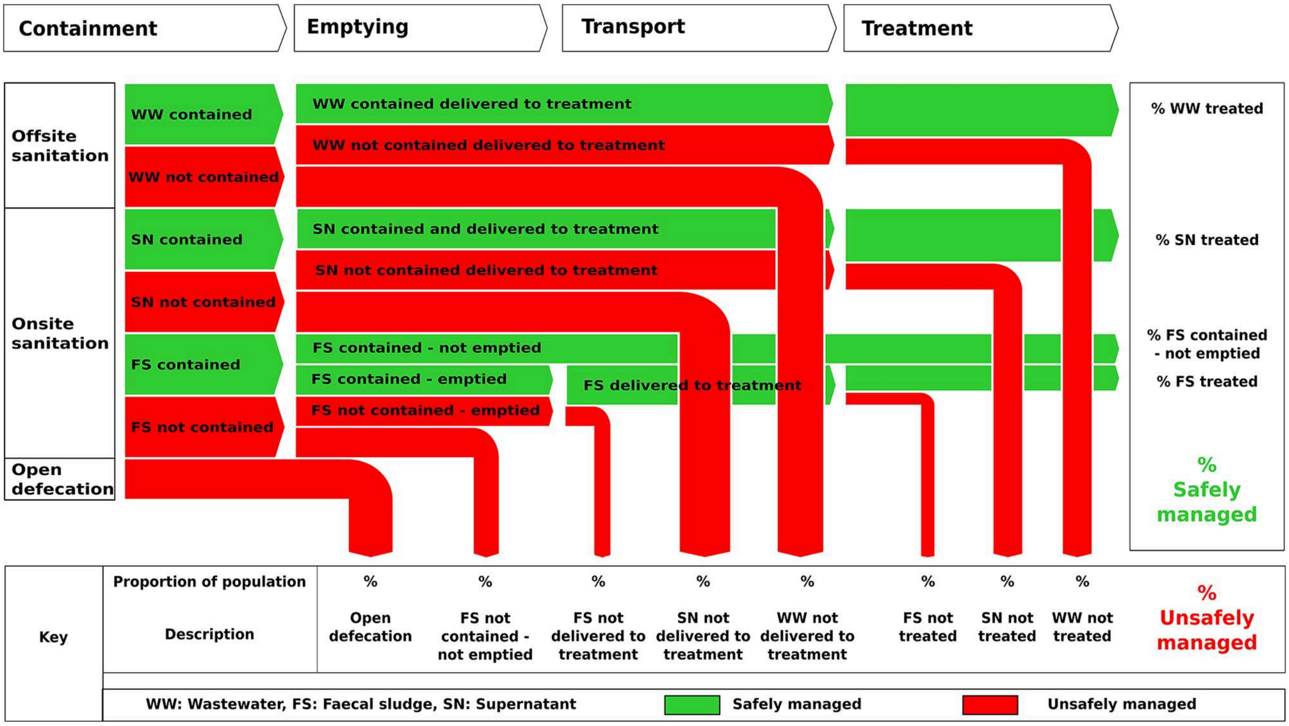

FIGURE 1 | SFD graphic used in SFD production process (from SFD-PI, 2018a).

A set of 33 generic "containment systems" were developed (**Table 2**). The systems are distinguished specifically by features that impact on "containment"—for example whether or not a tank is fully lined (sealed) or has permeable walls or a permeable bottom, and those which are damaged or flooded. An important distinction is made between septic tanks which, when properly designed and constructed, always have an effluent outlet connected to a soak pit, leach field or to sewerage, and basic tanks even if the latter are fully lined.

Four of the containment systems are always "contained". For example, excreta from toilets that discharge directly to sewers are "contained" because excreta within a sealed and impermeable sewer present a low public health risk.

Twenty systems are always "not contained" either because they are broken, flooded, or damaged, or because they discharge supernatant (liquid effluent) directly to the environment. This includes any kind of tank connected directly to open drains, water bodies or open ground which results in a high risk of population exposure to pathogens.

The remaining systems are designated as contained/not contained (**Table 2**). These are systems where some fraction of the excreta infiltrate to the ground including systems with a lined or unlined pit, a tank with open bottom or soak pit (which includes leach fields). These systems are assumed to be "contained" unless their use results in a significant risk of polluting groundwater which is used for drinking by people in the nearby vicinity. The risk of groundwater pollution is estimated from the depth of groundwater, the percentage of groundwater used for drinking water, local geology, and the distance between groundwater sources and the sanitation containment system (ARGOSS, 2001; Bains et al., 2014).

Emptying and Transport

"Emptying," the second step on **Figure 1**, is defined as "the manual or motorized removal of fecal sludge from onsite sanitation systems" (SFD-PI, 2018a). "Transport," includes "the manual or motorized conveyance of fecal sludge emptied from onsite sanitation systems" and "the conveyance of wastewater using a sewer network" (SFD-PI, 2018a).

Assessing safe management of both emptying and transport operations, from the perspective of workers and people in the immediate vicinity, is challenging and, as with containment, driven largely by behavioral issues. For this reason, the approach focuses on the *fate of the excreta* being emptied and transported. All excreta which are delivered to treatment contribute to the green "safely managed" arrows. This includes all fecal sludge which is trucked to treatment, and wastewater and supernatant which reaches treatment in a sewer, *irrespective of whether these originated in a system defined as "contained" or "not contained."*

Fecal sludge which is dumped into open drains or water bodies, or otherwise not delivered to treatment, plus sewer overflows caused by blockages and unregulated discharges of wastewater to open drains or water bodies are considered "not safely managed" and contribute to the red arrows at this point in the sanitation chain. This is also true of leakage from sewers

TABLE 2 | Containment systems (from SFD-PI, 2018a).

Containment: Where does the toilet discharge to?	**What is the containment connected to?**				
	To sewer	**To soakpit**	**To open drain or storm sewer**	**To water body, to open ground, or to don't know where**	**No outlet or overflow**
No onsite containment. Toilet discharges directly to sewer, or open drain etc.	C	C/NC	NC	NC	Not applicable
Septic tank	C	C/NC	NC	NC	
Fully lined tank (sealed)	C	C/NC	NC	NC	C
Lined tank with impermeable walls and open bottom	C/NC	C/NC	NC	NC	C/NC
Lined pit with semi-permeable walls and open bottom	Not applicable				C/NC
Unlined pit					C/NC
Pit (all types), never emptied but abandoned when full and covered with soil					C/NC
Pit (all types), never emptied, abandoned when full but NOT adequately covered with soil					NC
Toilet failed, damaged, collapsed or flooded	NC	NC	NC	NC	NC
Containment (septic tank or tank or pit latrine) failed, damaged, collapsed or flooded	NC	NC	NC	NC	NC
No toilet. Open defecation	Not applicable			NC	Not applicable

KEY: C *Excreta are contained* NC *Excreta are NOT contained*

C/NC *Extent to which excreta are contained is dependent on level of risk of groundwater pollution* Not applicable *Combination of technologies is not possible.*

where this is likely to result in a significant risk of polluting groundwater used for drinking.

Treatment

"Treatment" is any "process (or series of processes) that changes the physical, chemical, and biological characteristic or composition of any and all influent (wastewater or fecal sludge or supernatant) so that it is safe for end use" (SFD-PI, 2018a). The approach is aligned with the approach set out in the WHO Guidelines on Reuse of Wastewater and the SSP. Importantly, the SFD definition *does not specify treatment processes that are "safe" but calls on stakeholders in any given city to assess the risk to downstream populations and designate flows as "safe" or "not safe" accordingly*. Thus, wastewater discharging without treatment to a long sea outfall (a pipeline or tunnel that discharges wastewater to the sea) may be deemed safe, while partially-treated wastewater re-used to irrigate salad crops may be deemed unsafe. Stakeholders are also urged to take into account the extent to which treatment facilities meet national standards, operate reliably year-round, and the impact of climate events which may, for example, cause combined sewer overflows.

Fecal Sludge Which Remains in Containment Systems

A special case exists where excreta does not "flow" physically from a container, but remains within a containment system and does not create a risk of groundwater pollution. Typically, this would comprise a well-designed, properly managed pit latrine that has not yet been emptied or where the contents are covered over *in situ* once the container is full. This is *represented on the SFD Graphic by a green "safely managed" arrow, from containment to treatment although there is no actual flow*.

The 39 Cities

To date the SFD production process has been implemented in numerous cities by a wide range of organizations. The SFD reports for over 90 of these have been reviewed, published and are available on the open access project website (SFD-PI, 2018c). This paper presents findings for the 39 cities for which reports were finalized during phase 1 of the SFD Promotion Initiative project. The phase 1 cities were selected to ensure a spread in terms of region, size, and demographics; selection was also influenced by demand and the existence of links to the SFD Promotion Initiative's partners. Data from six of these cities—Dhaka, Bangladesh; Kampala, Uganda; New Delhi, India; Santa Cruz, Bolivia; Hawassa, Ethiopia and Lima, Peru—were previously studied (Peal et al., 2014b; Scott et al., 2019) and were subsequently updated in phase 1 of the SFD-PI.

The city with the largest population is New Delhi, India with 16.35 million inhabitants while Bure, Ethiopia has the smallest population, 27,386. Eight are either capital cities or cities with populations in excess of three million, 13 are secondary cities with populations between 500,000 and three million, and 18 have populations below 500,000. The total population of the 39 cities is 72 million (**Table 3**).

In most of the cities, sanitation is provided through a mix of onsite and offsite services with some open defecation. Three

TABLE 3 | Summary data for the 39 cities where the SFD production process was implemented (SFD-PI, 2018c).

Country	City	Population (millions)	Proportion of population using		
			Offsite sanitation (%)	Onsite sanitation (%)	Open defecation (%)
AFRICA					
Ethiopia	Axum	0.05	0	96	4
Ethiopia	Bahir Dar	0.32	0	72	28
Ethiopia	Bishoftu	0.13	0	99	1
Ethiopia	Bure	0.03	0	71	29
Ethiopia	Holleta	0.13	0	99	1
Ethiopia	Hawassa	0.35	0	100	0
Ghana	Kumasi	2.66	4	93	3
Kenya	Kisumu	0.42	20	75	5
Kenya	Nakuru	0.37	28	71	1
Senegal	Bignona	0.44	0	97	3
South Africa	Durban	3.60	57	42	1
South Sudan	Yei	0.23	0	94	6
Tanzania	Dar es Salaam	5.17	9	90	1
Tanzania	Moshi	0.19	17	81	2
Uganda	Kampala	2.25	22	78	0
EAST ASIA					
Thailand	Nonthaburi	0.26	0	100	0
Vietnam	Danang	1.01	0	100	0
Vietnam	Hanoi	3.15	12	88	0
LATIN AMERICA					
Bolivia	Santa Cruz	1.90	49	46	5
Peru	Lima	9.90	92	7	1
SOUTH ASIA					
Afghanistan	Kabul	3.50	9	90	1
Bangladesh	Dhaka	6.80	46	54	0
Bangladesh	Khulna	1.50	9	90	1
India	Agra	1.87	47	46	7
India	Aizawl	0.29	8	92	0
India	Bikaner	0.64	64	31	5
India	Cuttack	0.61	22	67	11
India	Dewas	0.31	9	76	15
India	Gwalior	1.05	80	14	6
India	Kochi	0.60	22	78	0
India	Nashik	1.49	42	54	4
India	New Delhi	16.35	68	28	4
India	Patna	1.68	24	71	5
India	Solapur	0.95	39	48	13
India	Srikakkulam	0.13	7	79	15
India	Tiruchirappalli	0.85	60	35	5
India	Tirupati	0.34	63	26	11
India	Tumakuru	0.31	53	40	7
Nepal	Tikapur	0.06	0	98	2

cities are completely reliant on onsite sanitation—Nonthaburi, Thailand; Danang, Vietnam and Hawassa, Ethiopia, while the cities with the highest proportion of the population connected to offsite sanitation services are Lima, Peru (92%) and Gwalior, India (80%). Only six cities reported no open defecation.

RESULTS

Assessment of Safely Managed Sanitation

The results broadly confirm analysis and findings from earlier implementation of the SFD method reported in Peal et al. (2014b). Overall, only two-fifths (42%) of the 72 million people living in the 39 cities use a sanitation system that results in safe management of their excreta (**Figure 2**). A summary of the main drivers of unsafe management is shown in **Table 4**.

Approximately one half (51%) of the total population (72 million) in the 39 cities use onsite sanitation. Of these one third (31%) are associated with excreta being ultimately safely managed. Just over half of the population (57%) who use offsite sanitation are using systems that are associated with safe management of excreta.

Modes of Failure at City Level

In only three cities are 75% or more of excreta safely managed, while in 13 cities <25% of excreta are safely managed. In Dhaka and Khulna, Bangladesh and Dewas, Solapur and Srikakkulam, India, <10% of excreta in each city are safely managed (**Figure 3**).

The SFD Report for each city highlights where "failures" in sanitation service are occurring, as indicated by the red arrows in each SFD Graphic. In most cities there are multiple service failures, see for example Kampala, Uganda; Patna, India or Santa Cruz, Bolivia, while in some cities there is a dominant mode of failure, see for example Bishoftu, Ethiopia; Khulna, Bangladesh and Kumasi, Ghana. Depending on local conditions failure can result either in contamination being concentrated at the community level or being spread more widely, primarily through drainage channels, placing a larger population at risk.

There are three failure modes for onsite sanitation (**Figure 4**) and two failure modes for offsite sanitation (**Figure 5**).

Failure Mode 1—Fecal Sludge Not Contained and Not Emptied From Onsite Sanitation Systems

Fifty-nine per cent of the total population using onsite sanitation use a containment system that does not "contain" excreta and nearly two thirds (59%) of these are also not emptied (**Figure 2**). This includes systems that have been unsafely abandoned or are intentionally or unintentionally discharging to open drains or water bodies and the surrounding environment, and are not emptied. This type of containment system is common in the Asian cities where in 10 of the 22 cities more than 30% of the population use this arrangement (**Figure 6**). Failure mode 1 affects 14% of the population (**Table 4**) and is most significant in Khulna and Dhaka, Bangladesh and Yei, South Sudan (**Figure 4**).

Failure Mode 2—Fecal Sludge and Supernatant Emptied/Discharged From Onsite Sanitation, but Not Delivered to Treatment

Non-delivery of fecal sludge and supernatant affects 18% of the total population (**Table 4**) and is most significant in Hanoi, Vietnam; Srikakkulam, India and Bishoftu, Ethiopia (**Figure 4**).

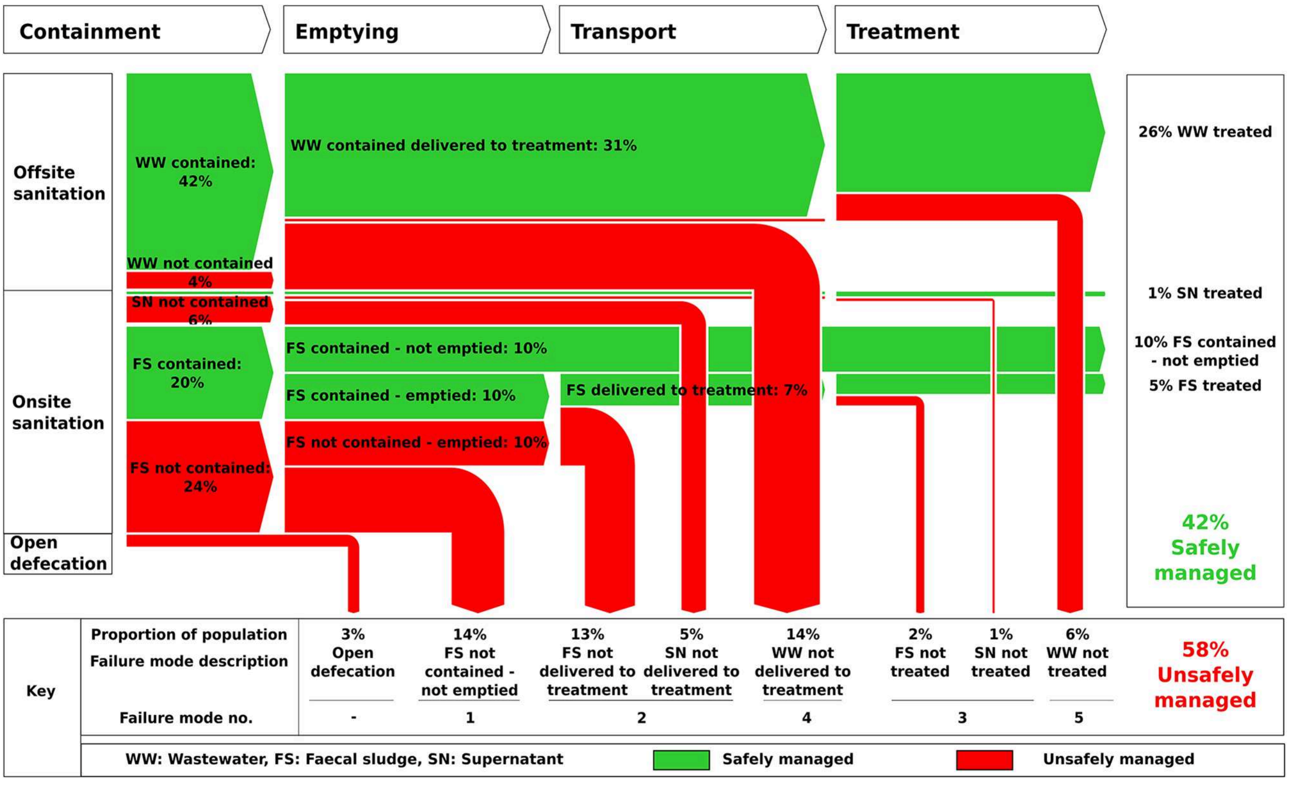

FIGURE 2 | Summary SFD Graphic for the 39 cities where the SFD production process was implemented (from SFD-PI, 2018c).

TABLE 4 | Summary of failure modes shown on **Figure 2** (SFD-PI, 2018c).

Failure mode	Description	Result (%)
1	Fecal sludge not contained and not emptied, from onsite sanitation systems	14
2	Fecal sludge and supernatant emptied/discharged from onsite sanitation systems, but not delivered to treatment	18[a]
3	Fecal sludge and supernatant from onsite sanitation systems delivered to treatment, but not treated	3[b]
4	Wastewater from offsite sanitation systems not delivered to treatment	14
5	Wastewater from offsite sanitation systems delivered to treatment, but not treated	6
–	Open defecation	3
Total excreta unsafely managed		**58**

[a]*Of which 13% is fecal sludge and 5% is supernatant.*
[b]*Of which 2% is fecal sludge and 1% is supernatant.*

The majority of material emptied from onsite systems is dumped into open drains, water bodies or on open ground either due to the absence of a treatment plant, or due to illegal dumping. Two-fifths (39%) of the total population using onsite sanitation have their containment system emptied (either manually or using motorized equipment), but only 35% of the emptied contents reaches treatment. Less than a third (28%) of the supernatant discharged to open drains reaches treatment (**Figure 2**).

Failure Mode 3—Fecal Sludge and Supernatant From Onsite Sanitation Delivered to Treatment, but Not Treated

Around two-thirds (66%) of the fecal sludge and/or supernatant delivered to treatment is reportedly treated, the remainder is either reused or discharged to the environment without treatment. Inadequate or absent treatment affects 3% of the total population (**Table 4**) and is most significant in Kumasi, Ghana (**Figure 4**).

Failure Mode 4—Wastewater From Offsite Sanitation Systems Not Delivered to Treatment

Of the 46% of the total population that are connected to offsite sanitation, 69% use a system where wastewater is collected and delivered to treatment (**Figure 2**). The remaining (31%) either leaks or overflows from sewers or open drains or is discharged to water bodies or to open ground. This may be due to poor design or poor management resulting in absent or broken sewer pipes, pump failures or power supply outages or to the absence of a treatment plant. Non-delivery of wastewater affects 14% of the total population (**Table 4**) and is most significant in Gwalior, India; Dhaka, Bangladesh and Lima, Peru (**Figure 5**).

Failure Mode 5—Wastewater From Offsite Sanitation Systems Delivered to Treatment, but Not Treated

Around four-fifths (81%) of the wastewater delivered to treatment is reportedly treated, the remainder is either reused or discharged to the environment without treatment. Inadequate or absent treatment affects 6% of the total population (**Table 4**) and is most significant in Solapur, India (**Figure 5**).

DISCUSSION

Implications of the Results

Containment

Many tanks are connected temporarily or permanently to open drains. In terms of public health and pathogen flow, this direct discharge to the environment is effectively open defecation, particularly since it occurs in densely-populated urban areas where exposure to polluted drainage water is likely to be frequent and often significant (Robb et al., 2017). However, it is difficult to gain momentum to change. The use of open drains to carry the supernatant to treatment is often preferred to the construction of soak pits or leach fields; reported reasons include high groundwater levels which limit infiltration, and concerns about polluting the shallow groundwater. The alternative option to install sewers is perceived to be both more technically challenging and expensive. The true costs and benefits of these options are rarely considered.

In these cases where tanks are connected to open drains, the SFD method divides the contents into two flows: (a) the fraction that is supernatant discharging from the tanks to a drainage network and (b) the fraction that is fecal sludge, which may or may not be emptied from the tanks. However, there is limited evidence on which to base estimates of the relative size of each flow, and therefore in the absence of data, the SFD method assumes that the two fractions are equal in size.

The findings from further research, with reference to the work in this field described by Millls et al. (2018) and Robb et al. (2017), could improve not only estimates of the relative size of these fractions but also understanding of their relative public health risks.

Emptying and Transport

Strande et al. (2014) report that the emptying frequency of tanks and pits varies greatly based on the volume and number of users and can be anywhere from weeks to years; while during the filling of onsite containment technologies, the fecal sludge will become denser at the bottom due to compaction, digestion, mineralization, and the ingress of soil. This fecal sludge is more difficult to remove by pumping and is therefore frequently not emptied and left at the bottom of the pit or tank. In addition, fecal sludge that has been stored in a septic tank for a period of years will have undergone more stabilization than for instance fecal sludge held in a tank connected to a public toilet, which has to be emptied frequently to prevent the contents from overflowing.

Although numerous variables influence the level of public health risk, in the absence of globally applicable data, the SFD method assumes that regardless of the frequency of emptying or method deployed, all fecal sludge emptying events are equally effective. The approach therefore focuses on the outcome of emptying and transport services, specifically asking whether or not the emptied fecal sludge reaches treatment or not. It does not consider how "safely" the emptying is performed—i.e., the health risk experienced by emptying service providers and/or the general public living in the immediate vicinity of an emptying event.

Further research into the relative health risks from fecal sludges of different characteristics, which are held in different onsite containment technologies, for different time intervals, under different conditions and emptied using different methods or buried (either *in situ* or locally), would enable better understanding of the relative public health risks, which could allow further sophistication of the SFD method.

Treatment

With no specified discharge standard, or level set for treatment effectiveness or efficiency, the definition of "treated" within the current SFD production process is agreed by local stakeholders in each city. This is considered reasonable as it both allows for use of the approach in many, varied settings, while potentially improving ownership of the SFD production process and its outputs in the host city.

However, although the main objective of "treatment" is commonly understood by local stakeholders to be linked to protection of public and environmental health, there was little appreciation that treatment technology designs and targets based on pathogen reduction rather than BOD/COD removal, as is the current norm, would improve safeguarding of public health. Many widely used treatment technologies are very poor at removing pathogens (World Health Organization, 2006).

An observation is that many stakeholders would benefit from further guidance to improve understanding of the multi-barrier approach as described in World Health Organization (2006, 2016) and to highlight the importance of linking treatment objectives to the intended end-use or disposal of both liquid effluents and fecal sludge, for instance as described by Strande et al. (2014).

Credibility of SFD Estimates

The intention of the SFD Graphic is to present a credible estimate of sanitation service delivery—a "snapshot" of the current situation—that is a useful starting point for planning purposes. However, using the SFD Graphic on its own (without reference to an accompanying SFD Report), or failing to take into account future scenarios, may provide an overly optimistic picture of urban sanitation service delivery. In the 39 cities this was noted in three key areas:

Proportion of Fecal Sludge "Not Emptied" From Onsite Containment

A significant proportion of excreta are managed using tanks or pits, part of which may remain inside the tank or pit because either it has not yet been emptied, or it is abandoned and covered over when full. For example, in Hawassa, Ethiopia it is estimated that 71% of excreta are currently safely managed in pits and tanks that are not emptied. These practices are significant; a quarter

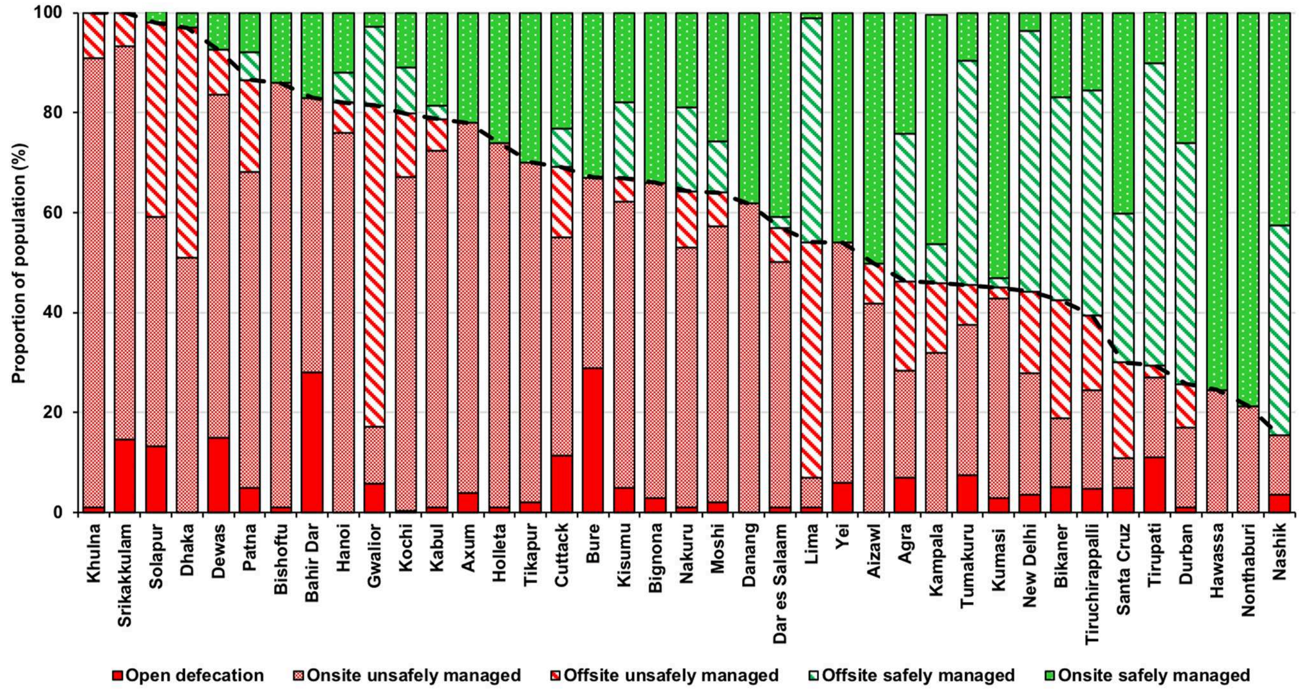

FIGURE 3 | Proportion of population with safely managed and unsafely managed sanitation (onsite and offsite) by city (SFD-PI, 2018c).

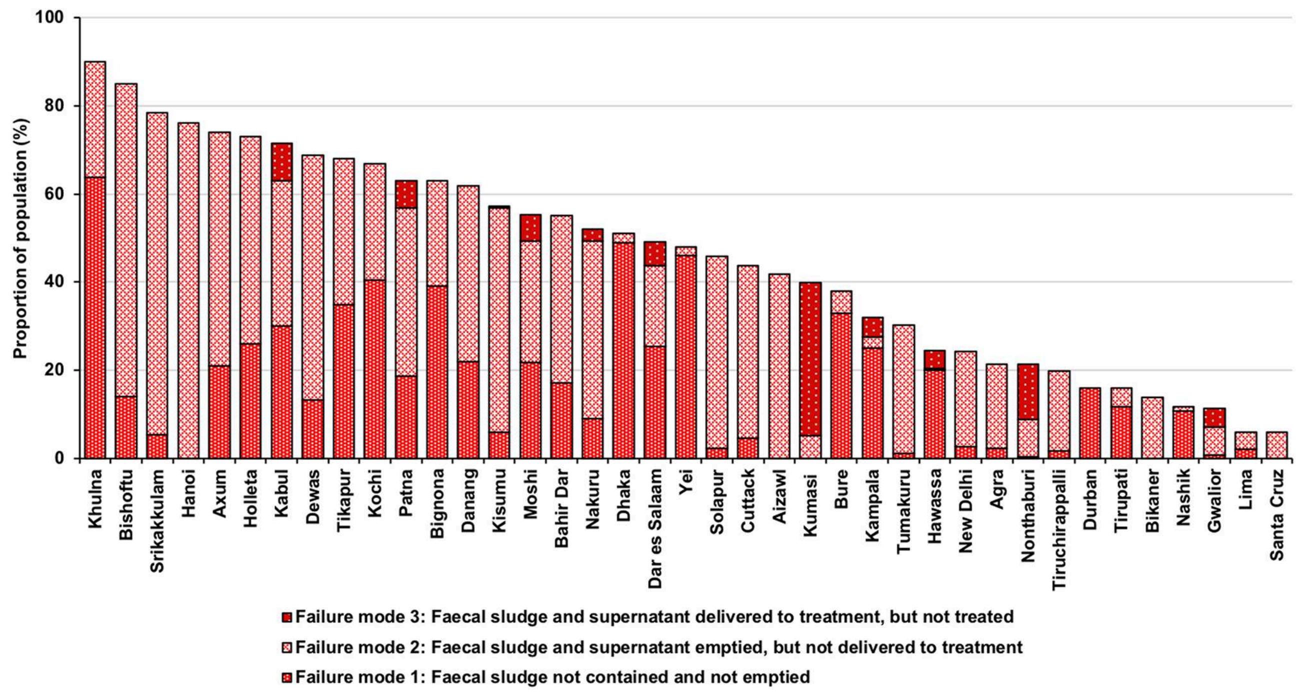

FIGURE 4 | Proportion of population with unsafely managed sanitation (onsite) by city, by failure mode (SFD-PI, 2018c).

(26%) of the population in the African cities manage their excreta this way, where the majority (58%) of onsite containment systems are pit latrines (**Supplemental Data**); and a quarter (24%) of the population with safely managed excreta across all the cities, manage their excreta this way (**Figure 2**). However, eventually all onsite pits and tanks will fill up and will need to be emptied or

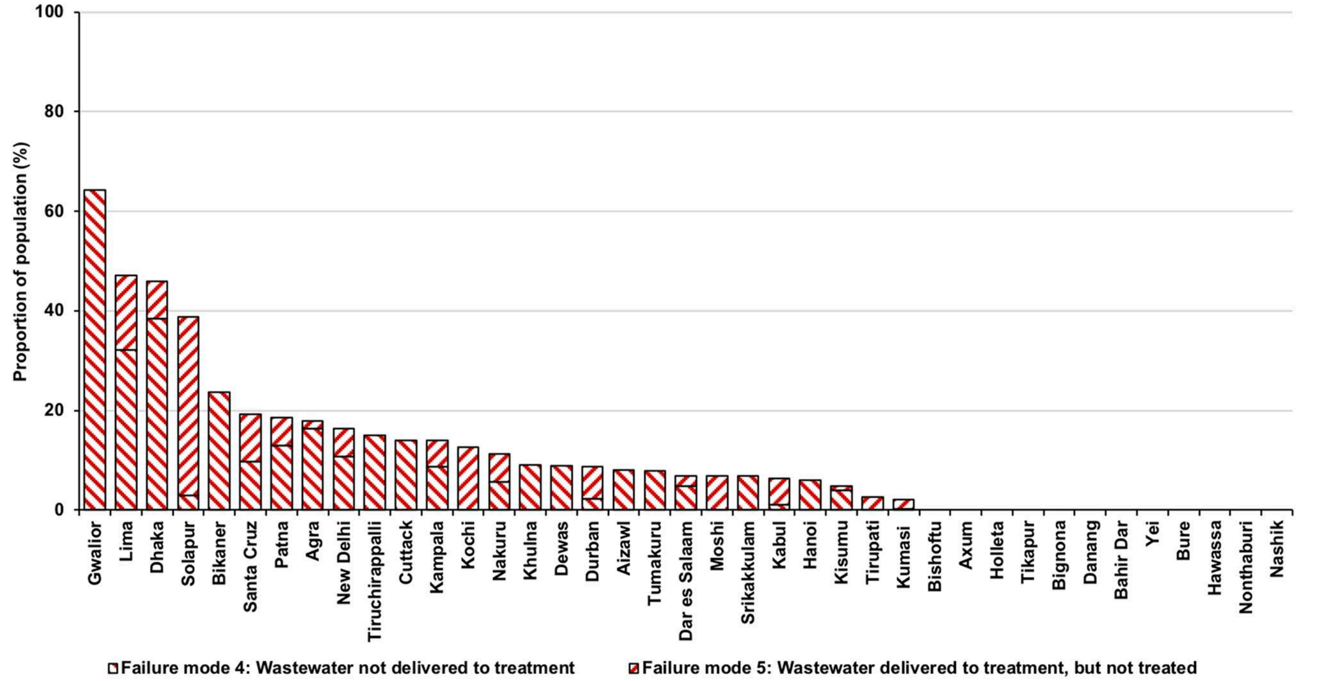

FIGURE 5 | Proportion of population with unsafely managed sanitation (offsite), by city, by failure mode (SFD-PI, 2018c).

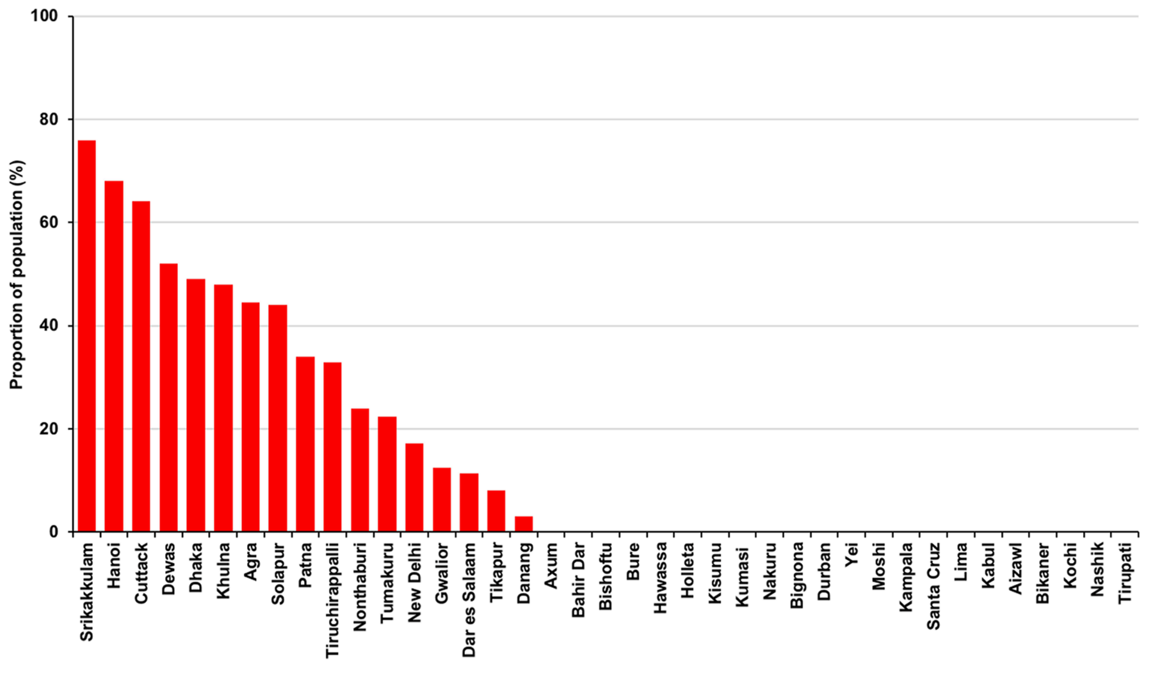

FIGURE 6 | Proportion of population using tanks connected to open drains by city (SFD-PI, 2018c).

relocated. If no emptying service is provided and if all available space for relocating a pit or locally burying fecal sludge is used up, the proportion of the population whose excreta are safely managed will fall.

Treatment of Wastewater, Fecal Sludge, and Supernatant

Across all the cities, approximately four fifths (79%) of all excreta delivered to treatment from the total population are reportedly treated. However, data on treatment was not always readily available, particularly where treatment facilities were poorly maintained or where monitoring protocols were not being followed. Information on reuse of wastewater and sludge was also lacking in many cases. This made estimating the proportion of excreta that are safely treated more challenging.

Where treatment performance data were incomplete, the expert opinion of key stakeholders was often used to guide estimations. For example, in Dar es Salaam, Tanzania and in Kampala, Uganda the lack of data was taken as a proxy that performance was low and a figure of 50% was assumed for specific treatment plants.

However, in other locations stakeholders were minded to agree estimates that probably do not reflect reality. For example, in the cities of Bikaner, Tiruchirapalli and Tumakuru, India, an estimate of 100% treatment efficiency was used, commonly based on treatment design capacity. This assumption is likely to result in estimates that would be higher than actual performance and could lead to an over estimate of the proportion safely managed.

Unsafe Flows Which Become Safe

In some cases, excreta may be managed unsafely at one step of the sanitation chain but then managed safely at the next step. For instance, in Cuttack, India where supernatant is reportedly conveyed in open drains to treatment plants; or in Kampala, Uganda where a proportion of the fecal sludge in pits and tanks is considered to be "not contained" but is then emptied and transported to treatment. In both these cities, it is reported that when these flows reach treatment plants a proportion is treated effectively. On the respective SFD Graphics, the treated fractions are drawn as "green" arrows and included in the overall safely managed total. It is important to highlight that this assumption may overestimate the proportion "safely managed" at preceding steps of the sanitation chain, and that the "red" arrows at any earlier steps still require active management to reduce or eliminate the hazard and/or risk of exposure.

Experience From the SFD Production Process

Urban sanitation in cities in low- and middle-income countries is usually delivered using a combination of formal and informal services and there is rarely a single agency in the city that has a reliable overall picture of the situation. The production of SFD Reports in the 39 cities was therefore strongly influenced by the levels of engagement and ownership amongst local stakeholders. Validation of results was significantly improved by using an iterative approach, and in some cases the level of engagement was significantly raised when SFD production was linked to local decision making. For example, in India the level of engagement with the SFD production process was increased by the prospect of it being used within the Government of India's City Sanitation Plans, which guide strategic planning and investment decisions (Centre for Science and Environment, 2018).

Accessing credible data was an issue in all the cities and specific challenges arose in three key areas.

Firstly, the capacity of local technical staff to identify different sanitation containment systems was often limited. This was exacerbated by the fact that it is difficult to assess the substructure of onsite sanitation systems such as septic tanks or the extent of leakage from sewerage.

Secondly there is often confusion over words in common use to describe elements of sanitation systems. Terminology was found to vary widely, not only across regions but within countries and even amongst stakeholders within a city. Tanks of all types were often given a range of names. Many that were referred to as "septic tanks" were not engineered correctly. For example, some had open bottoms, or permeable walls, inadequate retention times, no outlets or outlets discharging directly to open drains, open ground, or water bodies.

Finally there is a widespread lack of performance data, particularly relating to onsite sanitation services. For instance, in locations where emptying of tanks and pits is most commonly carried out by informal service providers, credible data were hard to obtain—especially where manual emptying is used and even more so where manual emptying is technically illegal. In the locations where formal emptying and transport services are used, such as in Kampala, Uganda, data was comparatively more available.

Addressing all three of these constraints, engagement with the SFD process was reported to create a much stronger understanding and concensus amongst key stakeholders about what the current sanitation system currently comprises and how well it is performing.

CONCLUSION

The SFD Promotion Initiative's standard methodology for the first time provides a consistent framework and increasing dataset with which to consider the urban sanitation challenge in terms of regional trends, common issues, and priorities.

The data present a stark picture with respect to SDG target 6.2. Three-fifths of the 72 million people living in the 39 cities use a sanitation system that does not result in safe management of their excreta (although it is important to recall that the definition of safe management used here is not the same as that used by the JMP when reporting progress on SDG 6.2). Both onsite sanitation with fecal sludge management and sewerage were associated with safe management and unsafe management with no discernable difference in outcomes between the two types of systems.

The performance of sanitation systems in these cities point to some urgent areas for improvement:

- The review and improvement in the quality of onsite containment systems to ensure that they protect against public health and wider environmental risks. The risks associated with the use of open drains as a means of conveying supernatant from tanks appear to be systematically underestimated.
- Scaling up of emptying, transport, treatment, and reuse options for fecal sludge from onsite containment systems, along with improved monitoring. These systems remain important and can provide appropriate containment at household level, but improvements in service delivery are

required to ensure safe management along the entire sanitation chain.
- Improved management and monitoring of sewerage to reduce leakage and overflows from piped systems.
- Greater emphasis on the importance of safeguarding public health by linking wastewater and fecal sludge treatment objectives to the intended end-use or disposal in line with WHO guidelines.
- Efforts to improve management and monitoring at national and local level could usefully be focused on development and dissemination of appropriate norms and standards at each step of the sanitation chain.

At the most fundamental level, adequate funding, training, and investment in human resources to secure sustained and active management of urban sanitation is imperative.

The process of analyzing excreta flows also supports more sophisticated means to analyse their complexity within any given city, enabling bespoke development of a range of appropriate, integrated sanitation solutions. The implications are the importance of recognizing that every city has its own specific sanitation characteristics, and that many and varied parallel solutions are needed to achieve city-wide integrated sanitation in each case.

DATA AVAILABILITY STATEMENT

The datasets on which the analysis described in this paper are based are available on https://sfd.susana.org/data-to-graphic. A downloadable excel file with an extract of the relevant data is available at https://sfd.susana.org/knowledge/resources/sfd-library.

AUTHOR CONTRIBUTIONS

All authors were active in the conception and delivery of the SFD-PI project on which this analysis is based. AP and BE led the conception and design of the analysis on which this paper is based. AS led the development of the SFD graphic generator and database. SA and OV carried out the preliminary analysis of data from the SFD database. AP performed the final analysis and wrote the first draft of the manuscript. BE wrote substantial sections and restructured the manuscript. LSt, LSc, RS, RB, IB, and PH contributed to the overall structure of the paper. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Citywide Inclusive Sanitation—Business as Unusual: Shifting the Paradigm by Shifting Minds

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As the world urbanizes, the challenges of urban sanitation increase, with urban population growth dramatically outpacing gains in sanitation access. Total global costs of inadequate sanitation are estimated at USD 260 billion annually, and reaching the SDG urban sanitation targets will require over USD 45 billion each year. '*Business as usual*' in urban sanitation—where conventional sewerage and wastewater treatment are considered as the only solution—will not get us to universal safely managed sanitation. Citywide Inclusive Sanitation (CWIS) looks to shift the urban sanitation paradigm, aiming to ensure everyone has access to safely managed sanitation by promoting a range of solutions—both onsite and sewered, centralized or decentralized—tailored to the realities of the world's burgeoning cities. CWIS means focusing on service provision and its enabling environment, rather than on building infrastructure. This shift in paradigm to CWIS requires a shift in mindsets. Governments and development agencies increasingly recognize that historic approaches to urban sanitation have not always worked and new approaches, such as CWIS, are required. Consulting firms need to think differently, and not simply replicate approaches found in high-income countries. Engineering curricula should include the design and management of non-conventional systems and should explore opportunities for leapfrogging to solutions that take full account of the public health and environmental imperatives of urban sanitation. We should rethink the way sanitation infrastructure is funded and challenge approaches that subsidize sewers but not onsite sanitation, that do not embrace innovation and do not consider running costs. CWIS, or '*business as unusual*', requires awareness raising and capacity building, the spreading around the world of successful experiences, and the development and use of tools and other resource materials to help better design and implement sustainable urban sanitation services for all. At the World Bank, we see that shifting mindsets toward CWIS principles can be achieved and that there is a growing appetite globally for embracing such principles. We see an important emerging global movement to engage on CWIS by governments and development partners, which provides an unprecedented opportunity to shift the urban sanitation paradigm in the pursuit of universal safely managed sanitation.

Keywords: citywide inclusive sanitation, sanitation, urban, onsite sanitation, sewerage, sanitation financing, sanitation services, sanitation institutions

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SYNOPSIS

An estimated 55 percent of the global population lack access to safely managed sanitation, which means that over 4.2 billion people do not have sanitation services that ensure their waste is safely handled and treated as well as being reused/disposed of in a safe manner (WHO/UNICEF, 2017). To date, the predominant approach globally to urban sanitation provision has suffered from focusing too heavily on infrastructure investments, especially those supporting conventional sewers and wastewater treatment plants, and has given comparatively little attention to ensuring sustained service delivery through appropriate policy and incentive frameworks, robust service providers, and sound financial planning. This approach has also resulted in many people being left without adequate sanitation services—these most often being the poorest urban residents. The World Bank, along with other sector partners, are prioritizing a new approach to urban sanitation service provision termed '*Citywide Inclusive Sanitation*' (CWIS). Over the past three years, the World Bank has been documenting good practices in urban sanitation service delivery from cities across the globe, sharing these positive experiences with governments from an increasing number of cities and countries around the world, and supporting government and service provider counterparts in the design and implementation of investment projects aligned with CWIS principles. This paper attempts to document the World Bank's rational for making this shift and to share the World Bank's initial experiences in engaging with its counterparts on the CWIS agenda.

THE GLOBAL URBAN SANITATION CRISIS

The Scale of the Problem

The urban sanitation sector has been characterized by persistent failures in providing sustainable services to certain populations, the so called unserved and underserved. The challenge of inadequate urban sanitation is further amplified when we consider the need to meet the sanitation target of the Sustainable Development Goals (SDGs) of achieving "*access to adequate and equitable sanitation and hygiene for all…paying special attention to the needs of women and girls and those in vulnerable situations*" (United Nations, 2015). As cities grow, services need to expand with them such that the disadvantaged residents living in low-income neighborhoods, including those in the ubiquitous, rapidly growing, informal settlements of cities in low- and middle-income countries, are also provided with services.

Currently, over 55 percent of the world's population live in urban areas (UN DESA, 2019). By 2050, the number of city dwellers is projected to increase from 4.2 to 6.7 billion (UN DESA, 2019), with much of this growth occurring in low and lower-middle income countries. This urban population growth dramatically outpaces gains in access to sanitation. The global Millennium Development Goal (MDG) target for sanitation was missed by almost 700 million people and, as of 2015, 2.4 billion people still lacked access to an improved sanitation facility (WHO/UNICEF, 2015). Today, 17 percent of the world's urban dwellers do not have access to basic sanitation (an improved toilet or latrine) and only 43 percent of urban residents have access to "*safely managed sanitation,*" that is to say where their waste is safely managed across the full sanitation service chain, including containment, conveyance, treatment and reuse/safe disposal (WHO/UNICEF, 2017).

Access is particularly low for poor urban households, as is consistently evidenced in data from the WHO/UNICEF Joint Monitoring Programme. For example, the gap in access between the richest and the poorest wealth quintiles in the countries of *Southeast Asia* exceeded 50 percentage points in 1995 (WHO/UNICEF, 2015). Although access to improved urban sanitation did increase more rapidly among the poorest in this region between 1995 and 2012, significant gaps remained, with only *Thailand* having managed to close the urban sanitation gap between the rich and the poor. JMP data shows that progress toward achieving the goal of improved sanitation in low- and middle-income countries has, overall, been far slower for the poorest urban inhabitants. Furthermore, while the gap between the richest and the poorest has been reduced in 52 countries, it has increased in 22 others (WHO/UNICEF, 2015). In six out of 14 countries where urban coverage decreased, the gap between the richest and poorest simultaneously increased (WHO/UNICEF, 2019).

The World Bank's Water Supply, Sanitation and Hygiene (WASH) Poverty Diagnostic Initiative (World Bank, 2017a) further demonstrates that differences in levels of wealth, location and other demographic characteristics are associated with significant disparities in the availability and in the quality of WASH services. The WASH Poverty Diagnostic's analyses in 18 countries across the world confirmed the pervasiveness of the gap in infrastructure availability and service delivery between the urban poor and non-poor and between small and large cities, as well as showing disparities between cities across and within geographic regions of the same country. Evidence shows that service delivery levels also vary within and between cities in the same country. Analysis of the coverage of improved water and sanitation by household-level characteristics in 2006 and 2014 in *Ecuador* shows that a large portion of the improvements at the national level are driven by urban areas, and in particular in the largest cities of Quito and Guayaquil, while unimproved sanitation remains high in secondary cities (World Bank, 2017b). The WASH Poverty Diagnostic for *Ethiopia* found that, in addition to household access constraints, many low-income residents are without sanitation services in urban centers where many of them work but where the number of public and communal toilets falls far short of demand (World Bank, 2018). And in *Bangladesh*, we found that only 13 percent of households in the slums of the five largest metropolises have their own sanitation facilities (World Bank, 2017a), further emphasizing the role of shared sanitation in helping meet the immediate needs of urban residents.

Furthermore, a key element of the SDG sanitation target is that household access is not the only important metric, since the safe management of sanitation along the full service chain also needs to be provided. Globally, of those households with access to safely managed services, an estimated 63 percent are connected to sewers, and an additional 32 percent use improved sanitation facilities with onsite systems such as flush or pour-flush toilets connected to septic tanks, or dry or wet pit latrines (including facilities shared with other households). However, this number is distorted by data from high-income countries, such as those in North America and Europe, where 93 percent of the population is connected to sewers, which contrasts sharply, for example, with an average sewerage coverage of less than 20 percent in Sub-Saharan Africa (WHO/UNICEF, 2017). Furthermore, although septic tanks and improved pit latrines are considered "*safely managed*" sanitation facilities, "*on-site storage and treatment systems may be compromised due to poor design, damage or flooding*" (WHO/UNICEF, 2019). Similarly, having a sewer connection does not mean that the wastewater is safely conveyed and treated before it is discharged or reused.

The Impacts of Insufficient Access to Safely Managed Sanitation

This lack of access to safe sanitation services within cities results in significant health, environmental and economic burdens. Limited sanitation in urban areas is a major cause of the transmission of enteric diseases such as cholera and those caused by other pathogens. Given the relatively new nature of the SDGs and their measurement/categorization system, there is currently no strong knowledge base regarding the comparative health impacts of safely managed sanitation as compared to those deriving from access to basic sanitation[1]. However, it is widely recognized that safely managed services are needed to ensure that household health is protected, that the health of other urban households is safeguarded, and that the well-being of the environment is maintained.

Diarrhea is the third leading cause of death globally of children under five years old, and an estimated 55 percent of these deaths is attributable to unsafe sanitation [Institute for Health Metrics and Evaluation (IHME), 2018]. Furthermore, poor sanitation and diarrhea are the second and third leading risk factors for stunting worldwide, with 7.2 and 5.8 million attributable cases, respectively (Danaei et al., 2016). In addition, there is evidence that a lack of sanitation leads to lower school attendance, especially for adolescent girls, who require school sanitation facilities to address their menstrual hygiene management needs. A meta-analysis of 138 studies in *India* found that a quarter of girls did not attend school during menstruation because of a lack of adequate toilets (Van Eijk et al., 2016). Menstrual hygiene management is important for women of all ages: in *Ghana*, 11.5 million women, or some 80 percent of all Ghanaian women, have no access to waste disposal facilities that adequately separate menstrual hygiene waste from human contact (World Bank, 2016). As is the case with disparities in access rates, low-income households are also more adversely affected by the poor quality of sanitation services. In *Haiti*, children in the bottom household income quintile are 2.4 times more vulnerable to the risk of contracting an enteric disease than those in the top quintile (World Bank, 2017a).

[1] "*Basic Sanitation*" is defined as the use of improved sanitation facilities which are not shared with other households (JMP; WHO/UNICEF, 2015).

Inadequate access to sanitation infrastructure, and the poor subsequent management of the waste streams along the sanitation service chain, also result in substantial negative environmental impacts. Most human activities that use water produce wastewater. As the overall demand for water grows, the quantity of wastewater produced, and its overall pollution loads, are continuously increasing worldwide. Over 80 percent of the world's wastewater, and over 95 percent in some of the least-developed countries, is released into the environment without treatment (United Nations, 2017). Once discharged into water bodies, wastewater is either diluted, transported downstream or infiltrates into aquifers, where it can affect the quality, and therefore the availability, of freshwater supplies. The ultimate destination of wastewater discharged into rivers and lakes is often our seas and oceans with negative consequences for the marine environment (United Nations, 2017). Similarly, onsite sanitation facilities which do not benefit from appropriate collection, conveyance and treatment of the generated fecal sludge and septage also contribute to the growing pollution burden of both groundwater and surface water bodies, as witnessed, for example, in the backwaters of Kerala in India (World Bank, 2013). Calculating the environmental costs of poor sanitation involves the measurement of these direct and indirect impacts on water bodies and their ecosystems. Additionally, given the increasing water scarcity challenges we see in many areas of the world, which are driven in part by climate change and by population increase, as well as by the associated increase in food consumption, the reuse of treated wastewater is becoming an increasingly attractive and feasible option which can provide positive environmental, economic and other benefits to society.

The negative health and environmental impacts associated with a lack of access to safely managed sanitation result in high economic costs which adversely impact economic growth. The total global costs of inadequate sanitation are estimated at USD 260 billion per year or, on average, some 1.5 percent of a country's gross domestic product (GDP) (Hutton, 2012). In cities around the world it is the norm that, even where piped water networks exist, latrine, septic tank, and sewerage coverage lag far behind. To reach the SDG urban sanitation targets, it is estimated that over USD 45 billion will be needed annually to meet the capital investment costs alone (Hutton and Varughese, 2016).

Obstacles to Scaling Solutions

The shift from the MDGs to the SDGs means that we have to think beyond just constructing additional sanitation facilities. We also need to ensure that the facilities are consistently used by all household members, that the associated human waste is safely managed along the whole sanitation service chain, and that this is the case in all urban neighborhoods, not just in the wealthiest. Furthermore, this access should be available both within and outside of the home environments. These two fundamental shifts—considering more holistic solutions and ensuring access for all—are impeded by the historic approach to urban sanitation.

In recent decades, in many countries around the world, the focus of urban sanitation programs has far too often been solely on the building of infrastructure. In addition, in many cases, these infrastructure investments are undertaken in a disconnected way, such that one investment program may construct a sewer network, for example, another build a treatment plant, and yet another would be responsible for the toilets and the related household installations (if the latter are contemplated at all). Without thinking holistically about the sanitation service chain, none of these investments alone will achieve the intended public health and environmental impacts. This focus on infrastructure has resulted in expensive investments in sewer networks and wastewater treatment plants which, all too frequently, have remained under-utilized as the associated links in the sanitation chain, namely effective sewer connections and the necessary household installations are, in many cases, never actually realized. For example, a World Bank review found that, in one project in *Cambodia*, only 20 percent of eligible households had connected to the sewer network; under a project in *Brazil*, only 30 percent of households had connected; and through a project in *Uruguay*, under 40 percent of targeted households had connected to the sewers resulting in five of the eight treatment plants remaining inoperational (World Bank, forthcoming).

Furthermore, by ignoring household demand and household priorities, sanitation infrastructure has at times been poorly adapted to the local context in which it is implemented, and it has all too frequently been assumed that households will change their behaviors regarding their sanitation practices without the incentives for them to do so being appropriately provided. For example, in cultures accustomed to 'washing' (i.e., using water for anal cleansing), as opposed to 'wiping' (using paper to clean), switching to dry, composting latrines would require significant changes in societal norms and individual behaviors.

It is also increasingly clear that solutions to urban sanitation cannot just focus on the sanitation service chain, and that consideration must also be given to how the sanitation services fit within the broader urban context in which they are placed. Sanitation is closely linked to water supply, as well as to solid waste management, drainage, land use and housing development—and this is especially the case in dense urban areas. Most cities around the world undertake sanitation planning and management separately from these other sectors. The resultant development 'silos' consequently hamper progress in the sector. These silos can inhibit the spread of good experiences between cities and between countries, can mean that efficient sanitation service provision does not capitalize upon the economy of scope provided by a good water supply provider in the city, and can result in broader urban development programs not embracing good practice approaches to sanitation provision. The silos can also mean that sanitation programs do not always take account of the broader issues of urban development with which the sanitation services should be aligned and which they should be leveraging.

In addition, sufficient attention has not been given to the enabling environment of policy, governance, institutions, regulation and funding that underpins the sustainable delivery of services. Too often the incentives that are in place—for policy decision making, for funding, for institutional arrangements, for regulation, among others—do not align with the expressed objectives of the sector (Mumssen et al., 2018). We also find that there are too few robust service providers in the sector and that these tend to concentrate on their water supply responsibilities while considering sanitation—if they do consider it at all—to only concern the construction of conventional sewers and wastewater treatment plants. Few such service providers have tariffs which manage to cover the operation and maintenance costs of those sanitation services that they are able to provide, much less their capital costs. The sanitation infrastructure that is built needs to be commensurate with the financial and human resources of those responsible for running it, and the services provided need to be responsive to the demands of urban residents and tailored to the varying realities in which they live.

In order to meet the aspirational goal of sanitation for all, the sector will also have to shift away from considering only sewered sanitation as a solution. Until recently, the sector's focus on infrastructure had also been a focus on conventional, sewered solutions as developed and implemented in high-income economies over many decades. To reach all households with sustainably and safely managed services in the rapidly growing cities of low- and middle-income countries, we will need to consider more than just conventional sewers—we must have a range of solutions which are tailored to the realities of different cities and different neighborhoods, encompassing onsite onsite sanitation and fecal sludge management, through to simplified sewerage approaches. In many ways, however, the sector is underprepared for supporting governments in implementing such a mix of technical solutions. Many, if not most, decision makers still aspire to the building of centralized conventional sewer systems and wastewater treatment plants, irrespective of the costs or the effectiveness of such solutions. Helping governments understand such trade-offs is challenging, particularly where there is limited data available on, and/or no consideration given to, the true capital and operational costs of different technical solutions.

This shift toward embracing a mix of onsite and reticulated technical solutions is further constrained by a lack of technical expertise in the sector. Most existing engineering education curricula continue to concentrate heavily, if not exclusively, on conventional sewerage and wastewater treatment approaches. Many engineering consultancy firms also focus on conventional sewered solutions, without giving the necessary consideration to the appropriateness of these responses in the context in which they will be built, to their operation and maintenance costs and requirements, nor to their effectiveness of reaching poor neighborhoods and households in low- and middle-income countries.

The challenge of access is further complicated when other factors come into play in what are often informal, unregulated settlements, including the issues of space constraints for installing sanitation systems (*where do you install a toilet facility in a single-roomed housing unit?*), of topographical and related constraints (*how do you ensure septic tanks function in high water table environments?*), of system design (*how do sewer networks function for households that have limited or intermittent water supply?*), and of uncertain land tenure (*how do you ensure that rents stay affordable for the poorest households while ensuring that landlords can recover their investment and maintenance costs?*).

Business as usual in urban sanitation, where conventional sewerage networks and wastewater treatment plants—which have been installed at great cost in most high-income economies around the world—are considered as the only solution, will simply not allow us to reach universal and safely managed sanitation for all, and especially not for the informal, unplanned low-income areas of rapidly expanding cities across the globe. Even though we have tried these approaches for decades, there are still billions of people globally without access to safely managed sanitation. It is therefore imperative that we revisit our approach to tackling the world's pressing urban sanitation challenges.

CITYWIDE INCLUSIVE SANITATION AT THE WORLD BANK

Initiating a Global Movement

Given all of the challenges that exist in the sector, it is encouraging to note the growing number of positive examples of urban sanitation service provision. There are good examples from around the world of efficient service providers which continually strive to deliver urban sanitation solutions to all of their customers including, for example, *eThekwini Water and Sanitation* in South Africa, *Maynilad* and *Manila Water* in the Philippines, and *Companhia de Saneamento Ambiental do Distrito Federal* (*CAESB*) together with other utilities in Brazil. There are also examples of innovation in urban sanitation service delivery, ranging from improved fecal sludge management systems and approaches, through '*condominial*' and other simplified sewerage systems, to container-based sanitation entrepreneurs. However, getting such experiences to be replicated and scaled up—both within countries and between countries—continues to be a significant hurdle.

In 2016, a group of development organizations[2] convened a series of meetings to discuss these urban sanitation challenges and the need for a change in approach in the sector, which resulted in the release of a Call to Action for Citywide Inclusive Sanitation[3]. Since then, the Citywide Inclusive Sanitation (CWIS) principles have strongly resonated with a number of other development partners and with numerous government and service provider counterparts around the world. The CWIS initiative has grown organically—an increasing number of key development partners have started to align their work programs with the principles of CWIS, as articulated in the Call to Action, thereby influencing their government and service delivery counterparts. CWIS-related research work and project support initiatives are also growing in number and in alignment. As a result, a cumulative shift in mindsets is gradually being achieved. The fact that the CWIS principles are not prescriptive but provide general guidance regarding how to respond to the challenges of urban sanitation in low- and middle-income countries, while breaking away from dogma and fixed positions, helps explain this gradual, broad and growing uptake.

The World Bank's Approach to CWIS

At the World Bank, we have been sharing these ideas with government counterparts across the globe and operationalizing the core Citywide Inclusive Sanitation principles in a range of countries. We emphasize that CWIS challenges us to ensure that everyone has access to safely managed sanitation by promoting a range of technical solutions—both onsite and sewered, centralized or decentralized—which are tailored to the realities of the world's burgeoning cities and which are flexible and adaptable so that, as cities grow and change, sanitation services adapt with them. In promoting this approach, we encourage governments to focus on service provision rather than on building specific infrastructure, which means considering the financial, institutional, policy, regulatory, social and environmental dimensions of the services. We also strive to work across disciplines within the World Bank and with governments to harmonize sanitation solutions with related urban services such as water supply, drainage and solid waste management. Additionally, we promote the thinking that design decisions and their related financial implications should be driven by the consideration of both capital and operational expenditures, rather than focusing solely on the initial investment costs. Furthermore, the World Bank needs to continue working with counterpart governments on their urban sanitation strategies and investment programs to ensure that full consideration is given to how these will encompass service provision to unserved and underserved populations.

We recognize that there is no single solution for responding to the immense urban sanitation backlog in cities of low- and middle-income countries. Instead we believe that locally relevant and innovative solutions need to be developed, tested and scaled up, and that good experiences from around the world need to be spread and adapted as appropriate to their new contexts. **Box 1** shows the priorities that the World Bank is encouraging cities to consider when developing their sanitation plans and investment programs.

Operationalizing CWIS Approaches in World Bank Projects

As the World Bank continues to work with governments across the globe on the planning and the implementation of urban sanitation interventions that align with the CWIS principles, we encounter a wide range of unique challenges that require specific responses. Each city and, in many cases, each neighborhood, represents a new opportunity to learn further about what CWIS can look like in practice. Nevertheless, as the World Bank works with its government counterparts to implement CWIS approaches, there are some emerging common challenges that we have seen come to light in a number of cities and countries where our urban sanitation portfolio is active.

We see that this shift in paradigm to Citywide Inclusive Sanitation requires a concomitant shift in mindsets. Development agencies, which collectively invest billions of dollars in urban sanitation projects each year, have started to

[2]The Bill & Melinda Gates Foundation, WaterAid, University of Leeds, Emory University, Plan International and the World Bank.

[3]http://pubdocs.worldbank.org/en/589771503512867370/Citywide-Inclusive-Sanitation.pdf

BOX 1 | Promoting Citywide Inclusive Sanitation at the World Bank.

A CWIS project is where…

- ✓ ***Everybody benefits*** from adequate sanitation service delivery outcomes that meet user aspirations and that protect the health of users.
- ✓ Human waste is ***safely managed along the whole sanitation service chain*** ensuring protection of the environment and of human health.
- ✓ A ***diversity of appropriate technical solutions*** is embraced, combining ***both onsite and sewered solutions***, in either ***centralized or decentralized systems***, with consideration of ***resource recovery and re-use.***
- ✓ Cities demonstrate ***political will,*** technical and managerial ***leadership***, and identify ***new and creative long-term funding options for*** sanitation.
- ✓ ***Institutional arrangements*** and ***regulations***, with well-aligned incentives, are in place for the operation and maintenance of the full sanitation service chain.
- ✓ Funding is allocated for ***non-infrastructure aspects of service delivery***, such as capacity building, household engagement and outreach, and sanitation marketing.
- ✓ ***Complementary urban services***, including water supply, drainage, graywater management and solid waste management, are incorporated into sanitation planning.
- ✓ Activities are included to ***target specific unserved and underserved groups***, such as women, ethnic minorities, the urban poor and people with disabilities.

recognize that the historic approach to urban sanitation has not always worked and that new approaches, such as CWIS, need to be considered. Similarly, the different levels of government involved in urban sanitation, and the entities responsible for service delivery, are increasingly recognizing the need for such a shift in approach. Equally importantly, we see that the consulting firms who assist governments in the preparation of master plans, engineering designs and related studies also need to think differently and be open to approaches that do not simply replicate those found in high-income countries, where the technical, social and institutional realities are very different. Shifting the mindsets of this range of actors is not easy, but it needs to be tackled if we are to achieve the urban sanitation SDG target. At the World Bank we have consequently been providing technical assistance to our government counterparts through capacity building events, knowledge exchanges and workshops, in which we share good practice approaches to urban sanitation service provision, and where we discuss how such experiences can be transferred, adapted and scaled up to new settings.

We also see that the existing cadre of managers, engineers, technicians and others working in the sector are all learning together about new approaches to responding to urban sanitation challenges. The educational systems in which sector professionals are taught, however, tend to focus on the so-called conventional solutions that have been developed over many decades in high-income countries but that cannot be simply imported into the contexts of rapidly expanding cities in low- and middle-income countries. We nevertheless continue to witness consulting firms still only wanting to focus on conventional sewer networks and wastewater treatment: additional time for advocacy and learning is needed so that they, too, start to embrace the planning and implementation of projects that include the necessary mix of technologies and services which are commensurate with the realities where they will be applied. We need to teach the engineers of tomorrow that, although seemingly obvious, we cannot design sewer systems in cities where there is insufficient water supply, just as we cannot design septic tank systems in situations where the ground conditions offer no effluent infiltration capacity. In addition, the implementation of CWIS requires a number of non-engineering skillsets including, for example, business skills for understanding the dynamics of formal and informal pit and tank emptiers, private sector oversight skills for services that are contracted out by public utilities, an understanding of the role of behavior change to facilitate the uptake of new approaches to sanitation service delivery, and household engagement skills for all service providers. In an effort to address these shortfalls, the World Bank has been undertaking capacity building and training events, as well as developing tools and guidance documents, for government counterparts and others in the sector, including doing so in collaboration with academia through online and in-person capacity building initiatives. These activities address a wide range of technical solutions as well as a suite of the non-technical dimensions of urban sanitation service delivery.

We see that those who are responsible for designing and implementing interventions, still struggle with how to operationalize fecal sludge management (FSM) systems and reuse at a citywide scale, including confronting difficulties related to: (i) the design and procurement of FSM service delivery arrangements which encompass the logistics of collection and conveyance, the siting of transfer stations and treatment plants, and the regularization of the informal private sector emptiers; and (ii) the review of roles and responsibilities with respect to the funding, the contracting out, the delivery and the regulation of FSM services. We also encounter difficulty in advancing the reuse agenda for both wastewater effluent and for fecal and wastewater sludge against prevailing regulatory standards and in the context of a general lack of understanding of business models and market demand for reuse products. Furthermore, many sewerage projects fail to get a critical mass of households to connect to the networks, thus resulting in wastewater treatment plants not operating at their design capacities and, consequently, the associated public health and environmental benefits not being accrued. In order to fill these knowledge gaps for operationalizing CWIS, the World Bank has been developing specific operational tools (generic terms of reference, guidance notes, technical manuals, planning and costing tools, etc.) designed to assist World Bank project teams and their government counterparts in better designing and implementing urban sanitation projects. These materials are complemented with a range of curated resources designed to support our government counterparts in considering and designing alternative approaches.

We also see that we need to rethink the way we fund sanitation infrastructure and we should challenge those who deem, for example, that onsite sanitation services, which overwhelming target the poor, should not be subsidized when sewer systems and wastewater treatment plants, which tend to benefit the richer, planned areas of cities, have consistently benefited from subsidies. We need to carefully consider the capital and the running costs and complexities of the systems we design and ensure that they are commensurate with the capacities of those responsible for operating them.

In many situations, the modalities of sanitation service provision also need to be reconsidered. We should harness, where appropriate, the benefits of the economies of scope that can be achieved by robust service providers delivering both water supply and sanitation services together, thereby leveraging the financial, organizational, management and human resources capacity, and the billing systems, that such combined service provision offers. Service provider arrangements and institutional and regulatory set-ups in which the traditional water supply utility only sees, or is only permitted to work with, conventional sewers, need rethinking. We should encourage service providers to embrace a culture of research and development aimed at improving service provision and customer satisfaction while lowering costs. In addition to such context-specific research and development, we also need to further develop an aligned research agenda at the global level. We are working with government counterparts on the development of sanitation business and management models, be they public, private or a mix of both, that are able to reach customers with services.

We also need to embed an inclusive approach to sanitation service provision and to design and manage sanitation systems based on the context in which they will be placed. The World Bank has conducted research on women in 28 water utilities (World Bank, 2019c) exploring the barriers women experience when entering into, remaining in, and advancing within the water and sanitation sector, looking specifically at the issue of the working conditions of women in water and sanitation utilities. Furthermore, the World Bank is looking at existing research on female-friendly public and communal toilets [United Nations Children's Fund (UNICEF), WaterAid and Water and Sanitation for the Urban Poor (WSUP), 2018], in order to better incorporate these design considerations into our sanitation projects. There is also an emerging set of projects where the World Bank has been collaborating with governments to formalize the work of septage/fecal sludge emptiers and to advance their health and safety operating environments. Projects that we are funding in Kinshasa and Lusaka, for example, are supporting the formalization of pit/septic tank emptiers, while also improving their working conditions. The World Bank also includes menstrual hygiene management initiatives under a growing number of the projects it funds, with a view to making the associated interventions more accessible to women and girls.

Encouragingly, there are a number of sanitation service innovations that can be drawn upon when designing investment programs, including: new innovations in treatment and reuse technologies; non-conventional approaches to implementing sewers; container-based sanitation (CBS) service delivery models (World Bank, 2019a); source separation of blackwater and graywater; and the use of mobile technology for improving billing and for the monitoring and evaluation of service provision. However, many of these innovations have failed to reach scale given a generalized conservatism within the urban sanitation sector, limited financing focused on innovation, the time it takes to pilot and refine new approaches, and a general lack of familiarity with many of these emerging practices. Financial support to aid start-ups in moving from pilot to larger scale could, through partnerships with more established or bigger service providers and other strategic entities, enable the more rapid implementation and scale up of such innovation.

Achieving the additional take up and roll out of Citywide Inclusive Sanitation will require the further development of relevant guidance and reference material and will involve the continued spreading of good practice approaches from one side of the world to the other. Such *business as unusual* that CWIS represents will entail significant efforts to raise awareness and build capacity—not only for those entering engineering school but also for those in government and those managing/working for service providers, both in the public and private sectors—who influence decisions today. We have seen at the World Bank how the shifting of mindsets to embrace CWIS principles can be achieved in relatively short time periods when tailored awareness raising and capacity building programs are carried out at the right time and with the appropriate content within the investment project cycle.

BOX 2 | Current World Bank CWIS engagements.

• Angola • Bangladesh • Benin • Bolivia • Botswana • Burundi • Cambodia • Colombia • Côte d'Ivoire • Democratic Republic of Congo • Dominican Republic	• Egypt • Ethiopia • eSwatini • Ghana • Haiti • India • Indonesia • Kenya • Lao • Lesotho	• Liberia • Malawi • Mozambique • Nigeria • Rwanda • Solomon Islands • Sri Lanka • Tanzania • Uganda • Uruguay • Zambia • Yemen

Examples of CWIS in World Bank Projects

At the World Bank we find that there is appetite for moving toward the principles of CWIS in our existing and new urban sanitation investment projects, in low- and middle-income countries alike and, increasingly, we see government and service provider counterparts interested in adopting CWIS approaches. We currently have engagements in a diversity of countries around the world (see **Box 2**) in which we are advancing CWIS principles, at large and small scales, be it in single or multiple cities in a given country. The CWIS team at the World Bank provides expertise to support World Bank and government project teams in operationalizing and embedding CWIS principles within their urban sanitation investments.

CWIS Planning

In line with the CWIS principles, urban sanitation planning processes are also in need of revisiting. The World Bank has been working with governments in the undertaking of participatory planning that focuses on the types of services that will be delivered, on the institutions needed to support these services, and on the financing streams for both their capital and operational expenses. In lieu of focusing exclusively on sewerage master plans, these planning processes begin with a clear assessment of existing sanitation services—for the full service chain and across all parts of the city. The methodology then aims to define the objectives of the sanitation planning process and to produce a plan which states the types of technologies and services that will be used in each neighborhood/division of the city, with the specific units/levels of planning being defined by the city decision makers and other key stakeholders.

The scale at which such strategic sanitation planning occurs may also vary depending on local realities and needs. For instance, in *Kenya* the World Bank has supported the government in undertaking an approach that provides a planning process at the county level termed *Countywide* Inclusive Sanitation, which encompasses the planning of sanitation services along the rural/small town/peri-urban/urban continuum.

CWIS Project Implementation

In *Ethiopia*, the World Bank is funding a large investment project that focuses on expanding access to urban sanitation services for 2.5 million people, while strengthening the institutions that provide these services. The project, which includes activities in the capital and in 22 other cities across the country, will support sewered and onsite solutions and incorporate consideration of the full sanitation service chain. The project is working with government counterparts and consulting firms to improve the planning process—both in terms of rapid assessments and the identification of priority 'no regret' investments. An issue of particular importance is the building of capacity of the country's water service providers whose mandate has recently been expanded to include urban sanitation services. One way of sharing knowledge is through experience exchanges between cities within the country. The World Bank's Citywide Inclusive Sanitation Costing and Planning Tool (World Bank, 2019b) has also been used under the project to help decision makers think through the technical feasibility and financial implications of different approaches to sanitation service delivery along the whole service chain.

In *Bolivia*, the World Bank has been providing technical assistance support to different levels of government and to service providers to help advance the country's urban sanitation agenda, with a focus on participatory CWIS strategic planning, on better assessing and improving fecal sludge management, on piloting the use of non-conventional sewers, and on improving the technical, financial, regulatory and customer outreach approach to connecting unconnected households to existing conventional sewer networks.

In *Bangladesh*, the World Bank is working with service providers and with city and municipal governments to advance urban sanitation provision for all by embracing approaches that include the rehabilitation and provision of conventional centralized sewers, but in conjunction with the implementation of approaches and policies to ensure that households actually connect to them, and the implementation of simplified sewer systems and of onsite sanitation and fecal sludge management, in both centralized and decentralized contexts.

For the Greater Accra Metropolitan Area in *Ghana*, the World Bank is supporting the government in implementing multiple technological and financing innovations in its efforts to provide sanitation services for all. The project has funded the implementation of a mobile money platform for households to save toward the cost of a toilet, representing a new, innovative use of mobile savings schemes. The savings platform allows participation by those who cannot otherwise access the traditional banking sector and who are often the poorest and thus also the most likely to lack proper sanitation at home. The project has also supported an innovation challenge fund that resulted in new technologies (such as different types of household level sanitation containment, and treatment solutions for high flood prone areas) becoming available on the market that are now being provided for low income households under the project.

CWIS Knowledge Sharing

The World Bank's global CWIS initiative is designed to bring about a shift in the mindsets of different groups of stakeholders through the implementation of tailored approaches to knowledge sharing. This includes providing awareness raising and capacity building activities for World Bank staff and their government counterparts (at the national, city and service delivery levels) who are responsible for the preparation and implementation of Bank-funded urban sanitation investment programs. A key aspect of this work involves the undertaking of knowledge sharing and capacity building activities, either tailored to a specific country or project, or designed for a group of countries and investment programs. A central element of these activities is the promotion of peer-to-peer learning from global good practice urban sanitation service delivery, and the sharing of tools and other resource materials to improve project design and implementation. The World Bank has delivered a number of country and regional CWIS knowledge and learning events in recent years that have brought together stakeholders from a broad range of locations[4].

Feedback from these national and regional knowledge and learning events has consistently shown very high ratings of satisfaction regarding their content and design, while highlighting the importance of the following elements: (i) presenting compelling examples of urban sanitation service delivery for all; (ii) sharing resource materials and tools developed to help better design and implement such interventions; (iii) providing a balance between presenting new knowledge and demonstrating examples of implementation in practice; (iv) creating opportunities to maximize the exchange of experiences within and between countries; (v) developing

[4]Regional CWIS Knowledge & Learning events have so far been conducted in: Durban, *South Africa* (December 2016); Brasilia, *Brazil* (March 2018); Accra, *Ghana* (May 2018); and Kampala, *Uganda* (November 2019), with the participation of government counterparts and Bank staff as well as experts from around the world. Country-focused events have been conducted in *Bangladesh*, *Ethiopia*, *India*, *Indonesia* and *Kenya*, among others.

action plans to help concretize learning from the events; and (vi) providing suggestions on how to maintain momentum in advancing CWIS principles and practices as follow up to the events. In order to sustain the knowledge sharing that occurs at these events, the World Bank's CWIS team and regional focal points support ongoing dialogue with government counterparts.

Partnerships for CWIS

As described above, a significant amount of the World Bank's efforts in CWIS is directed toward working with counterparts from different levels of government and from service providers to advance the concepts and the practice of sustainable urban sanitation service provision through the adoption and adaptation of CWIS principles. These partnerships between governments and the World Bank are at the heart of our work and of our *modus operandi* during both project preparation and implementation. In addition, we are also working across the world with a number of other key partners in the sector to advance the concepts of Citywide Inclusive Sanitation, including with other multilateral development banks, bilateral donors and various other development partners.

We are partnering with the Bill & Melinda Gates Foundation under a new *Urban Sanitation Innovation Partnership* to help both organizations and their government counterparts in working toward 'proof of scale' for innovative sanitation delivery services for all, with a focus on sustainable services for the poor. We are also working with a number of bilateral organizations. In *Angola*, for example, we are co-financing a project with the *Agence Française de Développement* that will support strategic sanitation planning in nine secondary cities and will pilot sanitation service provision for 35,000 people.

We are collaborating with WaterAid, GIZ and other development partners on the shared, community and public sanitation agenda; with WaterAid, the World Health Organization and the International Labour Organization on the challenges and realities facing sanitation workers; with pS-Eau on non-conventional approaches to designing and implementing sewers; with Eawag-SANDEC and the Gates Foundation on training material for a new generation of urban sanitation sector professionals; and with other non-governmental organizations, think tanks and research entities on various CWIS-related initiatives.

CONCLUSION

As the world urbanizes, the challenges of urban sanitation provision increase, with urban population growth dramatically outpacing gains in sanitation access. In low- and middle-income countries, much of this urban growth is taking place in rapidly expanding, unplanned informal settlements, where the provision of sanitation services is especially challenging. The economic, social and development impacts from a lack of sanitation on health, mortality and productivity are compounded by negative impacts on the environment and, ultimately, on economic growth. In cities across the world, it is the norm that, even where piped water networks exist, sanitation coverage lags far behind.

To reach the SDG urban sanitation goal of providing safely managed sanitation for all requires us to think beyond business as usual, in which conventional sewerage networks and wastewater treatment plants are seen as the only solution. Citywide Inclusive Sanitation is designed to shift the urban sanitation paradigm, with the aim of ensuring that everyone has access to safely managed sanitation by promoting a range of technical solutions—both onsite and sewered, centralized or decentralized—which are tailored to the realities of the world's burgeoning cities and which are flexible and adaptable so that, as cities grow and change, the sanitation services adapt with them. CWIS means focusing on service provision rather than on building infrastructure, while considering the financial, institutional, policy, regulatory and social dimensions of the services, and while harmonizing sanitation solutions with related urban services.

This shift in paradigm to Citywide Inclusive Sanitation requires a shift in mindsets. Governments and their development partners are increasingly recognizing that historic approaches to urban sanitation have not always worked and that new approaches, such as CWIS, are required. Consulting firms need to think differently, and not simply replicate approaches found in high-income countries. Engineering curricula should include the design and management of non-conventional systems and should explore opportunities for leapfrogging to solutions that take full account of the public health and environmental imperatives of urban sanitation.

CWIS, requires awareness raising and capacity building and the spreading of successful practices from one side of the world to the other. At the World Bank, we find that there is appetite for moving toward CWIS in our urban sanitation investment projects in low- and middle-income countries alike and, increasingly, we see government and service provider counterparts interested in embracing such approaches. We also see an important emerging global movement to engage on CWIS, which provides the sector with an unprecedented opportunity to shift the urban sanitation paradigm in the pursuit of universal safely managed sanitation. However, such paradigm shifts are by no means easily embraced, and efforts must continue in advocacy, awareness raising and capacity building in order to shift entrenched thinking. We have seen that shifting mindsets to move the paradigm to approaches which embrace CWIS principles can be achieved in relatively short time periods, if tailored awareness raising and capacity building programs are carried out at the right times and with the appropriate content throughout the investment project cycle.

At the World Bank we have been contributing to bringing about such changes through the curation and creation of knowledge products, including the documentation of good practices, the development of a suite of guidance material and tools, the provision of targeted technical assistance, and the delivery of knowledge sharing events—all aimed at improving the preparation and implementation of urban sanitation investment programs.

Despite these advances, there is a need to further expand our knowledge and experience with regard to the design and implementation of Citywide Inclusive Sanitation projects in practice, and to do so at scale. To that end, the World Bank continues to leverage its partnerships in the sector to further document what is working, what is not, and what areas still require further innovation and analysis.

In summary, there is a huge challenge confronting the world if it is to reach the SDG target of providing safely managed urban sanitation for all. If this ambitious goal is to be attained, governments and service providers, together with their development partners, will need to continue to collectively work toward changing the thinking behind, and the approaches to, urban sanitation service delivery.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Citywide Inclusive Sanitation: A Public Service Approach for Reaching the Urban Sanitation SDGs

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This policy brief sets out key concepts, principles and practical implications for the citywide inclusive sanitation (CWIS) approach. Rapid urbanization, aging infrastructure, and climate change are exacerbating a sanitation crisis. The focus of most urban sanitation interventions remains incremental expansion of centralized sewer infrastructure; little attention is paid to reaching the poor, long-term service provision, financial viability, or the public system functions required to achieve those outcomes. Meeting SDG targets requires a radical rethink of the urban sanitation sub-sector. CWIS offers this. This paper presents a public services framework, set out by the Gates Foundation, for pursuing equitable, safe and sustained service outcomes, at city scale. It reviews the genesis and evolution of the CWIS framework and shares key principles and policy implications.

Keywords: citywide inclusive sanitation, SDG, equity, urban sanitation, urban basic service

INTRODUCTION: THE URBAN SANITATION CRISIS

By 2018, 55% of the world lived in cities (United Nations [UN], 2014; World Bank, 2019); rapid urban growth will continue to occur in LDCs, where urban populations have already doubled in the last 15 years UNICEF (2019b). Based on the sustainable development goals, urban sanitation services should yield safe, equitable, and sustained sanitation outcomes for everyone, prioritizing vulnerable groups. Urban sanitation service expansion, however, has been slow and uneven (UNICEF, 2019b). Although most countries have increased urban sanitation coverage between 2000 and 2017, and many have shrunk the access gap between the richest and the poorest, in 36 low-income countries urban coverage is either decreasing (8 countries), becoming more unequal (22 countries), or both (6 countries). Over 622 million urban residents lack basic sanitation globally, and 2.2 billion urban residents, or 29% of the entire global population, do not use safely managed sanitation services (UNICEF, 2019b).

On-site hardware, such as pits and septic tanks, is the predominant containment used in urban Sub-Saharan Africa and South- and Central Asia, UNICEF (2019b). Yet, the focus of ministries, urban sanitation authorities, master plans, and development finance covering 60% of the population remains on incremental expansion of centralized sewers benefitting small, non-poor segments of urban populations. Little attention is paid to reaching the poor, non-sewered populations, long-term service provision, or prevailing climate and urban conditions.

Public investments are too few (UN-Water GLAAS, 2017), and consistently struggle to yield sustainable, pro-poor results. For example, a World Bank evaluation of US$30.3 billion of investments in water supply and sanitation between 2007 and 2016 found that over 40% of projects faced significant or high outcome risks, mainly due to lack of financial viability or institutional accountability; only 4% of projects declared financial viability as an explicit objective (The World Bank Group, 2017). Similarly, an evaluation of the Asian Development Bank's urban water and sanitation portfolio over a similar timeframe found that only 7 out of 63 evaluated projects included on-site components (in addition to centralized systems) and that the poor were given low priority in most projects (ADB, 2018).

The fact that the prevailing approaches struggle to provide inclusive and sustainable services is known among experienced professionals, but discussions tend to focus on insufficient finance. Systematic evidence and analysis of challenges are sparse and tend to be documented in gray literature, including fragmented, project-, and country specific reports. The mismatch between the urban sanitation needs in low-income countries and the prevailing interventions reflects how the sector – including WASH engineering education – have been shaped by historical factors and norms more than by data, transparency, and clear service delivery goals. This is exacerbated by neglected investment in service authorities' data collection systems. The sector tends to invest in expensive project estimates in the absence of data systems, to aggregate water and sanitation estimates, and to neglect collection of basic data on sanitary conditions in low-income areas and informal settlements.

Efforts to address the specific needs of those with on on-site containment by formalizing fecal sludge management (FSM) services have made substantial gains in the past 10 years (Strande and Ronteltap, 2014; Blackett and Hawkins, 2017), but these approaches are largely supported outside of mainstream or public planning and practice, thereby limiting their reach and impact (see table on page 5 for a comparison among the approaches). Framing the urban sanitation challenge from a technology lens (e.g., "sewered" vs. "non-sewered") establishes a false dichotomy. It retains focus on hardware inputs rather than how a city's service delivery system functions and the resulting outcomes. The latter requires planning and investment in incremental hardware and service improvements across diverse contexts within cities (The Bill and Melinda Gates Foundation [BMGF], 2016); it also requires planning and investment in the infrastructure of public service delivery, accountability and financing systems, including things like public information, monitoring, and grievance redressal mechanisms. This latter approach calls into focus the limitations of existing technologies and products to meet the needs of many urban contexts, and it illuminates the missing source of market demand for innovation.

TOWARD A NEW FRAMEWORK: DEFINING CITYWIDE INCLUSIVE SANITATION

Recognizing the urban sanitation crisis, its disproportionate burden on the urban poor, and the limited progress of prevailing approaches, a group of organizations met at the 2015 Hanoi FSM3 Conference to discuss the need for an urban "sanitation revolution[1]." The sector had failed to achieve the toilet-focused MDG targets for sanitation, but was preparing to commit to even more ambitious SDG targets for "safely managed" sanitation across the service chain. The conversation reflected lessons from a portfolio of DFID-BMGF city grants supporting outcome contracting. Weak or missing sanitation authority mandates and lack of accountability for services constrained efforts to formalize and improve them (Aquaconsult, 2018). A larger multi-disciplinary group of practitioners, development partners, researchers, and others convened in Atlanta in 2016 to identify ways to accelerate progress in providing sanitation services for the urban poor.

The Atlanta workshop resulted in the citywide inclusive sanitation (CWIS) concept and "Call to Action" (BMGF, 2016) signed by over 70 organizations and individuals. CWIS was characterized as:

Everyone benefits from adequate sanitation service delivery outcomes; human waste is safely managed along the whole sanitation service chain; effective resource recovery and re-use are considered; a diversity of technical solutions is embraced for adaptive, mixed and incremental approaches; and onsite and sewerage solutions are combined, in either centralized or decentralized systems, to better respond to the realities found in developing country cities.

The call to action highlighted the need for long-term planning, technical innovation, institutional reforms, and financial mobilization, as well as political will and technical and managerial leadership for systems change (BMGF, 2016). It outlined four CWIS building blocks: (1) Prioritization of the right of all to sanitation, with inclusive strategies reaching informal settlements and vulnerable populations; (2) Delivery of "safe management" along the entire sanitation service chain by focusing on service outcomes rather than technologies, and by embracing innovation and incrementalism; (3) Recognition of sanitation's contribution to a thriving urban economy by integrating sanitation into urban planning, reforming regulatory policies, and embracing resource recovery and reuse; and (4) Commitment to work in partnership across sectors and stakeholders to make progress through clear institutions with accountability, embedding sanitation within urban governance systems.

After a series of regional consultative workshops with ministerial, municipal and utility leaders, economic regulators, engineering firms, and development partners from over 40 countries, the CWIS building blocks and objectives (Gambrill et al., 2016), were refined into an SDG-aligned definition:

A public service approach to planning and implementing urban sanitation systems to achieve outcomes summarized by SDG 6: safe, adequate, equitable, and sustainable sanitation for everyone in an urban area, paying special attention to the needs of the poor, the marginalized, and of women and girls, a comprehensive set of seven CWIS principles (**Figure 1**), and service framework (**Figure 2**).

[1] Initial meeting included representatives from the Bill & Melinda Gates Foundation, Emory University, Plan International, the University of Leeds, WaterAid, and the World Bank.

SEVEN PRINCIPLES FOR CITYWIDE INCLUSIVE SANITATION

1. **EVERYONE IN AN URBAN AREA, INCLUDING THE URBAN POOR, BENEFITS FROM EQUITABLE SAFE SANITATION SERVICES**
   - Everyone. Legal mandate is based on urban planning principles, without restrictions based on land tenure, hardware type, or local political boundaries; Transient, permanent, worker, and downstream communities' needs are met;
   - Equitable. Prices reflect service levels, affordability; availability and legitimacy of public finance is decoupled from hardware type or on-plot/off-plot siting; subsidized finance prioritized for the poorest;
   - Safe. Users' waste is safely managed and all communities are free of others' waste.

2. **GENDER AND SOCIAL EQUITY ARE DESIGNED INTO PLANNING, MANAGEMENT, MONITORING**
   - Those who are marginalized, without formal land tenure or access to sewers, women, and children are intentionally engaged in decision making systems;
   - Users' and workers' needs, values, constraints, and voices are understood and incorporated into hiring, service delivery planning, and service delivery;
   - Workers' health and rights are protected by occupational health and safety measures.

3. **HUMAN WASTE IS SAFELY MANAGED ALONG SANITATION SERVICE CHAIN, STARTING WITH CONTAINMENT**
   - Infrastructure and service delivery systems protect workers, households, communities at all stages from containment through disposal/reuse;
   - Containment and connections are managed to protect groundwater and environmental health;
   - Hardware investments and service models position resource recovery as a tool to incentivize safe waste management.

4. **AUTHORITIES OPERATE WITH A CLEAR, INCLUSIVE MANDATE, PERFORMANCE TARGETS, RESOURCES, AND ACCOUNTABILITY**
   - Mandate for urban sanitation is clearly defined, assigned to service authorit(ies) without overlap, explicitly prioritizes serving the poor, and is reflected in the authority's key performance indicators;
   - Processes exist to establish performance levels and set progressive targets for achieving them;
   - Service authority performance targets are monitored and tied to regulatory penalties and incentives;
   - Financing and revenue opportunities are designed to sufficiently support implementation of mandates.

5. **AUTHORITIES DEPLOY A RANGE OF FUNDING, BUSINESS, AND HARDWARE APPROACHES—SEWERED / NON-SEWERED—TO MEET GOALS**
   - Sanitation service mandates are technology agnostic; planning and investments support incremental and integrated systems that prioritize resources for achieving safety, equity, and sustainability;
   - Service authorities may deploy a range of business models to reach different customer segments within a city efficiently and equitably.

6. **COMPREHENSIVE LONG-TERM PLANNING FOSTERS DEMAND FOR INNOVATION AND IS INFORMED BY ANALYSIS OF NEEDS/RESOURCES**
   - Investment and finance decisions are based on activity-based accounting of costs and revenues and inclusive performance targets;
   - Investment and planning are informed by climate change, water, and energy constraints;
   - Performance incentives foster service authority capacity, responsiveness, and innovation;
   - Investment planning and prioritization processes are documented, transparent, engage relevant stakeholders;
   - Processes are coordinated with those of other urban investments and services, e.g. neighborhood upgrades, water services, storm water and greywater management, roads.

7. **POLITICAL WILL AND ACCOUNTABILITY SYSTEMS INCENTIVIZE SERVICE IMPROVEMENTS IN PLANNING, CAPACITY, AND LEADERSHIP**
   - Commitment to safe inclusive urban sanitation is demonstrated at multiple levels of government;
   - Budget allocations and expenditures are transparent and set based on equity and performance accountability;
   - Accountability systems such as performance regulators are designed to be autonomous and independent and to empower marginalized voices;
   - Service authorities have support from politicians for effective institutional reforms, like tariff-setting and enforcement.

FIGURE 1 | Seven principles for citywide inclusive sanitation.

Service Outcomes	**EQUITY** 'Fairness' in distribution and prioritization of services, service quality, service prices, and use of public finance/subsidies	**SAFETY** All human waste is managed to protect public goods* for customers, workers and all communities	**SUSTAINABLITY** Management of revenues and resources--financial, labor, energy, water--sustain performance
System Functions	**RESPONSIBILITY** Authority or authorities execute a clear mandate to ensure inclusive, safe sanitation services	**ACCOUNTABILITY** Performance is monitored and managed with transparency, data, incentives and penalties	**RESOURCE PLANNING & MANAGEMENT** Resources are managed to support implementation of mandate and achieve goals across time / space

FIGURE 2 | CWIS service framework. *Public Goods are the elements of sanitation service delivery system characterized by market failures –technically, non-excludability and non-rivalry. Practically, they are the elements of sanitation service that are outside of individuals' direct private interests and can include safe on-site containment, network connections, transporting waste to safe disposal, and other activities required for long-term protection of water, land and public health along the value chain.

Citywide inclusive sanitation is explicitly agnostic about technology choice. Clear service outcomes – for all residents, in sewered and non-sewered areas – and system feasibility considerations (e.g., financial, environmental, political, organizational capacity, cultural, and other factors) inform system design and technology choice. CWIS is based on the fundamental understanding that urban human waste management is characterized by inherent market failures, and therefore must be organized as a public service – including ensuring safe containment – to achieve public interest components of sanitation (i.e., safety and inclusivity). This requires government engagement in market structuring; it does not preclude or diminish the role of the private sector. For service authorities to achieve the outcomes embedded within their legal mandates, they must ensure services are well executed. This expands opportunities for private sector participation by creating market incentives for investment and innovation.

Figure 2 presents a CWIS service framework which captures a simplified set of core outcomes and required functions of a public service delivery system for sanitation, relevant across diverse city contexts. Core outcomes of a system are equity, safety and sustainability, for everyone in an urban area, not just those in sewered areas. To achieve these outcomes, a system must demonstrate three functions: there must be a responsible authority(ies) executing a clear, legal mandate for inclusive urban service delivery; the legal authority(ies) must be accountable for performance against mandated responsibilities; and processes for planning and managing resources – financing, assets, people – across time and place must be transparently tied to mandated priorities and performance accountability.

The CWIS service framework identifies core outcomes and functions for public service delivery systems. The specifics of how outcomes are defined and how functions are institutionalized and executed will vary by country and city. Sanitation authorities need to consider an evolving range of diverse technologies and business models to generate service improvements over time, including delegation of service provision to the private sector when appropriate. Likewise, a range of models and tools are needed for meaningful accountability and resource management in different contexts, including but not limited to economic regulators. Irrespective of context, any well-functioning service system relies on robust, institutionalized performance indicators and effective monitoring systems to inform decisions.

The core elements of the CWIS service framework are not new; they reflect tenets of public service systems (Klein, 1996; Komives, 1999; Galli et al., 2014). In the urban water sub-sector, priority outcomes are defined and monitored using performance indicators such as service expansion, revenue collection, and non-revenue water. Performance monitoring systems are well established with institutions like economic regulation and supporting tools like ISO standards (ISO, n.d.), benchmarking (IBNET, n.d.), rating tools (Alegre et al., 2016), and the "utility turn-around" framework (Janson et al., 2018). In urban sanitation, these concepts have been lightly applied to utility sewerage but typically not to all types of urban sanitation services. Efforts to apply utility and urban service concepts to urban sanitation include the Urban Sanitation Fundamentals of Good Practice Note (Tayler and Parkinson, 2003), the Practitioner's Companion online Toolkit (MIT, 2001), the Sandec-UNITAR-WBI Sector Governance in Sanitation curriculum, the World Bank's city service delivery assessment (CSDA), and Water and Sanitation for the Urban Poor's Sector Functionality Framework (Sandec-UNITAR-WBI, 2008; Ross et al., 2016; Drabble et al., 2017). Unfortunately, all of these have seen limited adoption in practice.

The CWIS service framework attempts to close this gap. Based on existing literature, well-established utility service theory and practice, and SDGs, especially 6 and 11, it offers a simplified but coherent conceptual frame for public service delivery systems that mainstream low-income communities' needs, and a range of appropriate technologies, service models, and governance mechanisms. **Figure 3** highlights the shift

	Service Outcomes		
	Conventional approach	**FSM Approach**	**Citywide Inclusive Sanitation Approach**
Equity	• Sewerage/treatment investments for central districts; Small proportion of population -often in non-poor metro neighborhoods- receive largest share of public investment and highest level of service for the lowest household payment resulting in *de facto* regressive cross-subsidies.	• Low income communities dependent on projects, informal sector, social enterprises; serving the poorest remains a challenge external to core governance efforts; Focus on short term full-cost recovery from households; Public financing and subsidies often seen as inappropriate or unaffordable, especially for safe containment.	• Public investments and subsidies prioritize reaching the poor and most vulnerable; Prices and government support based on cost of service, service level, and ability to pay across sewered and non-sewered customer segments; gender intentionality explicit to achieving outcomes and proper execution of functions.
Safety	• Small portion of human waste is collected; Treatment works have limited / unreliable long-term performance; Poorest communities receive least public collection but face greatest environmental health risks / damage from poor city services.	• Small pilots have limited reach, variable and often unsustained performance; Informal providers provide services that are limited, inefficient and unsafe for city, households and workers and is challenging to improve. Interventions tend to focus on collection and treatment; unsafe containment often lower priority.	• Safely managed sanitation does not ignore safe containment; Focus on fit-for-purpose technology choice with citywide, systems lens, not specific hardware approach. Worker rights integrated into definition of safety requires inclusivity to achieve city-level safety outcomes.
Sustainability	O&M costs, technical, water and energy requirements for hardware acceptable for public investments and services (generally sewers) tend to exceed resources available or allocated; Capital maintenance deferred; infrastructure deteriorates/depreciates. All other approaches are relegated to private retail markets.	• Projectized approaches not integrated with broader public management systems limit post-project performance; Lack of institutional clarity, and/or lack of priority keeps FSM on the 'fringes' of mainstream planning and investments; FSM 'add-ons' to core centralized infrastructure plans.	• Investments, technologies, pricing and other systems features are designed and implemented to be viable in the context of financial, water, energy, land, human resource flows and limitations; system incentives are designed to perpetuate and improve service outcomes.
	System Functions		
	Conventional approach	**FSM Approach**	**Citywide Inclusive Sanitation Approach**
Responsibility	• Authority/utility often with legal or de facto mandate only for conventional sewered area; authority not expected to plan, invest or serve full city or larger urban-growth affected area; On-site services typically excluded from mandate, not executed, or mandate is fragmented to multiple authorities based on hardware and administrative definitions, boundaries not need or function.	• Lack of clear mandate and/or no active authority responsible for ensuring services in non-sewered areas; informal and formal private businesses (primarily emptiers) operate without recognition, regulation or engagement, despite providing the bulk of services; NGO and social enterprise interventions 'never fail, never scale.'	• Responsible public authority(ies) required to fully take on mandate for service outcomes for all; Private sector participation occurs within a clear institutional framework and with specific engagement models (e.g. service contracts, agreements) and regulations; Households, private sector and informal sector should benefit with proper market structuring and investments.
Accountability	• Regulators use nominal Key Performance Indicators (KPIs), for sewered systems only, if at all; Missing data collection systems (especially for on-site populations) limit performance or tariff accountability; sovereign loan guarantees weaken incentives to design and invest for appropriate or sustained outcomes.	• Weak or absent codes, local regulations; Lack of monitoring and enforcement in the absence of engaged mandated service authority; Often tense relationships between private operators and authorities, limiting trust.	• Outcomes are monitored and authorities held accountable for KPI targets using tools such as economic regulation and mix of positive and negative incentives. • Understanding progress and costs creates space, even demand, for improvements, innovative technologies and smarter business models.
Resource \ Management	• Central government and concessional finance, primarily for sewered infrastructure, primarily in largest cities; Resources typically reach first mile non-poor users first who tend to be able but not required to pay cost-recovery tariffs. *De facto* allocations not based on efficiency, inclusivity, performance or sector priorities.	• FSM interventions often projectized and short-term, suffer from unreliable revenues; Resource recovery is often highlighted, but not scaled or integrated into larger systems or market signals/coordination	• Clear, transparent financing frameworks guide data-driven decision making on resource allocations across government levels; finance can be tied to performance against goals and long-term plans

FIGURE 3 \| Comparing CWIS to conventional and FSM approaches.

from previous approaches to urban sanitation that were defined around hardware categories rather than service needs. "Conventional Approach" defined sewered sanitation as relevant for public investment and management, and all other technology approaches were managed outside of public service systems. The "FSM Approach" failed to course correct this by emphasizing its inherent advantage over sewers for reaching the poor without considering the context or need for broader planning and public service delivery systems.

This comparison illustrates some of the barriers to reaching sustainable development goals with hardware-focused interventions when those Goals are not integrated into mainstream planning, investments and institutional designs, and if interventions for low-income and on-site oriented populations remain relegated to pilot, "add-on" or phase two projects. The CWIS frame integrates FSM interventions into citywide service systems, improving likelihood and scale of safe, equitable and sustained service outcomes.

MAKING IT WORK: TOWARD CWIS IN PRACTICE

The CWIS framework and principles have and will continue to evolve as experience and practice grows. Since 2017, a growing number of public service authorities, policy makers, and development banks are aligning with the underlying imperatives of CWIS. Several global institutions are working to reframe their urban sanitation strategies and investments around public service system functions and outcomes, and to strengthen the focus on equity and inclusivity. The World Bank, Asian Development Bank, and the African Development Bank have all made substantial commitments to the adoption of CWIS within their investment portfolios (African Development Bank Group, 2018; Cheney, 2018; The World Bank, 2019). UNICEF has adopted CWIS as a key initiative within its new global framework for urban WASH (UNICEF, 2019a). Others are increasingly engaging.

While some national governments, for example the Government of Bangladesh (DPHE and ITN-BUET, 2019), as well as sub-national and city authorities have begun to consider how to integrate CWIS elements into their work, it is still a new concept and requires significant awareness-raising, advocacy and adaptation. To this end, regional organizations such as the Eastern and Southern African Water and Sanitation Regulators Association (ESAWAS) and the African Water Association (AFWA) have begun to frame their support to member regulators and utilities using the CWIS principles. Likewise, a growing number of capacity-building organizations, academic institutions, and other development partners are providing technical assistance and advocacy required to reorient the sector toward a public service delivery approach.

The emerging consensus and broad commitment to CWIS is promising, and essential if the principles are to influence sector priorities and practice. The Gates Foundation is hoping to amplify sector efforts by contributing to them in four ways: (1) demonstrating and documenting good practice, and creating space for learning; (2) building technical and human resource capacity; (3) supporting partners to enable policy and institutional reforms – including to establish or strengthen monitoring systems for outcomes at all levels – required for CWIS principles to translate into meaningful progress toward the SDGs; and (4) catalyzing technology and product innovation responsive to the challenges authorities face in delivering inclusive, viable services particularly in the context of climate change, rapid urbanization, and limited finance. The Foundation's CWIS City Partnership Portfolio includes eight "learning laboratory" city partnerships across five countries[2] where city authorities are experimenting with how to operationalize CWIS principles in a diversity of contexts and are informing replication and institutionalization efforts at state and national levels. Partnerships with international financing institutions and their national government clients, as mentioned above, are intended to accelerate mainstreaming of CWIS principles within large-scale urban investments. Support for capacity building activities, tools and peer exchange is enabling sector professionals to become familiar with the alternative engineering, institutional and organizational approaches required to implement CWIS.

Arguably a critical and urgent gap relates to how the sector measures and informs urban service system changes. Robust public data systems are required for iterative planning, practice, and accountability. Systems must be compatible with, inform and be informed by sector efforts to measure and track the urban SDGs. This means institutionalizing coordinated measurement systems on at least three levels:

City Level Data System for Planning and Improving Services

Municipal and utility driven performance indicators and systems for monitoring progress allow authorities to plan and improve city-level systems based on actual performance against goals. This must include, for example, household-level data (disaggregated to inform how services meet needs of women and marginalized populations), better assessments of containment infrastructure, and tracking of services along the service chain, and a better understanding of the links between infrastructure and service gaps and the context-specific public health risks.

National- and/or State-Level Data Collection Systems for Accountability and Resource Management

Explicitly inclusive Key Performance Indicators and associated data systems are required to translate authorities' mandates into clear goals and incremental targets and to hold them accountable for making progressive improvements using transparent incentives and penalties. Data systems are essential for operationalizing national financing and accountability frameworks and reporting meaningfully against SDG commitments. Currently, national-level reports of safely managed sanitation are largely

[2]These include: Dakar, Senegal; Kampala, Uganda; Lusaka, Zambia; Khulna, Bangladesh and Narsapur, Warangal, Wai, and Tiruchirapalli in India.

unavailable or remain high-level estimates (UNICEF, 2019b), and performance monitoring for sanitation services–particularly for on-site population segments–is rarely practiced.

Project-Level Lending and Investment in Data Collection Systems for Learning and Financing Efficiency

Scarce global finance for urban sanitation makes its efficient use an imperative. Consistent, CWIS-aligned project indicators for multinational, bilateral, and central government investments in urban sanitation are needed to improve design and implementation of new investments, to enable better understanding of planned and actual outcomes of investments, and to strengthen inherently weak feedback and accountability mechanisms associated with infrastructure financing. Investments need to prioritize establishing or strengthening authorities' data systems, rather than projectizing data collection to fill the gaps of missing public information management systems for discrete interventions.

SOME UNANSWERED QUESTIONS & IMPLICATIONS FOR POLICY & PRACTICE

Broad energy around still-early CWIS efforts indicates general support for the proposed concepts, but more importantly a clear consensus that the *status quo* must change. Reimagining sector goals and ways of working is a good first step. It is a far more complicated task to reshape them. At present, CWIS is a conceptual frame still largely unfamiliar to government stakeholders or sector professionals. Time will tell whether this frame can generate value for practitioners and service authorities, and whether its use can drive better service outcomes. At this stage, several important questions emerge:

- The CWIS public service approach to urban sanitation is new for most cities and countries. What does it take to institutionalize CWIS principles within national policies, regulatory frameworks, organizational arrangements? What financial and technical assistance is needed at national and city levels to support organizational change and transition from the *status quo* to CWIS implementation?
- What advocacy efforts are required to build an actionable understanding of the concepts underpinning the CWIS acronym? What advocacy is needed to drive the mainstreaming and improvement of FSM and inclusivity within CWIS – starting with establishing safe containment? How can local private and public innovations to improve CWIS outcomes be incentivized and integrated into systems and norms so they are sustained and scaled?
- What metrics and monitoring systems are needed to inform and monitor sector-, national-, and city-level progress? Global and regional SDG monitoring can be based on national estimates, but systems for monitoring city-level services, upon which national reports should be based, will be harder to normalize and implement.
- What do good incentives and investments look like when using CWIS principles? To what degree do the infrastructure to operational cost ratios change and what are the implications for existing financing tools? How should the sources and proportions of public, private and household financial contributions change to prioritize equity, safety and sustainability? How are capacity development and other real transition costs funded to ensure organizations like utilities achieve complex system-level transitions?
- What are the limitations of CWIS implementation given the limitations of existing urban sanitation technologies in the market? What do we need to learn in order to prioritize interventions that will optimize health and dignity benefits? What are the specific technology innovation opportunities that could stepwise improve inclusivity, safety or viability of service and business models in the context of weak or nascent sector governance and limited funds?
- What can we learn from reforms in other public service sectors that required deep change management, innovation and experimentation? What are realistic expectations in terms of the pace, scale and depth of change required to transition cities and countries toward entirely new approaches? How do we encourage experimentation, learning-by-doing, and acknowledgment of failure in the context of risk-aversion and strong incentives to continue with the *status quo*?
- How can a CWIS frame support integrated urban waste and water management? When is it necessary to consider integrated systems to advance sustainability and safety of service provision? What does the CWIS frame offer for drainage, solid waste management and other city service goals and investments?

These and other questions need to be considered in ways that inform practice, curriculum, policies, and tools if our pursuit of SDG 6, as well as SDGs 1, 3, and 11, is serious.

This paper outlines the evolution of CWIS and presents the CWIS service framework as an integrated systems-change approach for equitable, safe, and sustained urban sanitation service outcomes. It is a point of convergence, pulling together threads from the work and lessons of many. It is also a point of departure for all those committed to making progress in urban sanitation – government, utilities, service providers, private sector, NGOs, civil society, and funders. The impetus and momentum for CWIS rests on the notions that prevailing approaches to expand sanitation coverage are both inadequate and inappropriate for achieving urban sanitation SDGs, that inclusive urban sanitation requires a public service approach that prioritizes reaching the poor, and that making CWIS work in practice requires significant changes to how all sector professionals think, plan, and work.

AUTHOR CONTRIBUTIONS

AS, JR, DP, and RS conceived of the idea, and outlined the brief. AS created the comparison table and 2 × 3 framework. JR wrote a first outline of the manuscript and detailed the introduction. AS and DP detailed in sections "Toward a New Framework: Defining Citywide Inclusive Sanitation," "Making it Work: Toward Cwis in Practice," and "Some Unanswered Questions & Implications for Policy & Practice." RS provided in-depth review and additional materials for sections "Making it Work: Toward Cwis in Practice" and "Some Unanswered Questions & Implications for Policy & Practice." RB wrote the materials on monitoring systems. All authors contributed to manuscript revision, read and approved the submitted version.

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Structured Approach for Comparison of Treatment Options for Nutrient-Recovery From Fecal Sludge

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The aim of this study is to present a structured approach for comparing possible nutrient-recovery fecal sludge (FS) treatment systems in order to support transparent decision-making. The approach uses a multi-dimensional sustainability assessment of treatment technologies for nutrient recovery from FS, using a typical case of Kampala City, Uganda. A synthesized list of 22 treatment technologies was prepared from literature. This list included wastewater treatment technologies, which could be adapted to treat fecal sludge, and established fecal sludge treatment technologies that are available or potentially applicable in Kampala. Based on the local situation, the list was reduced to eight possible options, which were carried forward into a multi-dimensional sustainability assessment that incorporated input of stakeholders. The technologies included in the final assessment were optimization of the existing system, lactic acid fermentation (LAF), composting, vermicomposting, Black-Soldier Fly (BSF) composting, ammonia treatment, alkaline stabilization and solar drying. Optimization of the existing system performed well against the set criteria and is a recommended short-term solution. This will require e.g., adding narrower screens to remove more trash from the incoming sludge and respecting storage times prior to selling the sludge. To maximize the agricultural value of the recovered product, while respecting the need for safe reuse, a combination of technologies becomes relevant; the use of a combination of BSF, and subsequent ammonia or alkaline treatment of the remaining organic fraction would allow for maximized safe nutrient recovery and can be the aim for long-term sanitation planning in Kampala. The results of this process provide supporting information for a discussion of trade-offs between stakeholder groups as part of a decision-making process within a larger planning context.

Keywords: sanitation, resource recovery, multi-criteria, sustainability assessment, decision-support, wastewater

INTRODUCTION

The world is facing increasing (Koottatep et al., 2005) pressures on both ecological and human environments. Excreta from 60% of the world's population is currently released into the environment untreated (WHO and UNICEF, 2017). In addition, climate change, rapid urbanization, and environmental degradation coupled with economic uncertainty is creating changing conditions that mean that the world cannot continue with business as usual. With this as a backdrop, meeting the targets set out in the Sustainable Development Goals (SDGs), including providing sanitation for all, demands that we reduce long-term dependency on non-renewable resources through the adoption of innovative and adaptive systems that promote recycling and reuse (Cross and Coombes, 2013). An example of this is the on-going paradigm shift (Larsen et al., 2009) to viewing human waste as a resource for the recovery of nutrients, water and energy. In addition to critical energy and water needs, the biogeochemical cycles for nitrogen (N) and phosphorous (P) are part of the critical planetary boundaries that define a safe operating space for humanity and which keeps Earth's environmental system processes in a hospitable balance (Steffen et al., 2015). Closing the loop on the resources found in human waste can therefore contribute to a sustainable future.

In 2015, the world's leaders agreed that a sustainable future includes the provision of safely managed sanitation services for all. However, urban service providers are far from achieving these goals. According to the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene, 85% of fecal waste is safely managed in Europe and Northern America, while in Latin America the figure is 37% and in Sub-Saharan Africa <20% (WHO/UNICEF, 2019). Sewerage systems currently cover only a small fraction of urban populations (9.5%) in least developed countries (WHO/UNICEF, 2019) and the majority of cities lack fecal sludge (FS) treatment systems that can treat all FS produced from non-sewered systems (Peal et al., 2014). The Greater Kampala metropolitan area in Uganda is no exception; here 98% of the population rely on on-site sanitation and sewerage services serve only 1% of the population (Schoebitz et al., 2016). Rapid urbanization adds to the challenge of service provision as service providers struggle to keep up with growth rates. For example, the urbanization rate in Greater Kampala is over 5% per year, meaning that the city population will double by 2035 (United Nations, 2018). In order to reach the SDGs for safely managed sanitation in Kampala, there needs to be higher allocation of funds for fecal sludge treatment, given that even after implementation of the existing Kampala Sanitation Master Plan (2015) only 31% of Greater Kampala will be sewered by 2040. A recent study in Kampala found that annual per capita costs for the existing FS system are significantly less expensive than the sewage system (McConville et al., 2019). This means that nutrient-recovery technologies can feasibly be added to the FS management options in Kampala, while still keeping costs of treatment per capita lower than for sewage systems.

Rapidly changing urban areas without previously existing sanitation infrastructure also offer opportunities for redesigning and rethinking traditional structures for sanitation management. Expanding centralized sewerage systems to cover all urban inhabitants is expensive and in many cases impractical (McConville et al., 2019). Thus, demand is growing to develop innovative decentralized systems that protect public health and the environment, recover resource flows, and allow for rapid service expansion to underserved populations (Larsen et al., 2013). Many innovations focus on resource-recovery as a way to help offset costs, but also to create win-win scenarios between sanitation and other sustainability goals like clean energy, sustainable consumption and production, and food security. In contrast to conventional wastewater treatment, which solely focuses on removal of nutrients from wastewater, the systems under consideration in this study focus on recovery and reuse of nutrients as valuable products at the same time as they sanitize excreta for the removal of harmful pathogens. This can, for example, be achieved through conversion of waste to protein feed for livestock (Lalander et al., 2014), or agricultural fertilizers (Udert and Wächter, 2012). However, many current sanitation-planning practices do not consider the range of new treatment methods available. Urban sanitation planners need more knowledge regarding innovations and tools for structuring evaluation methods to determine the appropriateness of these innovations for their given context.

Addition of nutrients to agricultural fields, to replace what crops remove, is necessary to maintain soil fertility. Uganda, with its 80 kg/ha of annual nutrient losses, replaces only about 1–1.5 kg/ha of that with fertilizers (MAAIF, 2016). Prior to the recent commission of a phosphate fertilizer factory in the Tororo district, Uganda lacked fertilizer production and has been completely dependent on expensive fertilizer imports. In addition to the factory in Tororo, the National Fertilizer Policy (MAAIF, 2016), specifically mentions massive promotion of local production of fertilizers derived from organic residues as one important step to take to enhance fertilizer availability in Uganda. Recirculation of plant nutrients and organic matter from fecal sludge represents one possibility of local, organically derived fertilizer to avoid soil degradation and increase the affordability and accessibility of fertilizers to farmers.

It is widely recognized that there are several factors that determine if a sanitation system is appropriate and sustainable (Guest et al., 2009), and that these factors are context specific. Indeed, the Sustainable Sanitation Alliance defines a sustainable sanitation system as one that protects and promotes human health by providing a clean environment and breaking the cycle of disease, while at the same time being economically viable, socially acceptable, and technically and institutionally appropriate, while protecting the environment and the natural resource base. Accounting for this diversity of factors can be done using multi-criteria assessment techniques. These techniques can account for quantitative and qualitative assessments of system attributes and allow decision-makers to discuss trade-offs between different sustainability aspects when comparing alternative options (Mendoza and Martins, 2006).

The aim of this study is to present a structured approach for comparing possible nutrient-recovery FS treatment systems. The paper draws on experience with multi-criteria sustainability assessments and participatory planning processes, and links it strongly to the need to provide information on resource recovery innovations to decision-makers. The specific objectives of this paper are to (i) provide more information regarding the potential of nutrient recovery technologies; and (ii) present a method that can help decision-makers select the most appropriate FS treatment system that can protect public health and the environment, recover resource flows, and do so in an adaptable way that allows for rapid service expansion to underserved populations. The approach uses a multi-dimensional sustainability assessment of treatment processes for nutrient recovery from FS. The approach is illustrated through application of the method in the case of Kampala, a city that relies on on-site sanitation services for over 90% of its population (Schoebitz et al., 2016). The approach is not a stand-alone tool, but should be fitted in the larger urban planning cycle.

METHODS

This paper proposes a structured approach for comparing treatment options for nutrient-recovery from fecal sludge from non-sewered systems. The approach includes a four-step process: (1) Identification of available options; (2) Narrowing the options based on locally identified prerequisites; (3) Multi-dimensional sustainability assessment of the remaining options; and (4) Stakeholder weighting and discussion of the results. The novelty of this approach is its focus on including more innovative nutrient-recovery options in the decision-making process. The basic principle behind this method is that it should start with a process that opens up the range of options to capture possibly interesting new innovations before narrowing down the possible options based on locally-specific criteria. This paper uses a case study approach to illustrate how the first three steps can be performed, while the final step should be done with actual stakeholders within a planning process. This method would be most effective when applied within an actual sanitation planning process in which key stakeholders are involved. Local input from stakeholders will be critical in steps two through four to assure that the decision-making process includes locally specific prerequisites and sustainability criteria. While the example presented in this paper was not embedded within a participatory planning process in Uganda, stakeholder input was solicited in step two as explained below.

Step 1 in this process is to create a large list of potential options. In this study we used the results of two recent reviews (Harder et al., 2019; Johannesdottir S. et al., 2019), which focused on nutrient-recovery from wastewater, to identify a range of potential treatment options. Note that the focus of this study is on treatment technologies for collected FS (e.g., from lined and unlined pit latrines and septic tanks), and not on the entire FS service chain. When creating this list, no judgement was taken on whether the options were locally feasible. This means that the initial list of technologies used in this study could be used as a starting point in any study aiming at nutrient recovery. However, since there is rapid development occurring in the sanitation sector, it is recommended that each new planning process review this starting list and update with emerging technologies. The identified treatment technologies were categorized based on types of treatment process, possible inputs and products recovered.

The following two steps in this methodology aim to narrow down the possible options for decision-making based on the local context. Step 2 applies a list of case-specific prerequisites to the initial list of possible options. This step essentially sets the system boundaries for the decision space. The prerequisites should be case specific, but not too limiting. Relevant prerequisites can be related to the incoming material to be treated, resource(s) to be recovered, or case specific limitations regarding placement, space or applicability to context. For example, a relevant prerequisite would be to specify that the system should enable recovery of nitrogen; however, the form of recovered nitrogen should not be specified at this point. This study uses four prerequisites: (1) the treatment technology should be able to handle raw FS; (2) it should recover a majority of the macro nutrients (N, P, K, and S) from the incoming waste stream; (3) it should have a technical readiness level (TRL) of 6 or higher, meaning that it has been tested in a relevant environment to Uganda; and (4) it should be possible to implement the technology at the existing FS treatment plant. Determination whether the treatment technologies met the prerequisites was based on information available in published literature and, in the case of the fourth prerequisite, on the expert judgement of the authors.

In Step 3, a multi-dimensional sustainability assessment takes place. Selection of the criteria to use should recognize the holistic nature of sustainability, but also be adapted to the local context. In order to ensure a holistic sustainability assessment of sanitation systems, several different criteria are often proposed for use in planning and decision-making processes (Hellström et al., 2000; Balkema et al., 2002; Lennartsson et al., 2009; Molinos-senante et al., 2014; Vidal, 2018). For example, Hellström et al. (2000) proposed assessing a system's sustainability by identifying and evaluating system performance against criteria within five main categories: (1) health and hygiene; (2) social-cultural; (3) environmental; (4) economic; and (5) functional and technical. This broader understanding of sustainability is also reflected in the definition of sustainable sanitation by the Sustainable Sanitation Alliance, mentioned above. In this study, we applied these five main categories as a starting point for the assessment: Health, Financial, Social, Technical and Institutional; however, social and technical were regrouped as socio-technical.

The criteria used in a decision-making process may differ between different contexts and should therefore be adapted to the local context. Several sanitation planning tools encourage stakeholder engagement on different levels to capture different sustainability perspectives (Lüthi et al., 2011; Parkinson et al., 2014). One example is the Open Wastewater Planning method, described in Bodík and Ridderstolpe (2007). On an overarching level it is considered that stakeholder engagement and participation in planning will lead to a better decision-making process where the selected technologies are better adapted to the local context (Eawag, 2005). A study in Java concluded that consultative and collaborative participation process with the community in a community-based sanitation project increased the progress toward users' ownership of the technology (Roma and Jeffrey, 2010). In a recent interview study of sanitation professionals, the interviewees' emphasized the importance of gender-sensitive and community participation as critical for capturing sustainability issues in the decision-making process (Ramôa et al., 2018). Therefore, it is critical to involve local stakeholders in the selection of criteria to use in the multi-criteria assessment. Stakeholders should also be involved in Step 4, weighting and discussion of the results of Step 3 before final decision-making.

In this specific case, considering nutrient-recovery from a FS treatment plant in Uganda, the most important stakeholders to consult were professionals working with the treatment plant, research institutes and municipality representatives, rather than community members. In order to identify locally relevant criteria, a series of semi-structured interviews regarding important criteria that should be considered for treating FS with the intention to reuse it were held in 2017 and 2018, with representatives from five different municipalities in Metropolitan Kampala, the water and sanitation utility, one ministry, two research institutions and one NGO. Participants in these interviews generally held technical positions within their organization, including managers, engineers, agronomists and technicians. The interviews focused on general decision-making criteria related to on-site sanitation and reuse, with probing questions into specific categories of sustainability. This approach allowed the interviewees to identify by themselves the most important decision-making criteria (see the **Supplementary Material** for details of interview questions). The interviews were recorded and transcribed for post-interview analysis. The interviews were coded and categorized, i.e., grouping and labeling of similar aspects (Flick, 2009), in order to identify locally relevant criteria.

For the purposes of this article, we illustrate the first three steps by applying them in the context of selecting nutrient-recovery technologies for up-grading of a FS treatment plant in Kampala, Uganda. The population of the Greater Kampala metropolitan area is 3.2 million and the majority of the population is using on-site sanitation services. The Kampala Sanitation Master Plan (Government of Uganda/NWSC, 2015) estimates that 35% of the fecal sludge produced in the city is collected, transported, and delivered to the fecal sludge treatment plant (FSTP) at Lubigi. The Lubigi FSTP was commissioned in 2014 with a design capacity of 400 m^3/day, it consists of manual screening, and grit removal followed by covered settling/thickening tanks, covered drying beds and covered storage areas for dried sludge. The liquid effluent from the settling/thickening tanks is co-treated with wastewater in the WWTP at Lubigi, which consists of anaerobic and facultative ponds. The dried sludge is sold to farmers. There is evidence from observations and interviews with the FS treatment plant operators that the recommended storage times for the sludge are not respected, particularly prior to planting season.

RESULTS—ILLUSTRATION OF APPROACH

The results presented are for a hypothetical upgrade to improve nutrient-recovery at the Lubigi FS treatment plant in Kampala. Data collection was primarily based on literature reviews, supplemented with results from student experiments at the plant in 2018 and the research team's qualitative assessments in 2019. The student experiments tested the use of BSF composting, ammonia treatment and lime treatment. Their results provided details on costs, pathogen inactivation, organizational capacity and odor. Further details, including specific references used for scoring, can be found in the **Supplemental Material**.

Step 1: Identification of Available Options

Two recent reviews of technologies for nutrient-recovery from domestic wastewater and human excreta provided the basis for developing a broad list of possible treatment options for this case (Harder et al., 2019; Johannesdottir S. L et al., 2019). A synthesized list was developed that includes 22 treatment technologies (**Table 1**). The list includes treatment technologies that can produce a recoverable nutrient product. Complementary technologies such as dewatering were not included at this stage, although they should be included when comparing specific options in step three. The technologies were summarized, including the primary nutrient product recovered and what types of fecal sludge inputs can be used, e.g., raw fecal sludge (TS 1–5%), dewatered fecal sludge (TS>15%), or the filtrate/supernatant water from the dewatering technology. Note, that it is also possible to combine some of these technologies in series, e.g., dewatered FS can be used in fly larvae composting while the filtrate/supernatant can be used in a membrane nutrient-extraction technology. Combinations of technologies are not included in this study.

Step 2: Narrowing the Possible Options

In Step 2, a set of prerequisites was used to narrow down the number of possible options. Determination of whether the treatment technologies met the prerequisites was based on information available in published literature (references provided in Table 2), with the exception of the fourth prerequisite that was based on the expert judgement of the authors. The first prerequisite was that the technology should be able to handle raw or dewatered sludge (there is a dewatering technology already at the existing plant). Based on published literature regarding these technologies, algae production, stripping & capture, and membrane nutrient extraction where deemed inappropriate for treating FS due to the high levels of suspended solids. These three treatment technologies were also deemed non-feasible at the existing plant. Incineration and carbonization technologies failed to meet the prerequisite for macro nutrient recovery since these treatments fully eliminate nitrogen and sulfur. It is noted that hydrothermal carbonization can retain ∼30–60% of the nitrogen in the hydrochar, depending on process temperature and feedstock (He et al., 2015; Wang et al., 2018). However, the high temperatures, high pressure and complex processing needed for this technology are not deemed feasible at Lubigi.

TABLE 1 | Summary of possible treatment technologies for nutrient-recovery from fecal sludge, based on recent review studies that map a variety of treatment processes and products (Harder et al., 2019; Johannesdottir S. et al., 2019).

	Treatment technology	Input	Description	Potential products
Physical	Storage		Prolonged storage, open or enclosed. Degradation of material. Give a stabilized sludge Pathogen reduction is a function of time, temperature, moisture, competition etc.	Stabilized sludge
	Desiccation		Treatment decreasing water content to an extent that the product becomes pseudo stable. Pathogen reduction is a function of low moisture content. Moisture content below 5% required for inactivation of persistent pathogens.	Pseudo stabilized sludge
Biological	Aerobic treatment		Collective name for a number of treatments using aerobic microorganisms to break down biodegradable matter e.g., can be part of wastewater treatment. For composting processes, see below.	Stabilized sludge
	Composting		Aerobic, auto thermal process in which biodegradable matter is decomposed by microorganisms, fungi, and invertebrates. Pathogen inactivation depend on thermophilic temperatures.	Stabilized compost
	Vermicomposting		Aerobic process in which earthworms and microorganisms degrade the organic matter. Worms may be harvested as animal feed. Requires dewatering of sludge or addition of co-substrates.	Stabilized compost, worms
	Fly larvae composting		Aerobic process in which fly larvae and microorganisms degrade the organic matter. Larvae may be harvested as animal feed. Requires dewatering of sludge or addition of organic matter.	Active compost, larvae
	Anaerobic treatment		Collective name to a number of processes in which microorganisms break down biodegradable matter in the absence of oxygen while producing biogas. Pathogen inactivation depend on process temperature dependent on heating.	Stabilized sludge, biogas
	Lactic acid fermentation		Biological, anaerobic process in which the sludge is inoculated with lactic acid bacteria and commonly also a co-substrate. Preserve a majority of the material in a pseudo stable form. Low pH and carboxylic acids are involved in pathogen inactivation.	Pseudo stabilized sludge
	Productive wetland		An artificial wetland or planted drying bed used to treat wastewater, and sludge and produce biomass. Biochemical processes at the plant interface remove pollutants.	Stabilized sludge, biomass (plants)
	Algae production		Cultivation of phototrophic algae in nutrient-rich wastewater flows.	biomass (algae)
	Aquaculture		Rearing of fish in ponds that are fertilized by effluent or sludge. The fish feed on algae and other small aquatic organisms that grow in the nutrient enriched water.	stabilized sludge, fish
	Microbial fuel cells		A bio-electrochemical device that uses microorganisms to convert chemical energy into electrical energy using oxidation-reduction reactions.	Sludge, nutrient solution
Chemical	Precipitation		Nutrient extraction from liquids by converting the substance into an insoluble form or by changing the composition of the solvent to diminish its solubility.	Inorganic precipitate
	Stripping and capture		The transfer of volatile components from a liquid to a gas stream. Can be re-capture in a solvent through e.g., wet scrubbing. E.g. Ammonia can be stripped from conventional wastewater.	Nutrient solution
	Elution		Extraction of nutrients from solid material by washing with an alkaline or acid solvent, e.g., extraction of P from ash. Elution is often followed by membrane separation, sorption or solvent extraction.	Nutrient solution

(Continued)

TABLE 1 | Continued

	Treatment technology	Input	Description	Potential products
	Ammonia treatment		Addition of ammonia, often as urea. Pathogen inactivation is due to ammonia (NH_3) and carbonates. Shall be a closed treatment to minimize ammonia losses.	Pseudo stabilized sludge
	Alkaline stabilization		Addition of highly alkaline chemicals, e.g., lime, caustic soda or ash to increase the pH. Pathogen inactivation depend on a pH over 12 or when using CaO a combination of alkaline pH and heat from the exoterm reaction.	Stabilized sludge
Thermal	Carbonization		Carbonization of organic solids at elevated temperatures in the absence of oxygen. Heat energy may be captured. Non-volatile nutrients remain in the biochar.	Biochar
	Incineration		Combustion of organic substances in the presence of oxygen. Heat energy may be captured while non-volatile nutrients remain in the ash.	Ash
	Pasteurization		Heating of sludge to 65–75°C in order to inactivate pathogens. Often used as a pre-treatment to anaerobic treatment for biogas production.	Pseudo stabilized sludge
	Solar drying		Use of solar radiation to dry and sanitize sludge. Can be done in open or closed beds. Closed beds have been shown to have a higher drying efficiency. Temperature, reduced moisture content and partially UV contribute to pathogen inactivation.	Pseudo stabilized sludge
Physio-chemical	Membrane nutrient extraction		Treatment processes using semi-permeable membranes for selective separation of nutrients from wastewater fractions.	Nutrient solution
	Sorption		Process in which one substance becomes attracted to another, e.g., the capture of nutrients in filter material (zeopeats, P-filters, etc.).	Nutrient-enriched sorbent material

Possible input flows considered in this study are fecal sludge (black), dewatered fecal sludge (brown), and the supernatant from the dewatering process (blue). Potential products are shown for each process with the exception of water recovery.

The remaining treatment technologies do not eliminate one or more of the in-coming macronutrients. Several treatment technologies were deemed to have an insufficient TRL to treat FS solids, due to lack of evidence of their implementation in a context similar to Kampala: aquaculture, microbial fuel cells, stripping & capture, membrane nutrient extraction and sorption (**Table 2**).

Finally, the prerequisite that nutrient-recovery technologies should be feasible to implement as an upgrade of the existing treatment plant led to the exclusion of several other technologies. The exclusion of technologies with this prerequisite was primarily due to the lack of land available at the existing site for expansion of treatment works, e.g., for aquaculture ponds or wetlands, or due to the technology requiring expensive modifications, e.g., construction of heating units for hydrothermal carbonization or thermal technologies. It should be noted that this last prerequisite means that some of the treatment options that are excluded in this step could be interesting for future FS treatment plants in Kampala.

As a result of Step 2, eight possible options were carried forward in to a multi-criteria assessment in step three: storage and desiccation (e.g., optimization of the existing system), composting, vermicomposting, Black-Soldier Fly (BSF) composting, lactic acid fermentation (LAF), ammonia treatment, alkaline stabilization, and solar drying. Optimization of the existing system includes adding narrower trash screens (5 mm) to remove more trash from the incoming sludge and respecting storage times of 6 months prior to selling the sludge. It was deemed that a composting technology for FS would require the additional carbon material to maintain the correct C:N balance, thus further evaluation of this option is based on the assumption that the FS is composted with e.g., organic solid waste. Vermicomposting and BSF composting would need to be performed after a dewatering step. Both would require construction of specialized compartments for batch treatments of FS with the worms/larvae. Lactic acid fermentation is performed in closed containers and would require a pumping system to recirculate the sludge for inoculation of new batches with lactic acid bacteria. Similar to LAF, ammonia treatment should be performed in sealed containers where the urea (a common fertilizer) is added to each batch of FS to be treated. Alkaline treatment in Kampala could be performed with the addition of lime, such as CaOH or CaO. Solar drying could be performed by enclosing the existing drying beds or storage areas to make them greenhouses.

Step 3: Multi-Dimensional Sustainability Assessment

Analysis of the interviews with local stakeholders revealed several sustainability criteria of importance for nutrient recycling from

TABLE 2 | Narrowing the decision space based on prerequisites specific to the Kampala context.

		Prerequisites				
	Treatment technology	**Feasible with FS**	**Recovers nutrients[a]**	**TRL >6[b]**	**Feasible at lubigi[c]**	**References**
Physical	Storage and desiccation (existing system)	X	X	X	X	WHO, 2006; Strande et al., 2014
Biological	Aerobic treatment	X	X	X		Strande et al., 2014
	Composting*	X	X	X	X	Strauss et al., 2003; Strande et al., 2014; Komakech et al., 2015
	Vermicomposting*	X	X	X	X	Strande et al., 2014; Komakech et al., 2015; Bhat et al., 2018
	Fly larvae composting*	X	X	X	X	Strande et al., 2014; Komakech et al., 2015
	Anaerobic treatment	X	X	X		Diener et al., 2014; Strande et al., 2014
	Lactic acid fermentation	X	X	X	X	Anderson et al., 2015; Andreev, 2017; Odey et al., 2018
	Productive wetland	X	X	X		Koottatep et al., 2005; Strande et al., 2014
	Algae production		X	X		Grobbelaar, 2004; Barbera et al., 2018
	Aquaculture	X	X			Strande et al., 2014
	Microbial fuel cells	X	X			Raheem et al., 2018; Lu et al., 2019; Palanisamy et al., 2019
Chemical	Precipitation	X	X	X		Shiba and Ntuli, 2017; Chapeyama et al., 2018; Tarragó et al., 2018; Li et al., 2019
	Stripping and capture		X			Harder et al., 2019
	Elution	X	x	x		Shiba and Ntuli, 2017; Harder et al., 2019
	Ammonia treatment	X	X	X	X	Méndez et al., 2002; Nordin, 2010; Strande et al., 2014
	Alkaline stabilization	X	X	X	X	Bina et al., 2004; Strande et al., 2014; Anderson et al., 2015; Farrell et al., 2017
Thermal	Carbonization	X		X	X	Strande et al., 2014; Harder et al., 2019
	Incineration*	X		X	X	Rulkens, 2008; Diener et al., 2014; Strande et al., 2014
	Pasteurization	X	X	X		Forbis-Stokes et al., 2016; Chapeyama et al., 2018; Septien et al., 2018
	Solar drying	X	X	X	X	Bennamoun, 2012; Strande et al., 2014; Singh et al., 2017
Physical-chemical	Membrane nutrient extraction		x			Harder et al., 2019
	Sorption	X	X			Strande et al., 2014; Harder et al., 2019

*Treatment technologies marked with * are feasible with FS if they have a pre-treatment step of dewatering and/or addition of organic matter (e.g., solid waste).*
[a]*Recovers a majority of the macronutrients from the incoming waste stream.*
[b]*Technical Readiness Level (TRL) 6—System Adequacy Validated in in relevant environments, e.g., must have been tested in relevant environment to Uganda.*
[c]*By feasible at Lubigi, we mean that the process would be possible on the land available and that the treatment can be implemented without extensive & expensive infrastructure modification of the existing plant. NB: Some of the treatments that disappear in this step could be interesting for future FSTPs in Kampala.*

FS, **Table 3**. For practical reasons not all of the stakeholder-identified criteria were included in the assessment. For example, "precision fertilizer" was one criteria not included in this analysis, since the variability in fecal sludge quality is high and production of precision fertilizers will either demand technologies that were eliminated in Step 2, or an upstream approach (e.g., source-separated sanitation systems) not considered in this paper. The request for high pH in the final product is covered in the criteria "agricultural value." The criteria finally used in Step 3 are shown in the right column of **Table 3**. In addition to the stakeholder-identified criteria, the right-hand column includes two criteria in italics pertaining to technology and institutional capacity, namely robustness and organizational capacity. The rationale for including organizational capacity is that without

TABLE 3 | Stakeholder-identified criteria and criteria used in the sustainability assessment.

Dimension	Stakeholder-identified criteria	Criteria used in the assessment
Health	The product must be safe to use in agriculture	Pathogen exposure
Financial	The treatment options should be cost-effective	Capital costs
		O&M costs
	The product must be competitive on the fertilizer market, have a nitrogen content, and be affordable to farmers	Agricultural value—including the product's content of nutrients, organic matter, and pH
Socio-technical	The product should have no odor	Odor—during treatment and the final product
	Concentrated fertilizer to minimize transportation costs	Volume reduction
		Robustness—how well the technology can withstand e.g., shock loads
	Reduced pollution of water sources	
Institutional		*Organizational capacity—complexity of the technology and its demands on skills etc.*
	Need of local regulation for safe reuse	
Recycled product	Important that it has changed appearance into an actual product	
	Precision fertilizers is important	
	High pH to counteract Uganda's acidic soils	Included in Agricultural value—high pH is preferred

NB: criteria in italics were not identified by stakeholders, but added due to their suggested importance from other studies.

an adequate capacity within a utility to operate and maintain a given treatment technology there is a high risk that the system in question will fail (Davis et al., 2019). Systems and technologies that are complicated to operate will demand a higher level of organizational capacity. The introduction of more complicated technologies can therefore be of crucial importance in settings where the organizational capacity is already limited. Furthermore, a system's technical robustness in terms of withstanding, for example shock loads etc., is another important criteria to include to ensure continuous and reliable operation of a treatment method (Andersson et al., 2016).

Each of the eight alternative systems identified in Step 2 was qualitatively evaluated against the eight sustainability criteria. Evaluation was based on data found in published literature, experience gained through student experiments at Lubigi, and expert knowledge within the project team. Full details of the scoring can be found in **Tables S1, S2**. The existing operations at the Lubigi FS treatment plant were used as a reference and the alternatives were scored on the degree to which they improved or reduced the quality of each sustainability attribute, e.g., the degree to which pathogen exposure was reduced compared to the existing operations. The results are shown in **Table 4**.

The most important sustainability criteria from a reuse perspective in this study is health. It is the criterion most often mentioned by the interviewees, e.g., that the product must be safe for reuse (**Table 3**). None of the studied technologies would negatively affect the health criterion of the fecal sludge, but there is a range in the degree to which they would reduce pathogen exposure in the end product. Ammonia treatment, alkaline stabilization and composting (provide that the composting process is thermophilic) provided the greatest reduction in pathogen exposure. If the existing system were to follow World Health Organization recommendations for storage time (WHO, 2006), or if the sludge was desiccated using solar drying the pathogen content of the reused sludge would also be reduced compared to today's system. However, it is judged that vermicomposting, BSF composting and LAF would not change the risk for pathogen exposure. This is due to that fact that these systems do not create thermophilic conditions or chemical inhibitors necessary to result in pathogen reduction. There have been some studies indicating that vermicomposting can reduce fecal coliforms (Rodríguez-Canché et al., 2010), however, since other studies contradict these finding (Monroy et al., 2009), we have chosen to conservatively score vermicomposting as no improvement in hygienic quality of the product. Further treatment of the end-product from these systems would be necessary for safe reuse. Note, the health risks for workers at the treatment plant will depend on how any of the possible technologies are implemented, e.g., how mixing of chemicals or compost is performed. Proper safety equipment and following operational safety standards will be necessary precautions for implementation of any potential technology upgrades.

All of the studied nutrient-recovery options have higher capital costs than the existing system. In particular, vermicomposting and BSF composting are considered to require higher capital investments due to the need for specialized compartments for growing the worms or larvae. Ammonia treatment, LAF and solar drying would also have higher capital costs due to the construction of sealed containers or drying areas to enable optimum treatment. The other systems can be implemented by modifying the existing infrastructure at relatively low costs. Concerning operation and maintenance, the majority of the reuse options are also more expensive to operate. This is particularly the case for alkaline treatment that would require the addition of large quantities of lime to be purchased (∼UD$600,000 per year). Urea treatment would also require significant chemical inputs amounting to ∼UD$90,000 per year. Inputs to other treatment technologies require less expensive additives (e.g., organic solid waste) or additional labor costs (e.g., maintenance of worm and larvae beds or mixing of compost/urea). The exception for O&M costs are the options to optimize the existing plant or solar drying which are judged to have comparable costs to today's system. The high capital investment costs for vermicomposting and composting may be offset somewhat through the higher value of the end product. The worms and larvae produced in these systems can be harvested as

TABLE 4 | Results of the multi-criteria assessment for improving safe, nutrient-recovery from Lubigi Fecal Sludge Treatment Plant, Kampala Uganda.

	Health	Financial			Institutional	Socio-technical		
	Pathogen exposure in end-product	Capital costs	O&M costs	Value of product	Organizational capacity	Odor	Robustness	Volume reduction
Current system	Significant coliform die-off. Ascarsis likely remains.	Annualized capital investment for FSTP USD$650,000	Annual O&M costs for FSTP USD$200,000	Contains ~4.6 g P and 23 g N per kg sludge.	Exists	Slightly septic smell	Roofs leak leading to irregular treatment	Total sludge volume reduced ca 85% from incoming sludge.
Optimized existing system	+	–	0	0	0	0	+	0
Composting	++	–	–	+	– –	+	–	+
Vermicomposting	0	–	–	++	– –	+	– –	+
Black soldier fly composting	0	–	–	++	– –	–	0	+
Lactic acid fermentation	+	– –	–	0	– –	–	–	0
Ammonia treatment	++	– –	–	+	–	–	+	0
Alkaline stabilization	++	–	– –	+	–	0	+	–
Solar drying	+	–	0	0	0	0	+	+

*Basic information regarding the state of the existing plant is provided. Eight alternatives are qualitatively scored against the reference of the existing plant: Dark green (++) means considerable better, Light green (+) mean better, 0 means the same quality, Orange (–) means worse, Red (– –) means considerably worse. See **Supplementary Information** for scoring cut-offs and details regarding evaluation of performance.*

a protein fodder, which has a higher market value than compost. In addition, both composted and ammonia treated FS would have a higher agronomical value than the current sludge due to the extra organic material and nitrogen content, respectively. Limed sludge is also seen as more valuable than today's product due to its low pH that would improve soil quality in Uganda's acid soils (see **Table 3**).

From an institutional perspective, the biological treatment options would require considerably more organizational capacity. Composting, vermicomposting, BSF composting and LAF require managing biological life cycles of treatment organisms that would require additional training of operators. In the case of composting, the logistics of obtaining clean amendment material for the compost are deemed potentially challenging. Ammonia and alkaline treatments both require additions of potentially hazardous chemicals, thus staff would require additional health and safety training to properly operate these systems. The other options could probably be implemented with existing capacity and are thus similar to today's system.

The results from the socio-technical criteria show a wider variation between potential technologies. Several technologies are judged to have worse odor problems than the existing system. The odors from BSF larvae, fermentation, and ammonia are often perceived as unpleasant. In contrast, the "earthy" smell from composting or vermicomposting is typically perceived as positive. However, since most of these recovered nutrient products are rather new, further studies are needed regarding consumer acceptance and sensitivity to odor and physical appearance of the product. Concerning robustness, the chemical treatments and the solar drying are generally less sensitive to changing environment or inappropriate use, and thus score better than the existing system. Fixing the leaking roofs in the existing system would also improve the robustness of the system. In contrast, the biological technologies are often less robust as the organisms are sensitive to changes in temperature or material composition. This is particularly the case for vermicomposting where maintaining the correct environment for the worms can be challenging. The opposite is true for BSF larvae that have shown to be quite resilient and adaptable to changing conditions and feedstock. Composting, vermicomposting, BSF composting, and solar drying reduce the sludge volume, which is advantageous for subsequent transport of the treated sludge to agriculture. With regard to volume, alkaline stabilization performs worse that the current system since the addition of lime can lead to bulking, in some cases doubling the volume (Bina et al., 2004).

Step 4: Stakeholder Weighting and Discussion of the Results

Step 3 generates an overview of the pros and cons of different treatment approaches, which has merit in itself since it may be possible to use the matrix for choice of treatment technology without further work. In other cases, e.g., for a first step in pre-feasibility studies, the results from Step 3 can be used for narrowing down which technologies to further investigate. However, there may be times when the criteria identified in Step 3 will have different importance in different contexts. For example, when the recipient is a highly eutrophized lake it may be most important to decrease the release of N, P and organic matter to the recipient. In a setting with water scarcity, it may be most important to consider water consumption. The criteria may also be conflicting and trade-offs between meeting different criteria may be needed. In these cases, there may be a need to introduce a weighting of the identified criteria to show how weight on different criteria may change the outcome of Step 3. This introduction of weights to criteria is introducing subjectivity into the process and therefore it needs to be made in an explicit and transparent manner (Nardo et al., 2005). There are several different ways to assign weights to criteria. In sanitation planning processes it is common to have stakeholders assign weights to the identified criteria (Johannesdottir S. et al., 2019), e.g., by assigning percentage weights to different criteria. It is possible to assign weights when the criteria are defined in Step 3, in which case Step 4 starts in parallel with Step 3. Once the criteria are identified, the stakeholders are asked to put weights on them. It is recommended that the result matrix include both non-weighted and weighted results, to show the effect of weighting of different criteria on the results. It is further recommended to avoid the aggregation of the results, weighted or non-weighted, into a single score and ranking (even though several such methods exist). Rather it is recommended to use the result matrix to highlight each system's pros and cons to facilitate stakeholder discussion on trade-offs prior to decision-making. Important stakeholders to include in this process would be local decision-makers, technicians, engineers and other actors directly affected by the system, e.g., sanitation customers and users of end-products.

DISCUSSION

The aim of the structured process presented in this paper is to provide transparent supporting information for decision-making processes. Within a decision-making process the different criteria need to be weighed against each other in order to find the most acceptable solution given the necessary trade-offs and local constraints. Used in this way, the results can provide decision-making support for both short-term and long-term investments. For example, in the short-term organizational capacity and costs may prohibit implementation of systems that provide the best results regarding nutrient recovery. However, for long-term planning these options may be more relevant and can be linked to citywide sanitation master plans and policy.

Concerning technology selection at the FS treatment plant at Lubigi, Kampala, this structured approach identified several recommendations, depending on how the criteria are weighted. The stakeholders in this study assessed safe reuse (pathogen exposure) as the most important criterion. The most effective solution for reducing pathogen exposure at the lowest cost and with the least need for organization capacity development is to optimize the existing system. This would using narrower screens than today to remove trash and respecting storage times. To assure safe reuse, this option may be complemented with guidelines to farmers regarding proper handling measures for treated fecal sludge and recommendations for crop use. Such guidelines can be developed from World Health Organization for safe reuse of wastewater, excreta and greywater (WHO, 2006) and integrated into Ugandan agricultural extension services. This option is perhaps the most realistic from a short-term perceptive. However, such an improvement of the existing system will not maximize the agricultural value of the product.

To maximize the agricultural value of the recovered product, while respecting the need for safe reuse, a combination of technologies is relevant. Vermicomposting and BSF are the treatment options with the highest increase in value of product since they produce a valuable form of protein and an organic compost that can be used as a soil amendment. Of these two options, the BSF treatment is considerably more robust. However, neither of them is proven to reduce pathogen exposure risks. Lactic acid fermentation, ammonia treatment and alkaline treatment are the options that are assessed as reducing pathogen exposure most efficiently of the studied options. However, LAF is associated with high investment costs and higher need for organizational capacity, which makes it less appealing. Therefore, for maximum reduction of pathogen exposure and maximum nutrient reuse a combination of BSF and subsequent ammonia or alkaline treatment of the remaining organic fraction can be applied. This would mean increased investment costs and an increased demand on organizational capacity, but with unchanged or improved robustness. This combination of technologies can be the aim for long-term sanitation planning in Kampala with a focus on safe nutrient-recovery. With a long-term perspective, it is possible to develop the necessary organizational capacity and plan for financing structures.

The structured approach for comparison of FS treatment options proposed in this paper makes the decision-making process transparent and assures that a variety of possible options are evaluated, hopefully assuring the selection of the most appropriate technologies for a given context. The multi-dimensional sustainability assessment can clearly show the advantages and disadvantages of different options. The results of this process provide important supporting information for a discussion of trade-offs between various stakeholder groups (e.g., between utilities and politicians); a discussion which should be a critical part of the broader process of sanitation planning. The approach needs to be fitted into an actual sanitation planning process in which key stakeholders are involved. Local input from stakeholders is critical to assure that the decision-making process includes locally specific prerequisites and sustainability criteria.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

JM conceived the study, conducted the literature reviews, analysis, and coordinated the writing of this manuscript. EK assisted with structuring the multi-criteria assessment and contributed to the writing of the manuscript. AN, HJ, and CN were involved in the review of the results and proofreading of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2020.00036/full#supplementary-material

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Wastewater Discharge Standards in the Evolving Context of Urban Sustainability–The Case of India

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Across the world, recent decades have witnessed large scale and rapid urbanization. Centralized wastewater treatment is typically considered the most desirable solution to meet domestic wastewater treatment needs in growing urban centers. These rely on extensive—and often expensive—infrastructure and treatment solutions that require expert engineering management to ensure effective operation. It is argued that the urban sustainability challenge of inadequate sanitation, deteriorating water quality, and rising water stress are best met through poly-centric and integrated approaches that include nature-based solutions, community-scale and community-managed systems. Today's objectives are to create climate-resilient, enduring, self-governing systems—as well as systems that close the loop, encouraging resource re-use and recycling. This policy review informs on wastewater discharge (and related) standards for sewage treatment plants within the context of present-day India. With its booming urban population, highly visible and impactful pollution, water quality and insecurity challenges, India provides huge opportunities for creative approaches to urban sanitation—but to fully exploit these opportunities will require new policy and regulatory thinking. The current regulatory developments are undergoing frequent changes with observed inconsistencies over the last years leading to a growing confusion in the sector. Examined questions include: How clear are policy objectives and regulations? What are reasons for observed inconsistencies in current pollution control regulations and what are their implications? How well-aligned are standards and regulation with these objectives? How forward-looking? Are solutions sufficiently responsive to the urban sustainability challenge? In particular, this review considers whether regulatory approaches disadvantage decentralized and innovative approaches that could offer resilient, community-based systems—even within the megacities of the twenty-first century. This study further draws on examples from other emerging economies—and contextualizes these examples with the situation in Western Europe, where a single set of targets has let to diverse solutions. Standards and regulations need to be reimagined for this evolving urban context which might require it to become more

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nuanced, more holistic, more dynamic, more transparent, more participative, and more contextual. Enforcement mechanisms will need to incorporate phased/graded approaches to compliance—to suit various contexts that could include water reuse for different application areas.

Keywords: wastewater standards, reuse, sustainable sanitation, regulation, policy, decentralized integrated management, nature-based, India

INTRODUCTION

Globally water management systems are facing enormous challenges of accelerating water insecurity, flooding, and contamination of water resources. According to the UN 80% of sewage is currently discharged without treatment [UN WWAP (United Nations World Water Assessment Programme), 2017].

The lack of adequate sanitation infrastructure contaminates the environment and permeates through all societal functions increasing the burden on human health, which in turn leads to loss of economic activity and thus the overall development potential. The UN indicates that for every USD spent on sanitation, the estimated returning benefit to society accounts in 5.5 USD [UN WWAP (United Nations World Water Assessment Programme), 2017].

Feasible and financially viable wastewater treatment still represents a significant challenge in the Global South, particularly within a rapidly changing urban environment. It is increasingly recognized that the ideal of the "networked city" fails to address current SDG goals of the wastewater sector and is inadequate for the difficulties and reality of the Global South (MoUD, 2008; Massoud et al., 2009; Libralato et al., 2011; Larsen and Gujer, 2013). Innovative approaches and technologies are required, which enable the overall concept of sustainability in terms of economic feasibility, social equity and acceptance, technical and institutional applicability, environmental protection, and resource recovery—in addition to the central objective of protecting human health and environment (Balkema et al., 2002; MoUD, 2008; Molinos-Senante et al., 2010, 2015; Ganoulis, 2012; Wichelns et al., 2015; Ricart et al., 2019).

With the shifting paradigm from "waste"water treatment to resource recovery systems, the sanitation sector, among a few others, holds the most prospering potential in change toward a sustainability transition (Binz et al., 2012; UN WWAP (United Nations World Water Assessment Programme), 2017; Van Welie and Romijn, 2018; Van Welie et al., 2018). However, the transition faces considerable hurdles and requires changes along all levels, including regimes, landscapes and niches (Markard et al., 2012; Swilling and Annecke, 2012; Lachmann, 2013). While industrialized nations are dealing with the challenge of lock-in mechanisms due to historic investments in established centralized infrastructure and routines formed a passive involvement of society and consumer roles, the main challenge in the Global South remains the establishment of overall access to sanitary systems. This situation provides significant opportunities for emerging economies to leapfrog and establish new alternatives and more sustainable approaches to sanitation that address all dimensions of sustainability.

Decentralized and ecological systems can play a crucial role in delivering this new reality, since they represent comparatively more economically affordable and ecologically sustainable options, which are socially accepted and require low maintenance (Parkinson and Tayler, 2003; Massoud et al., 2009; Libralato et al., 2011; Larsen and Gujer, 2013). However, full and appropriate exploitation of these systems requires regulatory institutions to overcome historical barriers and create an enabling environment to open windows of opportunity.

In India wastewater treatment, especially in booming urban centers, continues to be a big challenge. While the Central Pollution Control Board (CPCB) reported in 2013 that 19,827 MLD out of 53,998 MLD generated were treated in metropolitan, class one and class two cities, it further indicates in 2017 that out of 18.6% of total treatment capacity, only 13.5% of sewage is effectively treated (CPCB, 2013 and CPCB, 2017c). Although the impact of diarrhea has decreased over last years, it still belongs to the five major health burden in India. The disease burden or Disability Adjusted Life Year (DALY) rate for diarrheal diseases, iron-deficiency anemia and tuberculosis was 2.5 to 3.5 times higher compared to global rates and countries with similar geographies (Indian Council for Medical Research, 2017). Alongside the given challenges, more than half the country faces high to extremely high water-stress, and future projections paint an even grimmer water availability scenario (MoWR, 2017; WBSCD, 2019). An integrated view of the wastewater and water supply sectors is not optional but an urgent imperative.

Recognizing these urgent pressures, several jurisdictions within India have established reuse policies and Zero Liquid Discharge regulations. However, implementing these initiatives is currently challenging due to national standards for treated wastewater—which undergo frequent change and have ceased to distinguish between wastewater re-use for irrigation and wastewater discharge to surface or ground waters. Furthermore, inconsistencies in approach and objectives between different governmental institutions, variations in policy at a state level and aggravated access to information are resulting in confusion and hesitation within the sector. The intention behind stringent standards in protecting the environment and public health represents a common shared aim between all stakeholders. However, without a long-range planning and reasonable budget allocation, stringent standards can result in pockets of excellence, leaving the majority of the Indian population and environment at high risk. In addition, one fixed set of standards for different application areas can tend to neglect, both the dangers and also the benefits of this resource.

In this paper, the outputs of a broader evidence review based on Indian policies and regulations and complementary interviews with governmental institutions, sectoral experts, and technology providers in India are combined to analyze and understand pollution control measures and approaches that focus on municipal domestic sewage treatment and wastewater reuse. While the first section of the assessment summarizes wastewater risk management approaches, section two reports the findings on the current scenario of wastewater discharge standards for sewage treatment plants in India and discusses the feasibility and possible implications. Although focused on the current situation in India, a comparative analysis in section three presents examples of institutional approaches and structures on discharge and wastewater reuse in other countries. Based on the review, the possible way forward for India and lessons for other nations of the Global South are suggested.

ASSESSMENT OF WASTEWATER RISK MANAGEMENT

Within the following the results of the assessment of wastewater risk management in India is presented and discussed. This assessment is built upon three sections to analyze and inform on (a) wastewater risk management approaches with special focus on wastewater reuse, (b) wastewater risk management and related wastewater discharge standards for sewage treatment plants (STPs) in India over time, and (c) wastewater discharge and reuse standards from other countries.

Methodology

Wastewater risk management approaches, central governmental policies and acts in the scope of wastewater risk management, sanitation, and water management in India have been identified through literature review based on government databases and website research. The Karnataka State policy on urban wastewater reuse was identified through website research and considered as reference for a comparative to central regulations.

Central governmental regulations for pollution control measures in the wastewater sector in India were identified through literature review based on governmental databases and website research. All historically applicable wastewater discharge standards for STPs in India were considered for the assessment.

International regulations on wastewater discharge and reuse standards were informed by representatives of the multinational (EU-funded) INNOQUA-Project with a further extended literature review based on website research. The range of selected countries for assessment was based on the development status, climatic conditions and water insecurity status in order to allow a broad overview and comparative relative to local conditions or limiting factors.

Qualitative interviews with former and present governmental officials at central and state level in India were carried out in order to access printed materials and missing information on (a) the standards setting process, (b) the applicability of wastewater discharge and reuse standards and related norms due to observed inconsistencies during the assessment process, (c) the reasons for observed changes of standards over the years and related inconsistencies in applied and recommended measures among governmental institutions at central level and central-state level, and (d) investment and development plans in the wastewater sector.

Literature review based on website research and complementary qualitative interviews with governmental officials, sectoral experts, and technology providers have been carried out in order to allow a broader perspective for the discussion on the feasibility of discharge and reuse standards and possible implications of recent observed developments in pollution control management in India.

Wastewater Risk Management Approaches

In the modern era, Britain was among the first nations to address environmental conditions of water bodies in its cities and plays a vital role due to historical regulations in India. The need for coordinated action in Britain was formed as response to growing industrialization, which lead to untreated effluents being discharged into water bodies and breaching their intrinsic carrying capacity. This created human health and environmental crises that are still a common occurrence in rapidly-urbanizing centers of the Global South (Lens et al., 2001). Whilst the initial response to these crises was to assume that "the solution to pollution is dilution," it was soon recognized that sewage treatment would be required. The Royal Commission on Sewage Disposal (which convened between 1898 and 1915) led to the formulation of the first standards for Biochemical Oxygen Demand (BOD) and suspended solids (TSS) in treated wastewater—at 20 and 30 mg/l, respectively. These standards remained in place for several decades, eventually being superseded by the Water Act of 1973 and the Urban Waste Water Treatment Directive at a European level (Johnstone and Horan, 1996). Britain has never set regulatory standards for water re-use, unlike a number of other nations of the Global North. However, regional demographic pressures coupled with changing patterns of precipitation mean that this is set to change. This section summarizes the conceptual underpinnings of wastewater risk management.

Wastewater Discharge Standards

Wastewater discharge standards are set (at least) at a national level for centralized treatment systems for salient receiving environments. The key feature of a water body from a discharge perspective is its assimilative capacity i.e., maximum amount of pollution that can be diluted or degraded without affecting preliminary defined designated best uses. Effluent discharge standards can be concentration-based or load-based. Concentration-based standards are the most common and specify a permissible mass of pollutant per liter. A limitation of concentration-based standards can be that it does not promote wastewater treatment, since dilution can be used to meet the discharge standard. The original standards developed in Britain were concentration-based—although those standards assumed a minimum 8-fold dilution in the receiving water body. Most countries in the Global South have adopted discharge standards from the Global North and they have not been developed for their local context.

Load-based standards, as applied in the US, harmonize concepts of ambient water quality and effluent discharge through risk modeling of the water body. The Total Maximum Daily Load (TMDL) allocates the threshold value for a pollutant that will ensure compliance with a desired water quality standard based on stakeholder preference for the use of that water body. Criteria for the prevention of (eco)toxicity are based on both short term and long-term effects. States calculate TMDL for their water bodies based on monitoring evidence and water quality modeling. TMDL is used to issue permits to discharge in the catchment, and risk modeling encompasses variations in flow—from the lowest daily flow occurring once every 10 years (for acute effects) and once every 10 years averaged over a 7-consecutive-day period (for chronic effects) (National Research Council, 2001; US EPA, 2020).

Different countries base their standards on various characteristics of treated wastewater—although BOD is almost universally used. A snapshot of regulated parameters across countries is illustrated in **Figure 1**, which also shows that discharge limits are most commonly set on the basis of organic pollutants and nutrients.

Once the desired discharge standard is fixed, the choice of technology is determined by the desired quality of treated wastewater, and two principle approaches to technology selection have been delineated in the literature: Best Available Technology (BAT) and Best Practicable Technology (BPT). Either approach works in tandem with a discharge standard. BAT is the dominant paradigm in the Global North where treatment technology costs are more affordable. BPT is followed in the Global South where the contextual factors must be considered. The economic and behavioral aspects of risk are considered using the "As Low as Reasonably Achievable" (ALARA) principle, which delimits the risk management envelope ("BPT plus") (CPCB, 2009).

Wastewater Reuse Approaches

Water is a finite resource with significant variations in spatial and temporal availability. This, and changing climate, are making a strong case for reuse of wastewater for specific applications. Wastewater contains valuable nutrients such as Nitrogen and Phosphorus, essential for plant growth, and further represents a resource for energy recovery. The increasing scarcity of phosphorus in conjunction with land degradation (which is a plant macronutrient and thus plays a major role in food security), paired with the fact that abstraction for agricultural use accounts for 70% of total water withdrawal, makes wastewater a lucrative resource for irrigation (Cordell et al., 2009; FAO - Aquastat, 2016).

However, depending on its source, wastewater carries a broad variety of impurities—which can be toxic, pathogenic, and inhibitory to public health and can harm the environment. In order to achieve maximum beneficial re-use, the extent of wastewater treatment depends on specific reuse applications and their associated characteristics/risks. There are two major categories for wastewater reuse: (a) potable uses and (b) non-potable uses such as: irrigation in agriculture; industrial reuse (e.g., water cooling); aquifer recharge and other urban reuses such as toilet flushing, subway washing, coach cleaning, ground cooling, or building construction. Two major approaches to address risks associated with wastewater re-use were developed

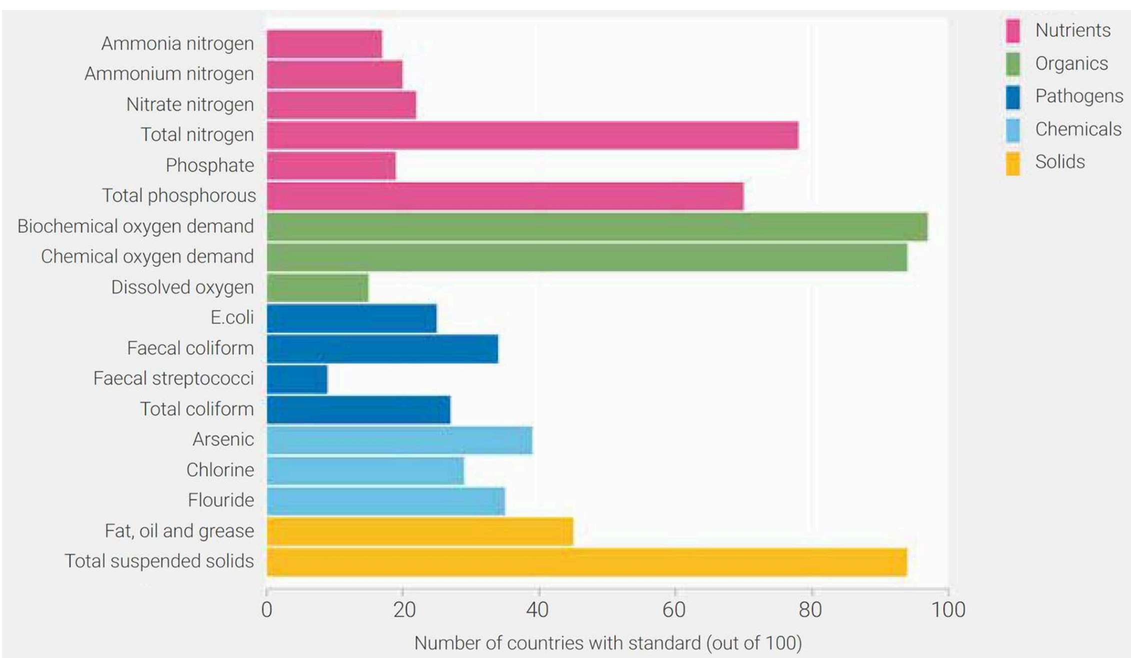

FIGURE 1 | National discharge standards of 100 countries (WHO, 2017b).

by the United States Environmental Protection Agency (US EPA) and the World Health Organization.

USEPA's single barrier approach to reuse risk management

USEPA follows the no risk approach for setting standards, and consequently adopts comparatively strict limits (US EPA, 2012) with recommendations on technology design to achieve these in the effluent or so-called "single barrier." WHO adherents critique the USEPA standards as impossible to achieve in developing countries, as technological solutions for the specified limits are highly cost intensive. Within the updated guidelines, the USEPA (2012) responded that these standards had evolved over a history of investment and capacity building and were not suitable for the Global South.

WHO's multiple barrier approach to reuse risk management

The WHO approach is characterized by: (a) the definition of a maximum tolerable additional burden of disease; and (b) a multi barrier perspective in impact and risk reduction along the whole chain (including treatment, crop restrictions, access to the public, vulnerable groups, irrigation techniques, and produce handling) (WHO, 2006 and WHO, 2016a). The WHO approach focuses on the need for alternative measures and targets locations where conventional and cost-intensive treatment technologies are economically not feasible. The Multi-Barrier Approach is illustrated in **Figure 2**.

Pathogen elimination along several different measures considered, can play in the range of 1–7 log reduction units, which are displayed according to barriers in the following **Table 1**.

Risk and Benefits of Wastewater Reuse

An integrated risk-benefit approach to wastewater risk management can address inadequate sanitation, waterbody pollution, and water scarcity. The risks and benefits of wastewater are summarized in **Figure 3** from following subsequently presented characteristics of specific parameters.

Organic matter

Total Organic Carbon (TOC), BOD, and Chemical Oxygen Demand (COD) represent indicators to identify the concentration of organic matter (OM) in water. The decomposition of OM can lead to a depletion of oxygen which is crucial for other aquatic organisms. In soil iron or manganese along with organic acids can disrupt the absorption of nutrients (Asano et al., 2007). As a nutritious ground for microbes, OM can cause difficulties in disinfection processes and further affects the color and odor of the water (US EPA, 2012). Excessive amounts of BOD can cause problems for irrigation infrastructure. Low to moderate concentration of OM, however, can be beneficial. The Central Public Health and Environmental Engineering Organization (CPHEEO) recommends in their report in 2013 that 11.0 to 28.0 kg/ha/day of organic loading (BOD_5) is required to maintain a static organic matter content in the soil to condition the soil with microorganisms and prevent clogging. However, higher rates are manageable depending upon the system type and resting period. The usage of primary effluent can result in loading rates exceeding 22.0 kg/ha and day but without causing problems.

Nutrients

Nutrients which are discharged to an aquatic environment can cause eutrophication, which in turn can lead to high accumulation of dead biomass and by this to depletion of oxygen in water bodies. While nutrients are beneficial for plant growth, they can cause water contamination if applied in excessive amounts and in areas with low groundwater table. Ammonia is harmful to freshwater aquatic life and can interfere with

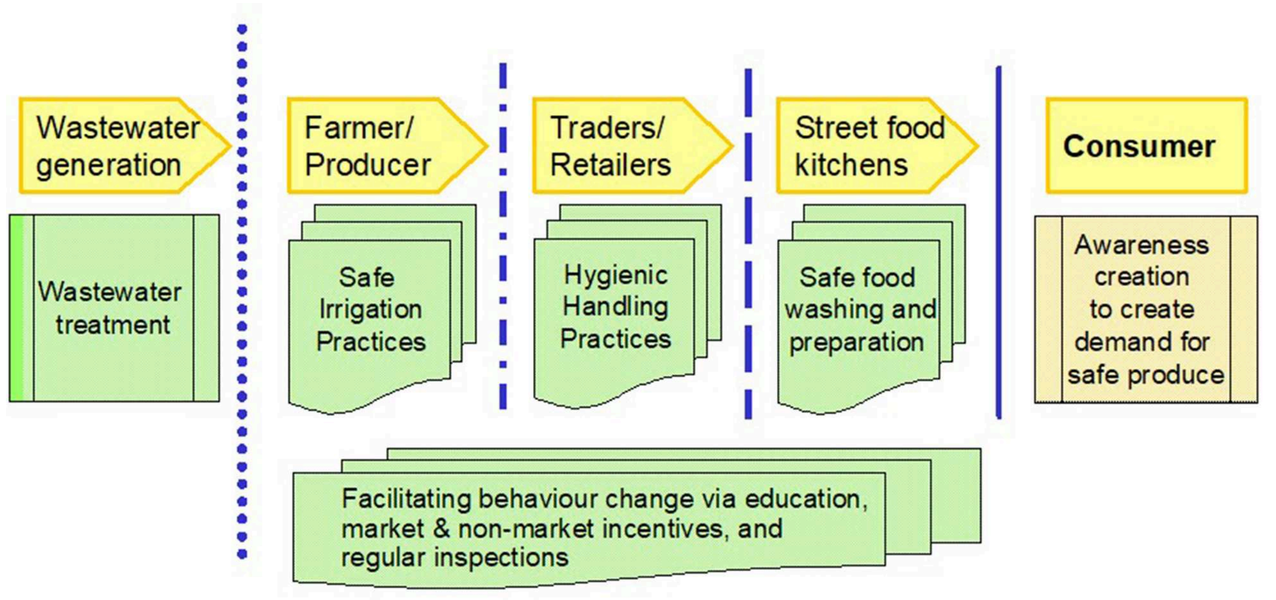

FIGURE 2 | Multi-Barrier Approach (Amoah et al., 2011).

TABLE 1 | Pathogen reduction along Multi Barrier Approach, modified from Mara et al. (2010).

Control measures	Pathogen reduction (log units)	Dependence of reduction and options
A. Wastewater treatment	1–7	Type and degree of treatment technology
B. On-farm options		
Crop restriction (i.e., no food crops, raw eaten)	6–7	(a) Effectiveness of local enforcement of crop restrictions, and (b) comparative profit margins of the alternative crop(s).
On-farm treatment	0.5–3	Type and degree of treatment, options can be tree tank system, simple sedimentation, filtration
Method of wastewater application		
Irrigation method	1–4	Method and system, such as furrow - drip irrigation, reduction of splashing
Irrigation cessation before harvest	0.5–2/day	Climate, time, crop type etc.
C. Post-harvest options at local markets		
Storage and handling	0.5–3	Overnight storage in basket, washing crops, removing the outer layer
D. In-kitchen produce preparation options		
Produce disinfection	2–7	Disinfection, produce peeling, cooking

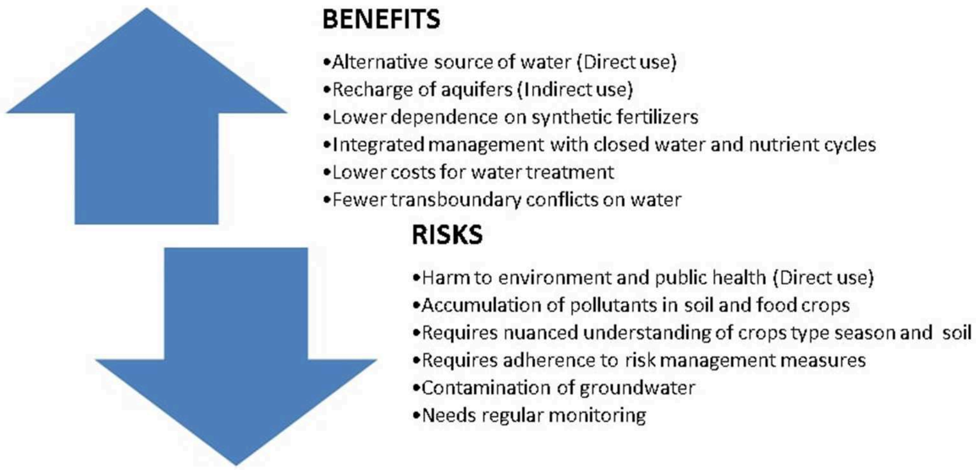

FIGURE 3 | Risks and benefits of wastewater reuse.

chlorination processes (US EPA, 2001). Wastewater contains 26–70 mg/l of nitrogen, 9–30 mg/l of phosphorus pentoxide, and 12–40 mg/l of potassium oxide (CPHEEO, 2013). The recommended Nitrogen-Phosphorus-Potassium dose ratio for crops is described as 5:3:2 (CPHEEO, 2013). High levels of total nitrogen concentrations can lead to a decrease in yield production due to lodging, reported especially for application on rice fields (Setter et al., 1997). With a resulting stimulation of algal and bacteria growth, it can further lead to clogging of irrigation infrastructure (Shatanawi and Fayyad, 1996). Application levels as for best practice in agriculture would depend on several factors, such as plant intake ratios, soil type, and groundwater level (WHO, 2006).

Solids

Total Suspended Solids (TSS) and turbidity are measures for particles in a medium, and in excess amounts can lead to clogging of infrastructure and soil, sludge deposition, and by this to anaerobic conditions. Providing a surface area for attachment of microbes, high TSS can be associated with higher microbial contamination. High turbidity levels can further complicate the disinfection processes (US EPA, 2012).

pH

The range of pH affects the solubility and by this also the mobility of metals, which in turn can be absorbed by plants. High levels of alkalinity or acidity have an impact on plant growth and the structure of the soil (WHO, 2006). Wide deviations in the pH can further cause damage to infrastructure.

Trace elements and heavy metals

Heavy metals such as lead or cadmium are usually found in industrial wastewater, which can accumulate in soil and plants and pose high toxicity to livestock or humans (Gupta and Gupta, 1998). While trace elements in specific doses are highly relevant for plant growth, applied in excessive amounts, they can be harmful to crops and may impact the productivity or root growth (Asano et al., 2007).

Salinity/dissolved inorganics
Electric conductivity (EC) is used as a parameter to measure the salinity level of a medium. Wastewater contains high levels of salt content. For the application on land via irrigation, this parameter according to the Food and Agriculture Organization (FAO) is considered as one of the most relevant parameters. High salinity can substantially affect plant growth, cause ion toxicity and affect nutrient absorption by plants (Beltran, 1999).

Pathogens
Health hazards form one of the main constraints in wastewater reuse and thus, the microbial composition is one of the most important parameters. While pathogens caused vast waves of epidemics in the past, they still constitute a significant health burden in many different countries. Diarrhea as an exemplar, forms the second leading cause of death in children under 5 years and is estimated to cause 485,000 deaths annually (WHO, 2017a, 2019). With restrictions by costs and complexity in analysis, *Escherichia coli* and Fecal Coliforms nowadays still form the major reference indicator for fecal contamination levels in wastewater effluents. However, there are wide debates that the sole quantification of *E. coli* is not sufficient to determine the overall risks in wastewater as some pathogens show higher resistance in disinfection processes (Salgot et al., 2006; WHO, 2016b). The WHO suggests reference indicators covering bacteria, viruses, and protozoa for safe water reuse and drinking water (WHO, 2006, 2011). Further critiques address the difficulty in assessing pathogens in media apart of water and the precision of current risk modeling methods (Salgot et al., 2006; Alcalde-Sanz and Gawlik, 2017). With risk being a function of the microbial agent, the human host and the given environment or application areas, overall risks can differ in a wide range or may not apply according to given local conditions.

Current Situation of Wastewater Management in India

While wastewater management in India currently faces many challenges, the pollution of rivers and water bodies has come under scrutiny, and their rejuvenation has been subject to much attention. Municipal wastewater has been identified as the chief source of pollution of the Ganga and Yamuna rivers, and the revitalization of these rivers has seen substantial investment over the last several decades (IIT Consortium, 2015; Government of Haryana, 2018). The Central Pollution Control Board has been monitoring water quality in rivers over the last 30 years and uses BOD data to classify river stretches in five priority groups (e.g., stretches where BOD value greater than 30 mg/l is termed "priority 1," while BOD values between 3.1 and 6 mg/l are "priority 5.") (Koshy, 2018). The CPCB observed sharp deterioration in water quality with 71 polluted stretches in 2005 and 375 polluted stretches in 2018 (Koshy, 2018). In September 2018 the Honorable National Green Tribunal (NGT) directed states to constitute a four-member' River Rejuvenation Committee' (RRC) in order to prepare and implement action plans for render polluted river stretches fit for bathing use (National Green Tribunal, 2018). While states have submitted action plans of varying detail, the Hindon River Action Plan, which envisions multi-stakeholder governance management of the Hindon basin till 2030, has been highlighted by CPCB as an example of a comprehensive action plan (State of Uttar Pradesh, 2014; CPCB, 2018a,b; Water Resources Group (WRG), 2018).

With fast depleting fresh and ground water resources, government bodies have also shown interest in centralized reuse of water. In another recent order, the Honorable NGT directed states to submit action plans for utilization of treated wastewater by June 2019 (Press Trust of India (PTI), 2019). In addition to providing a quota for desired applications, reuse action plans are also supposed to include infrastructure augmentation and monitoring plans for reuse (Press Trust of India (PTI), 2019). States including Gujarat and Karnataka have already promulgated reuse policies for some years, but this recent NGT order aims to promote the focused implementation of reuse throughout the whole country.

It is stated that almost half of the wastewater generated in urban India is already being reused [CSE, Bharat lal Seth, (nd)] and most of it is assumed to be reused indirectly and without treatment. Typical reuse applications in India include forestry, horticulture, toilet flushing, industrial use (e.g., non-human contact cooling towers), fish culture, and various indirect uses (CPHEEO, 2013).

Institutional Structure for Wastewater Management in India

In India pollution control activities are the joint responsibility of three different institutions: The Ministry of Environment Forest and Climate Change (MoEF&CC), the Ministry of Housing and Urban Affairs (MoHUA), and the recently formed Ministry of Jal Shakti. The MoEF&CC is the nodal agency and together with the Central Pollution Control Board these bodies are responsible for laying down policies, acts and related standards. **Table 2** below lists key institutions with related mandates, subunits, and functions.

With water as a precious resource and wastewater as a major pillar of societal infrastructure, wastewater management necessitates inclusion of various disciplines and perspectives. It is observed that other critical sectors such as public health and agriculture do not play an explicit role. While public health is represented indirectly through the MoHUA, the importance of public health and increasing reuse patterns is significant. The recent creation of the Ministry of Jal Shakti is indicative of India's move toward integrated water and wastewater management.

Institutions implement their functions through regulatory statutes. In 1974 the *Water Prevention and Control of Pollution Act* was released as a first regulation for the prevention and control of water pollution and led to the establishment of responsible bodies at central and state level for implementation. While this act was primarily focused on water bodies, in 1986, the *Environment Protection Act* was released—targeting protection and improvement of the wider human environment. With growing urbanization, the National Urban Sanitation Policy was established in 2008 mandating the total coverage of sanitation in all Indian cities and towns. **Table 3** below states important regulations and their functions chronologically.

TABLE 2 | Institutional structure for setting wastewater discharge standards.

Institution	Mandate	Subunit	Subunit function
MoEF&CC	Formulation of policies and programs for the conservation of natural resources and pollution abatement and guidance for sustainable development and enhancement of human well-being (MoEFCC, 2017a)	CPCB	Provision of technical services to MoFE&CC regarding the Environment (Protection) Act, 1986. According to the Water Act, 1974, their function is to promote cleanliness of streams and wells in different areas of the States by prevention, control and abatement of water pollution (CPCB, 2019)
		SPCB	Inspect wastewater treatment facilities; enabled to tighten standards; evolve methods of treatment and utilization of sewage or related disposal (Singh, 2014)
MoHUA	a) Formulation of policies, sponsorship and support programs b) Coordination of activities of various Central Ministries, State Governments and other nodal authorities c) Monitoring programs concerning housing and urban affairs (MoHUA, 2017a)	CPHEEO	Technical wing of the ministry with specialists in public health engineering/environmental engineering. The organization does not only support the ministry in policy formulation but also handholds states by way of technical advice, guidelines, scrutiny and appraisal of schemes, and propagation of new technologies. It acts as advisory body at central level for concerned state agencies and Urban Local Bodies (ULBs) in implementation, O&M (operation and maintenance) of urban water supply and sanitation projects (CPHEEO, 2019)
Ministry of Jal Shakti	Formed in May 2019 by merging Ministry of Drinking Water and Sanitation, Ministry of Water Resources, River Development and Ganga Rejuvenation for optimal sustainable development, maintenance of quality and efficient use of water resources	1. Overall planning, policy formulation, coordination and guidance for water resources 2. Technical guidance, scrutiny, clearance and monitoring of the irrigation, flood control and multi-purpose projects 3. General infrastructural, technical and research support for development 4. Providing special central financial assistance for specific projects 5.Overall policy formulation, planning and guidance in respect of irrigation management 6. Overall planning for the development of ground water resources 7. Formulation of national water development perspective 8. Coordination, mediation and facilitation of interstate interests 9. Operation of the central network for flood forecasting 10. Inter-state negotiations 11. Ensure effective abatement of pollution and rejuvenation of the river Ganga by river approach (Ministry of Jal Shakti, 2019)	

Setting Wastewater Discharge Standards for STPs in India

The fundamental basis for standards-setting is the identification of "designated best uses" (DBU), or the use from any particular water body that demands the highest water quality (CPCB, 2002). A classification system of five common human uses has been adopted that associates each DBU with related water quality criteria that must be fulfilled. **Table 4** below illustrates defined designated-best-uses with the related class of water and relevant criteria.

The DBU concept forms the fundament for risk management in India but is not without limitations. Human use-based water quality criteria may not satisfy ecological health criteria, and this has been found to be the case in practice (CPCB, 2002). Unorganized uses of waterbodies have not been considered, and these may constitute the majority of risks, particularly in rural India. Further, DBU may vary across seasons and stretches of the river and this results in a further challenge in the practical utility of the concept. These problems have been evident in the monitoring of large rivers like Ganga and Yamuna (IIT Consortium, 2015; Government of Haryana, 2018).

Following a review of international standards (USEPA, Europe, and Japan), and consideration of economic feasibility in India, first general discharge standards were proposed in 1986. These are concentration-based, and the first iteration considered four different application areas (MoEFCC, 1986b). Standards are set as minimum requirements for all states, allowing states to set more stringent standards based on the condition of their water bodies.

Current Scenario of Evolving Discharge and Reuse Standards

The established wastewater discharge standards for STPs have changed considerably over the past 4 years, with changes in terms of limits and overall parameters—as well as a move to just one fixed set of standards irrespective of end uses over land or discharge to inland water. After revision and the formulation of comparatively stringent draft norms in 2015 under one fixed set of standards, these underwent a second change in 2017 with a relaxation of limits and the inclusion of different criteria for metro cities. These norms, in turn, were followed by an order by the NGT (National Green Tribunal) (1995). The frequency of changes, coupled with observed difficulties in direct access to relevant information on central online platforms and the lack of transparency in standards-setting have led to confusion and hesitation within the sector on upcoming projects. An adaptation time of 7 years was proposed by a nominated expert committee for old STPs to comply with updated standards but rejected by the NGT. While water quality criteria form the baseline for setting standards, incoherence is observed. Detailed reports on standards setting procedures, relevant parameters for evaluation or detailed development plans are not accessible or existent and thus could not have been provided. **Table 5** below informs on Indian STP discharge standards over time.

TABLE 3 | Overview of policies and acts in India for wastewater management.

1974	Water (Prevention and Control of Pollution) Act	Prevention and control of water pollution in maintaining or restoring of the wholesomeness of water through the establishment of pollution control boards (central & state level) for implementation[a].
1986	Environment Protection Act	Provision of protection and improvement of the environment in a broader sense, including the human environment[b].
1995	National Environment Tribunal Act	Provision of strict liability for damages arising out of any accident by hazardous substances; establishment of a National Environment Tribunal for effective and expeditious disposal of cases arising from such accidents[c].
2008	National Urban Sanitation Policy	All Indian cities and towns become totally sanitized, healthy and liveable and ensure and sustain good public health and environmental outcomes for all their citizens with a particular focus on hygienic and affordable sanitation facilities for the urban poor and women[d].
2011	National Mission for Clean Ganga	Ensure effective abatement of pollution and rejuvenation of the river Ganga by adopting a river basin approach to a) promote intersectoral coordination for comprehensive planning and management and b) maintain minimum ecological flows in the river Ganga[e].
2012	National Water Policy (NWP)	NWP proposes the recycling and reuse of water including return flows for demand management and efficient use of water, incentives through efficient water pricing[f].

[a] *MoEFCC (1974), accessible via https://cpcb.nic.in/displaypdf.php?id=aG9tZS93YXRlci1wb2xsdXRpb24vRG9jMy5wZGY=.*
[b] *MoEFCC (1986a), accessible via https://cpcb.nic.in/displaypdf.php?id=aG9tZS9lcGEvZXByb3RlY3RfYWN0XzE5ODYucGRm.*
[c] *NGT (National Green Tribunal) (1995), accessible via http://www.greentribunal.gov.in/FileDisplay.aspx?file_id=hp6pqcrv0hY1hc2OYG8Sk8xCFfwF7gv7AbtSt83%2FRxrgXufTbWXFcg%3D%3D.*
[d] *MoUD (2008), accessible via http://www.indiaenvironmentportal.org.in/files/nusb.pdf.*
[e] *NMCG (2019), accessible via https://nmcg.nic.in/about_nmcg.aspx.*
[f] *MoWR (2012), accessible via http://mowr.gov.in/sites/default/files/NWP2012Eng6495132651_1.pdf.*

TABLE 4 | Water quality criteria under designated best use classes (CPCB, 2017a).

Designated-best-use	Class of water	Criteria
Drinking water source without conventional treatment but after disinfection	A	- Total Coliforms < 50 MPN/100 ml - pH between 6.5 and 8.5 - Dissolved Oxygen > 6 mg/l - BOD_5 days 20°C 2 mg/l or less
Outdoor bathing (organized)	B	- Total Coliforms < 500 MPN/100 ml - pH between 6.5 and 8.5 - Dissolved Oxygen > 5 mg/l - BOD_5 <3 mg/l or less
Drinking water source after conventional treatment and disinfection	C	- Total Coliforms < 5000 MPN/100 ml - pH between 6 to 9 - Dissolved Oxygen > 4 mg/l - BOD_5 < 3 mg/l
Propagation of wildlife and fisheries	D	- pH between 6.5 to 8.5 - Dissolved Oxygen > 4mg/l - Free Ammonia (as N) < 1.2 mg/l
Irrigation, industrial cooling, controlled waste disposal	E	- pH between 6.0 to 8.5 - Electrical conductivity at 25°C micro mhos/cm max. 2250 - Sodium absorption ratio max. 26 - Boron max. 2 mg/l
	Below-E	Not meeting A, B, C, D, & E criteria

While in 1986 standards, discharge to inland surface water and land irrigation was differentiated, the subsequent draft standards were applied for both categories where human contact with reused effluent was possible (though specific reuse applications were not defined). Apart from the standards set under the CPCB, several different recommended norms for wastewater reuse are provided in guidance documents such as the Manual on Sewerage released in 2013 under the CPHEEO and the MoHUA or the Urban Water Reuse Policy developed under the Urban Development Department in Karnataka state published in 2017 (Government of Karnataka, 2017). While the board for the formulation of the Karnataka policy included a wide range of sectoral bodies under various Ministries (including state pollution control boards) and given parameters and limits refer to CPHEEO norms, the recommended norms are rather different to standards set elsewhere. The recommended norms for wastewater reuse under the CPHEEO are shown in **Table 6**.

In comparison to norms recommended by the CPHEEO, the stated application areas under the Urban Reuse Policy in Karnataka are agriculture, industry, urban non-potable use and environment. For agricultural use, the norms cover pathogens and pH, whilst norms for discharging effluent into water bodies to increase flow (for example) are more stringent and cover similar parameters as to standards proposed.

Furthermore, while under the Open Defecation Free Agenda of the Swachh Bharat Mission decentralized onsite sanitation systems were widely built in urban areas, a specific set of standards for onsite or decentralized systems does not exist, neither standards along the whole sanitation value chain, including fecal sludge management (MoHUA, 2017b).

Technology Considerations Under the Regulatory Framework

Reported wastewater treatment systems in India comprised a range of 13 different technologies in 2013, with Upflow Anaerobic Sludge Blanket (UASB) as the most commonly used technology. However, current trends and STPs under development include Activated Sludge Process (ASP), Moving Bed Biofilm Reactor (MBBR), and Sequencing Batch Reactor (SBR) plants (CPCB, 2013, 2015). An overview for decentralized technologies is not given. CPCB has previously evaluated several technologies according to performance and cost (CPCB, 2013).

TABLE 5 | Overview Indian STP discharge standards over time (MoEFCC, 1986b, 2015, 2017b; National Green Tribunal order, 2019).

	Parameters	General norms[g] 1986				Draft norms Nov. 2015**	MoEF & CC notification, Oct. 2017**	NGT order 2019**
		Inland surface water	Public sewers	Land irrigation	Marine coastal areas			
1	BOD [mg/l]	30	350	100	100	10	30 20 (metro cities)[h]	10
2	COD [mg/l]	250	–	–	250	50	–	50
3	TSS[i] [mg/l]	100	600	200	100 (process water)	20	100 50 (metro cities)	20
4	pH	5.5–9	5.5–9	5.5–9	5.5–9	6.5–9	6.5–9	5.5–9
5	TN[j] [mg/l]	100	–	–	100	10	–	10
6	Ammonical Nitrogen as N [mg/l]	50		–	50	5[k]	–	–
7	Free NH3 [mg/l]	5			5	–	–	–
8	Nitrate [mg/l]	10			20	–	–	–
9	Diss. PO4 as P [mg/l]	5	–	–	–	–	–	1[l]
10	Fecal Coliform [MPN/100ml]	–	–	–	–	<100	<1,000	<230

[g] *Standards set in 1986 cover in total 40 parameters, which are not depicted in this illustration. NOTE: industrial wastewater standards are regulated under CETP (Common Effluent Treatment Plant) set, which is not focus of this this study.*

[h] *Metro Cities, all state capitals except in the state of Arunachal Pradesh, Assam, Manipur, Meghalaya Mizoram, Nagaland, Tripura Sikkim, Himachal Pradesh, Uttarakhand, Jammu and Kashmir and Union Territory of Andaman and Nicobar Islands, Dadar and Nagar Haveli Daman and Diu and Lakshadweep Areas/Regions. **Standards applicable for discharge into water bodies and land disposal/applications, while reuse is encouraged.*

[i] *As SS in [mg/l] in General Norms, 1986.*

[j] *As Total Kjedahl Nitrogen in General Norms, 1986.*

[k] *As NH_4-N.*

[l] *Valid for Phosphorus Total (for discharge into ponds and lakes).*

The technologies included ASP, MBBR, SBR, Upflow UASB-EA, Membrane Bioreactor (MBR), and Waste Stabilization Pond (WSP). The following **Table 7** presents the CPCB evaluation alongside DEWATS (Decentralized Wastewater Treatment System), which follows a concept with low cost, O&M and energy intensive nature-based systems, mostly composed of anaerobic treatment and extended planted gravel filtration.

The Challenges of a Changing Wastewater Management Regime

In light of the changing landscape of pollution control measures and the lack of transparency in standards-setting, literature review, and interviews with several governmental officials, sectoral experts, and technology providers in India have been carried out, to assess applicability of standards and norms set, the reasons for the changes, associated challenges and discuss possible implications. The interviewees provided their comments on an anonymous basis. Their feedback with findings is synthesized and discussed in the following sections.

Background for revision of general standards in 2015

CPCB reported a severe deterioration of river quality, which formed the initial ground for a revision of general standards as indicated in interviews. While polluted river stretches in 2005 only numbered 71, the number rose to 300 in 2012 and further to 351 in 2017 (Bhardwaj, 2005; CPCB, 2018b), although it should be noted that the monitoring network developed over this period from an initial 784 to 3,000 stations in 2018. Considering the increase in both monitoring stations and polluted river stretches, a qualitative analysis of pollution levels at the given stretches would deliver a more holistic picture on the dimension of contamination levels. Reasons for increased pollution in rivers are multiple, ranging from increased water withdrawals coupled with an increase in wastewater volumes and climatic and seasonal variations. Historically, some rivers had base flows only during the monsoon season (for around 3 months annually) while nowadays most streams are perennial as a result of wastewater discharge. Norms for effluent quality were tightened in 2015 since it was argued that dilution effects within water bodies could no longer be considered. Analyzing the compatibility of discharge standards and required water quality criteria for designated best uses, it is observed that set limits under a zero dilution factor cannot fulfill intended thresholds and thus can fail to eliminate risks as to given objectives (compare **Tables 4**, **5**).

Background on frequency of constant changes

In contrast to 1986, standards in 2015 were formulated under the mandate of the MoEF&CC to combat high pollution levels. Since parameters such as economic feasibility were the responsibility of other Ministries, interviewees reported that they were not considered under the first draft. The disparity in the management environment of wastewater discharge and reuse standards is reflected in the contrasting landscape of varying interest and requirements. With water as the central resource and wastewater

TABLE 6 | Recommended norms of treated sewage quality for different uses (CPHEEO, 2013).

Parameter	Toilet flushing	Fire protection	Vehicle exterior washing	Non-contact impound-ments	Landscaping, horticulture & agriculture			
					horticulture, golf courses	Crops		
						Non-edible crops	Edible crops	
							Raw	Cooked
Turbidity (NTU)	<2	<2	<2	<2	<2	AA	<2	AA
SS	nil	nil	nil	nil	nil	30	nil	30
TDS				2100				
pH				6.5 to 8.3				
Temp. (°C)				Ambient				
Oil and Grease	10	nil	nil	nil	10	10	nil	nil
Minimum Residual Chlorine	1	1	1	0.5	1	nil	nil	nil
Total Kjeldal Nitrogen	10	10	10	10	10	10	10	10
BOD	10	10	10	10	10	20	10	20
COD	AA	AA	AA	AA	AA	30	AA	30
Dissolved Phosphorus as P	1	1	1	1	2	5	2	5
Nitrate	10	10	10	5	10	10	10	10
Fecal Coliform/ 100 ml	nil	nil	nil	nil	nil	230	nil	230
Helminthic eggs/liter	AA[m]	AA	AA	AA	AA	<1	<1	<1
Color	Colorless	Colorless	Colorless	Colorless	Colorless	AA	Colorless	Colorless
Odor				Aseptic (Not septic and no foul odor)				

[m] *as arising when other parameters are satisfied.*

TABLE 7 | Technology performance (CPCB, 2013; adapted with data based on DEWATS by Singh et al., 2019).

Assessment parameter/technology	ASP	MBBR	SBR	UASB+EA	MBR	WSP	DEWATS[n]
Performance after Secondary Treatment							
BOD (mg/l)	<20	<30	<10	<20	<5	<40	
SS (mg/l)	<30	<30	<10	<30	<5	<100	
Fecal Coliform, Log unit	Upto 2<3	Upto 2<3	Upto 3<4	Upto 2<3	Upto 5<6	Upto 2<3	
T-N removal efficiency (%)	10–20	10–20	70–80	10–20	70–80	10–20	
Performance after Tertiary Treatment							
BOD (mg/l)	<10	<10	<10	<10	<10	<10	<20
SS (mg/l)	<5	<5	<5	<5	<5	<5	<40
TN							<10
NH_3N (mg/l)	<1	<1	<1	<1	<1	<1	
Total Coliforms, MPN/100 ml	10	10	10	10	10	10	

[n] *DEWATS technology serves as comparative for nature-based solutions due to lack in data availability for other systems.*

treatment as significant pillar of societal infrastructure, a cross-sectional interest is formed. However, it is stated that the process of standards-setting and related decision making does not consider a regulated consensus phase including all stakeholders to devise feasible solutions to complex problems. The lack of consultation or consensus during the development of the 2015 MoEF&CC draft norms meant that they were published and went into application before being reviewed by other institutions and stakeholders. Given the lack of communication and inclusion, the draft norms subsequently underwent two rounds of reversal, while the applicability of current enforced standards is reported to remain under further revision.

Aside from individual stakeholder perspectives, interviewees stated that detailed assessment through health risk or river basin modeling has not been undertaken due to capacity constraints. While the aspiration of the regulatory authorities is toward BAT and zero risk, the absence of detailed human or environmental impact assessments, indicative budgets, and targets for infrastructure implementation mean that the eventual outcome cannot be predicted with any certainty. It was further reported that international limits may not reflect characteristic or the impact of parameters under given environmental conditions found in the Global South. While in the North coliforms may persist for longer timescales, increased UV radiation in the South can have an effect on their elimination. In turn increased temperatures may enhance organic decomposition processes. The given uncertainty due to a lack in profound risk management for local conditions leaves behind room for fundamental recurring questions and discussions. To facilitate a more structured and holistic management process, big data for water bodies, environmental, and public health must be collected and analyzed, and this capacity is yet to be developed within the relevant Indian institutions.

Background for the change to fixed set of standards

Although in interviews it is widely agreed that standards set do not necessarily represent required limits for certain application areas, one fixed set of standards for discharge and reuse has been set because of high mistrust of illegal discharge. It was stated that many STPs cannot meet 1986 standards because of electricity break downs, O&M intensive technologies and the lack of interest in investing in training of operators by the private sector who is often responsible for the O&M of treatment plants. Further dysfunction in the wastewater analysis sector was reported as observation, while illegal disposal of sludge due to lack of appropriate disposal options is a common occurrence. With insufficient resources in monitoring, one fixed set of discharge standards was considered to facilitate pollution control. Illegal discharges are observed along the whole wastewater chain. The causality and net benefit resulting from the implementation of one fixed set of standards remains unclear and fails to address the root cause—which is formed by insufficient capacity in monitoring. Further, without proposing nuanced and feasible pollution control measures for reuse, regulations can fail to address the reality on ground and existing risks to a large proportion of the population, particularly farm laborer and the poor.

While one fixed set of standards can simplify implementation and monitoring, it can also neglect the benefits and risks of wastewater. For example, in an irrigation context, wastewater composition, soil characteristics, type of crop, and protection measures can influence risk. Certain trace elements can affect the integrity of soil structure and accumulate in crops, rendering them unfit for human consumption. Considering the quantities of wastewater used for irrigation in India, and the growth in agriculture in peri-urban areas as a response to perennial flows, the elimination of nutrients essential for crop growth at high cost remains indefensible (CPCB, 2013).

Changes in the standards setting approach

As a primary driving objective indicated in the protection of water bodies, the NGT order envisages stringent standards achieved through the implementation of the BAT approach. Under the focus of one application area and a limited set of technologies considered in the evaluation process, the resulting implementation would require energy and mechanically-intensive technologies that increase electricity consumption and rule out opportunities for direct nutrient recycling. Smith et al. (2019) perform a benefit-cost assessment of China's stringent wastewater standards in 2015, and find an additional annual electricity consumption of 3–6% and a 7-fold benefit to agricultural reuse. There is an ever-increasing landscape of technology options, many of which were not considered during the 2013 CPCB review (CSE 2019; CPCB 2013). While it is claimed that the BAT approach is technology-neutral, it was commonly stated that decentralized and nature-based solutions are disadvantaged under the proposed discharge and reuse standards.

Economic and risk implications

The immense pollution arising from improper or inexistent sanitation requests for allocation of adequate funding schemes in order to achieve set targets. However, most interviewees stated that strict standards were not applicable at the current time in India due to the lack of economic and technical feasibility, with substantial constraints around operation and maintenance. Detailed development plans of the sector including financing schemes and related targets in treatment coverage over time could not have been shared. It is stated that the economic feasibility for implementation of the MoEF&CC norms at all levels has not been fully explored, and the efforts of the wastewater sector to provide sanitation has stalled due to a lack of clarity on goals and a lack of applicable technologies.

It was indicated that the sector would face a mammoth challenge in acquiring finances to retrofit current systems to meet the proposed limits—not just in terms of the infrastructure required, but also the additional land area required to accommodate that infrastructure, especially in highly dense urban areas. According to the Bangalore Water Supply and Sewerage Board, 50 out of 57 STPs would have to be adapted and a budget of 2,000 crore Rs (260 Mio. €) has been already drawn up (Deccan Herald, 2019). It is further reported that 134 STP projects are currently in the bidding stages and that tenders may have to be revised—both for these as well as for proposals that have already been issued (Global Water Intelligence, 2019). The detailed implications for institutional costs and technological retrofitting are not known but are presumably quite large.

When analyzing the capital costs of treatment systems considered in the CPCB report in 2013, prices are indicated in the range from 23 lakhs Rs/MLD (0.029 Mio. €/MLD)[1] for WSP to 300 lakhs Rs/MLD (0.382 Mio. €/MLD) for MBR. While this is a wide range, capital expenditures (CAPEX) for other treatment systems fell within the range of 68–75 lakhs Rs/MLD (around 0.087 to 0.096 Mio. €/MLD). Capital costs for tertiary treatment were indicated as 40 lakhs Rs/MLD (0.051 Mio. €/MLD) representing $\sim$ 60% of total capital investment for ASP, MBBR, SBR or UASB+EA, 13% for MBR and 173% for WSP. Against the intensive investment in tertiary treatment, the overall additional gain in BOD removal rate as for ASP is indicated in 10 mg/l while a comparative for removal efficiencies for nutrients at the different stages is not directly given and cost calculation in relation to removal rates cannot be derived. Considering that half of the wastewater is reused informally for irrigation in India, decentralized plants near agricultural areas could allow to recover

[1]Conversion rate based on 78.87 Rs/EURO annual average for 2019, dated 13th of December, 2019, sourced at https://www.x-rates.com/average/?from=EUR&to=INR&amount=1&year=2019 (X-Rates, 2019).

resources instead of their cost intensive elimination, which in turn could be used for the development of broader coverage of treatment infrastructure.

Unless the total governmental budget for wastewater infrastructure development increases drastically, infrastructural development and coverage are likely to slow down even as the population continues to grow. This trend can result in higher pollution and health burden and enforce higher risk inequalities as only certain areas could be served while others would be exposed to an unsafe and dangerous environment. Overall, it can be stated that there is a wide gap in institutional capacity at all levels—highlighting a pressing need for more holistic management processes.

International Comparison

In the following chapter an international comparison has been carried out in collaboration with the INNOQUA consortium, informing on institutional approaches and pollution control measures in different countries.

International Comparison of Approaches and Discharge Standards

The international comparison of approaches and discharge standards provides insights from regulations on the European level, Ireland, France, Tanzania, and different set of standards in a wider perspective in relation to India.

The European Union

As with India, legislation in Europe has to cover a broad range of geographies with different environmental sensitivities. The initial priority was to ensure that wastewater was captured and treated—with an emphasis on wastewater from "agglomerations" of more than 2,000 Population Equivalent (PE). PE is used as a metric since it allows for the inclusion of combined sewerage systems that are common across Europe—in which mixtures of surface runoff, domestic, commercial, and industrial effluents are conveyed to treatment facilities. This regulatory structure was set out in the 1991 Urban Wastewater Treatment Directive (UWWTD), obligating European member states to:

a. collect and treat wastewater, where PE is higher than 2,000
b. preauthorize industrial discharges into urban treatment plants
c. achieve effluent standards by secondary or equivalent treatment
d. apply nutrient removal objectives, where receiving catchment are sensitive
e. monitor treatment plants and receiving waters
f. control sewage sludge disposal.

The nutrient removal objectives apply to agglomerations of 10,000 PE and above, where the treated wastewater, discharged into water bodies, can cause eutrophication. They cover nitrogen and phosphorus and set limits for these elements.

In principle, the UWWTD prevents the use of decentralized systems within population centers (of >2,000 PE). However, the Directive does include the following caveat: "Where the establishment of a collecting system is not justified either because it would produce no environmental benefit or because it would involve excessive cost, individual systems or other appropriate systems which achieve the same level of environmental protection shall be used" (EEC, 1991). In the following **Figure 4**, the coverage in wastewater treatment and related stages is presented. As it can be seen, there are significant differences in EU countries. It can be assumed that wastewater from the percentage of the population not covered in these statistics is managed in decentralized systems and as illustrated apart of the UK, decentralized systems still represent a significant fraction. Further as illustrated, tertiary treatment is not yet universally applied throughout all EU countries and the implementation of this treatment stage is still a comparatively young development.

More recently, European legislation has moved away from setting specific discharge standards to consider water quality as a whole. Under the 2000 Water Framework Directive (WFD) (European Commission, 2019c), member states are required to understand the current ecological condition of their water bodies (both surface and ground water) and compare this with "good" ecological status. Good ecological status is defined through a number of metrics that are based on the quality of water bodies that might be expected where there was minimal human interference. Programs of measures must then be defined and implemented to improve poor quality water bodies until they achieve at least "good" ecological status. The WFD operates at river basin scale, requiring international cooperation where (for example) rivers pass through more than one country. Since the programs of measures can target point and diffuse sources of pollution, the WFD interacts with a large number of other regulatory instruments—including those relevant to agriculture. Since it is left to individual member states to determine how "good" ecological status should be interpreted for each water body, the WFD does not set prescribed limits for wastewater discharge.

Ireland

Over 80% of rural households (accounting for one third of Ireland's population) treat and discharge wastewater onsite with a resulting estimated 500,000 domestic wastewater treatment systems (DWWTS) treating wastewater from single houses that are not connected to a public sewer system An Taisce (2015). The Irish Environmental Protection Agency (EPA) has published a *Code of Practice: Wastewater Treatment and Disposal Systems Serving Single Houses* (PE $\leq$ 10) which serves as the key guideline and design practice for DWWTS (EPA, 2010). Technologies considered under the EPA include

a. Septic tanks for primary treatment
b. Constructed wetlands, soil filters and sand filters for secondary treatment
c. Package plants (primary and secondary treatment)
d. Constructed wetlands, soil filters and sand filters for tertiary treatment.

Wastewater treatment plants, processing loads of between 500 and 10,000 PE, must meet the standards listed in the UWWTD, whilst larger plants must meet tighter, site-specific standards—that allow water bodies to comply with the requirements of

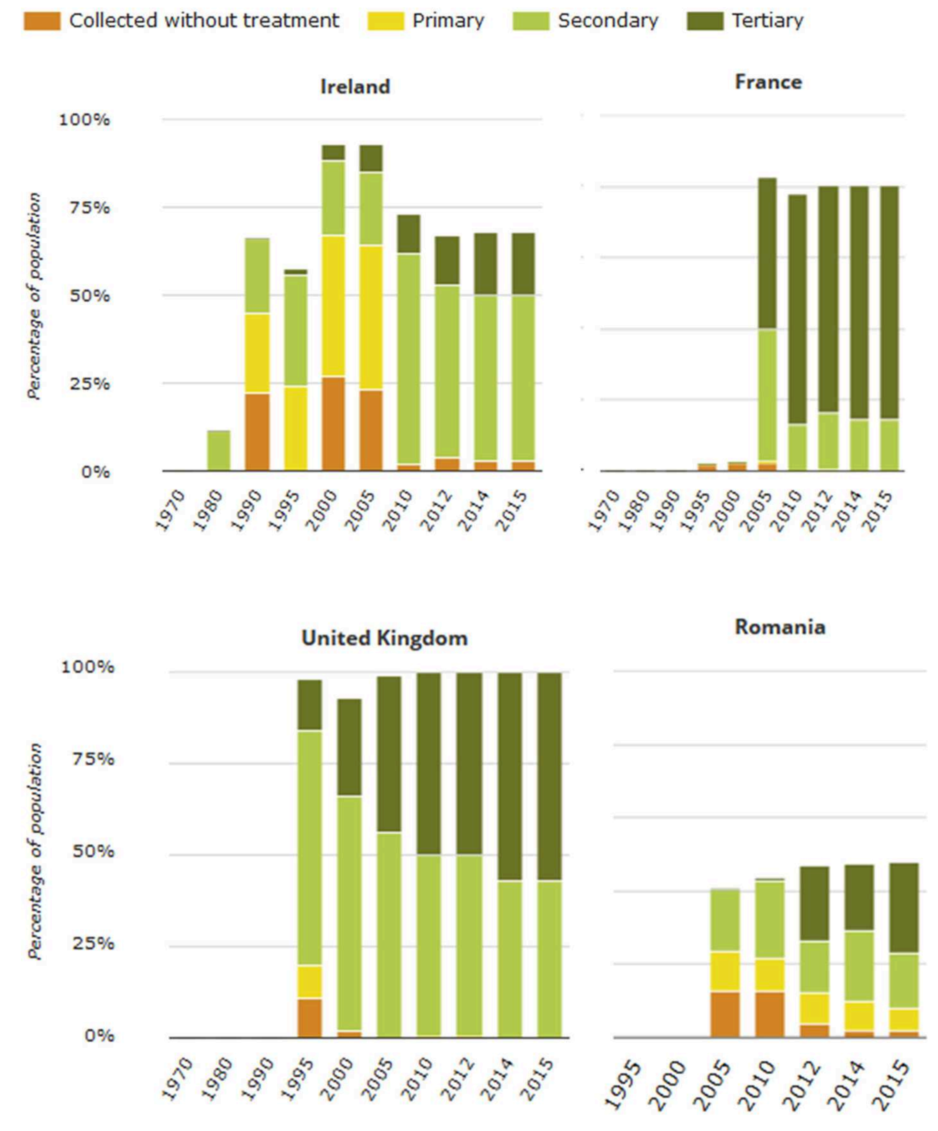

FIGURE 4 | Evolution of wastewater treatment in Ireland, France, UK, Romania (European Environment Agency, 2017a,b,c,d).

the Water Framework Directive. Ireland has no specific reuse standards in place.

France

As in the case of Ireland, France has set standards for smaller treatment plants. Unlike Ireland, France has standards for reuse, as set out below. Standards are classified amongst systems with a capacity below 1.2 kg of BOD_5 per day and above 1.2 kg of BOD_5 per day but below 120 kg per day and address BOD, COD and SS as presented in **Table 8** (Legifrance, 2007, 2009).

Tanzania

In 1991 the Government of Tanzania prepared the first National Water Policy to address the challenges on water supply and sanitation services (Tanzania Bureau of Standards (TBS), 2005). This policy identified the Government as the sole implementer and provider of water and sanitation services. Under the framework of the National Water Policy, Water Supply and Sanitation Authorities (WSSAs) are mandated with sanitation and sewerage service provision. The policy's objective for urban areas is to implement more appropriate environmentally-friendly technologies for wastewater treatment and recycling. Although discharge standards are comparatively stringent, wastewater treatment only covers a fraction of wastewater production.

Unlike in India, in Tanzania the formulation of discharge standards follows a national standardized participatory process involving stakeholders from several sectors over a phase of up to 5 years. The standards are based on information from other countries (notably Brazil and India, which have similar characteristics in terms of economy and environment). Following the initial expert revision, the draft standards are opened for

TABLE 8 | Discharge standards in different countries[o] (MoEFCC, 1986b, 2015, 2017b; EEC, 1991; Tanzania Bureau of Standards (TBS), 2005; Legifrance, 2007, 2009; EPA, 2010; MWI, 2012; Ministerio del Ambiente, 2015; National Green Tribunal order, 2019).

Country	PE treated	pH	t (°C)	SS (mg SS/l)	DO (mg O_2/l)	COD (mg COD/l)	BOD_5 (mg BOD_5/l)	TN (mg N/L)	Total ammonium (mg NH_4-N/l)	Total ammonia (mg NH_3-N/l)	TP (mg P/l)	Microbial indicators
EU Urban Wastewater Treatment Directive (UWWTD)[p]	>2,000			35/90% reduction		125/75% reduction	25/70-90% reduction	–			–	
	10,000 – 100,000							15			2	
	>100,000							10			1	
Ireland	≤10			30			20	5	20		2	
	>2,000	UWWTD apply as a minimum, but may be more stringent to comply with Water Framework Directive (WFD)										
France	<20			30			35					
	20 - 2000	6–8.5	<25	50% reduction		60% reduction	35, 60% reduction					
	>2000	UWWTD apply as a minimum, but may be more stringent to comply with Water Framework Directive (WFD)										
Romania	>2,000	UWWTD apply as a minimum, but may be more stringent to comply with Water Framework Directive (WFD)										
Ecuador		6 - 9	±3[q]	130		200	100	50 TKN	30		10	<2000 FC MPN/100 ml
Tanzania		6.5–8.5	20–35	100 TSS		60	30	15 TKN			6	<10,000 TC counts/ 100 ml
Jordan				60 TSS	>1	150	60	70			15 as T-PO_4	<1,000 *E. coli* MPN/100 ml Nematodes < 1
India 2015		6.5–9		20 TSS		50	10	10	<5			<100 FC MPN/100 ml
India 2017/18	Metro	6.5–9		50 TSS			20					<1,000 FC MPN/100 ml
	Non-metro			100 TSS			30					
India NGT 2019		5.5–9		20 TSS		50	10	10			1	<230 FC MPN/100 ml
India 1986[r] Inland water		5.5–9	<5	100		250	30	100 TKN		5 as free NH_3	5 diss. PO_4 as P	
Land irrigation				200			100					

Note to the table: Coliforms represented include E. coli, Fecal Coliforms (FC) and Total Coliforms (TC).
[o] *Detail for ranges of permitted consents omitted from this version for clarity.*
[p] *TP and TN only considered in designated "sensitive" areas.*
[q] *Of the receiving water body.*
[r] *Total set covers a range of 40 parameters and three further application areas for discharge into public sewer, marine coastal areas.*

public comments. The review takes place every 5 years and is thus a constant process. Under the current revision, it is indicated that discharge standards for decentralized systems will be developed. However, a nuanced set of re-use standards is not included, despite reported high volumes of re-use.

When comparing wastewater discharge standards, it can be seen that limits vary considerably—although there is some commonality in determinants, such as TSS, COD, and BOD, TN. It is noticeable that the planned Indian standards have the strictest levels in terms of BOD_5, TSS, and TN removal, followed by Peru, Romania and Tanzania. In contrast, Ecuador and Jordan show the most relaxed limits. It can also be observed that—while EU countries must all comply with the same legislation—this still allows individual member states such as Ireland and France to apply discharge standards for small systems that suit their situations. A first iteration toward the principle of load-based standards categorized as metro and non-metro city could be observed in 2017 but contested in 2019.

International Comparison of Standards for Wastewater Reuse

Globally, a rising number of countries is incorporating regulations for wastewater reuse. In Alcalde-Sanz and Gawlik (2014) reported that criteria were applied in Australia, Canada, China, Israel, Japan, Jordan, Mexico, South Africa, Tunisia, the USA, and several states of the EU. Within the following insights and pollution measures of different countries are presented.

The European Union

Pressures from climate change, droughts and urban development have put a significant strain on freshwater supplies in Europe (European Environment Agency, 2012). Europe's ability to respond to the increasing risks to water resources could be enhanced by broader reuse of treated wastewater—but to date only six member states have established regulatory or voluntary standards for reuse.

In order to stimulate increased water reuse across Europe, the European Commission has recently proposed a set of standards for implementation across all member states (European Commission, 2019a,b)—but only for water reuse in agricultural irrigation. It classifies four minimum reclaimed water quality classes in relation to crop category, irrigation method, and indication for water treatment (secondary in combination with filtration/disinfection). The quality requirements include: *E. coli*, BOD, TSS, turbidity, and pathogens, as listed in **Table 9**.

France

Among European nations, France was one of the first countries to issue wastewater reuse standards in 1991. These follow the WHO guidelines, with additional restrictions on irrigation and distances from irrigated areas (Hanseok et al., 2016). They include limits for COD, TSS, Enterococci, phages, and spores (Paranychianakis et al., 2015).

Jordan

ACWUA reports that Jordan is considered one of the most advanced countries in its approach to the application and safety of wastewater reuse. Due to severe water scarcity, 90% of treated wastewater is reused, mainly for irrigation in agriculture. A pragmatic approach to safety was developed that focusses on water quality at the point of use as outlined by the WHO. Farmers are aware of the nutrient content in wastewater, and this allows to reduce fertilizer application by up to 60%, which in turn provides economic benefits and can reduce the contamination of water (ACWUA, 2010, 2011). In an analysis of the public health indicators in terms of deaths, episodes and DALYs attributable to diarrheal diseases published under Lancet in 2017 (The Lancet, 2017), Jordan indicates one of the lowest ranges globally despite the very high urbanization rate of 83.91% and high reuse (The United Nations Population Division's World Urbanization, 2018).

The comparison of different wastewater reuse standards in different countries shows vast differences in limits, allowable applications and overall approaches. Most commonly, restrictions vary according to the intended use of crops. However, combinative measures are also considered, such as for France or the new standards proposed by Europe, which both vary according to different combinations of crop and irrigation methods. With the proposed regulation on reuse in the EU it can be observed that standards are indicating an evolved combination of safety measures.

The most stringent standards are observed in South Korea, USEPA, and Israel in terms of BOD, however here it can be seen that no limits for TN or TP are applied and there is some variation for TSS. Approaches to pathogen management also vary widely—both from country to country and between uses within a country. For example, *E. coli* limits range from 250 to less than 100,000 CFU per 100 ml in France depending on whether crops are consumed without cooking or whether fruits are harvested from drip-irrigated trees. By comparison, the implementation of just one set of standards for both discharge to inland water and use on land in India is regressive with international practice and discourages nutrient recycling.

CONCLUSION AND KEY RECOMMENDATIONS FOR THE WAY FORWARD

In the face of continuously growing population and the lack of proportionate sanitation infrastructure, authorities in India face a mammoth task to safeguard the environment and citizens' public health. This paper has explored recent developments in Indian wastewater discharge and reuse standards alongside the approaches adopted elsewhere. Observed constant changes and inconsistencies have led to a widespread confusion and further reported hesitation in sectoral development. Reasons for these developments are rooted in the shortages of adequate institutional capacity, related lack of detailed risk assessment and a missing consensus phase in the standards setting process including all stakeholders. While the contamination of Indian rivers is reported to be tremendously increasing and requires action, the implementation of a single set of stringent standards without a detailed development plan can risk to slow down the

TABLE 9 | Wastewater reuse standards in different countries (MoEFCC, 1986b, 2015, 2017b; MWI, 2012; CPHEEO, 2013; Ministerio del Ambiente, 2015; Hanseok et al., 2016; European Commission, 2019a; National Green Tribunal order, 2019).

		Parameter	BOD	COD	TN	TP	Coliforms	TSS	pH	Helminth eggs (HE)/Intestinal Nematodes (IN)	Turbidity	Conductivity
		Unit	mg/l	mg/l	mg/l	mg/l	CFU/100ml	mg/l	–	egg/l or applicable	NTU	
WHO		Unrestricted					<1,000 *E. coli*			<1 (IN)		
		Restricted					<10,000 *E. coli*					
US EPA		Food crops	<10				ND FC (median)		6.0-9.0		<2	
		Processed food crops	<30				<200 FC (median)	<30			–	
EU directive[s]	A	All irrigation methods	<10				<10 or ND *E. coli*	<10		<1 HE and <1,000 CFU/l Legionella spp.	<5	
	B	All irrigation methods	25				<100 *E. coli*	35				
	C	Drip irrigation	25				<1,000 *E. coli*	35				
	D	All irrigation methods	25				<10,000 *E. coli*	35				
Jordan		Cut flowers	30	100	70	NA	<1.1 *E. coli*	15	6–9	<1 (HE)		
		Field crops, industrial crops and forest trees (C)	300	500	70	30	–	300				
		Fruit trees, side of road outside city and landscape (B)	200	500	45	30	1,000 *E. coli*	200				
		Cooked vegetables, parks, playground, side road in city (A)	30	100	45	30	100 *E. coli*	50				
Israel			<10	<100	<25	<5	FC <10	<10	6.5–8.5			<1,400
South Korea		Food crops	<8				ND TC		5.8–8.5		<2	<700
		Processed food crops					<200 TC (MPN)				<5	<2,000
Italy			<20	<100	<15	<2	<100 (max); <10 (80%) *E. coli*	<10	6.0–9.5			<3,000
Spain		Uncooked vegetables					<100 *E. coli*	<20		<1/10l (IN)		<10
		Crops for human consumption					<1000 *E. coli*	<35				
		Unit	mg/l	mg/l	mg/l	mg/l	CFU/100ml	mg/l	-	egg/l or applicable	NTU	
Portugal		Vegetables consumed raw					<100 F	<60	6.5-8.4	<1 (IN)		<1000
		Cooked vegetables					<1,000 FC					
France[t]		Unrestricted		<60			≤250	<15				
		All crops except those consumed raw		varies			<10,000	varies				
Ecuador[u]							1,000 FC (MPN)		6-9	absent		
India 2015			10	50	10; 5 for NH_4-N		<100 FC (MPN)	20	6.5-9			
India 2017		Other than metro cities	30				<1000 FC (MPN)	100	6.5-9			
		Metro cities	20					50				
NGT 2019			<10	50	10	1[v]	<230 FC (MPN)	20	5.5-9			
India old norms 1986, Land for irrigation[w]			100					200	5.5-9			
CPHEEO[x] 2013		Horticulture, golf course	10	AA	10	2	NIL	NIL (SS)	6.5-8.3	<1 (HE)	<2	2100
		Non-edible crops	20	30	10	5	230 FC (MPN)	30			AA	
		Crops eaten raw	10	AA	10	2	NIL	NIL (SS)			<2	
		Crops eaten cooked	20	30	10	5	230 FC (MPN)	30 (SS)			AA	

Note to the table: Coliforms represented include E.Coli, Fecal Coliforms (FC) and Total Coliforms (TC).

[s] *A-Food crops consumed raw, direct contact; B and C-Food crops consumed raw where edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops to feed milk- or meat-producing animals, D-Industrial, energy, and seeded crops; recommendation for all classes is secondary treatment+disinfection.*

[t] *Except during period from blossoming to picking, allowed if drop by drop irrigation; Enterococcus, F-specific bacteriophages, spores of sulfate reducing anaerobic bacteria (all log reduction).*

[u] *additional regulations exist for Al, Fe, Pb, Cd, As, Cr, Zn, Cu, Mn, Ni, sulfate, nitrite, DO; fecal bacteriophages and spores of sulfate-reducing anaerobic bacteria > 4log reduction.*

[v] *Valid for discharge to ponds and lakes.*

[w] *Further include arsenic, oil and grease, cyanide, alpha and beta emitter, a bio-assay test.*

[x] *Values both for TN and N; TP as dissolved P; further includes, oil and grease, color, odor and temperature.*

overall sectoral development through heavy investment and by this result in higher pollution levels and public health concerns for unserved regions. One fixed set of standards for both discharge and reuse is unlikely to be effective in controlling the risks from domestic wastewater pollution and increasing water insecurity in the majority of Indian cities. India's challenges might be better addressed by aiming for treatment throughout the country first, while building-up an evidence base that will allow more nuanced future regulations. Toward this end, the 1986 discharge standards, specifying four receiving environments and location classification, offer a more realistic national level discharge framework with more feasible limits than currently proposed standards. In alignment with the objective to encourage reuse, CPCB could prescribe a range of appropriate norms and best practices for various wastewater reuse applications. Given the risks associated with raw wastewater reuse, "safe reuse" should be operationalized using the best available evidence on the treatment needed for specific environmental and human health exposure scenarios.

CPCB's surface water monitoring guidelines stipulate 25 parameters during the pre-monsoon period and 11 parameters at 2-monthly intervals for the rest of the year (CPCB, 2017b). However, capacity constraints have meant that this frequency has not been achieved in practice. To build a strong evidence base for future water quality modeling, monitoring of four key parameters should be mandated, namely pH, BOD, TSS, and Fecal Coliforms. BOD data is already collected as part of CPCB's National Water Quality Monitoring Program. In addition, information on seasonal flows, surface water and groundwater quantity, and information on existing treatment capacity (quantities collected in sewers and treated at STP, quantities collected on-site and transported and treated off-site, quantities collected and treated *in situ*) will facilitate the development of location-specific discharge standards.

The wholesomeness of rivers must be restored under the River Monitoring Committees, comprising central and state bodies. The State Pollution Control Boards have the authority to set location-specific stringent standards (CPCB, 2009), and this approach could be implemented for specific highly polluted stretches or dry season flows. However, the implementation of these stringent standards must be supported by a targeted investment plan providing comprehensive wastewater treatment coverage and water conservation measures at a catchment scale, following a long-term infrastructure plan. Such a plan (e.g., the 2041 sewerage investment plans for Delhi and Bengaluru) would provide recommendations for sewer networks and appropriate combinations of centralized and decentralized systems for each city based on: population projections, type of buildings, climate and financial aspects—under an urban planning approach (Delhi Jal Board, 2014).

Most exercises to compare technologies in India show a bias toward the state of art or best available technology approaches. This bias has led to a focus on a limited set of mostly conventional systems, thereby omitting innovative, decentralized, nature-based solutions that could provide cost-effective and appropriate treatment. India has a broad landscape in technology innovation. However, many innovative technologies lack real-world and long-term demonstration mainly due to economic factors. Since most funding for research is located in the North, the feasibility of studied systems may not apply in the Global South. Given the lack of appropriate performance trials and data, mistrust of new alternative systems, the comfort provided by widely deployed conventional technologies or capacity constraints in gathering information on novel systems, innovative technologies face many challenges and opportunities are missed. This implies that discharge and reuse standards may be set without due reference to technologies that can be both economically and environmentally suited to the situation at hand. Wider commercial and research portfolios are under constant development and include a broad range of alternative technologies and system configurations that are resilient, sustainable, low O&M, low/zero energy and low/zero chemical consuming, making them economical and technically feasible options (CSE, 2019). Such technologies should be included in future standards-setting to ensure that thresholds for discharge or reuse are both adequate and affordable, while constant research would be required to progress on further technology innovation and prove feasibility through long-term demonstration projects.

While the comparative analysis shows that there is a variety of options for more nuanced setting of standards, the perspective of the paradigm shift in the wastewater sector is still nascent. The European Union directive and experiences of countries under the EU illustrate that legislation for a broad range of countries can be formulated, allowing more flexibility to address given variations of a local context. An integrated river basin approach provides a more holistic ground for assessment, regulation through the facilitation of an overall common target in water body protection; apart of territorial management difficulties and in focus of local requirements. The consideration of all water uses and related stakeholders of a water body is essential to incorporate a consensus on management and avoid incoherence. The EU case shows that both for sensitive areas, more stringent discharge standards can be set, while other areas can have more relaxation. It is observed that proposed wastewater reuse standards consider a set of several measures, including water quality criteria in tandem with irrigation methods and suggested technological options. Although nowadays still most institutional frameworks are lagging in setting regulated measures, despite the reality of reuse on the ground, there is a given trend in adapting regulations and by this also more contextualized solutions will evolve. However, comprehensive risk management and assessment are fundamental and along with long-term studies on water quality and public health to provide further detailed necessary insights for appropriate pollution control measures in the local context and an extended set of application areas.

To address sustainability on a broader level, the whole sanitation chain would have to be considered, starting from rising awareness with active "consumers" rather than a "flush and forget" society, involving the "reduce, reuse, recycle" principle. This would require less water consuming toilets, sewerage systems with smaller loops and separated collection systems.

TABLE 10 | Observations and related recommendations for the way forward.

Observation		Recommendation
Frequent changes and inconsistencies	Standards and recommendations throughout involved institutions and policies are not conform	a. Implementation of technical and qualitative consensus finding phase amongst all stakeholders to achieve a better and overall alignment of all interests. b. India has wide variations in environmental conditions and necessities. Formulated standards should be guiding, and target based, providing the possibility for adequate local requirements/interests.
	Standards are not aligned to water quality criteria	c. With given high deviations in seasonal patterns, diminishing resources due to increased water use and associated water pollution, the river basin approach and integrated water resources management would offer a holistic solution. Detailed assessment and modeling could help to a) identify uses, pollution and risks, b) understand dimensions of river characteristics better and c) take appropriate practical and justifiable control measures. d. Water quality criteria and wastewater discharge standards have to consider all designated uses and standards have to be aligned.
Confusion and hesitation amongst sectoral stakeholders due to frequent, not transparent changes		Accessible, more transparent and better-structured information systems.
Deficits in institutional capacity for regulation and implementation of standards		Adequate institutional capacity is fundamental for regulation and implementation of pollution control. a. Incremental approach to capacity development b. Partnering with NGOs and address the current trend in rising citizen groups as a window of opportunity to drive further societal awareness, responsibility and community involvement in direct actions and participatory bottom up approaches.
Insufficient risk assessment		a. Better monitoring and assessment of prevalent risks, e.g. detailed data on public health burden. b. Wider interaction and exchange with involved sectors. c. Setting a health-based target, rather than assuming a no risk scenario despite given high risk reality on ground d. Detailed risk modeling, assessment of possible safety measures along multi barriers, including a wider set of urban planning approaches and technological options with detailed plans for coverage targets and related budget allocation over time.
"Copied" guidelines targeting at best available technology are adopted as national standards		a. Each country should follow a holistic risk assessment according to local conditions and by this develop applicable standards. The sectoral development in the Global North took centuries, long-term investment at many stages to arrive at given standards. b. Stringent standards can create pockets of excellence if not aligned with economic feasibility, and by this reinforce inequality and increased risks. A broad coverage and equal access for all should be set as first target.
Mistrust on implementing more nuanced standards due to assumed illegal discharge		a. Increase necessary resources and capacity for monitoring. b. Provision of different discharge options to avoid illegal dumping and establishment of infrastructure along the whole chain.
Targeted standards cannot be achieved by treatment plants		a. Set realistic pollution control measures. b. Treatment technologies have to be aligned to local conditions. Treatment technologies, which are electricity and O&M intensive are reported as not feasible. c. Intensive training campaigns for certified operators. Eliminate conflict of interest by private operators of STPs, through reinforcement of trained operators and increase in monitoring capacity of STPs.
Conflicting interest and disfunction of water analysis sector		More stringent certification process with certified personnel and frequent monitoring
The range of parameters in standards set and the limits of given parameters are not adequate		a. Standards and related limits should address the targeted risk elimination in consideration of economic feasibility and coverage of all relevant parameters b. Water uses and related water quality criteria have to be reassessed and a more nuanced set of standards has to be formulated to address both the dangers and benefits of wastewater for all use and discharge categories.
High expenses for overall sectoral development		a. Sectoral development should consider economic feasible and suitable technologies for application targeted treatment. b. Comparative technology assessment has to cover a broader range of technologies to address best suitable solutions instead of favoring conventional systems, which are capital and O&M cost-intensive c. Identification of polluters and enforced suitable revenue collection d. Associated risk and economic loss due to lack of sanitation is immense. Overall expenses for the development of the sector have to be increased. Regarding reuse the Multi-Barrier-Approach offers a viable and more economic solution.
Inadequate monitoring		a. A nationwide online monitoring was implemented as a first step to address monitoring with related challenges. However, training of operators for proper calibration and maintenance is required to achieve qualitative results. b. Include citizen-based monitoring to achieve a quantitatively wider monitoring.

(Continued)

TABLE 10 | Continued

Observation	Recommendation
Low acceptance toward innovative and low-tech sanitation solutions	a. Increase in acceptance through information transfer at all levels, including decision-makers and population. b. Increase in capacity for demonstration projects and innovation research in the Global South to collect more data.
Lack in awareness on risks of wastewater	Nation-wide awareness and education campaigns on WASH-related topics.
Wastewater composition is not suitable for further reuse	a. Holistic urban planning with designated areas for different sectors. b. Separate collection of varying wastewater streams with appropriate treatment and according to aimed reuse application area. c. Creation of smaller loops through poly- and decentralized solutions.

Decentralized, onsite, nature and community-based sanitation systems can help to address the urban sustainability challenge, but they would require an enabling environment throughout all levels. Based on the findings and observations of this study, the following related recommendations for the way forward in India are summarized in **Table 10**.

AUTHOR'S NOTE

Interviewees have requested strict anonymity and that no data from qualitative interviews to be presented that can be traced to individuals and institutions. Hence only insights have been presented.

AUTHOR CONTRIBUTIONS

GG conceived of the original idea and helped to supervise this study. TS took the lead in assessment and writing of the publication. VS and DT contributed in assessment of data and information and in writing of the publication. RP assisted in assessment through interviews and review of the publication. All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Governance Arrangements for the Scaling Up of Small-Scale Wastewater Treatment and Reuse Systems – Lessons From India

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Environmental pollution and increasing water scarcity are key features of the urban landscape of India today. The extension of centralized sewerage networks cannot keep up with city growth, and alternative sanitation systems are needed for citywide inclusive sanitation (CWIS). The government of India mandated larger buildings to be equipped with small-scale wastewater treatment plants (SSTP). This resulted in the emergence of a large number of technology and service providers, and in the implementation of thousands of private SSTPs. However, this quick scaling up was not accompanied by the development of appropriate governance arrangements. As a result, a significant proportion of SSTPs underperform and do not meet the effluent standards. Through a systematic analysis of governance arrangements around SSTPs, this contribution analyses the scaling up process of small-scale wastewater management and reuse at building level in India, in particular in the state of Karnataka and the city of Bengaluru. This paper identifies the gaps in this multi-level, polycentric governance framework and investigates which arrangements are needed to enable the performance of SSTPs on the ground and to create the necessary synergies between the relevant governmental agencies, the private sector and civil society. The scaling up of SSTPs in India mainly followed a market governance approach within a governance environment that is traditionally very hierarchical. The authors argue that hybrid governance arrangements, blending hierarchical, market and network governance are needed to foster market regulation and stakeholder coordination, and increase the performance of the sector. They conclude that an efficient governance of SSS requires the creation of dedicated SSS units at state and city level, and the development of an online platform collating all databases, streamlining and supporting processes from establishment to monitoring, and allowing meaningful collaboration between stakeholders. Through the case study of India, this paper contributes to understand the governance arrangements necessary for the successful scaling up of decentralized sanitation systems, and how to fulfill the potential of alternative solutions for sustainable urban water management. It contributes to governance studies by substantiating the concept of hybrid governance approach and proposing concrete measures to make it work for such distributed systems.

Keywords: decentralized wastewater management, sanitation governance, polycentric governance, small-scale sanitation, sustainable urban water management, transition management, sustainability transition, water reuse

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INTRODUCTION

Small-scale sanitation (SSS, also termed "decentralized" or "distributed" sanitation), here defined as wastewater treatment systems serving from 10 to 1,000 households, have proven to be a viable alternative to conventional systems for contexts such as large residential buildings, compounds, peri-urban areas, communities and small rural settlements (Wilderer and Schreff, 2000; Newman, 2001; Parkinson and Tayler, 2003; Gikas and Tchobanoglous, 2009; Van De Meene et al., 2011; Larsen et al., 2013; Singh et al., 2015; Larsen et al., 2016). They are a key component of citywide inclusive sanitation, complementing conventional centralized sewered systems and fecal sludge management (i.e., the management of the sludge from onsite sanitation systems) (Reymond et al., 2016). While they are already widespread in rural areas in western countries, they still remain an innovative approach in most of the world. Countries like India and China are notable exceptions, first because small-scale wastewater treatment systems scaled up to thousands of units, but also because it predominantly happened in urban areas. While a key rationale for small-scale wastewater treatment in rural areas is to avoid transporting wastewater at high cost over long distances, in urban areas it is a solution to rapid urban growth and the increasing need for local water reuse.

Some of the most significant advantages of small-scale wastewater treatment systems are their flexibility, modularity, and cost-effectiveness (Massoud et al., 2009; Libralato et al., 2012), as well as increased water reuse potential (Gikas and Tchobanoglous, 2009; Larsen et al., 2016). They can be implemented in stages and dimensioned as close as possible to the actual wastewater volume, reducing the possibility of accruing idle capacity costs (Maurer, 2009). There are various reasons why conventional large-scale sanitation systems are not always the best solution for rapidly growing cities and peri-urban areas: very high capital and operational costs, the lack of stable energy supplies, spare parts and know-how for reliable operation are factors that limit their expansion (Lüthi and Panesar, 2013); the limited water availability may be another factors in some cities. From a governmental perspective, small-scale sanitation may also have the advantage to shift all or part of the investment for sanitation coverage increase to the private sector, especially to the real estate developers.

Scaling up small-scale wastewater management faces numerous challenges in many low- and middle-income countries, where it remained at pilot stage (Reymond et al., 2018). On the other extreme, where a wide scale implementation of small-scale sanitation systems happened, like in India, China and Indonesia, it often lacks appropriate governance arrangements and monitoring, which leads to a significant number of failed systems (McKinsey, 2014; Ross et al., 2014; Mitchell et al., 2015; Binz and Truffer, 2017). A "failed" system is here defined as a system that is not working according to design, and more specifically which does not fulfill the effluent standards. Successful scaling up entails more than replicating a large number of discrete projects (Eales et al., 2013). It requires innovative management and governance arrangements, financing plans and, often, bringing on board the private sector (Willetts et al., 2007; Abeysuriya et al., 2007; Pahl-Wostl, 2009; Evans, 2013; Gebauer and Saul, 2014; Gebauer et al., 2017). Japan went this path with its Johkasou Act regulating the building-level wastewater treatment plants and related private sector service providers (MoE, 2018).

Scholars have identified numerous systemic and interrelated socio-institutional barriers impeding the implementation of sustainable urban water management (SUWM) (Mitchell, 2006; Van De Meene et al., 2011; Farrelly and Brown, 2011). Barriers include, among others, institutional fragmentation, poor political leadership, unproductive intergovernmental relations, limited long-term strategic planning, and inadequate community participation (see for e.g., Vlachos and Braga, 2001; Brown, 2005; Brown and Farrelly, 2009; Van De Meene et al., 2011; Starkl et al., 2013; Davis et al., 2019). Scaling up innovative distributed SUWM solutions requires mechanisms to strengthen multi-sectoral coordination, cooperation and accountability between sector departments. Governments or parastatal utilities often do not have the capacity and resources to shape and nurture a multitude of small projects (Eales et al., 2013). Small-scale systems often show a mismatch with many institutional conditions (regulations, professional codes or user expectations) (Willetts et al., 2007; Truffer et al., 2013; Binz et al., 2016). While national legislation and programs may provide important guidelines and incentives, the final functioning of the sector and the outcome in terms of actual increase in sanitation coverage with sanitation systems meeting the effluent standards crucially depends on how legislation is implemented and enforced at the local level by public as well as private stakeholders. The enabling conditions and implications for the successful operation and management of scaled up small-scale sanitation systems are addressed in few specific contexts like Indonesia (Mitchell et al., 2015) and Malaysia (Narayana, 2017). However, literature about the governance and scaling up processes of small-scale wastewater management systems in low- and middle income countries remains very scarce. Overall, governance arrangements needed to fulfill the potential of alternative sanitation solutions for urban water management need further research (Hoffmann et al., 2020).

The transition management and governance literature informs about the conditions for the successful scaling-up of distributed systems in urban water management. According to Truffer et al. (2013), the success of a scaling-up depends on the organization of innovation processes in three domains: (i) technological components and system integration, (ii) value chain formation and the development of new business models, and (iii) institutional innovations to create appropriate conditions under which these systems can reliably operate. Linked to these three domains, Binz et al. (2015) identified four key system building processes, that, taken together, enable the diffusion of radically novel socio-technical systems like SSS: knowledge creation; market formation; investment mobilization; and technology legitimation. "Technology legitimation" is defined as the "activities that embed a new technology in existing institutional structures or adapt the institutional environment to the needs of the technology." Pahl-Wostl (2009, 2019) differentiates three governance approaches which may shape the sector: hierarchical, market and network governance. Along with sustainability practitioners, Van De Meene et al. (2011) advocate for hybrid governance arrangements at a practical and operational level, comprising network and hierarchical approaches with market governance instruments. Moving beyond conventional approaches toward citywide inclusive sanitation needs to be both top-down and bottom-up (Reymond et al., 2016). The classical distinction between hierarchies, networks and markets as ideal-typical governance modes has proven to be very useful for analyzing complex and hybrid governance settings (Pahl-Wostl, 2019). The conceptual basis provided by Truffer, Binz, Pahl-Wostl and Van de Meene will be used to understand the findings about the SSS sector in India and frame the authors' recommendations about improved governance arrangements.

Klinger et al. (2020) estimated that more than 20,000 small-scale wastewater treatment plants (SSTPs), mostly privately funded, were implemented in India following a policy drive for decentralized sanitation systems, aiming to address fast urban growth, an increasing water scarcity, and the need for more water reuse (MoEF, 2006). In Bengaluru, SSS has an installed capacity to treat an estimated 10–20% of the city's sewage (Kuttuva et al., 2018; Srinavas, 2018). This quick and unprecedented scaling up process of SSS in large buildings has not been thoroughly studied, and lessons learnt are scarce. Studies are hindered by the lack of a centralized database and the nature of the SSTPs (privately owned and privately managed, and often hard to access). The governance framework did not develop at the same pace as the implementation of the SSTPs, and the governmental bodies are still not fully equipped to monitor the scaling up process and the performance of the systems. Studies have found that many of these SSTPs are experiencing performance problems (Suneethi et al., 2015; Chatterjee et al., 2016; Starkl et al., 2018; Klinger et al., 2020).

Through a systematic analysis of governance arrangements around small-scale wastewater treatment and reuse systems, this paper identifies the gaps and loopholes in the current governance framework for SSTPs at building (or cluster of buildings) level in India and in the state of Karnataka in particular. It proposes measures to optimize the efficiency of policies and create synergies between the different relevant governmental agencies. In this paper, "governance" refers to the rules, roles and relations that make sanitation systems work. It includes the formulation, establishment and implementation of sanitation policies, legislation and institutions, and clarification of the roles and responsibilities of government, civil society and the private sector in relation to sanitation systems and services (UNDP-SIWI, 2016a,b). Institutions are used here according to the convention in institutional analyses in the social sciences to denote rules governing the behavior of actors (Pahl-Wostl, 2009): "Institutions do not refer to organizations or physical structures. Formal and informal institutions refer to nature of processes of development, codification, communication and enforcement." The governance framework in India involves multiple stakeholders at national, state and city level. It is a multi-level, polycentric governance system, a concept which Pahl-Wostl (2009) defines as a "complex, modular system where differently sized governance units with different purpose, organization, spatial location interact to form together a largely self-organized governance regime."

In this contribution, the authors (i) analyze the scaling up process and governance framework of small-scale wastewater management at building (or cluster of buildings) level in India; (ii) analyze the particular case of the state of Karnataka and its capital city Bengaluru, which are spearheading the implementation of SSS systems in India; (iii) identify the gaps in the governance framework; and (iv) propose governance arrangements which foster the performance of SSTPs and the creation of the necessary synergies between the relevant governmental agencies, the private sector and civil society. Despite the complexity of Indian institutions, the case of Karnataka and Bengaluru is quite typical of the issues faced by governments when scaling up innovative systems such as small-scale wastewater treatment plants. It can thus inform similar processes in many countries worldwide, especially in terms of administrative processes and governance arrangements which allow economies of scale and proper monitoring. It also provides an insight on how to deal with multi-level, polycentric governance systems in sustainable urban water management and substantiates the concept of hybrid governance approach for distributed systems.

METHODOLOGY

The results presented in this paper are part of a broader study on small-scale sanitation in India consisting of three components: (i) a technical analysis; (ii) a financial analysis; (iii) a governance analysis. The technical analysis consisted of a questionnaire-based assessment of 279 SSTPs in the field, as well as three rounds of 24-h effluent sampling in 35 of them (Klinger et al., 2020). In this paper, reference will be made to Klinger et al. (2020) when building on methodologies and results from the technical analysis component. The structured questionnaire was performed with SSTP managers, operators, and users when available. It provides insights on the performance of SSTPs, operation and maintenance, reuse practices, general perception of users and the skills and training level of the managers and operators, and informs about the effects of the governance framework on the ground.

The methodology used specifically for the governance analysis component consists of a mix of qualitative methods:

- A review of the policies, laws and regulations around small-scale wastewater treatment in India, with a special focus on the state of Karnataka.
- Identification of key public and private stakeholders at national level, in the state of Karnataka, and in the city of Bengaluru.
- Desk-based stakeholder and procedure mapping and analysis of the stakeholders' roles and responsibilities along the project cycle of SSTPs.
- Semi-structured qualitative expert interviews with key informants of the sector, aiming to get a general

understanding of the situation. These interviews were conducted by the project team in different local languages, and were not recorded as many stakeholders, especially government stakeholders, are afraid that truthful answers could be used against them. For that reason focus was given on trust-building and informality. Key information was then extracted and compiled.
- Consultations and informal discussions with sector experts and concerned citizens.

Thirty-five key informants were interviewed from different groups, as synthesized in **Table 1**. **Table 1** does not include the stakeholders interviewed during the assessment of the 279 SSTPs. Knoke (1996) and Fischer et al. (2017) propose a systematic strategy for identifying stakeholders in a policy sector, relying on three criteria: (i) "decisional criteria": those stakeholders that participate in important decision-making venues of the sector; (ii) "positional criteria": those stakeholders that are in an institutional position to influence the policy sector; (iii) "reputational criteria": those stakeholders that are identified by other stakeholders as being influential in the policy sector. During interviews, respondents were asked to mention important stakeholders not identified at first (*snowball principle*). This strategy of relying on "crowd knowledge" ensured that the study captured the most important stakeholders. The higher number of interviews with governmental stakeholders at state level and with private sector stakeholders reflect the fact that sanitation is primarily a state-level matter and that SSS is mainly driven by the private sector.

The governance issues are thus analyzed both from the top (the national and state policy level) and from the bottom (the impact at sanitation system level). The analysis looks at the overall governance framework for small-scale sanitation, and at the governance arrangements along the project cycle of SSTPs. This approach allowed to obtain an understanding of the strengths and weaknesses of the current governance framework and to identify key factors impairing the efficiency of SSS at scale. The results were then reflected through the conceptual framework provided by Pahl-Wostl (2009), Van De Meene et al. (2011), Truffer et al. (2013), and Binz et al. (2015), presented in the introduction.

The governance framework for small-scale wastewater treatment slightly differs in every Indian state. This paper focusses particularly on the state of Karnataka, as it is the most advanced state respective to SSS (advanced policies and highest numbers of units) and is therefore appropriate to understand the challenges of the scaling up process. Such challenges are not (yet) apparent in other states that do not implement small-scale wastewater treatment policies to the same extent. Although this approach gives a good overview of what the challenges can be and what is needed for an efficient governance framework around SSS, it remains a partial view, and cannot fully represent what is happening all around India. In order to achieve the latter goal, an analysis of the governance framework in each state in view of our findings would be needed.

TABLE 1 | Number of interviewees per stakeholder group.

Stakeholder group	Number of interviewees
Governmental agencies at national level	2
Governmental agencies at state level	14
Governmental agencies at city level	4
Private sector	11
NGO	4

REVIEW OF THE POLICIES, LAWS AND REGULATIONS

Small-scale sanitation is increasingly contributing to sanitation coverage in urban India, and is imposing itself as a key component of citywide inclusive sanitation in the country's cities, next to conventional centralized systems and fecal sludge management (FSM) (Ulrich, 2018). SSS systems have the potential to complement large-scale plants in the non-sewered zones of cities, while significantly reducing the time needed for planning and implementation. Besides, shortage of funds has not been able to allow for the blanket coverage of entire cities with a centralized sewer network (Singh et al., 2018). However, whereas the governance framework for centralized systems is already established and the one for FSM under quick development, the governance framework of small-scale sanitation is still weak, despite its growing role in increasing sanitation coverage, water reuse and protecting the environment. Besides, as with many environmental policies in India (Brunner et al., 2010; Sakthivel et al., 2015), there is an important gap between the policies and the actual implementation on the ground.

Urban wastewater management in India is mainly driven by the Ministry of Housing and Urban Affairs (MoHUA), the Ministry of Environment, Forest and Climate Change (MoEFCC) and their line agencies, as illustrated in **Figure 1**. In the Constitution of India, the responsibility of sanitation is delegated to the states, under purview of MoHUA (formerly Ministry of Urban Development – MoUD) at national level. Constitutionally, MoHUA's role is confined to advocate policies, design guidelines and standards, clearly demarcating sanitation as a state subject (Bhullar, 2013). MoHUA is the principal policy-making agency in the field of urban sanitation and also largest funder of the sector (Wankhade, 2015). State governments are vested with powers to legislate on sanitation either directly or indirectly. With the enforcement of the 74th constitutional amendment in 1992, Urban Local Bodies (ULBs), which are in charge of approving new buildings, are given the responsibility of devising and implementing sanitation strategies. In a few metropolitan cities, utilities are responsible to deliver water supply and sewerage services (Water Supply and Sewerage Boards – WSSB). Such bodies are partly or wholly owned or controlled by state government (Bhullar, 2013). Where a WSSB exists, it takes over the responsibility of sanitation from the ULB. In that case, the ULB's role is limited to devising building regulations, which can encourage small-scale sanitation.

In practice, ULBs and WSSBs (in metropolitan cities) do not have sufficient institutional and financial capacities to

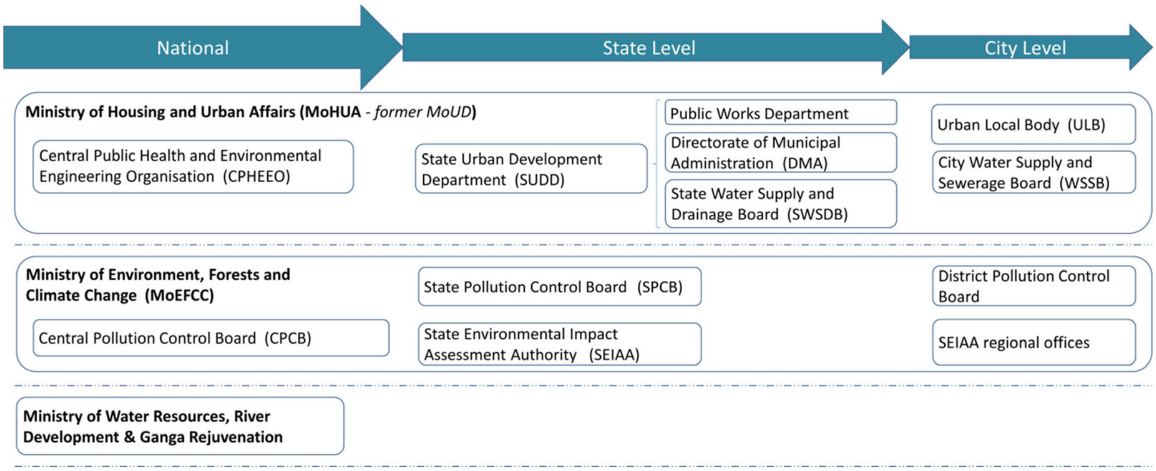

FIGURE 1 | Government agencies responsible for urban wastewater management in India (in January 2019).

build, operate and maintain sewage infrastructure with city-wide coverage (Ahluwalia, 2011; Planning Commission, 2011). To tackle the gaps in provision of sewage collection and treatment services in the absence of a WSSB, State Water Supply and Drainage Boards (SWSDBs) were formed at state level to support ULBs in planning, designing and implementing sewerage and wastewater treatment infrastructure. SWSDBs draw funds from national and state governments. They can build treatment plants and then hand them over to ULBs for operation and maintenance. Similarly, parastatal agencies also rely on state government or donor agencies for financial resources to construct large-scale wastewater management infrastructure.

Ministry of Environment, Forest and Climate Change and line agencies are in charge of minimizing environmental pollution, as well as planning, promoting and coordinating environmental policies and programs in the country. They are responsible for setting environmental standards (especially the discharge standards for treated wastewater). The Central Pollution Control Board (CPCB) was constituted under the Water Act in 1974 as a line agency of MoEFCC with the responsibility to prevent, control and abate environmental pollution and to set the wastewater discharge standards for the entire country. All the sewage treatment plants in India should adhere to the standards issued by CPCB. At state level, State Pollution Control Boards (SPCBs) are responsible for the implementation of legislations related to environmental pollution. SPCBs are provided freedom to toughen the regulations enforced by CPCB. SPCBs are responsible to monitor the performance of all wastewater discharging entities (buildings, industries, large and small-scale sanitation systems).

Recognizing that Indian cities grew faster than the pace at which centralized wastewater management systems could be extended, the Ministry of Environment and Forests (today MoEFCC) prescribed SSS systems for large residential, institutional and commercial buildings in 2004 through an amendment to the Environmental Impact Assessment (EIA) notification (MoEF, 2004). MoEF further amended the EIA notification in 2006, prescribing SSS for buildings with a total built up area above 20,000 m^2 throughout the country (MoEF, 2006). The key rationale behind EIA notification 2006 is that large buildings tend to have a greater environmental impact and mandating SSS was a mitigating measure. This national policy was followed by uptake and adaptation to various extents at state and at city levels, which generated a boom in private sector small-scale wastewater treatment service providers (Klinger et al., 2020). SSS was fostered in various policy guiding documents, ‘model building bylaws’ and small-scale wastewater management guidelines, which are suggestive measures leaving enforcement and application to the willingness of Urban Local Bodies.

Several SPCBs decided the application of a stricter threshold for the construction of SSS, like in the case of Karnataka. Thousands of units have been implemented since then throughout India (Klinger et al., 2020). In view of increasing water scarcity and the high price of conventional centralized systems, scaling up of SSS will only accelerate in the years to come.

FACTORS IMPAIRING THE EFFICIENCY OF SSS AT SCALE

The assessment of 279 SSTPs showed that a large number of SSTPs do not perform according to their technical design and to the effluent standards (Klinger et al., 2020). Effluent quality was tested for 35 of these plants, which showed that more than two thirds from all categories of treatment technologies exceeded BOD standards at least in one sample, and microbial quality of effluent consistently did not meet CPCB standards in almost all systems analyzed (Klinger et al., 2020). This provides evidence that the current governance framework for small-scale wastewater treatment systems does not provide the necessary incentives to guarantee system performance on a wide scale. The governance analysis shows that weaknesses exist at all governance levels, from the governance arrangements at national level to the details of the implementation and operation processes of small-scale wastewater treatment systems. Based on the analysis, the authors conclude that, from a governance perspective, the overall performance and success of small-scale wastewater treatment in India is impaired by a number of interlinked factors:

(i) Lack of recognition of SSS by the government agencies responsible for urban sanitation planning;

(ii) Lack of coordination between relevant governmental agencies;

(iii) Lack of dedicated budget and human resources for consent delivery and monitoring;

(iv) Loopholes in the establishment, handover and monitoring procedures;

(v) Inadequate operation & maintenance (O&M);

(vi) No specific effluent and reuse standards for SSTPs;

(vii) Insufficient integration of SSS in water reuse planning;

(viii) Lack of key centralized governance structures, such as training and information platforms.

The results for each of these aspects are developed in the following paragraphs.

Lack of Recognition of SSS

The study highlights that although more than 20,000 small-scale wastewater treatment systems were constructed in India with an ongoing increase, the authorities in charge of sanitation planning (MoHUA and line agencies) are unaware of the number and location of these systems (Klinger et al., 2020). SPCBs and SEIAA are the only agencies which possess some databases, but the latter are not harmonized nor digitized. As a consequence, SSS is still not on the sanitation map next to conventional centralized wastewater management and FSM. The analysis shows that it is because the drive for small-scale wastewater systems did not come from the governmental agencies in charge of the wastewater sector (i.e., MoHUA and line agencies at state and city levels), but from MoEFCC and line agencies, based on an environment protection and sometimes water saving rationale. Based on the review of policies, laws and regulations, **Figure 2** highlights how the roles and responsibilities dramatically differ between large-scale and small-scale wastewater management in terms of policy, funding and implementation. For the former, MoHUA and line agencies are entirely in charge, whereas MoHUA is almost absent from the current small-scale wastewater management sector. The latter is under the responsibility of MoEFCC and line agencies and the private sector. In particular, funding and implementation of SSS are entirely delegated to the private sector.

The governmental agencies that are in charge of urban sanitation planning do not have the overview of the growing number of SSS systems and their functional status. As highlighted by Reymond et al. (2018), government agencies are often risk averse and reluctant to get out of business-as-usual and to take up responsibilities on new systems that seem to demand important budget and human resources. Despite the growing contribution of SSS to sanitation coverage, the WSSBs and ULBs, which are the governmental bodies in charge of sanitation planning at local level, do not show ownership for small-scale systems, nor do they integrate them in their sanitation masterplans. The main responsibility as well as most of the existing information regarding SSS are in the hands of the State Pollution Control Boards, although they are only in charge of monitoring and not sanitation planning *per se*. There are attempts to involve the ULBs in monitoring of SSS, but this was not enforced at the time of the study.

Lack of Coordination Between Relevant Governmental Agencies

The lack of coordination manifests itself in different domains: databases; policies; planning. Currently, Indian states and cities do not have a comprehensive electronic database of small-scale wastewater treatment systems (unified across states and, more importantly, among their own governmental agencies) (Klinger et al., 2020). A lot of information is still being stored on paper (e.g., sampling results). State pollution control boards, the regulatory agencies in charge of approving and monitoring SSS at state level, do not have a curated, up-to-date database in electronic form. This impairs proper georeferencing and monitoring of SSTPs, which would be the basis for further urban planning, including the development of efficient water reuse strategies and assessment of the sanitation coverage.

Policies are not coordinated, as highlighted by the lack of recognition of SSS by MoHUA and line agencies and their investment strategies. Finally, urban planning is not coordinated, which sometimes results in double investment, e.g., in cases where an SSTP is mandated in a building that will be shortly connected to the main sewer network.

Lack of Dedicated Budget and Human Resources

The policies devised by the Indian government were successful in enforcing the implementation of SSS in certain building categories. Interview results and visits to relevant government agencies tend to confirm that they were not followed by the budget and human resources allocation necessary to monitor the implementation and operation of thousands of units, nor were the institutions governing these prepared to the management of a large number of distributed systems. Similar to the situation in other emerging economies (Binz and Truffer, 2017), SSS systems thus got successfully installed, yet without the creation of an actor network, financial infrastructure and institutional arrangements that would be able to effectively monitor the spatially dispersed plants and enforce regulation.

The authors assume that it is a main cause for the following shortcomings, highlighted during the interviews of experts and own observations:

- General lack of human resources dedicated to SSS, especially in the SPCBs for monitoring;

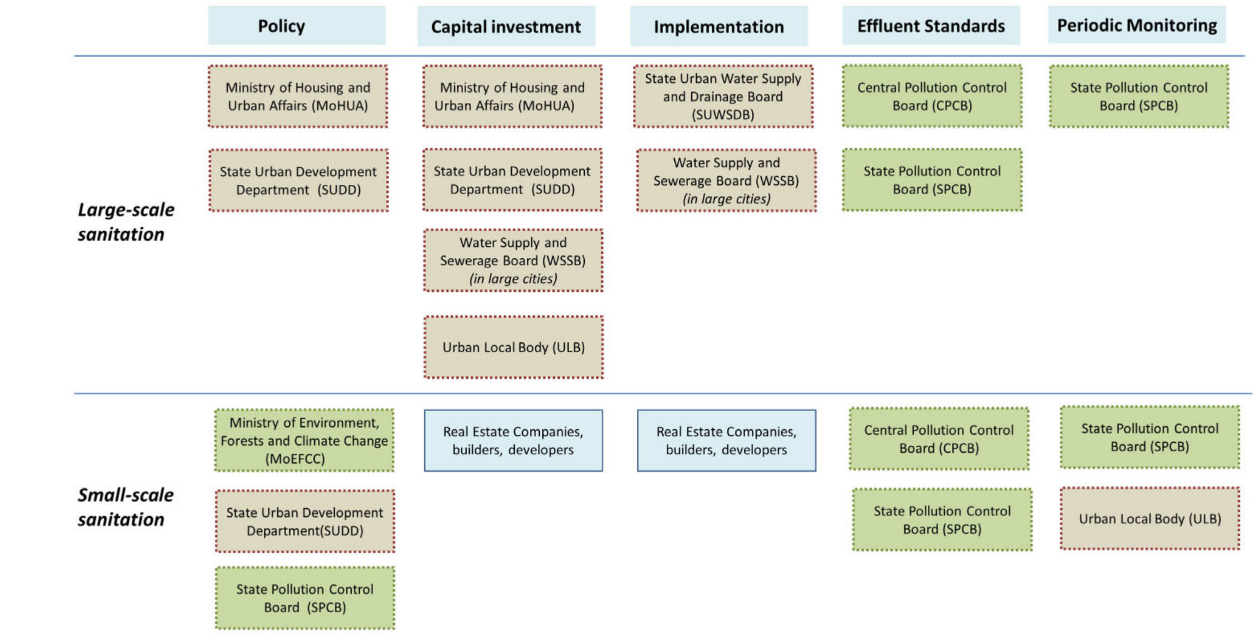

FIGURE 2 | Comparison of responsibilities in the large-scale and small-scale sanitation sectors; the governmental agencies highlighted in brown fall under MoHUA and the ones in green under MoEFCC.

- Lack of technical support for planning, operation and maintenance of such systems from the responsible government agencies to the private sector;
- Lack of capacity building and training, both for government workers and private service providers;
- Inadequate monitoring mechanisms due to lack of funds, lack of staff and lack of coordination between governmental agencies;
- Weak enforcement of laws and regulations and insufficient penalization.

Loopholes in the Establishment, Handover and Monitoring Procedures

The procedures to establish and monitor private small-scale wastewater treatment systems were systematically analyzed for the case of the state of Karnataka, through desk-based research and discussion with experts. The process can be broken down into (a) the preliminary approval, obtained through the building approval; (b) design; (c) implementation; (d) post-implementation check, start of operation and handover; (e) monitoring. Real estate developers appoint SSS designers. There are two types of consents required to establish and operate SSS systems, which are granted by the State Pollution Control Board (SPCB) for projects with an area below 20,000 m^2 in Karnataka: (a) the Consent to Establish (CTE), to be obtained at the end of the design phase, and (b) the Consent to Operate (CTO), to be obtained at the end of the implementation phase, before the commissioning of the plant, and to be renewed at a defined frequency. Inspectors from the Water Supply and Sewerage Board (WSSB) in large cities or from the ULB in small and medium towns carry out inspections once the whole building is complete, which mainly focus on setbacks, height of the building and presence of the SSS system. There are no defined guidelines for the validation of SSS systems for any available technology.

In the residential context, real estate companies (builders) are responsible for the operation and maintenance of the systems until a formal resident welfare association (RWA) is formed. Then, the newly constituted RWA has to take up the responsibility for the systems. There is no defined period since real estate companies are obliged to maintain all the common areas within the building premises till the creation of the RWA.

The study highlights the main weaknesses along the establishment, handover and monitoring procedures. **Figure 3** illustrates these weaknesses by representing the different interactions between the government agencies and the private sector in the state of Karnataka. The private sector is responsible for planning, design, implementation and operation and maintenance, whereas the main roles of the government agencies are consent issuance and monitoring. The numbers in the list below refer to the number tags in **Figure 3**, placed at the relevant location on the stakeholder and processes map:

1. *Technology selection which is not based on long-term sustainability and life-cycle cost of the future treatment plant:* the stakeholders in charge of technology selection are usually not the ones who will operate the plant on the long-term (real estate developers vs. building management body) (Klinger et al., 2020). Capital costs are the main selection criteria, and not O&M cost. Life cycle costs and management implications are not taken into consideration. Besides, there is insufficient knowledge of the different options and the implications of choices;

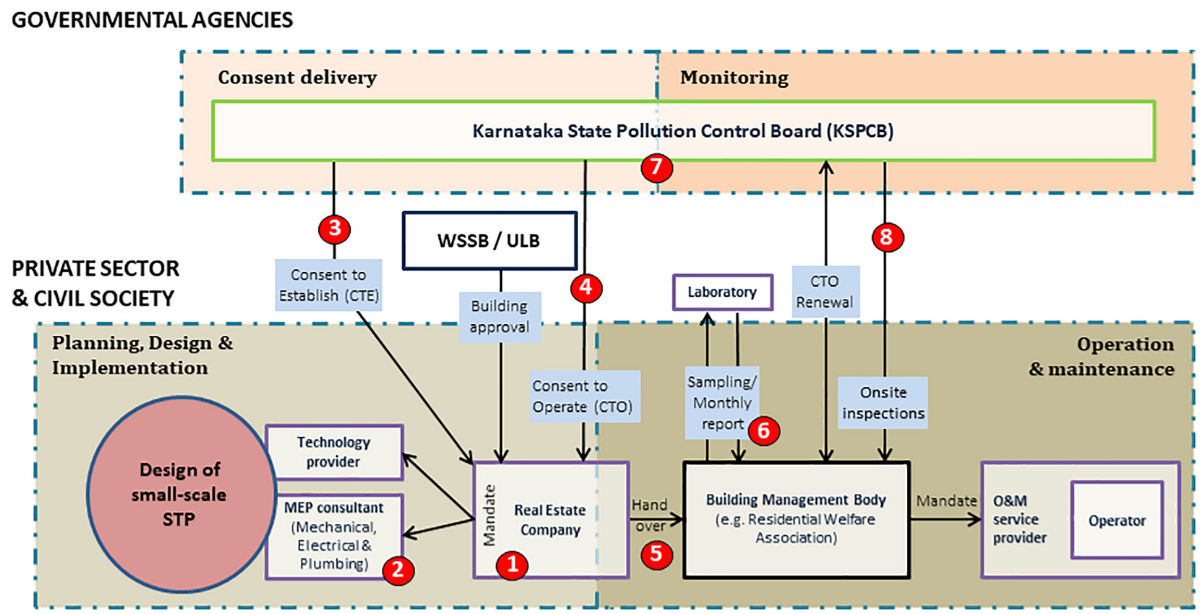

FIGURE 3 | Stakeholders, procedures and governance arrangements through the life-cycle of a small-scale wastewater treatment system in the state of Karnataka. The red numbers refer to the main weaknesses explained in the text.

relevant governmental bodies do not provide guidance nor control.

2. *Unqualified consultants:* lack of experience and expertise for design and implementation on the side of consultants, such as Mechanical, Electrical and Plumbing (MEP) consultants.
3. *Consent to Establish:* lack of rigor in design evaluation, mainly linked to a lack of capacities and guiding documents.
4. *Consent to Operate:* lack of capacities at PCB to carry out an effective inspection of the infrastructure.
5. *Handover:* absence of formal transfer process between (most often) the real estate company and the building management body (e.g., a RWA). The newly constituted building management bodies were not involved in technology decisions, are not well prepared to assume their new operational responsibilities, and the relevant training and documentation is often lacking.
6. *Sampling and reporting:* the building management body takes samples and sends them to a certified laboratory. The laboratory sends the results back to the building management entity, who then transfers them to the PCB. This results in a high risk of data manipulation during one of the different steps of the process.
7. *Inexistence of unified, georeferenced online database of SSTPs:* this results in a difficulty for the PCB and other agencies involved to track the SSTPs.
8. *Lack of financial and human resources for the PCB to do sufficient onsite inspections.*

Although this process bears the features of a hierarchical governance approach, the lack of guidance, competency, resources and enforcement leaves a lot of freedom to the private sector. The authors argue that in such a weak hierarchical governance framework, market governance dominates *de facto*. The market grew with very little restriction from the government, and the lack of capacities and enforcement of the latter enables the different private stakeholders to easily work around the regulations.

Inadequate Operation & Maintenance

The operation and maintenance (O&M) of SSTPs is under the responsibility of the real estate developer or the building management body, and the assessment of 279 SSTPs found that many systems were not properly operated (Klinger et al., 2020). The private sector plays a key role in the operation and maintenance. Different management arrangements exist: (a) real estate companies keep the responsibility of O&M against a fee, (b) the entire operation and maintenance is outsourced to a private player based on annual contracts, (c) skilled operational personnel is hired to run the systems, or (d) RWA manages on their own with the available local staff (mostly unskilled). Whatever arrangement is in place, there is a lack of capacity of building owners to hold contracted service providers accountable (Klinger et al., 2020).

The field survey questionnaire to SSTP operators about their education and training level showed that they often do not have the required skills nor the understanding of the treatment processes at stake (Klinger et al., 2020). This is also confirmed by the findings from Suneethi et al. (2015), Chatterjee et al. (2016) and Davis et al. (2019). The latter highlight that the lack of technical support, lack of clear O&M plans and insufficient O&M funds are major failure factors for SSS in India. There are no licensing/certification mechanisms and no training available.

The operators are often left alone, and the SSTPs are often not operated toward performance, but cost reduction: the O&M service provider or building management body may run the treatment plant in order to reduce the energy costs, in a way that can be detrimental to the treatment performance (Chatterjee et al., 2016; Klinger et al., 2020). There is insufficient incentive to properly operate plants. In some cases, water reuse may play as an incentive, especially where treated wastewater is used for toilet flushing (Klinger et al., 2020).

The review of regulations show that they do not state how the systems should be operated. Guidelines for operation and maintenance for wastewater treatment systems are developed by line agencies of MoHUA, but it was not done for SSS due to the lack of institutional ownership. The lack of proper monitoring from the relevant government agencies leaves a poor O&M by the responsible private or civil society stakeholders largely without consequence.

This study did not allow showing clearly if one management arrangement leads to better treatment performance outcomes than the others. Further research comparing management and contractual arrangements is needed. The authors assume that awarding performance-based contracts to private companies specialized in O&M of SSTPs is the most promising schemes. Increasing service provider accountability through design-build-operate contracts should also be considered.

No Specific Effluent and Reuse Standards for SSTPs

The Indian effluent discharge standards apply for all wastewater treatment plants; there is no specific discharge standards for small-scale systems. The standards prescribed by the Central Pollution Control Board (CPCB) are mandatorily applicable throughout the country. However, state pollution control boards (SPCBs) have the freedom to toughen these regulations and standards. SSS have to adhere with the standards set by the SPCBs. The state of Karnataka adhered to the latest modifications in 2018 after having been more stringent than the national standards: treatment plants in metro cities and all the major state capitals should now adhere to BOD < 20 mg/L.

Starkl et al. (2018) and Klinger et al. (2020) showed that the standards are too stringent for most SSTPs to comply. As effluent sampling is left to the entity responsible for O&M, and there is little direct monitoring by the government, SSTP owners have little incentive to comply. Standards that are realistically difficult to meet combined with a weak monitoring framework, leads SSTP owners to focus on circumventing the monitoring system in place rather than investing in improving the performance of their plant. The authors would advocate for more network governance allowing a transparent discussion between SSTP owners and the governmental agencies in charge of setting the standards. The review of newspaper articles showed that the civil society and private sector are currently not involved in the development of standards, but can influence them retroactively at state level through collective action.

The interviews of experts showed that the introduction of differentiated standards for different reuse purposes is debated. On the one hand, such measure can provide incentives to SSTP owners, but on the other side, it is very difficult to monitor and enforce, and may lead to new loopholes. Besides, tightening standards may overtask the government agencies in charge (Starkl et al., 2018).

Insufficient Integration of SSS in Water Reuse Planning

Water reuse policies can trigger SSS (Larsen et al., 2013). MoHUA's National Urban Sanitation Policy (NUSP) of 2008 (MoUD, 2008) encourages reuse of reclaimed water, especially for construction, irrigation and gardening, and recommends a minimum of 20% reuse of wastewater in every city. The National Water Policy from 2012 promotes and incentivizes the reuse of wastewater (MoWR, 2012). Bylaws for the construction industry and power plants state that only treated wastewater should be used (Never, 2016). SSS, through its distributed nature, fosters the onsite or neighborhood-level reuse of treated wastewater. It thus plays a crucial role in fulfilling water reuse strategies, but its potential role and advantages compared to conventional sewered systems are not fully taken into account by the responsible government agencies.

Some states and cities proactively developed policies to bring these concepts closer to the ground. Already in 2003, in a situation of drinking water shortage, Karnataka issued a government order for Bengaluru, making it mandatory to use tertiary treated water for non-potable purposes, with penal provisions in case of non-compliance. The order clearly states that the Bengaluru Water Supply and Sewerage Board (BWSSB) shall not provide potable water supply for activities including gardening, vehicle cleaning and construction (GoK, 2003). In 2015, The Karnataka State Pollution Control Board issued an order which stipulates that secondary treated sewage mandatorily be sold for use for non-potable purposes, such as industrial use, railway and bus cleaning, flushing of toilets, horticulture and irrigation (KSPCB, 2015). According to that order, no potable water shall be allowed for such activities. The enforcement is, however, difficult and not strictly done. Nonetheless, the present study shows that the reuse of treated wastewater from SSS is widely practiced in Bengaluru and the other surveyed cities. While it is hard to quantify the actual amount of water reused, the field survey showed that more than 75% of the studied 279 systems reused at least parts of the treated water for irrigation, toilet flushing and sometimes air conditioning (Klinger et al., 2020).

Lack of Key Centralized Governance Structures

The study shows that the potential for economies of scale at government and private sector levels is hardly exploited. Numerous private sector stakeholders are competing for technology provision and O&M service provision (Klinger et al., 2020). Despite the high number of units, the management schemes are very diverse and scattered, with hardly any monitoring. Operators are left alone, without a network to rely on. The observed market governance approach lacks centralized coordination around urban development plans, linked with monitoring and enforcement to ensure performance meets standards. Besides, training programs for operators and municipal sanitation officers are lacking. This results in the observed shortcomings not being addressed, the best practice not incentivized, and the absence of an information sharing platform.

A higher degree of centralization would benefit the performance of the sector, especially for O&M and training, and robust standardized monitoring structures would allow sector learning and optimization.

MEASURES RECOMMENDED TO IMPROVE THE GOVERNANCE OF SSS

The governance analysis presented in this paper shows that the scaling up of small-scale wastewater treatment and reuse systems in India mainly follows a market governance approach and is very little impregnated by network governance. Even though the hierarchical governance approach is dominant in India, the lack of coordination of the different government agencies resulted in market governance playing a crucial role. More centralized coordination, especially around monitoring, enforcement and training, and to some extent more network governance with intermediary structures linking effectively the different government agencies, the private sector and the civil society (mainly represented by building owners associations), are needed for a more robust governance framework. This tends to confirm the claim by Van De Meene et al. (2011), Pahl-Wostl (2009), and other scholars that hybrid governance frameworks are likely to deliver more sustainable outcomes. This study also reinforces the findings from Van De Meene et al. (2011) highlighting the practitioners' perception that the hybrid governance approach would facilitate sustainable urban water management.

This analysis shows that among the three domains pointed out by Truffer et al. (2013) for a successful scaling up, the "technological components and system integration" materialized through the private sector, as well as the "value chain formation and the development of new business models"; these include the "market formation" and "investment mobilization" mentioned by Binz et al. (2015). The market formation is well advanced, except for the services around O&M which still show development potential. "Knowledge creation", another key system building processes identified by Binz et al. (2015), is led by the private sector, but was not yet transferred to the relevant governmental agencies and translated into guidelines because of the lack of knowledge sharing and the lack of a structured monitoring that would allow lessons learnt and the diffusion of best practice. The "institutional innovations to create appropriate conditions under which these systems can reliably operate", third domain pointed by Truffer et al., are still not adequately developed. While SSS is explicitly mentioned in regulations, and increasingly in water reuse policies, the structures that can guarantee its performance are still not mature, because the legitimacy of SSS is not yet anchored in MoHUA and line agencies. This is in line with Binz et al. (2016), who argue that the successful scaling up of innovations crucially depends on technology legitimation by the main stakeholders, from the user to the relevant government agencies.

The authors identify the main weaknesses in the governance framework and recommend measures to address them. **Table 2** synthesizes the authors' recommendations. Most proposed measures are geared toward more effectiveness and efficiency of the hierarchical governance, as it remains the main driver of policy change in India. The need for new hierarchical governance structures to strengthen the centralized monitoring of SSTPs and the overall coordination of the sector is reflected in the two following key proposals, as illustrated in red in **Figure 4** (adapted from **Figure 3**):

1. *Creation of an online platform* for small-scale wastewater treatment plants, functioning as a unified database to which all relevant governmental agencies have access and where all the documents and information related to each unit are collated via a unique ID for each plant.
2. *Creation of dedicated governmental SSS units* at state level, with sub-units in every city, embedded in the Water Supply and Sewerage Board (WSSB) where existing or in the Urban Local Body (ULB) otherwise. This is justified by the need for a higher coherence of urban water and wastewater management planning at city level. It is recommended that these agencies take over the oversight responsibility of SSS. PCBs would remain the main agency in charge of long-term monitoring, as per their constitutional mandate.

An online platform is seen as a powerful tool for urban water management and infrastructure planning, partially automated performance monitoring, as well as sector learning and benchmarking. It would contribute to clearly locate SSS next to conventional wastewater management and FSM in citywide inclusive sanitation. Such a platform would be well aligned with the current digitalization trend in India. Digitalization is increasingly implemented and fostered by the Government of India, for example in these initiatives: Digital India Mission, Swachh Barat Toilets with GIS tracking, consent management platform in the state of Tamil Nadu, National rural drinking water monitoring (Wescoat et al., 2016), etc.

The authors recommend that these two structures be endorsed at national level, but developed and validated at city and state level. Testing and validating the new structures in a progressive state would allow to make them more robust, create a role model and facilitate their replication in the other states. The state of Karnataka could take the role of pioneer state, as it is currently spearheading the scaling up of SSS in India and is experiencing serious water scarcity.

The two proposed structures would strengthen the technology legitimation, knowledge creation and monitoring & evaluation of SSS and thus create "appropriate conditions under which these systems can reliably operate." They have the potential to improve the current governance framework, through:

1. Facilitating the merging and completing of existing databases, standardizing data collection and removing certain loopholes.

TABLE 2 | Weaknesses in the governance framework and measures recommended by the authors.

Weaknesses in the governance framework	Possible measures
Recognition of SSS by the governmental agencies responsible for urban sanitation planning	• Specify role and scope of SSS in national policies, state sanitation strategies and city sanitation plans • MoHUA: develop technical specifications and guidelines, so that funds can be channeled for SSS from national level down to ULBs and WSSBs • Create a unified database of SSTPs, with georeferenced data • Draw statistics on the contribution of SSS to urban sanitation coverage, and introduction of a SSS category in the census
Coordination between governmental agencies	• Online platform with unified database
Lack of dedicated budget and human resources	• Create dedicated SSS units at state and city level to monitor SSS implementation and operation and to provide technical assistance if needed. • Provide training to staff of SSS units and SSTP operators through capacitated training centers
Loopholes in the establishment, handover and monitoring procedures	• Online platform centralizing all information for each SSTP • Management of building approval, CTE and CTO by the same governmental agency • Create dedicated SSS units at state and city level • Standardized handover between real estate developers and building management body • Create mechanisms increasing the accountability of real estate developers in technology selection and design • Automated verification procedures and prioritization of field visits • Streamline sample management, with results directly uploaded on the online platform by certified laboratories
Operation & maintenance	• Delegate management to specialized private service providers managing the O&M of several SSTPs, along with performance-based contracts • Certification/licensing of O&M service providers • Develop financial incentives for building management bodies (e.g., property tax rebate) • Create an operator network allowing experience exchange and cross-fertilization
Effluent standards	• Develop effluent standards that are specific to SSS and reuse purposes
Insufficient integration in water reuse planning	• Specify role and scope of SSS in water reuse policies • Geo-reference the SSTPs • Draw statistics on the contribution of SSS to water reuse • Develop an app to link supply and demand of treated wastewater • Higher level of centralization (cluster of buildings, street) if water reuse is not possible at building-level
Key centralized institutional structures	• Create an online platform decided at national level and developed for the whole country • Develop training programs for SSS • Develop guidelines at national level for decision-support on SSS technology selection and O&M, fostering "informed decisions"

2. Fostering coordination and harmonization between the governmental agencies concerned with small-scale sanitation through one single database, which (a) fills data gaps, and increase the transparency and accessibility of information; and (b) allows data analysis, statistics and mapping by all concerned governmental agencies.
3. Allowing monitoring of the contribution of SSS to the progress of wastewater management and water reuse, at national, state and city levels.
4. Allowing better integration of SSS in citywide urban sanitation planning, as well as in water reuse planning, through geo-localization and mapping of the SSTPs.
5. Simplifying administrative procedures through digitalization, in order to (a) avoid SSTP owners to physically visit several governmental agencies; (b) increase the transparency of the procedures and the ease to find and upload relevant documents; (c) streamline water sampling and direct upload of the results by accredited laboratories.
6. Allowing prioritization of monitoring visits based on automated verification procedures aimed at identifying potential risks or compliance failure; the water sampling data uploaded on the platform can be analyzed by simple algorithms performing plausibility checks (ratios between water parameters and variance of results over time), and the identification of contradictions or parameters exceeding thresholds.
7. Improving the efficiency of the available staff for SSTP monitoring, through automation and efficient data archiving.
8. Enabling learning through big data analysis of all existing SSTPs and the assessment of different types of systems and management schemes.

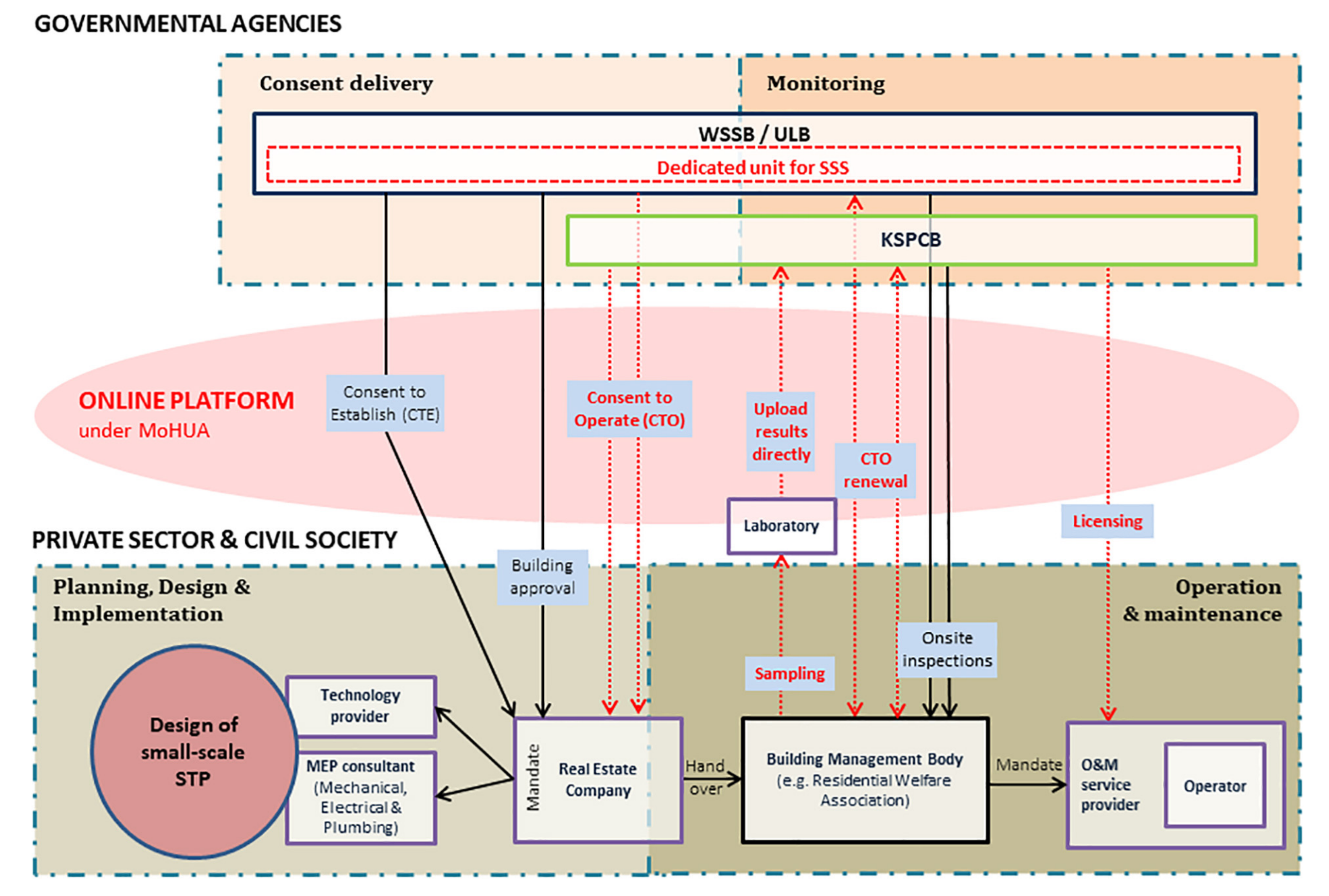

FIGURE 4 | New governance arrangements and streamlined procedures proposed by the authors (in red color).

9. Creating governmental SSS expert pools within the dedicated units, which would allow the provision of targeted training.

The authors assume that more effective hierarchical governance arrangements can lead to more coordination, more transparency and more information toward the private sector and civil society. In turn, this will enable the private sector and civil society to make better informed decision, foster learning, and enable feedback to relevant government agencies. Both structures would allow a better information flow between the government agencies, the private sector and the building owners. Reference documents can be made available on the online platform, and the SSS units can act as contact partners in case of queries regarding SSS.

Civil society participation is also crucial for the evaluation of innovative systems implemented at building level. Review of newspaper articles in Bengaluru highlighted that the lack of considerations of constraints on the ground when developing new policies, laws and regulations can result in a public outcry if there are not realistic to comply with in an affordable manner. The creation of network governance arrangements allowing two-way information flow between the relevant government agencies and civil society stakeholders is important in such a scaling up process.

The large number of SSTPs allows economies of scale, in terms of management, O&M and capacity-building. Design-build-operate contracting can raise accountability and the success rate of SSS. Companies providing O&M services to several units need less staff and can access higher skills. Promoting delegated management to specialized private service providers can strengthen market governance, while setting clearer rules. This is in line with the postulate from Van De Meene et al. (2011), who advocate for hybrid governance arrangements at a practical and operational level, comprising network and hierarchical approaches with market governance instruments.

Network governance arrangements need to be fostered, both with SSTP operators and civil society organizations. The online platform can contribute to more network governance if data is available to all stakeholders and if it increases exchange between them. Information flows with civil society organizations such as building owners organizations need to be strengthened, and SSTP operators need to be linked to each other. The SSS units could include a hotline which can help SSTP operators to solve problems that they could not solve alone. Operator networks can be formed to help operators to support each other, prevent them from being isolated and allow them to participate in exchange or capacity-building events. Networks and collaborative arrangements showed promise in the countries which established decentralized water or wastewater management schemes in rural communities (WHO, 2016). Such schemes will result in an increase in capacities and efficiency, a higher level of professionalism in the sector and ultimately in increasing legitimacy for small-scale sanitation concepts (Harris-Lovett et al., 2015).

Skills in SSS are rare, and it is important to concentrate them. The creation of dedicated SSS units within city and state authorities, and the fostering of SSS O&M companies, leads toward the concentration of expertise, which can then more easily be reinforced and multiplied. All the governmental agencies which are currently dealing with SSS are experiencing staff shortages. Especially in metropolitan cities, WSSBs are severely understaffed. Enhancing the institutional capacities and offering capacity-building on SSS should be a priority and go on par with implementation and enforcement of SSS policy. There is a need for guidance and capacity building for state level agencies and ULBs on how to integrate SSS systems next to large-scale systems and FSM. Governmental agencies can create training centers and curriculum about SSS. Malaysia successfully took this path of centralized management and capacity-building after a long period of trial and error with decentralized systems (Narayana, 2017).

CONCLUSION: TOWARDS AN EFFICIENT GOVERNANCE FRAMEWORK FOR SMALL-SCALE WASTEWATER TREATMENT SYSTEMS

This paper contributes to governance studies by substantiating the concept of hybrid governance approach (Pahl-Wostl, 2009, 2019) and by proposing concrete measures to make it work for distributed systems in a multi-level, polycentric governance framework like India: (a) Increasing the effectiveness and efficiency of hierarchical governance arrangements; (b) Fostering and optimizing the role of the private sector; (c) Creating network governance structures. It also provides insights into a regime shift toward citywide inclusive sanitation.

India presents a set of conditions for small-scale wastewater treatment systems to take a very significant role in increasing sanitation coverage and water security: fast urban growth, large middle- and high-income housing areas, water scarcity and urgent need for water reuse. The political drive is there, but hierarchical governance alone cannot work. This paper shows that for the successful scaling up of SSS requires: (a) a certain degree of market governance to enable the scaling up process; (b) a high degree of coordination between government agencies for a hierarchical governance approach to be effective and efficient in such a multi-level, polycentric governance framework. For the governance framework to be robust, it has to become an actively managed process with all key stakeholders on board. Legitimation strategies are needed, as are robust monitoring and evaluation governance structures. Full recognition of SSS by MoHUA and line agencies would quickly allow the implementation of the measures proposed in this paper, and to overcome most of the identified weaknesses in the governance framework. The Government of India can make use of the strong skills available in the "Indian Silicon Valley" and "Digital India Mission" to implement online tools that will enable the necessary "centralized digital management" of small-scale wastewater treatment and reuse systems at scale.

In such a multi-level governance framework (national, state, and city), it is important to have selected centralized governance structures that ensure economies of scale in terms of information technologies development, knowledge management and trainings, and the harmonization of data management. It is crucial for the devolvement of competencies to city level, where capacities in the field of SSS need to be built. The whole system would also benefit from intermediary actors who would act as knowledge brokers and take over some coordination, training and knowledge transfer functions. More research is needed to define the optimal features of such intermediaries within the governance framework.

The use of digitalization and the creation of the governance structures that allow meaningful collaboration between stakeholders, facilitate learning and support robust O&M and monitoring are at the core of the current thinking to fulfill the potential of alternative solutions for urban water management (Hoffmann et al., 2020). This paper provides a vision on how this could take shape in one of the contexts that is most advanced worldwide in the implementation of distributed systems in urban areas.

In 2017, the Government of Karnataka promoted a new urban wastewater reuse policy, to be implemented by a committee composed of representatives from the wastewater, industries and agriculture sectors. This new policy explicitly encourages decentralized treatment and reuse practices. The overall goal is to establish an enabling environment for the reuse of municipal wastewater to maximize efficient resource use, protect the environment, address water scarcity, and enhance economic output (KUDD, 2017). In particular, this policy initiates the development of a "Wastewater Resource Center" within the Urban Development Department, aimed at awareness and capacity-building, project assistance, performance monitoring and financing of wastewater reuse projects. Such committee has the potential to play the role of "intermediary" between the different stakeholders, a role that is essential for a robust governance framework. Such pioneering initiatives, involving representatives of the relevant government agencies, private sector and civil society can provide the required fertile soil on which promising governance innovations can grow, if they can remain autonomous and informal enough (Pahl-Wostl, 2009).

The effects of this policy on the ground are still to be seen, but it shows how dynamic the development of wastewater policies and regulations is in India. Some of the information collected within this paper may be quickly outdated. This only reinforces the belief that a strong multi-stakeholder platform and dedicated units are needed for the governance of small-scale sanitation, in order to be able to accommodate political changes and fulfill the potential of SSS in the sanitation landscape at national, state and city levels.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

We believe that an ethical review process was not required for this study. We did not use citizen science. Information was collected through meetings with key sector stakeholders from different government agencies and private sector, who were all aware about our project. Oral informed consent was obtained for participation in this study, as a preliminary explanation of why we wanted to discuss these topics with them. Ethical approval and written informed consent was not required in line with local legislation. To be mentioned that this research was conducted in agreement with the Indian government.

AUTHOR CONTRIBUTIONS

PR was the main author and the lead of the governance analysis. RC did most of the data collection and policy review in India. His main contributions are in the context and results sections, and the development of the first draft of figures. LU was the project coordinator and participated in the data analysis and development of recommendations. His main contributions are in the recommendations section and discussion of the tables and figures.

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The Sanitation Cityscape – Toward a Conceptual Framework for Integrated and Citywide Urban Sanitation

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In the last decade, the sanitation service chain model has become the *de facto* framework for much research and development in urban non-networked sanitation. People, their priorities and urban ways of living, as well as the conditions that underpin sustainable services, are too often overlooked in current conceptualizations of urban sanitation service delivery. This paper suggests that, as the sector moves toward a new paradigm of Citywide Inclusive Urban Sanitation, it is timely to revisit the conceptual framing of urban sanitation. The Sanitation Cityscape is a conceptual framework for citywide urban sanitation. It identifies the key factors of urban sanitation and locates those within a framework using three conceptual environments: The *Living Environment*, the *Service Delivery Environment*, and the *Enabling Environment.* Using a proposed set of 16 indicators and locating existing tools (for example, the Living Conditions Diamond, the fecal flow diagram, and the Citywide Service Delivery Assessment), the framework looks beyond the linear framing of sanitation services to gain a better understanding of the surrounding context and externalities. For the researcher and practitioner alike, we suggest that the Sanitation Cityscape can provide a coherent "frame" to locate the components of the urban sanitation puzzle predictably and systematically. It lends itself to rapid diagnostic analysis and more appropriate targeting of appropriate sanitation interventions. The paper includes insights from application of the Sanitation Cityscape framework including moving toward an outcome-based sanitation service delivery model, efficiencies in data collection, creating area typologies to align sanitation responses, setting enabling environment analyses boundaries purposefully and intentionally, and identifying key interfaces as potential intervention points or system levers. We hope that the Sanitation Cityscape might provide a foundation for greater consistency and a common vocabulary around the fundamental concepts and indicators relevant to urban sanitation.

Keywords: sanitation, urban, conceptual framework, urban governance, sanitation cityscape

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INTRODUCTION

Overview and Problem Statement

In the last decade, the sanitation service chain model, which articulates the typical components of fecal sludge management (FSM) i.e., the capture, storage, transport, treatment, and reuse/disposal of fecal waste, has become the *de facto* framework for much research and development in urban non-networked urban sanitation. This linear framing has been hugely instrumental in the past decade's advances; its simplicity and widespread adoption has catalyzed sector specialization and a granular understanding of urban sanitation. It has significantly raised the profile of non-sewered sanitation activities. Nevertheless, the focus on fecal flow mapping is insufficient to grasp the inherent complexity of human – technology – environment urban sanitation systems. Previous conceptualizations in sanitation discourse, for example, Sanitation Safety Planning (WHO, 2015), CLUES (Lüthi et al., 2011), Sanitation21 (IWA, 2006; Parkinson et al., 2014), Household Centered Environmental Sanitation (Kalbermatten et al., 1999), and the Strategic Sanitation Approach (Wright, 1997), tend to have been pitched as planning tools, which are dense to grasp and have seen limited uptake. We suggest that the widespread uptake of the sanitation service chain has been due to its conceptual simplicity, from which tools and approaches have been developed.

A conceptual framework explains, either graphically or in narrative form, the main things to be studied, the key factors, concepts, or variables, and the presumed relationship between them (Miles and Huberman, 1994, p. 18). We suggest that, as the sector moves toward a new paradigm of Citywide Inclusive Urban Sanitation, the linear framing is limiting. Furthermore, there is little consensus on what a standard set of factors, concepts, and variables might be for urban sanitation. We suggest that a wider conceptual framing, one that embeds both networked and non-networked sanitation systems more explicitly within urban governance, is more appropriate to the complexities of urban service delivery. We therefore suggest that it is timely to revisit what a conceptual framework for urban sanitation might look like in an effort to consolidate sector efforts and hone the discourse vocabulary. One such model, termed the Sanitation Cityscape, builds upon past frameworks; its latest iteration is the focus of this paper.

METHODS

Jabareen (2009) describes eight iterative stages of building a conceptual framework ranging from review of existing knowledge, through identifying and categorizing key concepts; locating those within a framework; and validating the framework. Concepts are a generalized idea that may not be measurable therefore, through identifying criteria that reflects the concept, can provide a measurable indicator (what you are measuring) and research variable (how change will be measured). The focus of this paper describes identifying and categorizing key concepts and proposes a conceptual framework in which to locate them coherently. While this paper makes reference to how the framework was applied in practice, that experience is documented elsewhere (Scott and Henry, 2018) and is not the focus of this paper.

This paper begins to build a conceptual framework by identifying and categorizing key concepts for urban sanitation (Jabareen, 2009). These were identified and informed through review of recent and current urban sanitation discourse drawn from peer-reviewed and gray literature. It also draws upon previous peer-reviewed presented work of the authors reviewing the evolution of urban sanitation discourse (Scott et al., 2017) and earlier iterations by the authors of the Sanitation Cityscape framework (Scott et al., 2015, 2017; Scott, 2019).

DISCUSSION

Current Urban Sanitation Discourse

The global indicator selected by UN Member States for monitoring SDG target 6.2 "Safely managed sanitation" is the "Proportion of population using safely managed sanitation services including a handwashing facility with soap and water" where "safely managed" is defined as the use of an improved sanitation facility that is not shared with other households and where excreta is safely disposed *in situ* or excreta is transported and treated off-site (WHO/JMP, 2016). Measuring SDG 6.2 is problematic due to a lack of reliable measures; combing data from different source households and utilities and lack of data itself. The component parts of non-networked sanitation systems are commonly framed using the five components of the sanitation service chain: *capture*, *containment*, *transport*, *treatment*, and *reuse/disposal*[1] (Tilley et al., 2008). The sanitation service chain has been a key area of focus in the sanitation sector in recent years and tools and standard protocols or what data types and sources are needed, such as the fecal sludge or shit-flow diagram (SFD)-type analysis, for collecting evidence along these components of the chain (Shit Flow Diagram Initiative, 2018). The prevalence, the frequency, and the pathways of each of these components describe the different components of sanitation service delivery present. These provide an effective snapshot of the volumes of waste (both networked and non-networked sanitation side by side) and the array of services and infrastructure in place.

The *enabling environment* affects the potential to bring about effective change; it describes the set of interrelated and contextually specific functions that either facilitate or hinder sanitation service delivery, where universal access can only be sustained through well-functioning enabling environments (WSUP, 2018). There is growing consensus about what constitutes an enabling environment for sanitation, typically consisting of: *policy and strategy*, *institutional arrangements*, *sector planning and monitoring*, and *budgeting and finance and capacity*. Several tools have been developed to assess the enabling environment, including the SFD Manual

[1] This specifically focuses on contexts where non-networked urban sanitation is the norm, acknowledging that, for less densely populated areas, *in situ* treatment as well as networked sanitation (sewers) can both achieve safely managed sanitation in appropriate contexts.

(Shit Flow Diagram Initiative, 2018), UNICEF Guidance on Strengthening the Enabling Environment for WASH (UNICEF, 2016), the Citywide Service Delivery Assessment (CSDA) (Peal et al., 2014; Ross et al., 2016) and CWIS CSDA review (Blackett and Hawkins, 2019), and the WSUP Conceptual Framework for Enabling Environments for Inclusive Citywide Sanitation (WSUP, 2018).

The importance of demand in sanitation programming was a major lesson to emerge from the International Decade of International Drinking Water Supply and Sanitation Decade (IDWSSD) 1981–1990 (Cairncross, 1992). Demand-led approaches to sanitation aim to create demand for improved sanitation by changing behaviors while strengthening the availability of supporting products and services. Advances in assessing demand are offering alternative experimental designs, such as discrete choice experiments, to the often-criticized contingent valuation method (CVM) techniques due to lack of accuracy and hypothetical bias (Tidwell et al., 2019). A number of theoretical models, frameworks, and decision-making tools have been developed around WASH behavior change (Dreibelbis et al., 2013) offering sanitation specific insights that demand is created when consumers have motivation (preference), opportunity, and ability to purchase sanitation technology that suits their needs (Jenkins and Scott, 2007; Devine, 2009).

Limitations of Urban Sanitation Discourse

Clearly, great progress has been made in developing tools and frameworks to understand the different components of the sanitation services delivery component parts. However, do these sufficiently describe the urban sanitation landscape as a whole? Does the *de facto* sanitation service chain framework sufficiently capture the key concepts to be studied? We suggest it does not, that a graphical representation of a linear chain means the enabling environment (i.e., the conditions that underpin sustainable services) and the people, and their inherent priorities, behaviors, interests, and ways of living, are too often missing or overlooked current conceptualizations of urban sanitation service delivery. Furthermore, when looking through the lens of service delivery at either the enabling environment or people, it is not uncommon to assume a narrow single-sector view of those issues, whereas due to their very nature, they are wider.

The reality of urban living (and not just low income) introduces complexities around the demand for, and the provision of, basic services. The services themselves are physically interlinked; sustainable planning for one service (e.g., sanitation) cannot proceed in isolation from others, e.g., water supply, drainage, and/or solid waste management (Cotton and Franceys, 1987, 1991). At the consumer side, demand for urban services manifests in a more nuanced way than isolated single-sector interventions; residents seek improvements across the totality of their lives (Kar, 1997; Scott et al., 2017). For sanitation, the (often latent) nature of the demand and the way issues such as space, tenure, and road access influence the planning and uptake (IWA, 2006; Tidwell et al., 2019) further compound the modes of implementation for sanitation compared to other infrastructure and services. The unit of measurement of urban living is complicated where boundaries of urban households are blurred; it is not uncommon across the world for several urban "household" units to live under one roof or on one plot; adjacent urban households often share infrastructure (such as toilets, taps, or solid waste bins)[2]. Enabling environment analysis, through a single-sector lens, fails to take into account wider urban governance issues, priorities, and challenges across the many facets of urban development.

The Sanitation Cityscape Framework

Current Urban Sanitation Discourse and *Limitations of Urban Sanitation Discourse* draw upon key factors, concepts, variables, and tools that are relevant to urban sanitation. We suggest that the application of these tools without understanding other parts of the urban system are, at best, capturing part of the story and, at worst, could do harm. We therefore suggest that a stronger conceptual framework for urban sanitation would aggregate a set of factors into key concepts and locate them, and the appropriate tools, with a wider analytical framework. The aggregate concepts we suggest can be articulated in three conceptual environments:

- *The living environment* is about people. It describes the domestic and peridomestic characteristics private sphere within which households make decisions. Demand and behaviors are key components here. The living environment includes sanitation but acknowledges that any given urban household, residents' priorities are heavily influenced by the living conditions that surround it and that demand for urban services manifests in a more nuanced way than single-sector interventions.
- *The service delivery environment* describes the functions of basic services and their infrastructure that deliver services to households. For sanitation inquiry, the service delivery environment is where the nature and mechanisms of service delivery can be focused upon. Importantly, in the framework, sanitation services are located alongside other basic services acknowledging the fundamental physical interlinkages of water supply, drainage, solid waste management, and other basic services and provide a potential placeholder to align and integrate with adjacent services.
- *The enabling environment* describes the wider structural and institutional context that frame overall service delivery such as policy and strategy, institutional arrangements, sector planning and monitoring, and budgeting and finance and capacity.
- *The interfaces and the nature of relationships* describes the relationships within and between each of these three conceptual environments, highlighting interfaces, gaps, and intervention opportunities.

We suggest that these three conceptual environments of the Sanitation Cityscape, drawn together, provide a useful analytical framework for urban sanitation systems (see **Figure 1**).

[2]This zone beyond the household, the area located near but not within the dwelling walls, is termed peridomestic zone (Sanitation 21, 2006).

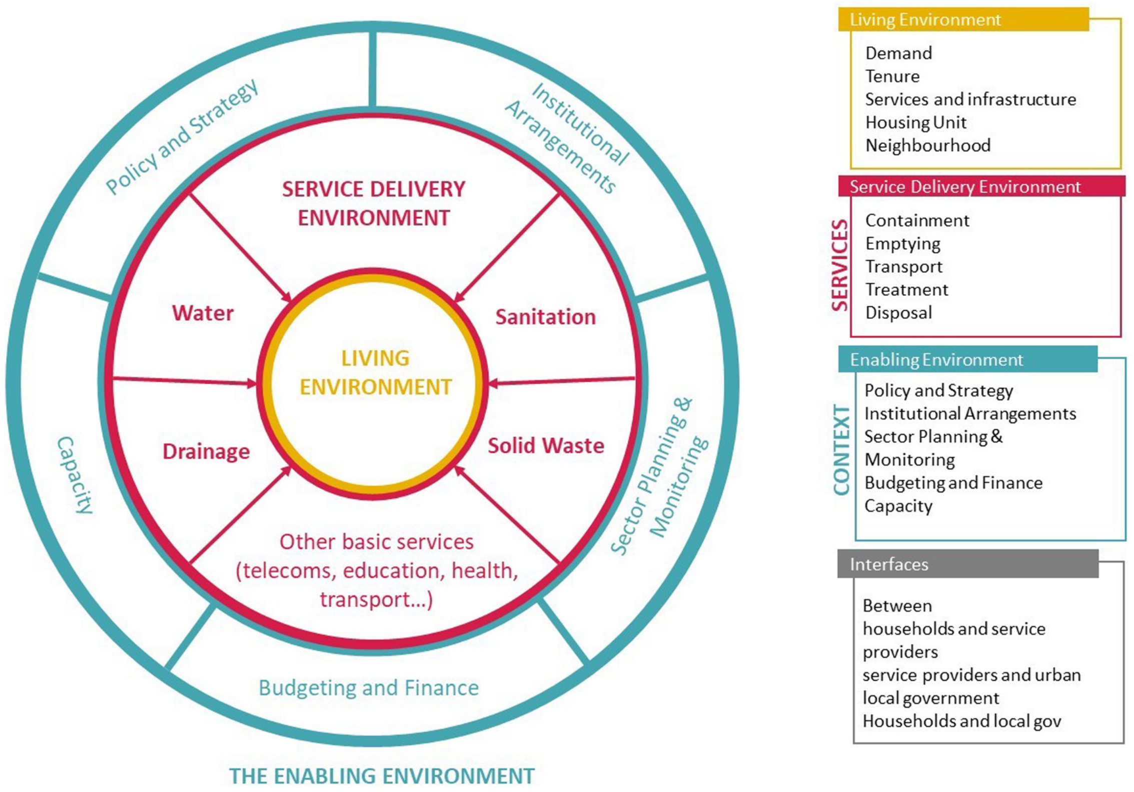

FIGURE 1 | The Sanitation Cityscape conceptual framework.

The framework can provide coherence and structure to locate granular detail within a much more complex system, allowing for specific parts of sanitation service delivery to be the focus of inquiry. In the following section, 16 core indicators are proposed to describe these three conceptual environments and the relationships between them. **Figure 2** gives an overview of the main indicators we suggest could be understood in each conceptual environment and why they are relevant. It also suggests some tools and ways to measure the proposed indicators. Neither the framework itself nor the proposed indicator list are intended to be prescriptive. Different framing or applications may include other indicators, but we suggest that the approach of locating the indicators and the tools being applied within the conceptual environments is a useful one.

The Living Environment

The Living Environment describes people, their behaviors, and the peridomestic environment. Placing the Living Environment at the core of the framework echoes the development rationale of centering frameworks on the main development objective (Chambers, 1983) and earlier concentric sanitation frameworks[3]. We suggest that, at the Living Environment level, it is important to understand what citizens want and what their development priorities are (for which we term an indicator *demand*). We note that demand often does not manifest by sector, rather people seek improvements of their overall living conditions (Kar, 1997; Scott et al., 2017); assessment of demand should not be blinkered to demand for sanitation only. To understand the living conditions of any urban settlement, the *Living Conditions Diamond* is a useful tool (Gulyani and Basset, 2010). It describes the living environment of any given settlement, using only four variables: *tenure*, *housing unit*, *infrastructure*, and *neighborhood*. Plotting each variable on an axis, it generates diamond profiles offering an objective comparability between settlement types both within and between urban environments. We therefore suggest that the Living Environment can be captured using five core indicators[4]: the four indicators of the living conditions diamond *tenure*, *housing unit*, *infrastructure*, and *neighborhood*, as a comparable composite indicator of the living conditions of any urban settlement, with the addition of *demand* to reflect resident's development priorities. Measuring these five indicators, we suggest, would provide an insightful view of was happening in an urban Living Environment (see **Figure 2**).

The Service Delivery Environment

The five components of the sanitation service chain: *capture*, *containment*, *transport*, *treatment*, and *reuse/disposal* provide

[3]Such as Sanitation 21 (IWA, 2006; Parkinson et al., 2014), Household Centered Environmental Sanitation (Kalbermatten et al., 1999), Strategic Sanitation Approach (Wright, 1997), and CLUES (Lüthi et al., 2011).

[4]In addition to appropriate socioeconomic indicators such as age, gender, income, etc., as relevant.

WHAT? Indicators		*WHY? Why are these important?*	*HOW? Suggested variables*	*TOOLS*
1	**THE LIVING ENVIRONMENT**			
1.1	**Demand**	To understand residents' priorities and behaviours	Development priorities of residents; satisfaction levels; willingness to pay; specific behaviours	Sani FOAM (Devine 2009); Discrete Choice Experiments (Tidwell et al. 2019).
1.2	**Tenure**	Tenure affects households' investment decisions. The tenure mix of a neighbourhood affects the overall housing stock	Owner vs. occupiers; owner on/off-site; length of stay; fear of eviction	Living Conditions Diamond Gulyani & Bassett (2010)
1.3	**Housing Unit**	The private domain, linked to residents' development priorities and technical options	Construction of walls, floors, roof; overall building quality	
1.4	**Infrastructure and Services**	Linked to residents' development priorities and technical options	Is the plot serviced by water, electricity, solid waste collection, street lighting, paved roads, roads (vehicle access)?	
1.5	**Neighbourhood**	To understand the different neighbourhood typologies to be able to provide appropriate solutions to different neighbourhoods.	Quality of neighbourhood (cleanliness, location, transport, safety/crime, cost of land)	
2	**THE SERVICE DELIVERY ENVIRONMENT**			
2.1	**Containment**	To understand the different sanitation options, pathways, and prevalence of each in the context, including both networked and non-networked sanitation options. Type of service, equipment, diversification of customer base; practices; technologies	Outcome: Access and use of a hygienic toilet	SFD Protocol (SFD Manual 2018) Outcome-based sanitation value chain (Figure 3)
2.2	**Emptying**		Outcome: Fecal sludge is safely contained on-site	
2.3	**Transport**		Outcome: Fecal sludge is hygienically removed from containment site	
2.4	**Treatment**		Outcome: Pathogen removal (reduction or inactivation)	
2.5	**Re-use / disposal**		Outcome: Cost and resource recovery	
3	**THE ENABLING ENVIRONMENT**			
3.1	**Policy and Strategy**	To understand if the policy exists and is appropriate to the context and activities; to understand the direction of travel.	Policy, regulation; enforcement; pro-poor; Urban Local Government role	WHO Sanitation Guidelines (2018); WSUP Enabling Environment (2018); The World Bank's FSM Diagnostic Tools (Peal, Evans, Blackett *et al*. 2014; Ross *et al*. 2016), including Citywide Service Delivery Assessment, UNICEF (2016); CLUES (Lüthi C., Morel, A. Tilley, E. *et al*. 2011); CWIS CSDA (Blackett and Hawkins 2019)
3.2	**Institutional Arrangements**	To understand the players (both informal and formal) and the rules of the game, coordination between them	Roles and responsibilities; coordination	
3.3	**Sector Planning and Monitoring**	To understand what drive changes	Service targets; monitoring; planning	
3.4	**Budgeting and Finance**	To understand financial planning and procurement processes.	Financial planning and procurement practices and power; cost recovery;	
3.5	**Capacity**	To understand who the decision makers are, their capacity and competing priorities.	Skills; knowledge; training; resourcing (national to lowest administrative unit)	
4	**THE INTERFACES AND RELATIONSHIPS**			
4.1	**Key interfaces and /or relationships**	To understand the nature of the relationships, both within, and between the groups. To highlight gaps and opportunities (i.e., key and missing relationships and/or interfaces).	What is the relationship/interface/mechanisms of contact, etc between households (i.e. social cohesion); service providers (e.g., association); and local-national government actors (e.g., task force)?	Relationship mapping; network analysis

FIGURE 2 | Proposed Sanitation Cityscape indicators (WHO, 2018).

useful foundation for indicators to describe the way sanitation services are delivered. In **Figure 1**, the basic services listed are solid waste, drainage, water supply, and sanitation, but these could expand to include other services such as health, education, mobile connectivity, transport, and more, depending on the desired lens of analysis. For sanitation, the Service Delivery Environment assessment should include both formal and informal sanitation providers from across the range of sanitation technologies and service models, including networked and non-networked sanitation systems. We therefore suggest the component stages of the sanitation service chain: *capture*, *containment*, *transport*, *treatment*, and *reuse/disposal* are described using five outcome-based indicators respectively to describe the sanitation service environment (see **Figure 2**).

The Enabling Environment

The Enabling Environment describes the wider structural and institutional context that frame the service delivery. In the Sanitation Cityscape framework, the Enabling Environment is designated by the outer ring. This placing acts as a reminder that, while the focus of enquiry may be on sanitation, there are inherent dependencies on other basic services; the Enabling Environment for sanitation may involve wider urban governance beyond sanitation. Current Enabling Environment analysis for sanitation typically consists of *policy and strategy*, *institutional arrangements*, *sector planning and monitoring*, and *budgeting and finance and capacity.* Tools such as the Citywide Service Delivery Assessment (Ross et al., 2016) initially focused only on FSM but have recently been adapted to include both networked and non-networked sanitation (Blackett and Hawkins, 2019). The existing tools and approaches to assess the enabling environment for sanitation are comprehensive; therefore, we suggest using the common indicators to describe the Enabling Environment such as *policy and strategy*, *institutional arrangements*, *sector planning and monitoring*, and *budgeting and finance and capacity* (see **Figure 2**). Being intentional in setting the boundaries of the Enabling Environment analysis (i.e., as a single or multisector lens and across the appropriate range of service provision) is fundamentally important.

The Interfaces and the Nature of Relationships

The final concept of the Sanitation Cityscape is understanding some of the relationships within and between these three conceptual environments to highlight interfaces, gaps, and intervention opportunities. The components of this analysis is likely to vary depending on the objective of inquiry, but the aim is to understand the people, the nature of organization, leadership, and cohesion in the Living Environment, and the dynamics between the service providers and decision makers and to identify if there are existing communication channels and interfaces between different groups that can be reinforced (see **Figure 2**). At this initial stage, just one indicator was used to describe the interfaces and relationships, but there is scope to deploy tools such as network analysis or political economy analysis for deeper insights into these interactions.

Validating the Sanitation Cityscape Framework for Urban Sanitation

The final stage of Jabareen (2009) process of building a conceptual framework is validation. This is an iterative process to test if the framework and its concepts make sense not only to the researcher but also to other scholars and practitioners.

To this aim, the Sanitation Cityscape framework has been presented at a number of sanitation focused workshops and events[5]. Feedback from both practitioners and academics to date has been positive, including comments such as "a *useful conceptual framework*," "*provides clarity*," "*a useful way of organizing thoughts*," "a *helpful dashboard*," and "*a systems approach*." This has led to the practical application of the framework to design and assess the baseline situation of the sanitation systems in a town in Ethiopia, Debre Birhan as part of a USAID Sustainable WASH Systems project[6]. The experience of adapting the CSDA tool through the Sanitation Cityscape lens was shared with the CWIS CSDA tool revision team, and the framework has supported the design of several rapid diagnostic assessments of sanitation. The section below offers some conceptual and practical insights from this validation thus far.

Conceptual Insights

- *Alignment to the Citywide Inclusive Sanitation (CWIS) Principals*. The Sanitation Cityscape Framework aligns to the Citywide Inclusive Sanitation (CWIS) principals[7] in that (i) it provides a framework that works for all urban settlements, ranging from informal to formal and specifically integrating tenure as a critical factor of urban development and investment at both the household and public funding level; (ii) it purposefully embraces the complexity of urban environments; (iii) it focuses on outcomes and allowing for a diversity of solutions; and (iv) it embeds sanitation within a wider urban governance framework, where the unit of change becomes the city itself.
- *An Outcome-Based Sanitation Service Chain*. The sanitation service chain is typically measured using descriptors of technologies or activities; we suggest that a useful adaption to this is to attribute outcome-based indicators for each stage of the sanitation service chain as an objective comparison across technologies and systems (see **Figure 3**).
- *Data Collection and Sources*. Collecting primary data is expensive and time consuming. Several of the existing tools described in this paper rely on extensive primary data collection. The proposed indicator set for the Sanitation Cityscape comprises of 16 indicators, which focuses the data collection to a manageable number. Nevertheless, we suggest that future developments of the tools and the framework consider possible synergies with existing data sets as well as parallel urban development work to further make the best use of available data. This is specifically relevant around indicators that may be shared across urban development initiatives (such as tenure the enabling environment or in area-based approaches) as well as more localized data collection mechanisms including community-led informal settlement profiling initiatives[8] and other national and subnational monitoring systems.

Insights From the Field

In 2018, the Sanitation Cityscape was used to design a citywide baseline assessment of the sanitation systems of a small town in Ethiopia, Debre Birhan. The 16 indicators captured data across the three main conceptual environments and the relationships between them using, where possible, standard and validated variables or tools, or adaptations thereof.

The baseline included a representative stratified random household survey ($N = 308$) across the nine administrative units of the town. It deployed the Living Conditions Diamond tool (Gulyani and Basset, 2010) to map the living environment, plus collecting data on residents' development priorities to reflect demand. It collected primary data from key informant interviews and secondary data sources using the SFD protocol to generate an initial fecal flow diagram (Shit Flow Diagram Initiative, 2018), which was validated with stakeholders. It also deployed an adapted version of the CSDA (Ross et al., 2016) to capture data on both FSM as well as the other sanitation services within the

[5]Including the 21st Sanitation Community of Practice (SanCoP) Meeting: "Addressing the Complexities of Citywide Environmental Sanitation," Leeds, 2018; 40th WEDC International Conference, Loughborough, UK, 2017; The IRC All Systems Go! Symposium, The Hague, 2019.

[6]In addition to appropriate socioeconomic indicators such as age, gender, income, etc., as relevant.

[7]Citywide sanitation has been endorsed as the future paradigm for urban sanitation, and several organizations are applying the founding principles of Citywide Inclusive Sanitation (CWIS) in their work.

[8]For example https://knowyourcity.info/

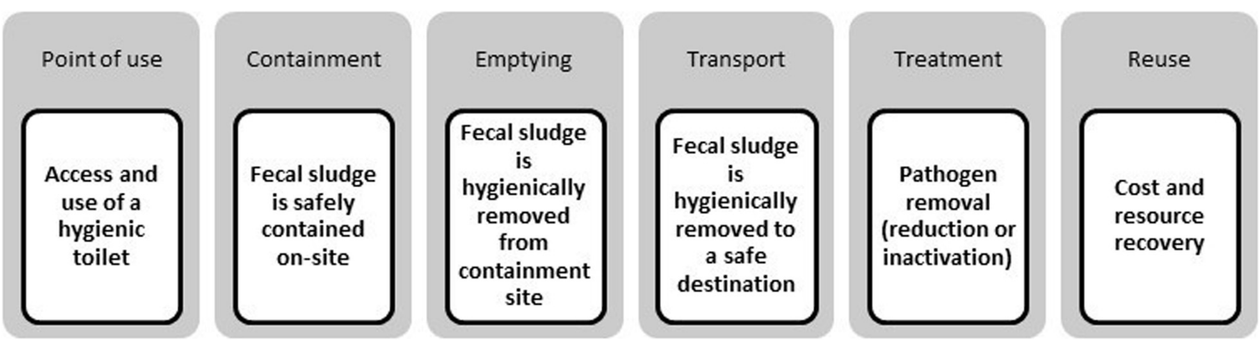

FIGURE 3 | Outcome-based sanitation service chain.

town (specifically communal and public toilets) (see **Figure 2**)[9]. To understand the interfaces between the different environments for the Debre Birhan baseline, data were gathered with key informants about the nature and frequency of their relationships with other urban stakeholders. Key insights from applying the framework are summarized below; the baseline results themselves are documented elsewhere (Scott and Henry, 2018).

- *Efficiency of Design and Data Collection*. The 16 indicators used for the Debre Birhan provided a manageable data set. Data were collected across the three conceptual environments for a town (population of 100,000) by a small research team in < 1 week. Aggregating the data from a well-defined indicator set that fed into the larger concepts provided a systematic and efficient way of designing the study, collecting, and processing data, and navigating a complex urban sanitation system.
- *Neighborhood Typologies*. Applying the Living Conditions Diamond analysis across each of the nine administrative units in Debre Birhan generated four settlement typologies with distinct characteristics: one was typical of a central urban neighborhood where residents pay a premium for the location and infrastructure over housing quality, and space is at a premium; another had a tenure mix of more tenants than owner occupiers with a rapid turnover of residents, which is typical of a lower-income urban area; a third typology had a higher ratio of owner occupiers and better housing stock compared to the former two typologies. Identifying area typologies can help identify which type of sanitation service delivery model is likely to be the most appropriate (see **Figure 4**). In the first two typologies described above, communal latrines were commonplace. We suggest that an appropriate sanitation response in settlements of that type would likely include service-based models (i.e., shared, public, and container-based toilets) rather than sanitation marketing of individual household toilets. Aligning sanitation responses to settlement typologies is an approach used in the current Guidance on Programming for Rural Sanitation (WaterAid et al., 2019). At the time of the 2018 baseline study, using a similar principle of creating area typologies to align sanitation responses was unique in the urban context. We suggest the Living Conditions Diamond tool, or adaption thereof, might be a useful way to align sanitation responses to urban settlement typologies, or indeed along the urban–rural continuum.
- *Boundarying the Enabling Environment*. One important finding from the Debre Birhan baseline was that the enabling environments can be very different for different parts of sanitation services. The baseline deployed an adapted version of the CSDA (Ross et al., 2016) to capture data on both FSM as well as the other sanitation services within the town (i.e., communal and public toilets) in parallel (see **Figure 2**)[10]. What the baseline study showed was a marked difference between the enabling environments of different parts of sanitation services. The enabling environment for FSM was relatively good; thanks to a well-functioning utility, the enabling environment for other sanitation services was much weaker. More recent CWIS revisions of the CSDA tool (Blackett and Hawkins, 2019) have gone some way to address including both networked and non-networked sanitation. However, the fundamental point here is that care needs to be taken to set boundaries purposefully and intentionally for the enabling environment analyses to adequately cover the intended services and governance arrangements.

Key Urban Interfaces. Collecting data around the interfaces between the conceptual environments in Debre Birhan unveiled some "unusual suspects" of sanitation service planning in the town (i.e., those who would not normally emerge in an SFD study or WASH-only enabling environment analysis). Respondents were asked about the nature and frequency of interactions with actors in the other environments. Interview responses highlighted the pivotal role of officers at the lowest administrative units, specifically the highest ranking official as well as the health extension and enforcement officers on the front line. This workforce is often overlooked and underresourced but were identified as critical in terms of sustaining urban sanitation provision for both achieving access and maintaining environmental health. Edirs, or self-organized community savings groups[11], also emerged as key interfaces at

[9]At the time of the study, the CSDA was limited to FSM. This has since been updated (Blackett and Hawkins, 2019) with inputs from experience of adapting the CSDA tool through the Sanitation Cityscape lens.

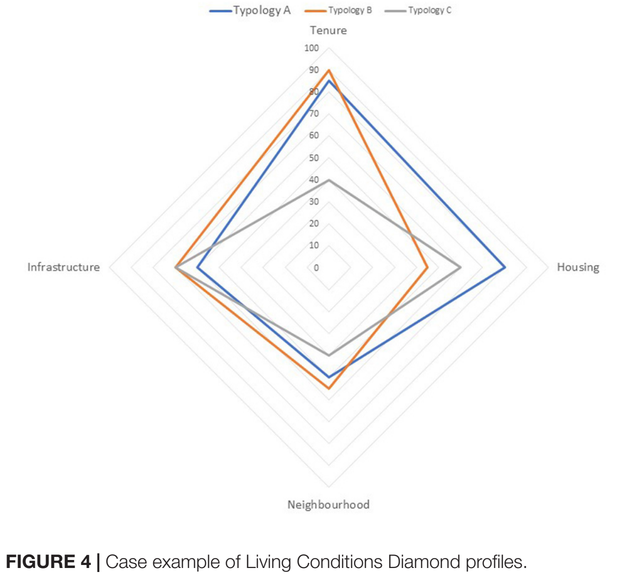

FIGURE 4 | Case example of Living Conditions Diamond profiles.

[10]At the time of the study, the CSDA was limited to FSM. This has since been updated (Blackett and Hawkins, 2019) with inputs from experience of adapting the CSDA tool through the Sanitation Cityscape lens.

[11]Typically used to cover funeral costs and support deceased families, the Debre Birhan baseline found Edirs were being used to support development activities such as building houses for the poorest members of the community.

the community level. This is noteworthy as the ability of an urban community to self-organize into savings groups has been identified a proxy for social cohesion and a predeterminant for public finance for local development initiatives (Bhatkal and Lucci, 2015). Finally, large-scale private sector such as hotels and breweries were identified through key informant interviews about the relationships between urban actors as largest polluters but also the largest employers in the town, presenting challenges in terms of power dynamics.

CONCLUSION

The last decade has seen great advances in the understanding of the Sanitation Service Delivery Environment, but the "business as usual" approach for the sanitation sector will not achieve SDG 6.2 and 6.3. There needs to be a substantial effort to understand the wider human–technology–environment systems at play and embed sanitation into urban governance. Citywide Inclusive Sanitation has been endorsed as the future paradigm for urban sanitation, and several organizations are applying the founding principles in their work. There is, as yet, however, little consistency in how urban sanitation systems are described and measured.

For the researcher and practitioner alike, the Sanitation Cityscape narrows the complexity of urban sanitation into three main concepts: the *Living Environment*, the *Service Delivery Environment*, and the *Enabling Environment*. We suggest that it is the aggregation of the concepts that adds value, providing a coherent "frame" to locate the components of the urban sanitation puzzle predictably and systematically. The framework and indicator set lends itself to rapid diagnostic analysis and more appropriate targeting of appropriate sanitation interventions. By breaking the urban sanitation system down into conceptual environments, there is scope, within each conceptual environment, for a deeper granularity of analysis: the living and service delivery assessments indicate *what* are priority areas for urban sanitation. It locates the importance of sanitation in relative terms to other urban development issues. The enabling environment analysis lends insights as to *why* the situation is the way it is. Finally, examining the interfaces and relationships between the different conceptual environments helps to highlight *how* things can change, identifying potential intervention points or system levers. Considered together, the three conceptual environments provide useful insights into *what*, *why*, and *how* to address sanitation as an urban governance issue.

Building a conceptual framework is an iterative process, and we welcome new insights or developments to further validate the Sanitation Cityscape framework. We have proposed a set of 16 key indicators in this paper, although these are not intended to be prescriptive; rather, we suggest the approach of locating them within the conceptual environments is a useful one. The validation efforts to date suggest that the Sanitation Cityscape offers a useful framing in moving toward Citywide Inclusive Sanitation and embedding sanitation within urban governance frameworks. We hope the framework might provide a foundation for greater consistency and a common vocabulary around the fundamental concepts and indicators relevant to urban sanitation. This, in turn, we hope might lead to more purposeful inquiry and cumulative knowledge base, both within and beyond the sanitation sector, that serves multiple sets of interests.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

PS developed the conceptual framework in consultation with AC. Both authors wrote the manuscript.

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Sustaining Community-Scale Sanitation Services: Co-management by Local Government and Low-Income Communities in Indonesia

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Ensuring sustainability of sanitation infrastructure assets and services over the long-term is crucial for achieving safe sanitation for all. Co-management is an emerging approach that balances state and citizen responsibility for services, with applicability to community-scale (or decentralized) sanitation systems in a city-wide context. In Indonesia more than 30,000 of these systems are typically managed solely by communities, however, due to challenges in technical, social and financial aspects, commonly fall to disrepair. This paper presents qualitative research comprising document review, interviews and co-design workshops with local government and community management groups that developed a model for co-management of community-scale systems. The co-management model articulated four minimum responsibilities for local government: monitoring and corrective action; provision of technical and institutional support to community groups; formalization of fee collection; and funding of large costs for rehabilitation and expansion. This model was developed and tested in two case study locations, and through this process, was deemed appropriate, acceptable and feasible for both local government and community management groups. Related changes to Indonesia's national program guidelines were also identified to clearly articulate local government's role. The agreed co-management approach aligns with the human right to sanitation by supporting local governments fulfill their legal mandate for services, promotes professionalized sustainable management arrangements, ensuring community-scale systems can contribute effectively to future citywide solutions.

Keywords: co-management, sanitation, sustainability, local government, institutional arrangements

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INTRODUCTION

Providing sanitation services at city-scale is expected to require a combination of different system types, including on-site, decentralized and off-site centralized treatment. To ensure sustainable services into the future, each system type requires an accompanying effective management approach. This article is focused on community-scale systems (also known as decentralized or small-scale systems), and experience of their large-scale implementation in Indonesia in low-income areas. Community-scale systems have also been implemented elsewhere at scale, including in India (Ulrich, 2018) and Egypt (Reymond et al., 2018), and are considered an important component in city-wide sanitation solutions (BMGF, 2017; Lüthi and Sankara Narayan, 2018; Reymond et al., 2018; and Larsen et al., 2013). Existing literature promoting decentralized solutions in the citywide context largely focuses on the technical aspects (Lüthi et al., 2011; Willetts et al., 2013b; Bright-Davies and Luthi, 2015; Capodaglio, 2017) or economic aspects (Retamal et al., 2011; Willetts et al., 2013a), whereas this paper deals with the institutional aspects, building on a small number of studies examining the latter (Etnier et al., 2005; Willetts et al., 2007; Mitchell et al., 2008; and Reymond et al., 2018).

The Government of Indonesia (GoI) has made significant investments in community-scale sanitation (also known as SANIMAS) over the last 10 years with at least 20,000 systems built as part government and donor urban sanitation programs (Mitchell et al., 2016). These systems can include communal toilet and bathing blocks, simplified sewer systems serving up to 200 households or mixed systems combining these. Wastewater treatment is typically with Anaerobic Baffle Reactors (ABR), both cast-in-situ and prefabricated, and may also include chambers of anaerobic filter or discharge to a constructed wetland or other secondary treatment process. Based on current estimates, there were expected to be almost 30,000 systems by the end of 2017. The medium-term development plan (RPJMN) targets 100% access to sanitation by 2019, of which community-scale systems are proposed to contribute 7.5% of sanitation coverage, the same proportion as centralised sewerage systems, with the remainder covered by on-site systems.

In Indonesia, local government has a legal mandate to provide access to sanitation as a 'basic, mandatory and concurrent affair' based on local regulations introduced in 2014 (Al'Afghani et al., 2015). However, to date in there are varied institutional arrangements for managing urban sanitation, with different local government departments, water and wastewater utilities responsible for all or parts of sanitation services depending on the city (Eales et al., 2013). Community-scale wastewater systems (known as SANIMAS systems), to date, have been funded under a model that promotes community responsibility for ongoing service delivery. A community group is formed to implement each system (known as a *Kelompok Swadaya Masyarakat* – KSM) and another group to operate and maintain it (known as a *Kelompok Pemanfaat dan Pemelihara* KPP). Since in reality these groups are often merged, and the commonly used term is KSM, in this paper we refer to the relevant community management group as KSM only.

Weak or unsuitable organization models and institutional arrangements have been blamed for poor performance and failures of decentralized systems installed worldwide (Brown and Farrelly, 2009; Mitchell et al., 2010; Kiparsky et al., 2016; Larsen et al., 2016). The institutional arrangements which prescribe sole community responsibility for ongoing service delivery in Indonesia have been found to be unsustainable, particularly financially (Eales et al., 2013; Mitchell et al., 2015). The problems identified in these reports included: systems not operating at capacity, on average utilizing less than half of their design capacity; approximately 80% of systems had not been desludged; only 60% of community groups collected any fees, and those fees collected were insufficient to cover needs; many tasks allocated to KSM were beyond their financial or technical capacity; and most KSM were not legal entities and land ownership for the community-scale wastewater systems was typically insecure. While effluent data from Eales et al. (2013) indicated acceptable performance, effluent quality appeared to be decreasing with increasing scale-up, and Mitchell et al. (2015) confirmed that there was limited data on the status or performance of systems, with effluent quality testing only available for 2% of systems.

Given these challenges, this research sought to examine the feasibility of a co-management approach, in which responsibilities for on-going management of the community-scale wastewater systems would be shared between local government and communities. The proposed co-management approach was based on the recommendations of the previous research (Eales et al., 2013; Mitchell et al., 2016) that there was a need for greater local government involvement to effectively sustain services. As such, the research sought to define appropriate roles suitable for local government and communities to jointly manage community-scale systems in the long-term.

MATERIALS AND METHODS

This research employed document review, semi-structured interviews and facilitated co-design workshops in 2016–2018. Two city case studies were employed. This methodological choice took into account that case studies provide opportunity to investigate a contemporary phenomenon (in this case management of community-scale wastewater) within its real life context, acknowledging that the phenomenon is not distinct from the context, and the contextual details are also important and must be analyzed (Yin, 2003). The two selected case study locations were Kota Bogor, West Java and Kabupaten Bantaeng, South Sulawesi. These locations were selected based on local governments' willingness and interest to change and extend their roles to support the effective ongoing operation and management of community-scale systems. In each location, the technology employed was anaerobic baffled reactors, serving 10–120 households in Bogor and 30–50 households in Bantaeng (average four people per household). These comprised a mix of communal toilets, shared septic tanks and decentralized sewer systems.

The research addressed three research questions, the first focused on developing and articulating what "co-management" might look like in practice, the second focused on the case studies the city level, and the third addressing the national level with regards to program implementation guidelines for community-scale sanitation in Indonesia.

The conceptualization of a co-management approach answered the question: What balance of responsibilities should be sought between local government and communities in sustainably managing community-scale sanitation services, including which minimum responsibilities should be taken on by local government?

At the city level the research investigated: What enablers and constraints are revealed when local government increase responsibility for community scale sanitation in two case study areas (Kota Bogor and Kabupaten Bantaeng)? Including three sub-questions:

(i) To what extent are proposed minimum responsibilities for local government appropriate, acceptable and feasible in terms of improving sustainability of community-scale sanitation services?
(ii) How could the institutional arrangements be modified to increase local government responsibility for community-scale sanitation in the case study locations? What should be the role of different actors [e.g., relevant local agency or work unity, cross-agency working group (*Pokja sanitasi*)]?
(iii) How do national implementation approaches and regulations shape the way local government could take on the proposed minimum responsibilities?

At the national level, the research investigated: What revisions to the national program guidelines would clarify local government responsibility and guide all stakeholders on the options and implementation of a co-management approach?

Document review comprised drawing on literature on governance and management of community-scale systems in Indonesia and elsewhere, as well as detailed review of the Indonesian national program guidelines for community-scale sanitation (Technical Guidelines SANIMAS Regular and Appendix (*Petunjuk Teknis SANIMAS Regular dan Lampiran*) 2016; and Implementation Guidelines for Special Allocation Fund (DAK) Infrastructure Sector Sub Sector Sanitation (*Petunjuk Pelaksanaan Dana Alokasi Khusus (DAK) Bidang Ingrastrucktur Sub Bidang Sanitasi*) 2016.

Semi-structured interviews were undertaken with 17 government and community stakeholders in Bantaeng and 12 government and community stakeholders in Bogor. The interview guide covered key areas of community and government proposed responsibility for community-scale systems under a co-management model and was designed to test perceptions and reactions to the proposed arrangements.

A co-design and a follow-up workshop were undertaken in each case study location. This research approach valued engagement by relevant stakeholders in the research process, with an intent to prompt changes in their thinking through their involvement in the research, and to ensure the research was relevant to their work. Co-design is an emerging discipline that proactively brings together actors to address a particular issue or problem (Blomkamp, 2018). In Bantaeng the initial workshop was attended by 25 participants (7 women, 18 men) and included the following organizations: planning agency, public works agency, technical work unity for wastewater management,[1] health agency, environment agency, water utility, two KSM and AKSANSI (National association of KSM) and a representative of a sanitation development cooperation program. The follow-up workshop was attended by eight members of the sanitation working group. In Bogor, the workshop was attended by 20 participants (11 women, 9 men) including planning agency, public works agency, waste management unit, environment agency, water utility, city development group, AKSANSI and a representative of a sanitation development cooperation program. The follow-up workshop was attended by nine members of the sanitation working group. The participatory methods drew on Mitchell and Ross (2016) and the work of Rosenqvist (2018) and focused on how responsibilities could be partitioned between different actors and designing scenarios for how roles and relationships could be shifted and changed.

The qualitative research approach described above has the advantage of providing in-depth analysis for the two cases including specific details that illustrate the co-management concept. A limitation of the study is its scope, in covering only two case study locations and limited numbers of research participants due to the qualitative approach. The careful selection of research participants based on relevance of their role to the research topic serves to mitigate this concern.

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RESULTS

The findings of this research are presented in three sections, addressing the three key research questions in sequence.

Conceptualizing a Co-management Approach

Previous research recommended greater local government involvement in the management and governance of community-scale systems (Eales et al., 2013; Mitchell et al., 2016). However, it was recognized that the community plays an important role, and community empowerment remains a strong national government norm in Indonesia. Therefore, a co-management approach was proposed that comprised the KSM managing daily operation, with local government supporting the KSM in more complex tasks. Following the document review and co-design workshop four minimum responsibilities were identified for local government alongside related community roles (see **Table 1**). These minimum responsibilities are elaborated and justified in the sections below.

TABLE 1 | Co-management approach to community scale sanitation.

Community operate	Local government support
Within community capacity: 1. Day-to-day operation and maintenance (regular cleaning, removing rubbish, unblocking pipes etc.) 2. Collect user fees and fund regular costs (e.g. pay operator) 3. Request support	Proposed minimum responsibilities: 1. Monitor and maintain records and plan corrective action 2. Provide technical and social support to community management group 3. Formalise process of fee setting and collection 4. Fund major costs (rehabilitation, extension, retrofitting)

Monitor and Maintain Records and Plan Corrective Action

Local government responsibility to monitor services constitutes and integral part of their legal mandate to ensure on-going services. The proposed task includes monitoring and maintaining records of all community-scale systems, including technical assessment of performance and damage, as well as the institutional and financial status of KSM, and to inform KSM of any immediate concerns and share data with relevant local government department (e.g., health or public works) and ensure corrective follow-up actions. Previous research found that limited monitoring occurs (Mitchell et al., 2016). The system operation and the institutional and financial status of KSM are not formally monitored by local government, only informally through AKSANSI (Mitchell et al., 2016).

Monitoring needs to consider different information needs. First, at the strategic level, there is a need for city or national scale monitoring to understand the status and performance of the systems with respect to city-wide sanitation planning and development, and to determine the extent to which community-scale systems are a cost-effective, appropriate way to achieve city and national-level sanitation strategies. Such information could be compiled at local level and then integrated with national strategic monitoring through the national database NAWASIS.[2] Second, at the tactical level (or management level) there is a need for monitoring of technical, institutional and financial status of systems. Monitoring should be ongoing (i.e., annually) and should inform the sanitation department of priorities for investment and planning. The responsibility for tactical level monitoring is already allocated to local government in the national guidelines. However, the lead actor to consolidate data and share the findings is often unclear and current monitoring, if it occurs, focuses only on the effluent quality. Lastly, at the operational level there is a need for KSM's daily and weekly monitoring of the system operations to inform immediate needs and maintenance or make requests for additional support.

Provide Technical and Social Support to KSM

There is significant need for local governments to proactively provide KSM with technical and institutional support post-construction for operation, maintenance and management. Previous research (Eales et al., 2013) found that one-third of systems did not have an active management group, most did not collect user fees and over half the operators surveyed were working without cash payment. While these systems were built with an effort to enable community empowerment, instead, several communities reported that the system becomes a burden due to malfunctioning, and that there was a missing line of communication or assistance from local government (Rosenqvist, 2018).

The specific activities that KSM found challenging included both technical and non-technical activities (Mitchell et al., 2016). Technical challenges included: monitoring of effluent; major repairs and rehabilitation; retrofitting unused facilities (community toilets and unconnected simplified sewerage systems; conducting biogas maintenance; monthly de-scumming and desludging every 2–4 years. Non-technical challenges included: collecting user fees; managing the accounting books; reporting and managing bank accounts; paying operators, planning and budgeting for recurrent or major/unexpected costs; sourcing supplementary income; ensuring operator is active and has legitimacy in community; and educating households about the benefits of the system to encourage them to connect or increase their willingness to pay.

Formalize Fee Setting and Collection

The approach to community-scale sanitation in Indonesia requires that households commit to paying a monthly fee for operation and maintenance to be collected and managed by the KSM. The amount and method of collection are left to the community to define. In shifting to a more professionalized service, it is important to formalize fee setting and collection, as this provides authority and legitimacy for KSM in this domain, and as a consequence, enable sustainable financing of operational costs. Although during system development a given community commits to paying the ongoing costs as part of the initial selection criteria, previous research found that more than a quarter of community sanitation centers have no regular income at all, and over half of simplified sewer systems rely solely on ad hoc collections as necessary (Eales et al., 2013) and that fee collection is the most common challenge for KSM (Mitchell et al., 2016).

This research revealed that these challenges related to fee collection are due to four main reasons. First, a lack of perceived need, particularly for community sewer systems, since the operator is typically not paid and major costs such as desludging or maintenance are not planned for. Second, lack of legitimacy for wastewater fees. According to the national program guidelines the fees were "*iuran*" which is a voluntary contribution rather than a 'tariff' or 'retribution' which are regulated payments. Nor are sanitation fees set at village or sub-village levels, whereas this is done for other community service fees (i.e., security or waste collection). Third, there is a lack of authority to collect fees in the case that the allocated collector is the operator, or someone not linked to the community power system (community/neighborhood group, RW/RT) who typically collect other community service fees. Lastly, there is low willingness to pay – with education and empowerment activities with the wider community typically only undertaken pre-construction, the understanding of the benefits of the system is lost over time, resulting in low commitment to pay.

Fund Major Costs

A minimum local government responsibility to fund major costs that are greater than community financial capacity is a way to ensure that major repairs and rehabilitation take place in a timely manner, and that additional connections and retrofitting can be undertaken. This role is strongly needed as most KSM are not able to collect sufficient fees to cover routine operational costs, let alone the major and significant costs which need to be met for successful operation. Nor are KSM capable of planning and

[2]NAWASIS or the National Water Supply and Sanitation Information Service is an internet-based data center being developed to monitor the development of water and sanitation sector in Indonesia www.nawasis.info.

budgeting for such costs (Mitchell et al., 2016). Full life-cycle costs (Abeysuriya et al., 2015) for sustainable operation of community-scale sanitation systems include:

- **Capital investment:** initial investment cost for infrastructure.
- **Routine operation:** such as the operator's salary, costs of cleaning materials and equipment, electricity and water costs for communal toilet facilities, etc.
- **Minor repairs:** small maintenance costs such as unclogging the system, desludging, fixing pumps, desludging (every 4,5 years).
- **Major costs:** Larger repairs such as main pipe or outlet repairs, rehabilitation from major damage, system expansion and new connections or retrofitting (i.e., converting a community toilet to a simplified sewerage system with household connections).

Given regular collection of adequate user fees, the KSM should be able to recover the routine operational costs and minor repair costs. However, the major costs described above are unlikely to be funded, even with improved fee collection. In addition, to date there has been limited guidance on available options for KSM to request financial support from local government.

A key issue arising in relation to financing large costs is asset ownership. Legitimate expenditure for local governments relies on either government ownership of the asset (and the related land) with registration of the asset on the local government asset register, or, payment of a grant (hibah) to a legal entity (Al'Afghani et al., 2019). As currently few KSM are legal entities, this raises issues that require further resolution by sector stakeholders and are discussed in the two case studies below.

Findings in Bantaeng

Kabupaten Bantaeng is a Regency in south Sulawesi located on the coast, with a population of 185,581 and a population density of 469 people/km^2 (Badan Pusat Stastistik [BPS], 2019). Bantaeng undertook a city sanitation planning process in 2013,2014, which was further expanded in 2016 with a more comprehensive poverty, health and sanitation survey, and set targets for reducing open defecation, increasing toilet connections to existing community-scale systems and building new ones. At the time of this research, 68% of Bantaeng households used septic tanks, 10% used community-scale systems (communal toilets or simplified sewerage systems) and 22% practiced open defecation.

At the time of this research, there were 22 community-scale systems built since 2010, with the majority in recent years, and including 16 simplified sewerage systems, 1 communal toilet and four mixed (communal toilet and simplified sewerage) systems. Based on an expected design capacity of 50hh/system, approximately 4,400 people could be served by these systems which equates to 2.5% of the city population. However, this study confirmed that utilization was approximately 66% or 2,444 people.

Sanitation was managed by a local wastewater work unit (UPTD-PAL- *Unit Pelaksana Teknis Dinas (UPTD) Pengelolaan Air Limbah (PAL)*) established in 2014 under the public works (PU) department. At the time of research, it consisted of one technical staff, one support staff, four truck operators and two treatment plant operators. Based on a local regulation (3/2015 PU decree- *PU Decree 3/2015 on UPTD-PAL position description "Keputusan kepala dinas pekerjaan umum dan kimpreswil Nomor 03 Tahun 2015"*), UPTD-PAL was responsible for the operation of the planned centralized wastewater treatment system, treatment for special community apartments and sludge treatment, and although the responsibility for community-scale systems was not clearly defined, there was one specific position allocated for a patron or "guide" for community-scale facilities and community participation management, with that role vacant at the time of this research.

The proposed four minimum local government responsibilities were discussed in interviews, the co-management workshop and follow-up workshop with the Pokja Sanitasi, with the findings presented below.

Monitor and Maintain Records and Plan Corrective Action

Prior to this research there was limited data on the technical status of community-scale sanitation systems and no data on KSM institutional or financial status. While effluent monitoring was conducted by the environmental agency (BAPPEDALDA) the available data was not for all sites, infrequent and only monitored environmental parameters that do not indicate treatment performance. Both the health department (DINKES) and Bappedalda monitored groundwater quality, however, this information was not shared with other departments or consolidated with other data to inform sanitation improvements.

The planning agency (Bappeda) suggested that investment should follow planning and planning requires data and were supportive of an increased focus on monitoring. Additional drivers for monitoring identified by participants included: the need for data on the status of sanitation in order to receive national funding to provide on-site sanitation, to improve river and sea water quality, and to improve planning for system repairs. Following the workshop, the city had already taken steps to improve monitoring, specifically for the community-scale systems. UPTD-PAL accompanied AKSANSI to conduct monitoring of the technical, institutional and financial status of the existing systems in 2016. Bappeda was also in the process of conducting city-wide sanitation status and health surveys and proposed to add this data to their poverty database.

To improve monitoring and corrective action, it was agreed that clarity of responsibilities was needed across agencies. A proposition was made that PU lead and coordinate ongoing monitoring and data collection for community-scale systems, as they are the agency responsible for sanitation and with the authority able to fund improvements. The PU decree (3/2015) allocates responsibility to UPTD-PAL for wastewater monitoring, however, they did not yet have a laboratory so Bappedalda would continue to support. Monitoring was agreed to include both technical and social aspects and would require additional resources for the UPTD-PAL (or to outsource some tasks to a locally registered unit of AKSANSI or other provider) and support from the *Pokja Sanitasi* to enable coordination and appropriate sharing of data and responses across agencies.

Technical and Social Support

As a part of this research, AKSANSI and UPTD-PAL reviewed all 22 community-scale systems and found various technical problems, with eight systems damaged, and problems with main sewer pipes and backflow. Utilization was only at 66% of the system capacity across the 22 systems, and of those households utilizing the systems, only a quarter had connected both their toilet and their greywater, which the systems are designed for. Surprisingly, most had not connected their toilet and did not realize this was the intended purpose of the community-scale sanitation system. Despite the relatively recent development of the systems, 38% of the 21 systems monitored did not have an active KSM and 33% did not have an active operator (see **Figure 1**). While UPTD-PAL had provided some technical support for major repairs to three systems, there was no ongoing technical or social support for KSMs, and KSM members reported that they did not know where to go if they required support.

To develop a way forward for local government to provide a strengthened support role to KSM, research participants identified a number of key directions, and took action on several of these between the co-management workshop and the follow-up workshop six months later. Local regulations and plans already allocated a key role to UPTD-PAL in the form of the local wastewater decree[3] and the UPTD-PAL Roadmap, covering their upcoming planning, mentioned annual institutional strengthening of KSM. It was suggested that improvements could be made to the social support to KSM by leveraging from existing sub-district/village healthy city programs and placing greater responsibility on sub-district leaders. In addition, following the co-management workshop, a coordination meeting with sub-districts had been held and DINKES (health agency) had started build capacity amongst its health center staff *(Puskesmas*) to address existing mis-perceptions and promote greater acceptance of blackwater connections to community-scale systems, not just greywater. Another identified strategy was to provide rewards for high performing KSMs as a means to recognize good management. Finally, the UPTD-PAL agreed to provide additional technical support to the KSM by directly paying four operators to oversee the operation of all systems in Bantaeng, covering approximately five systems each.

Setting the User Fee and Authority for Collection

AKSANSI's monitoring in 2016 revealed that only 33% of KSM (7 systems) had set a user fee (**Figure 2**). The other KSM reported that either: they didn't know a fee was expected, did not think it was necessary, assumed the community would not pay so didn't set one, or thought the area was too poor to pay. Only 14% (3 locations) collected user fees and of these only one provided a salary to the operator **Figure 1**) while one other provided cigarettes for work done. The collected monthly fees were between IDR 3,000 and 5,000/month (US$0.18–0.31, see **Figure 2**). This equates to 0.2–0.4% of the average monthly household expenditure in urban areas of South Sulawesi in 2016 (Badan Pusat Stastistik [BPS], 2016), and while it is low in relation to operational expenses, it is similar to the US$0.31/month tariff applied in other Indonesian cities (Eales et al., 2013).

Interviews with four operators as a part of this research indicated that many wished to be paid but were also likely to continue their work unpaid out of a sense of obligation and personal responsibility for the systems: "*feel I have to make a contribution to my community and keeping it clean*" and "*I am not the allocated operator but I realize that if there is no money then no one else will work. Since the community trusted me to be head of KSM, I feel responsible to maintain the system*". The operators also reported that they are not always supported by the community/neighborhood group (RT/RW) which is why sub-district support was deemed important. Regulations regarding the user fee and its use are also necessary to support KSM treasurers, as one noted that there is an expectation that any saved money will be made available for emergency community expenses rather than saved for major repairs or desludging.

Through the co-management workshop, it was agreed that the formalization of fees and KSM responsibility for collection through a sub-district level decree (Surat Keputusan, SK) rather than through a higher Kabupaten regulation, was appropriate. Discussions had started with sub-district/village regarding their roles in supporting KSM and the management of communal scale systems, and plans were made for providing training in financial management to KSM.

Major Costs

This research investigated and found three areas in which the KSM required financial support for major costs. These included: (i) increasing the number of household connections due to systems operating at only 66% of design capacity; (ii) connection of blackwater (from toilet) since 65% of households connect only greywater (from shower, washing); and (iii) major maintenance efforts to fix damage to main pipes or treatment and issues that had already been identified in 2016 (see **Figure 3**). In addition, the research identified one system that was not in use and another that had very low usage.

To date, local government has already provided funding for some major costs. For example, they funded major repairs including IDR 50 million (USD 3,700) in 2015 to build an outlet chamber to reduce backflow from the river, and IDR 75 million (USD 5,700) in 2016 to repair a subsided inlet pipe, resurface the treatment plant, install grease traps and build 17 new household connections. This research found there was uncertainty within some local governments about the legality of funding community-scale sanitation systems if they were not on their asset register, however, in Kabupaten Bantaeng, the local government was able to legitimately fund these repairs since the majority of systems were funded through a direct allocation fund, and for most capital budget (*belanja modal*) expenditure had been used and assets kept on the local government asset register rather than being handed over to community.

[3] 2015 Bupati decree about domestic wastewater No 37/2015.

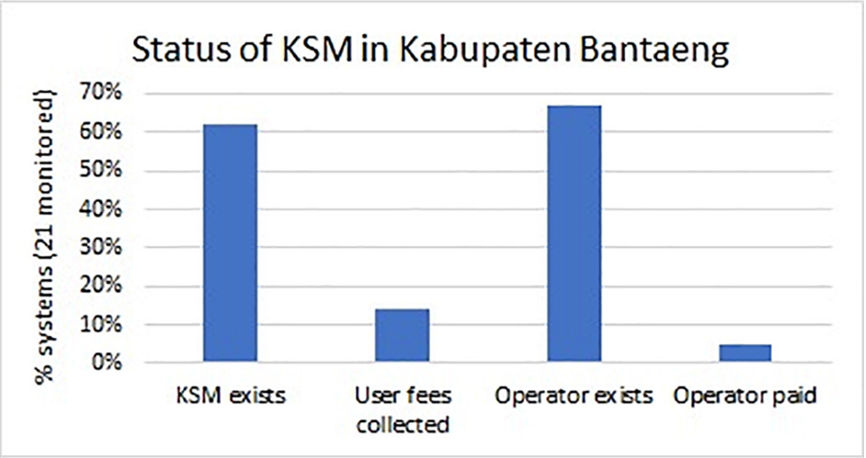

FIGURE 1 | Management status based on review of community-scale systems.

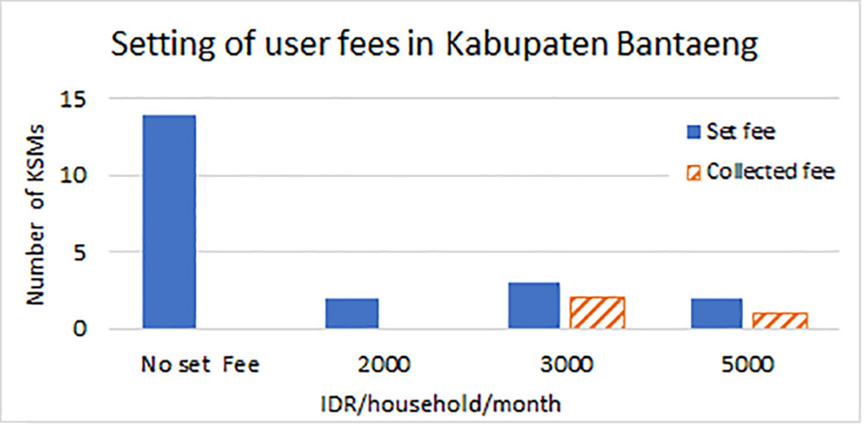

FIGURE 2 | Setting of user fees in Kabupaten Bantaeng.

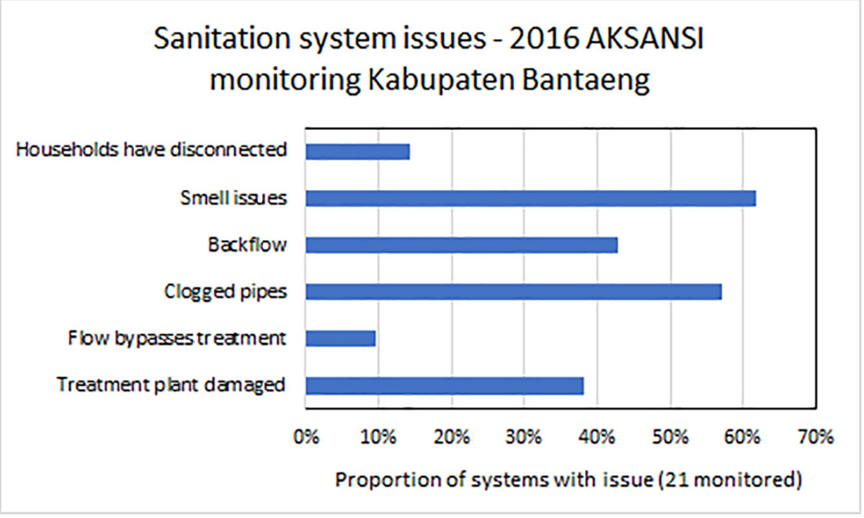

FIGURE 3 | System issues and damages in Kabupaten Bantaeng (AKSANSI monitoring 2016).

For 2017 PU had planned for and requested IDR 90 million (USD 6,900) for maintenance, additional connections and monitoring of existing systems. Based on AKSANSI monitoring and the results provided during this research, they specified the locations for support, with an intention in future to develop clear criteria for support requests. For the systems not on the local government asset register, PU were interested to investigate ways to financially support these systems or have them formally handed from community-ownership to local government ownership.

Findings in Bogor

Kota Bogor is a city in West Java with a population of just over 1 million (2017) and a population density of 9,359/km^2 (Badan Pusat Stastistik [BPS], 2018). Kota Bogor completed their city sanitation strategy (SSK) in 2011 and at the time of this research were investing in extending centralized sewerage in some areas. A new wastewater local government decree (*Perda*) was in the approval process intended for all scales of sanitation was under development.

Sanitation in Kota Bogor was predominantly on-site (71%), although many households' toilets discharged directly to the river (22%) and open defecation still occurred (4%) (Bogor, 2014). A centralized wastewater treatment plant was built in 1997 for 600 households but only 393 were connected. Fifty-two community-scale sanitation systems were built from 2007 to 2014 serving over 8,000 people (1% of the population). A further 40 systems were proposed to be built in 2016 and 83 in 2017.

Institutional responsibilities were spread across different agencies and also lay directly with communities. Wasbangkim (the department of building and housing supervision, WBK) was assigned responsibility for community-scale sanitation systems in 2015. Prior to this the wastewater technical implementation unit UPTD-PAL (under the cleaning department, DKP) were responsible as they also managed the centralized sewerage system and fecal sludge. The Healthy City Forum (*Forum Kota Sehat*, FKS) was established in 2007 and it supported the implementation of communal scale systems, while an AKSANSI branch was established in 2013 to support the KSM in the operation phase. A draft local regulation allocated responsibility for community-scale sanitation to the community (*masyarakat*), however, several participants in this research also suggested that the UPTD-PAL should potentially also take on the role of supporting community-scale sanitation.

Monitor and Maintain Records and Plan Corrective Action

With 52 existing community-scale systems and many additional planned systems for 2016 and 2017, the total comprises over 170 systems which would require monitoring. Due to this large number, a systematic way of assessing issues and prioritizing and planning major maintenance, rehabilitation and expansion investment was needed. Existing responsibility for these systems has been dispersed and ad hoc, with the environment agency (BPLHD) monitoring effluent annually and the local health agency (Dinkes) monitoring water quality. WBK had conducted a one-off technical assessment of all systems. AKSANSI had also undertaken preliminary monitoring of technical and institutional dimensions. Data was typically not shared and not available to inform decisions.

Over recent years Kota Bogor had initiated action in the domain of monitoring, including formally shifting responsibility for the monitoring from the community to local government in a new local regulation. During this research, one local government participant confirmed that: "*Data entry would be centralized with one agency and we and will continue discussing at Pokja saniatsi. We will also make a city mayor regulation (Perwali) to specify the roles for monitoring*" such that information from WBK, AKSANSI and BPLHD could be consolidated, and transparent decisions made about which systems should then receive support.

Technical and Social Support to KSM

An investigation conducted as part of this research identified a number of institutional issues: 13%of systems monitored did not have an operator, 44% did not have a user fee, only one system has been desludged and 19% systems had issues with wastewater flow. Similarly, the Wasbangkim assessment report included reports of blocked and damaged pipes, and damaged superstructure or treatment systems.

Technical support to KSM was particularly necessary for desludging, as many systems were likely to soon require emptying. However, access was difficult to many systems due to steep terrain, narrow access lanes and long distances from main roads suitable for the emptying trucks. The small carts provided through awards or grants to some KSM were unsuitable in some locations because they were too big for alleys or, due to their small volumes and short hose lengths, would require complex arrangements to empty the systems. Through the research process it was decided that the UPTD-PAL would support desludging, however, the technical solutions remained unclear for steep areas.

Social support was also required, with reports that many KSM were dissolving and neighborhood leaders then became tasked with managing the community-scale systems. AKSANSI was active and provided some social support to KSMs but did this voluntarily without recompense and did not have the authority to enforce KSM activity, unlike government institutions.

Local government has attempted to incentivise better functioning of KSM and since 2014 the local government has presented Sanitation Awards for KSM with the aim of recognizing KSMs, motivating good operations and maintenance, and raising awareness in the community about the need to maintain systems. Wasbangkim also conducted one-off empowerment workshops for KSM in 2016. Through this research further roles were also defined, in particular to allocate primary responsibility for social and institutional support to the relevant subdistricts (*Kelurahan*).

At the co-management and follow-up workshops, it was also proposed that budget funds should be allocated for both supporting technical issues and for empowerment of KSM, including instilling a sense of responsibility, operations training, and setting and collecting tariffs. However, at the time of this research, grants could not be provided on an ongoing basis, and only to legal entities, whereas none of the KSM in Bogor were legal entities.

Setting User Fee and Authority for Collection

Fees are needed to cover daily costs including operator fees, maintenance equipment, electricity and water charges for communal toilets. The existing fee collection was low and justified increased attention to this area by local government. Monitoring revealed that 44% of systems do not have a set user fee, and those that do charge IDR 1,000–25,000 (0.08–1.9 USD) per household per month, with an average of IDR 2,400 (USD 0.18) per household per month (see **Figure 4**). These tariffs equate to 0.1–2.2% of the average monthly household expenditure for urban areas of West Java in 2016 (Badan Pusat Stastistik [BPS], 2016). This is lower than national target for affordability of 4% for water supply, however, as these systems often serve low income populations the affordability of the connected community should be considered. Data was not collected on whether the KSM are collecting the fees, or on the percentage of households paying. Co-management workshop participants noted that fees are insufficient to cover costs and the monitoring showed only 13 of 52 KSMs pay the operator a salary (see **Figure 4**).

Barriers to fee collection included the perception from households that sanitation was a free service and they did not see the need to pay, while some KSM acknowledge the households are low income and do not think they can afford a fee. Very few KSMs were saving money to pay for the intermittent expenses of desludging and minor repairs, therefore such often did not occur or the KSM leadership or operator paid.

During co-management and follow-up workshops, the *Pokja Sanitasi* agreed that a user fee should be paid for communal scale systems, so long as that fee were affordable for low income households. It was agreed that the neighborhood group and sub-district should be engaged to support the formalization of *iuran* (contribution) or else that a local regulation should include the possibility of a tariff or *retribusi* (which have a different status to *iuran*) to support institutionally based fee collection. In a scenario where the UPTD-PAL would be made responsible for community-scale systems, this agency could support formalized fee collection, as is undertaken for centralized sewerage.

Major Costs

The feasibility study commissioned by Wasbangkim identified a number of technical issues, with 12 systems requiring priority improvements due to damage and idle capacity. This included five systems which needed replacement due to severely damaged treatment plants or issues with the inlet or outlet pipes, and requests for expansions. These repairs and expansions were beyond community ability to fund. During co-management workshops participants recognized that the users of community-scale sanitation systems are typically low income and local government should responsible for paying for these major expenses.

To date, the Wasbangkim had funded eight systems for rehabilitation or optimization in 2016 and requested a similar amount for 2017. Improvements supported by local government funding to date included the following: repaired the communal toilet roof and added a room for community use, repaired the main pipe that was not previously flowing; repaired and painted a communal toilet building and built another level for community use; created a new well water supply and fixed some manholes; provided a new water supply; and increased the size of the inlet pipe, built a new water supply and added a washing area at a communal toilet. The latter system also required desludging but it was inaccessible with current equipment.

A proposed local regulation for wastewater allocated sole responsibility to the community for financing the operation and maintenance of community-scale systems. However, this regulation also noted that funds could be "*sourced from iuran or other legitimate sources*" which could include government sources, but there was no requirement for local government to provide funds, a matter which was left to further discussion subsequent to this research.

One complication regarding funding major costs was the asset ownership status. The national guidelines implied that assets were to be handed over to communities, and indeed in many cases the relevant land was owned by the community. However, this situation precludes local government legitimately

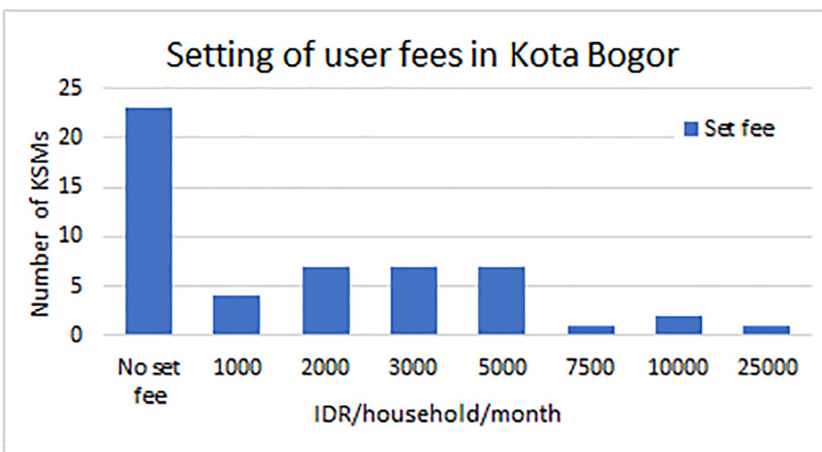

FIGURE 4 | Setting of user fees in Kota Bogor.

funding maintenance, rehabilitation of repair of these systems from the local government capital maintenance budget, since they would not appear on the local government asset register. Hence the possibility of handing assets back to local government was discussed, as was the potential for KSM to become legal entities such that KSM could instead receive funds from local government for repairing sanitation systems.

During the co-management and follow-up workshop, the *Pokja sanitasi* also suggested that the Wasbangkim should develop a standard operating procedure for the local government funding of rehabilitation and expansion. This would ensure strategic investment and the planning of funding, improve equity and provide an incentive for KSM to improve their institutional functioning.

Review of National Program Guidelines

Recent updates to the National Guidelines had moved from allocating full responsibility with the community, to assigning at least some responsibilities to local government. However, these roles were not always well defined. Our review therefore focused on how the Guidelines could more explicitly support and articulate a co-management approach in which community and government are both responsible for different aspects of management and governance. The review covered three elements: (i) allocation of responsibilities to community and to local government (ii) post-construction financing and (iii) asset ownership and KSM legal status. These represent areas where decisions made in the implementation phase directly affect subsequent local government and community roles in service delivery. The review focused on two different programs (with different funding arrangements between national and local level). Firstly, Sanimas DAK (70% of systems built in 2015), a funding mechanism whereby local government directly receives a grant and itself chooses how to invest. Secondly, Sanimas Regular (10% of systems built in 2015), a nationally run program in which provincial level representation of the Ministry of Public Works provided support to communities and local governments play a lesser role. The latter program was reported by local governments to inappropriately by-pass their own planning processes due to the direct engagement with communities, compounding the issue of their low sense of ownership and responsibility for the systems.

Review of the *allocation of responsibilities* in the Guidelines revealed that success and sustainability were described as dependent only on community roles rather than on both community and local government. The Guidelines allocated responsibilities to community that, based on previous research, are beyond their capacity while local government roles were not fully clarified. The focus on building capacity of the community organization was stronger for the Regular program compared with DAK program. Overall, the national guidelines were based on a norm to support 'community empowerment' to create ownership of the community-scale sanitation systems. For example, "*Management of infrastructure and facilities can run well if [it is] realized with a real working plan and contributions (funding) from beneficiaries as [a form of] self-reliance for sustainability. This is done to foster a sense of belonging*". (Regular guidelines Article 6.2). This vision of empowerment is unfortunately not realized, as roles allocated to community are beyond their capacity. The Guidelines include numerous activities that are allocated to the KSM. These include: prepare the operation and maintenance plan; operate and maintain the sanitation facilities; conduct or organize desludging; conduct effluent monitoring; monitor and record damage and plan repairs; perform repairs or rehabilitate; develop, expand or increase the quality of service and number of house connections; conduct behavior change campaigns; set and collect user fees; manage and report finances. As demonstrated through previous research and the case studies in Bantaeng and Bogor, it is not realistic that communities fulfill these responsibilities, and hence the suggestion for co-management discussed in this paper. In places, the Guidelines do mention some of the proposed minimum local government responsibilities, specifically monitoring, extension and major repairs, however, these mentions are vague and it was not clear whether such roles were intended to be optional or obligatory.

Review of post-construction financing showed that that the Guidelines need to provide clearer guidance on how to calculate a cost-recovery tariff that fits with the prescribed community role. The expectation of communities to collect and manage fees described in the Guidelines was likely exceed community capacity, particularly in terms of book-keeping, reporting and seeking additional financial sources. Lastly, whilst the Regular Guidelines mentioned the local government role in financing large costs such as rehabilitation and replication, the DAK Guidelines did not. In general, it was not made clear if this local government role was obligatory or optional, nor which budget line items could legitimately be used or how the initial budget mechanism used to fund the system directly affected this.

A review of asset ownership and legal status revealed that the Guidelines had omissions regarding the key elements that affect asset ownership – namely land ownership, land transfer and KSM legal status. Handover processes described in both Regular and DAK Guidelines were vague, and only include the handover from KSM to KPP, and were unlikely to be legally binding. Finally, and most importantly, the Guidelines did not make clear if or how local governments could register assets on their asset registers. It is important to ensure this is an option, since expenditure analysis makes clear that for local government to easily fund large costs (rehabilitation, extension and retrofitting) they must own the asset.

DISCUSSION

The discussion below is on three areas to situate the proposed co-management approach for community-scale sanitation systems in the wider framework of sanitation service delivery in a city-wide context. These areas include reference to the human right to sanitation and how co-management might provide a stepping stone towards the expected roles of government in enabling services, the requirement for professionalized service delivery to secure on-going city-wide services across different scales of technology and management, and finally, links to wider governance context of decentralization that is prevalent throughout many low and middle income countries.

Firstly, the co-management approach described in this paper aligns well with the internationally recognized human right to sanitation (de Albuquerque, 2010) as well as national legislation in Indonesia that gives local government legal responsibility for sanitation as a basic, concurrent, mandatory affair. The resolutions made by the UN General Assembly and the UN Human Rights Council impose obligations on governments to respect, protect, and fulfill right to sanitation services that are safe, sufficient, accessible, affordable, and acceptable to everyone. As a part of this, governments are expected to use the *maximum resources* to take *progressive, incremental steps* towards realizing the human right to sanitation. Monitoring, the first of the minimum responsibilities proposed for local governments in this paper, is directly in line with expectations under the human rights, such that governments are able to assess and demonstrate to both their citizens and the global community the extent to which the rights are being met in their country, and also to inform decisions on planning and resource allocation (de Albuquerque, 2014). In addition, in circumstances where non-state service providers such as a community management group are involved, a key obligation of the state is to regulate through setting standards, establishing accountability mechanisms, and ensuring that grievance mechanisms are in place (de Albuquerque, 2010). Such responsibilities move beyond the proposed approach described in this paper but could form a future trajectory once better functioning sanitation systems were achieved through the proposed approach as a starting point. For instance, an area not tackled in this paper is questions of where responsibility would lie, for instance, in the case of a significant irregular discharge of sludge, or effluent discharge high in contaminants, due to poor or incorrect operation. Such accountabilities must ultimately be defined and operationalised as part of a robust co-management arrangement. Finally, in the contexts of the rights, particular attention should be paid to the equity of service provision across a city. With the community-scale sanitation program, at least in Indonesia, targeting low-income communities, there is a risk that these systems become a greater financial responsibility or time burden on users as compared with other scales of sanitation infrastructure and services.

A second area worth raising is the value of de-coupling the scale of management from the scale of technology in the provision of city-wide services. In Indonesia the scale of service for the community-scale systems described in this paper has to date directly dictated the management model, also assumed to need to operate at community scale. However, it is possible to provide centralized management across multiple community-scale systems, and which can provide economies of scale. In particular, for local governments to fulfill the proposed co-management minimum responsibilities, this will require relevant human resource capacity, financial capacity and skills, ideally housed within a central purpose-built work unit. This is true for the technologies employed in the cases described in this research (small gravity sewer networks connected to an anaerobic baffled reactor) and is even more true if more complex technologies were to be utilized. This would also ensure professionals can be specifically trained and retrained which addresses the issue of the lack of trained operators found to be a major reason for malfunctioning of small plants in a study in Egypt (Reymond et al., 2018). Such units dedicated to wastewater are an emerging institution within some local governments in Indonesia, particularly in cities where sewerage networks exist, but are not yet common (IndII, 2011). Equally, there could be potential to combine responsibilities with those of water utilities (PDAM), since some functions such as fee collection, are already well-established in such entities (Rosenqvist, 2018). Other countries are also looking to the potential roles of private sector to overcome the human resources bottleneck of utilities responsible for services (Reymond et al., 2018). Regardless of the particular chosen arrangement, the key objective should be a critical mass of suitably skilled professionals who can provide professionalized management, since sanitation, as well as being a human right, is also a public good, and without safely managed services, public health will be compromised (WHO, 2018).

Thirdly, in highly decentralized governance contexts such as Indonesia, wider policy and legal support for co-management arrangements need to be secured for co-management models to be feasible and achievable, including with respect to lines of accountability. Such policy and legal support reflect the areas described in this paper concerning public financial management and funding flows from central to local level, as well as rules and regulations pertaining to relevant asset and land ownership (Al'Afghani et al., 2019). As demonstrated in this study, the way in which funding is transferred from national to local level can significantly impact the outcomes, resulting in negative impacts if local government engagement is bypassed. Conversely, other studies have shown how carefully designed performance-based financing can instead incentivise improved institutional functions and arrangements at local government level (Willetts and Howard, 2017, IndII). A conducive environment for local government leadership, authority, capacity and management of sanitation requires national programs funding sanitation to pro-actively incentivise such roles in local governments (Chong et al., 2016; Abeysuriya et al., 2019), rather than on the contrary, as described in this paper, to potentially undermine this possibility or create barriers for such roles to be assumed. Specifically, in relation to supporting citywide inclusive sanitation services and based on this study, local government should be involved in all city sanitation planning and implementation, both for their buy-in and to ensure the asset is under their ownership. Ultimately the lines of accountability need to rest with local government responsible to ensure these services. Systems financed by donors or national government should coordinate and involve local governments if systems are to be included in citywide management arrangements. More broadly, development of a coherent policy, planning, financing and implementation approach across national and local level emerge as key factors in supporting effective institutional arrangements for community-scale sanitation in a citywide context.

CONCLUSION

Decentralized sanitation services are often promoted as an important component of citywide sanitation, the lessons learned from the scaling up of community-scale sanitation systems in Indonesia can provide valuable insights to implementation and governance. This paper described how responsibility for managing community-scale systems could be fulfilled through a co-management approach by local government and low-income communities in Indonesia, with local government assuming four proposed minimum responsibilities. Two case study cities demonstrated that these proposed minimum responsibilities were appropriate, acceptable and feasible for local governments. These minimum responsibilities included for monitoring, technical and social support to community management groups, funding large costs and supporting formalization of fees and fee collection. Such an approach would be aligned with the human right to sanitation, support improved equity and professionalization in the provision of sanitation services, and provide a viable component of a wider city-wide service delivery approach.

DATA AVAILABILITY STATEMENT

The datasets generated for this study will not be made publicly available as the datasets include named respondents and participants and this would contravene the research ethics approval. Requests to access the dataset can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Technology Sydney. The participants provided their verbal informed consent to participate in this study, documented by the researchers.

AUTHOR CONTRIBUTIONS

JW and FM were involved in all stages of the research from conceptualization to implementation, analysis and writing. JW led the authorship of this manuscript, drawing on secondary material that was prepared jointly by JW and FM with some inputs from MA'A. MA'A was involved in research conceptualization and components of the research related to legal and institutional arrangements, particularly for budgeting and financing. FM supported the monitoring reviews undertaken of the community-scale systems in both locations and analyzed this data. All authors have reviewed and agreed on the final manuscript.

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Costs, Climate and Contamination: Three Drivers for Citywide Sanitation Investment Decisions

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Significant progress is needed, in both large cities and small towns, to meet the ambitious targets set at international and national levels relating to universal access to safely managed sanitation. There has been increased recognition in the urban sanitation sector that in rapidly growing cities, there is unlikely to be a single centralized sanitation solution which can effectively deliver services to all demographics, and that heterogeneous approaches to urban sanitation are required. At the same time, due to competing investment priorities, there is a greater focus on the need for sanitation investments to address multiple objectives. However, calls for more informed sanitation planning and a more dynamic and disaggregated approach to the delivery and management of sanitation services have had limited impacts. This is in part due to the complexity of the drivers for sanitation investment, and the difficulties involved in identifying and addressing these multiple, often conflicting, goals. This paper examines three potential drivers of citywide sanitation decision-making – public health, sustainability and economic performance – via the three proxies of contamination, climate change and costs. It examines the importance of each driver and proxies, how they are considered in investment decisions, the current state of knowledge about them, and priority aspects to be included in decisions. At present, while public health is a common driver for improving sanitation, there are significant gaps in our understanding of fecal contamination spread and exposure, and how to select sanitation solutions which can best address them. Climate change is sometimes seen as a low priority for the sanitation sector given the immediacy and scale of existing challenges and the uncertainty of future climate predictions. However, potential risks are significant, and uninformed decisions may result in greater costs and increased inequalities. Cost data are sparse and unreliable, and it is challenging to build robust cost-effectiveness analyses. Yet these are needed to compare citywide options based on least-cost over their full life cycle. This paper provides insights into how existing evidence on contamination, climate change and costs can inform decisions on sanitation investments and help chart a sustainable way forward for achieving citywide services.

Keywords: urban sanitation, decision-making, contamination, climate change, cost-effectiveness, wastewater, sustainability

INTRODUCTION

The re-emergence of a citywide perspective on sanitation has focused much-needed attention on sustainable solutions that consider the full sanitation service chain for the entire urban population. This perspective echoes many earlier calls for a radical shift from business as usual to address the inequalities, inadequate coverage and sustainability issues of current poor sanitation in many low- and middle-income countries (LMICs) (e.g., Kalbermatten et al., 1982; Wright, 1997). Globally, one billion people in urban areas are without even basic access to sanitation, considered a basic human right, and inequalities persist, with an increasing gap in access between the richest and poorest urban households in 30% of countries (UNICEF and WHO, 2019). An estimated 53% of the global urban population does not have safely managed sanitation (UNICEF and WHO, 2019), reflecting numerous failures across the service chain and resulting in the discharge of untreated fecal waste across the urban environment (Peal et al., 2014). This situation disproportionately affects poor and marginalized groups (UNICEF and WHO, 2019).

Urban sanitation specialists have long recognized that to achieve citywide sanitation there needs to be a shift away from fixed conventional sanitation technologies toward planning approaches that incorporate a range of solutions to address sanitation in ways which are disaggregated, both geographically across the city and along the sanitation value chain (Wright, 1997; BMGF et al., 2017). Yet the persistent focus of technicians and investors on centralized sewerage systems has resulted in investments concentrating on small, often wealthier, areas of cities, with low-income and challenging areas left with sub-standard services (McGranahan, 2015). Illustrating this point, a recent assessment of the outcomes of investment by development banks found that between 2010 and 2017, banks invested 20 times more in sewerage than in fecal sludge management (FSM) despite the much larger populations serviced by onsite systems (Hutchings et al., 2018). While FSM has received growing attention, onsite and centralized options are often considered independently of each other, without an understanding that combined solutions are the likely way forward in most cities (Hawkins et al., 2013). There is a growing consensus that achieving 'sanitation for all' requires a mix of different contextualized solutions that embrace various scales of technologies and services (Lüthi and Sankara, 2018), and that inequalities in exposure to fecal waste must be actively monitored and progressively reduced (UNICEF and WHO, 2019).

Shifting from business as usual requires improved decision-making frameworks to assist in selecting appropriate investments that balance economic, public health and environmental objectives (WHO, 2018). While these three overarching objectives are often said to drive sanitation investment, it is not always clear how the options considered will contribute to achieving each objective (Kennedy-Walker et al., 2014). In many cases, competing or interlinked objectives are brushed over or only briefly considered. For example, even economic performance, which is usually explicitly examined in development bank operations, is rarely used to compare and prioritize different sanitation delivery options. It is even rarer to see an explicit discussion of the relative importance, for example, of public health, economic performance and sustainability when sanitation options are being prioritized. This is in part due to the lack of requisite data and the absence of institutions with the ability to balance multiple, often conflicting, drivers of investment.

To illustrate the challenges and opportunities inherent in moving toward a more nuanced approach to decision-making, this paper examines contamination, climate and costs as critical lenses for considering the public health, sustainability and economic dimensions of citywide sanitation. These three areas were identified as traditional and emerging drivers that in practice are not being adequately addressed in decisions on citywide sanitation. While investment decision-makers may recognize the importance of these three areas, they may fail to consider them for a number of reasons, including: uncertainty about how to practically include different drivers in option comparisons (fecal contamination, climate), the low priority they assign to these drivers (climate, at times fecal contamination), and inconsistent or limited data and approaches for analysis (costs, contamination). As detailed in the following sections, recent publications have also identified contamination, climate and costs as requiring greater attention. The World Health Organisation (WHO) has reaffirmed that widespread fecal contamination, particularly in low-income urban areas, means that the public health objective for sanitation requires renewed attention (WHO, 2018). Various authors (World Bank, 2011; Oates et al., 2014; ISF-UTS and SNV, 2019; UN Water, 2019; WHO, 2019) have called for climate resilience to become an integral part of decision-making frameworks and implementation approaches. Finally, a recent review of the costs of urban sanitation highlights data gaps in cost reporting and life cycle costings (Daudey, 2018) pointing to inadequate attention to this dimension. This article extends existing analyses by synthesizing a broad set of recent literature and identifying how the three drivers may be better considered when developing citywide services.

This paper reviews the English language literature and draw on both academic literature as well as high-quality gray literature, predominantly published in the last five years, found through systematic literature searches of titles, abstracts and keywords including sanitation and any of: decision-making; planning; options; climate; public health; pathogens; costing; or finance. We discuss each of the three areas in terms of its significance to urban sanitation, the state of knowledge and knowledge gaps, the extent to which it is currently considered in decision-making, and priorities for increasing the attention given to each issue. Recognizing the challenge of balancing these multiple drivers, we also identify interconnections between contamination, climate change and costs, and the implications of these connections for achieving the overarching objectives of sustainable, equitable citywide sanitation.

CONTAMINATION

Given the central aim for sanitation to prevent human exposure to disease, and the wide evidence base concerning the burden of disease related to poor sanitation (Freeman et al., 2017; Prüss-Ustün et al., 2014 and Pullan et al., 2014), this section argues for greater consideration of fecal contamination in sanitation decision-making. Although health has previously been an incentive for prioritizing sanitation, there is little evidence that health is central to long-run investment planning for sanitation in many LMICs (Cummings et al., 2016). The health and economic impacts of poor sanitation are often poorly understood and "invisible," so sanitation tends to be seen as a technical engineering task undertaken in formal areas of a city (Cummings et al., 2016). Indeed, mainstream approaches to the planning and design of sanitation systems reflect this framing, and typically focus on the protection of downstream waterways by instituting environmental discharge standards, often without explicit consideration of pathogen removal (Mills et al., 2018). Even when discharge standards exist; their enforcement is limited and political will is needed to regulate and enforce pollution control measures (UN Water, 2017; WHO and UN Habitat, 2018). Whilst chemical contamination, for example by nitrates, heavy metals and other emerging contaminants, is relevant for public health (Cronin et al., 2007; WHO, 2015; UN Water, 2017), in this paper focus on fecal contamination. This is because of its significance for achieving genuinely 'safely managed' citywide sanitation in LMICs, as demanded by the Sustainable Development Goals (SDGs), and also because it acts as a useful proxy for the effectiveness of urban sanitation systems in interrupting transmission pathways for infectious excreta-related diseases.

Understanding fecal pathogen contamination in urban areas is particularly important in cities and towns with low levels of effective sanitation infrastructure and services. Low levels of access to sanitation are associated with an increased prevalence of disease, particularly diseases that continue to inflict a heavy burden in low-income settings, including diarrhea, soil-transmitted helminth infections, trachoma, cholera and schistosomiasis (Speich et al., 2016; Freeman et al., 2017). In locations with high prevalence rates of infectious disease, pathogen concentrations discharged to sanitation systems or into the environment are correspondingly high, particularly during outbreaks (Lusk et al., 2014). The risk to human health is not only driven by pathogen occurrence but also by their persistence in the environment, the presence of vectors or intermediate hosts, and the level of infectivity of individual pathogens (Aw, 2018). In addition, several diseases such as pathogenic *E. Coli*, salmonellae, and shigella have low infectious doses (e.g., can cause infection in humans with fewer than 20 organisms), whilst they are present in much higher concentrations in wastewater (e.g., more than 10,000 organisms/L) (Lusk et al., 2014). Pathogens that are discharged across the urban environment can be transmitted through multiple exposure pathways, including through contact with drain water, surface water or flood water during activities such as playing, washing and bathing, and through food pathways (Wang et al., 2017). When assessing the potential risks associated with different sanitation systems in decision-making, these numerous exposure pathways and high persistence must be considered. There is limited information about the relative importance (in terms of hazard and exposure) of the multiple sources of fecal waste discharged to the environment across the sanitation chain (for example from open defecation, overflowing pits, discharge of effluent to drains or dumping of sludge). A clear understanding of existing knowledge and knowledge gaps is critical, and in this section we review the status of knowledge related to different sanitation systems and approaches to assessing risks.

On-site sanitation systems are the dominant type of sanitation in urban areas in low- and middle-income countries (UNICEF and WHO, 2019). Confusion abounds regarding definitions of onsite sanitation systems. Key distinctions are frequently conflated. In relation to contamination, the main distinction is between lined tanks and partially lined tanks that are effectively sealed (often erroneously described as 'septic tanks'), and systems which are designed for infiltration of liquid fractions into the ground surrounding the tank.

Starting with septic tanks and sealed tanks that are often described as septic tanks, WHO (2006) note that pathogen removal in septic tanks is poor. Authors variously suggest a treatment effectiveness of 0–2 log removal of pathogens, with several suggesting 0.5 log removal (Feachem et al., 1983; Stenström et al., 2011). As such, septic tanks alone are not considered to be a significant barrier against pathogen transmission, and it is recommended that they discharge to a properly designed and sited soil absorption system (Adegoke and Stenstrom, 2019). Adegoke and Stenstrom (2019) research also notes that treatment effectiveness assumes that the septic tank is operating as it is designed to, that it has at least two chambers and that it is regularly emptied of sludge to ensure adequate hydraulic retention time. Often these conditions are not met, and in these cases treatment effectiveness is unknown. WHO (2018) suggests that poorly designed or constructed onsite systems are not expected to reduce the likelihood or severity of exposure to hazardous events. Large numbers of such sealed tanks discharge directly to surface water bodies and drains, resulting in a direct risk of exposure (Peal et al., 2014). In addition, most studies examining pathogen removal from septic tanks have been conducted in high income countries where high water use and connection of both blackwater and graywater to sanitation systems result in lower pathogen concentrations than those typically seen in LMICs. One factor compounding misperceptions by sector practitioners about pathogen removal is that removal is often reported arithmetically rather than using logarithmic scales, which are more appropriate when dealing with large numbers. This can mask the high numbers of excreted pathogens that remain after primary onsite treatment. For example 99% pathogen removal is equivalent to 2 log removal, so with excreted pathogen concentrations potentially 9–10 log, after 99% removal the effluent may still contain 7 log pathogen concentrations (Mitchell et al., 2016).

Overall, there is a paucity of literature on the fate of pathogens in effluent from onsite systems as it enters the environment (e.g., into soil, groundwater, drains, etc.) and the magnitude of related public health risks (WHO, 2018). Despite this, current mainstream approaches to improving sanitation in LMIC frequently focus on emptying and treatment of fecal sludge, with more limited attention given to the construction quality of onsite and offsite systems and to the pathways the liquid portion of the waste may take in an urban environment (Mitchell et al., 2016; Peal et al., 2014). Further, while there is known variation in the fate of different pathogen types (including viruses, bacteria, protozoa and helminths) in onsite systems and the environment given their different sizes, properties and characteristics (Mitchell et al., 2016), there is limited information available on their relative inactivation and persistence under different environmental conditions (Murphy, 2017). Finally, there is a knowledge gap regarding the partitioning of different pathogen types between the sludge and effluent in onsite systems.

With minimal pathogen removal in onsite systems, the effluent presents significant risks to health. We discuss this firstly from a groundwater contamination perspective, and then from the perspective of surface water and drains. Recent WHO (2018) design guidelines require that wet pit latrines only be used in areas of deep groundwater, and that if groundwater is used for domestic water supply then: pits should be located at least 1.5 m above the water table; 15 m horizontally down-gradient from the water supply; no graywater should be added; and septic tanks should discharge to a soak pit or leach field. However, appropriately designed soak-aways and absorption trenches are typically missing in dense urban areas or may be used in unfavorable groundwater conditions (high water table, highly porous soils) (World Bank, 2015; Peal et al., 2020). In addition, research has found that the travel distance of pathogens varies widely, questioning the validity of generalized separation guidance between pits and wells (Williams and Overbo, 2015). Recent studies in the United States have shown that the number of septic tanks in an area has a significant influence on the level of human fecal pollution in groundwater (Sowah et al., 2017). There are also concerns that pathogens from pit latrines can reach groundwater of varying depths, with a review of the existing literature noting that viruses in particular can travel long distances. Whereas protozoa and helminths could be expected to be retained by the soil beneath pits (Orner et al., 2018), viruses have been found in groundwater tube wells up to 50 m away from toilets (Verheyen et al., 2009). However, most research relating to the contamination of groundwater tube wells fails to distinguish between contamination from toilets via the groundwater and direct contamination of the tube wells from the surface. The significance of groundwater contamination will vary by city. Importantly, contamination of shallow groundwater from non-toilet sources is usually high, and in general the use of shallow groundwater for urban water supplies is not recommended, though its use is a reality in many contexts. In some locations where piped water is available, both fecal and other contamination may be a minor consideration. In other contexts, for instance in Indonesia where 32% of the two lowest quintiles in urban areas use on-premises self-supplied groundwater (BPS, 2018), such contamination may be a cause for concern, requiring the application of related tools to assist in risk assessment (e.g., see SanitContam in Krishnan, 2011). However, it is worth mentioning here that the complete replacement of sanitation systems that rely on leaching (to avoid fecal contamination of the surface environment) may need to be weighed up against options for water supply improvements to reduce groundwater use.

Where infiltrating pit soak-aways or leach fields are impractical, there is little evidence of the widespread adoption of safe alternatives (which would primarily focus on either the provision of solid-free sewage to convey liquid effluent to treatment, or the adoption of alternative technologies such as sewerage or container-based sanitation). The most common approach is to discharge pits and tanks directly to water bodies or open ground. In many locations, discharge from septic tanks or pit latrines to drains or waterways presents a significant hazard; often there is inadequate space for a soak pit or the groundwater level is too high to permit infiltration. The Sanitation and Health Guidelines (WHO, 2018) consider any containment units, including septic tanks, that are connected to a drain or a water body are unsafe due to the exposure hazard of the effluent. Despite this, at present the management of liquid waste from containment systems is not included in common FSM solutions and diagrams (see Parkinson et al., 2014; Strande et al., 2014) and insufficient consideration is given to the health risks of onsite systems in dense urban areas (Satterthwaite et al., 2015). WHO (2018) argues that there is currently a lack of options for improving containment and reducing the exposure to effluent from onsite systems discharged to open drains. Indeed, it is highly probable that additional effluent conveyance and treatment, which is a considerable additional cost (Tilley et al., 2014), might be needed to prevent exposure.

Anaerobic baffle reactors (ABR), which have a similar primary treatment function to septic tanks, also achieve limited pathogen removal. ABRs are commonly installed in decentralized wastewater treatment systems in LMICs. While the retention time is longer than for septic tanks, research in South Africa found approximately 1 log removal for bacteria, viruses, and protozoa, and about 2 log removal for helminths (Foxon, 2009). Further treatment is necessary to meet most national effluent standards (Tayler, 2018). Analysis of the performance of 50 small-scale sanitation systems in South Asia, including ABR-based systems and more advanced technologies, found that almost all systems consistently failed to meet microbial water quality standards, with no improvement in systems fitted with a disinfection step (EAWAG, 2018). Most of the systems in this analysis had effluent fecal coliform concentrations of 10^4–10^6 MPN/100 mL. In line with this, WHO (2018) guidelines state that the effluent and sludge from ABR and anaerobic filters have high pathogen levels and require further treatment. However, these systems often discharge directly to local drains or waterways. Constructed wetlands provide a simple additional pathogen reduction option, but they require additional land area (Tayler, 2018).

Off-site sewerage may avoid many of the above challenges, but it does not necessarily solve all contamination issues as leakage can occur during conveyance, and even with advanced treatment processes some wastewater effluent still contains high levels of pathogens (WHO, 2018). Leakage can happen due to: misconnections (where a sanitary or graywater sewer pipe is connected to a surface drain unintentionally); structural deficiencies resulting in exfiltration into groundwater supplies; flooding events resulting in combined sewer overflows entering surface water; or sanitary system overflows whereby sewage flows into stormwater systems due to clogged or broken pipes, infiltration, or power failures, and results in discharge of untreated wastewater into surface water bodies (Williams and Overbo, 2015). Most national wastewater effluent standards do not include pathogen targets (WHO, 2018; Tayler, 2018), despite the continued exposure risk if the receiving waterway is used in agriculture or for recreation. Similarly, the target SDG 6.2 also considers secondary treatment to be safe (WHO, and UNICEF, 2017) despite the fact that pathogen reduction in accepted technologies is typically inadequate (WHO, 2006). Ultimately, decisions about the level of treatment must consider the downstream exposure risk, as proposed in the draft SDG definitions (WHO, 2016) or as suggested in sanitation safety planning (SSP) (WHO, 2015).

Container-based sanitation (CBS) is a recent development that may provide opportunities to prevent contamination of groundwater and surface water, particularly in dense low-income settlements. In general, these are mostly urine-separating toilets in which fecal matter is collected in a bag or container (replaced regularly by a local enterprise and taken away for further fecal sludge treatment) and diverted urine is typically disposed of in drains or sewers, or infiltrated into the soil (Mara, 2018; World Bank, 2019). In Cape Town, South Africa, a utility is operating a related low water-use system with a 20 L container collected twice weekly then emptied, cleaned and disinfected mechanically at the local sewage treatment plant (Willetts, 2019). Yet CBS and onsite systems requiring pits or tanks to be emptied all potentially create significant risks to sanitary workers, and this issue requires proactive management (Mackinnon et al., 2019; World Bank, 2019).

The risks to public health arising from inadequate sanitation are driven by both the extent of the hazard that enters the environment and the probability of human exposure to that hazard. In addition to understanding the source and ability of different 'technologies' to reduce contamination of the urban living environment, it is important to understand the *exposure* and how this varies across a city context, including related inequalities. Low-income households are at greater risk from exposure, as they are more likely to be in areas affected by sewage and septage overflow during floods (Hawkins et al., 2013).The identification of locally important key fecal transmission pathways, and an understanding of a person's full exposure to fecal pathogens, can provide valuable information for the prioritization of interventions (Robb et al., 2017; WHO, 2018; Wang et al., 2018). Various studies have found that exposure and health risks are associated not only with an individual's sanitation but also the sanitation of their communities (Hunter and Prüss-Ustün, 2016; Wolf et al., 2019). For example, in Timor-Leste, although only 7% of the urban population uses toilets that flush to an open drain, 55% live in communities where at least one household uses a toilet that flushes to an open drain, potentially exposing many households in the neighborhood to pathogens (UNICEF and WHO, 2019). Equally, not all fecal contamination may be an exposure risk. For example, if shallow groundwater is not used due to alternative available, affordable and convenient drinking water options, then groundwater contamination may carry a lower risk. A citywide approach also calls for the exposure risk of all population groups to be addressed, including at-risk groups such as sanitation workers and farmers who are exposed to dumped sludge or untreated wastewater (Farling et al., 2019).

One of the major challenges in assessing contamination and health risk is the complexity of the science involved. Several efforts have been made in recent years to create simple assessment tools and approaches that can facilitate a general conversation about the relative scale of risks and the consequent investments that could be prioritized to reduce such risks. Since 2006, WHO has been focusing attention on the fact that the health impacts of sanitation and wastewater management are a product of both hazard and exposure. The 2006 Guidelines for the Safe Use of Wastewater, Excreta and Graywater (WHO, 2006) provide a framework for this analysis but have been widely reported to be complex and difficult to apply. SSP is a city-level tool based on this risk-assessment approach, which provides a more simplified framework that can be used to identify and assess health hazards and exposure pathways in a city (WHO, 2016). Where the application of SSP is challenging, an even simpler starting point is provided by the Shit Flow Diagram (SFD), a simple graphical representation and assessment of the fate of excreta in urban areas across the sanitation service chain (Peal et al., 2014). The SFD highlights the relative scale of flows from all relevant sanitation systems, and it identifies those which are broadly 'safely managed' and those which are broadly 'unsafe.' The SFD distinguishes between hazards that remain in the neighborhood and those that reach citywide drainage or are discharged downstream of treatment facilities. At a smaller scale, the Sanipath assessment tool provides much more detail on the relative importance of different exposure pathways in a neighborhood (Robb et al., 2017).

All these tools are based on risk assessment methodologies, and a further step is to draw on dose–response and infection–disease models. These are often brought together using quantitative microbial risk assessment (QMRA), which has been applied to determine the magnitude of risks to different population groups from contamination (Labite et al., 2010; Fuhrimann et al., 2017; WHO, 2019) and informed a conceptual approach developed to assess different sanitation options (Mills et al., 2018). The sanitation option generation model developed by Spuhler et al. (2018) includes public health as one of five criteria, although the assessment is limited to a scoring of technology compliance against effluent discharge standards. Further quantifiable methods for comparing and prioritizing sanitation improvements are needed that can address the risks caused by different failures along the service chain, to different user groups and at different scales.

The recent synthesis of sanitation and health-related research (Murphy, 2017; WHO, 2018) has highlighted several remaining knowledge gaps, particularly the absence of information relevant to conditions in LMICs. A key area for further research is the fate of pathogens in urban environments, particularly protozoa and helminths in sewers or drains (Murphy, 2017). Where onsite systems are prevalent, key research gaps include: the partitioning of different pathogen types in sludge and effluent; the effects of efforts to improve the performance of existing systems (e.g., regular emptying); and the potential for further pathogen reduction through additional onsite or decentralized secondary treatment processes. While modeling pathogen flows and improvement options can begin to inform options and priorities, there is also a need to balance complex analysis with simple decision trees or rules of thumb that can be more easily applied by decision-makers to ensure the highest-priority areas are given attention. Context-specific risk-based thinking is key, as promoted by the SSP approach, since population density, soil type, environmental conditions, stormwater hydraulics, groundwater contamination vulnerability and exposure pathways will inevitably differ from place to place. Without this approach, there can be no sound basis for comparing sanitation options in terms of their potential to meet public health risk objectives.

CLIMATE CHANGE

Climate change is a critical issue of our time and stands to severely impact sanitation systems both directly and indirectly. One way it may do so is by exacerbating the risks of fecal contamination and disease spread discussed above. The gravity of the situation has only recently been recognized, and it is timely to consider how climate change could and should be incorporated into sanitation decision-making frameworks to improve resilience (World Bank, 2011; ISF-UTS and SNV, 2019; WHO, 2019). When adopting a citywide, inclusive perspective, the issue becomes even more relevant, since the worst impacts are likely to fall upon vulnerable and marginalized groups (OHCHR, 2010). Climate change demands that we ask how technologies and service arrangements at various scales could be expected to perform under different climate-related scenarios, such as increased flooding or drought, such that this can be considered in decision-making processes. Equally, it represents an imperative to consider the mitigation potential of different options when selecting optimal solutions.

If global warming continues at current rates, it is predicted that climate change will substantially increase the frequency and magnitude of extreme flooding and drought in many regions, cause sea-level rise that will critically impact infrastructure in low-lying coasts, and drive increased variability in precipitation (Pendergrass et al., 2017; Hoegh-Guldberg et al., 2018). While the magnitude and complexity of the threats posed by climate change are increasingly well understood and documented, relatively little attention has been given to how these threats will impact drinking water and sanitation services and their management, despite their importance to human health (Howard et al., 2016). In this section we highlight key impacts of climate change on sanitation and disease spread, and current predictions about the performance of different solutions. It provides insights that can help ensure climate resilience becomes an integral consideration in decision-making about sanitation.

The impacts of climate change on sanitation are expected to be at least as significant as those on water supply, and in some circumstances, they may be even greater (Howard et al., 2016). The most frequently reported hazard to sanitation systems is high-intensity rainfall, causing flooding of onsite systems such as pit latrines and septic tanks, which poses serious public health risks (Braks and De Roda, 2013; Cann et al., 2013; Howard et al., 2016; Bornemann et al., 2019). Flooding of pit latrines, due to rising groundwater or the inundation of surface water, renders them inoperable and may readily disperse excreta into the groundwater or surface flood waters, creating a severe risk in areas where they are present in high numbers (UN-Habitat, 2008; Charles et al., 2009) or for low-lying or densely populated areas (UN Water, 2019). In the United States, England, and Wales, cryptosporidium outbreaks have been associated with flood events (Hunter, 2003) and a systematic review shows vibrio cholera as the most common pathogen implicated in extreme water-related weather events (Cann et al., 2013). While raising latrines is a commonly proposed adaptation solution, it needs to be considered in the context of the population that will be using the facilities, as some adaptions may cause the latrines to become inaccessible for the elderly, children and people with disabilities (Charles et al., 2009). Various studies have indicated an additional hazard from flooding of on-site systems when residents take advantage of floodwater to flush out their latrine contents (Chaggu et al., 2002, as cited in Charles et al., 2009; Williams and Overbo, 2015). In contrast, the effects of flooding on container-based systems (CBS) could be expected to be minimal because they do not leak into the environment (World Bank, 2019). However, CBS faces similar risks to onsite systems if access for emptying or treatment is affected.

High intensity rainfall also affects centralized sanitation systems, including potential damage to wastewater treatment plants (Howard et al., 2016), destruction or interruption of sewer mains and pump stations (Moyer, 2007) or sewer overflows (Major et al., 2011). In many cities, combined sewerage systems are used instead of separate sewers due to lower capital costs, particularly where the existing drainage network is used. However, in areas where there is expected to be an increasing risk of wet weather, the high risk of pathogen exposure from combined sewer overflows means they should be considered as an incremental control measure only, and must be combined with other measures to prevent exposure during or following rain events (e.g., public awareness of overflows and temporary closure of contaminated bathing sites) (WHO, 2018).

Drought and water scarcity have different impacts on each sanitation system type. In fact, it is the risk of drought and water scarcity that identifies centralized sewer systems, and to a lesser extent septic tanks, as the most vulnerable types of sanitation (Charles et al., 2009; Howard et al., 2010; Sherpa et al., 2014; Luh et al., 2017; Fleming et al., 2019). This is because drought and water scarcity can reduce the usability of water-based sanitation and cause sewers to block (Howard et al., 2010). During periods of water scarcity in a peri-urban community in Botswana, residents with toilets connected to a sewer reverted to using old pit latrines, or built new ones, putting water supplies further at risk due to contamination (McGill et al., 2019). Other studies have found composting toilets and pit latrines are the most resilient to climate change, as they do not rely on water supply

(Sherpa et al., 2014; Luh et al., 2017) or because adaptations are feasible (Howard et al., 2010). Septic tanks are considered more reliable than sewers, as the risk of clogging during water scarcity is lower due to the shorter pipe distance, with decentralized or solid-free sewers also found to be more resilient than centralized sewerage (Sherpa et al., 2014).

Whilst less commonly reported in the literature, sea level rise can have direct impacts on sanitation systems. Sea level rise and surges present a risk to the sewer outfalls that are common in coastal areas, as wastewater can back up and flood through manholes in roads and the toilets and washbasins of homes and buildings (PAHO, 1998; CEHI, 2003). Saltwater intrusion to sewers or wastewater treatment plants may also affect biological treatment processes (WHO, 2019).

More generally, climate change is expected to affect the fate and mobility of pathogens (Charles et al., 2009). As a result, climate change is likely to exacerbate existing health problems, including those related to poor sanitation (IPCC, 2014) and the spread of water-borne diseases (UN Water, 2019). Rising temperatures are also expected to increase the incidence of diarrheal disease (Hutton and Chase, 2016*).* Climate factors determine the number, type, virulence and infectivity of pathogens transmitted through water or vectors that breed in water, and thus they may impact the associated infectious diseases (Vo et al., 2014). Increased precipitation intensity will create peak concentrations of pathogens in waterways due to sewage overflow and runoff (Vo et al., 2014). Increased groundwater flows and levels due to more rainfall and frequent or larger floods promote the spread of pathogens through greater mobility and survival, and greater saturation of soil increases pathogen survival (Charles et al., 2009).

In efforts to satisfy environmental objectives for sanitation, mitigation is also an important consideration. Human excreta is a source of greenhouse gas (GHG) emissions, and pit latrines have been estimated to account for approximately 1% of anthropogenic methane emissions globally (Reid et al., 2014). Biological processes in wastewater treatment plants are also believed to be significant GHG contributors in some countries (Mannina et al., 2016) and septic tanks are considered to be major contributors (González et al., 2018; Somlai et al., 2019). Composting toilets and regular emptying of septic tanks are proposed to reduce GHG emissions (Reid et al., 2014, IPCC, 2006), as are options that limit energy use in sewage conveyance. Examples include gravity-based systems and decentralized systems that reduce pumping distances as compared with centralized solutions (Carrard and Willetts, 2017) and blended gray-green-blue[1] infrastructure (UN Water, 2019). Further research is needed to develop a more nuanced understanding of GHG emissions from different types of onsite systems under common usage across LMICs.

So what does this mean for decision-making and options assessment? Global comparative studies on the performance of each technology under varied climate change scenarios, and evidence on emissions, need to be carefully applied in context-specific decision-making processes, taking into account the local climate, and technical and environmental factors. Risk-based approaches, as discussed above under 'Contamination,' remain applicable. However, they must be complemented by new thinking in relation to addressing uncertainty.

Climate change creates uncertainty due to our limited understanding of how climate hazards will change in specific locations, how climate change interacts with other forces (e.g., urbanization and land-use change), and how society will respond (Dessai and Hulme, 2004). In addition, the social systems connected to service use and management, and the interactions between social and bio-physical systems, need to be considered (Kohlitz et al., 2019). Often, technical and management systems for urban sanitation are poorly equipped to handle uncertainty and changing conditions. Addressing both dry and wet extremes calls for solutions at different scales ranging from the household level up to the city level (UN Water, 2019). A study on adaptability by Luh et al. (2017) found that no sanitation system performed well in all hazards, suggesting that the resilience of sanitation technologies is highly dependent on which climate-related hazards are considered. Despite uncertainties about the specific future impacts of climate change, cities can make informed decisions about how to increase resilience and adapt based on the best available information (Dessler and Parson, 2010). The field of climate adaptation commonly promotes nature-based systems and blended gray-green-blue infrastructure, which are suggested to be more cost effective, less vulnerable to climate change, offer mitigation co-benefits and provide better service and protection over its lifetime (UN Water, 2019). 'Low regrets' approaches to sanitation development – approaches that are beneficial regardless of the climate scenario – should also be pursued (Oates et al., 2014). Examples include: the scheduled emptying of latrines in advance of flood seasons, low water-use toilets and improved construction quality to reduce the infiltration of water into septic tanks or sewers.

Incorporating principles of adaptivity and flexibility into infrastructure and service arrangements is expected to assist managing sanitation systems in the context of uncertainty. Several water and sanitation professionals have argued that as an adaptation strategy, the diversification of facilities is preferable to focusing on just one type of facility or a centralized system, as a mix of facilities can increase resilience and diversify risk (Charles et al., 2009; ISF-UTS and SNV, 2019). Being able to change the management and operation of sanitation services and ensuring operators have a good understanding of sanitation system components increases the adaptability of services to changing conditions (WHO, 2019). Adaptive management improves responsiveness to different conditions by promoting continued learning through experimentation, feedback and innovation. Adaptive management measures could include preventative maintenance, involving operators in design and decision-making, and increased system monitoring connected to response or warning mechanisms (ISF-UTS and SNV, 2019).

In the context of supporting inclusive citywide sanitation decisions, attention must be given to vulnerable populations. Climate change does not affect everyone equally, and low-income

[1]Gray infrastructure refers to entirely human-built 'hard' systems such as pipes, levies and concrete dams. Green and blue infrastructure includes natural elements such as a floodplains or coastal forest but can also be engineered by humans (UN Water, 2019).

households are more likely to be in areas affected by sewage and septage overflow during floods (Hawkins et al., 2013). Low-income households are also more likely to use precarious sanitation systems that are easily destroyed or disrupted by climate hazards, and they typically possess the least capacity to cope with and adapt to shocks (Grasham et al., 2019). Urban sanitation decisions must take account of the differential impacts of climate change across social groups and their capacity to respond to those impacts. Climate risk assessments, the mapping of areas exposed to climate-related hazards, and social vulnerability indexes can be used to measure the vulnerability of populations, and overlaid with maps of flood, water scarcity or landslide hazards to identify areas where sanitation services could be disrupted (WHO, 2019).

It is critical that resilience and mitigation efforts be mainstreamed into current decision-making, rather than seen as an additional concern, given the long-term implications of today's development decisions and the need to avoid even greater costs in the future (World Bank, 2011). Acknowledging the uncertainty of climate predictions, and recognizing that in many cities sanitation systems will be affected by varied climate impacts, options should be selected that minimize regret (Oates et al., 2014; Hallegatte et al., 2019). When bridging the gap between climate science and infrastructure planning, addressing the complexity and uncertainty of climate impacts could result in paralysis in planning. Bornemann et al. (2019) suggests the need for better communication and explicit training designed to provide the next generation of key decision makers with additional appropriate analytical and problem-solving skills. Stress testing options under a range of plausible climate conditions relevant to the local context may assist in the management of uncertainty, and may help decision-makers to debate trade-offs between robustness, cost, safety margins, flexibility and regret (Hallegatte et al., 2019). More broadly, considering climate adaptation and mitigation also means that planning and policies need to incorporate and address the interconnections between climate, water resources, sanitation and water infrastructure, rather than consider these issues separately (McGill et al., 2019).

COST

Achieving citywide inclusive sanitation requires investment in infrastructure that meets the needs of all urban areas, including low-income settlements. It is widely recognized that ensuring the provision of citywide sanitation services involves high capital and operational costs. Cities need to consider how to provide universal access to safe sanitation through suites of technologies and operating configurations that incur the lowest cost to society as a whole. This requires addressing long-term financial liabilities, rather than short-run investments or budgeting constraints, and it therefore requires an understanding of the full life-cycle costs and relevant externalities of different sanitation options (Mitchell et al., 2007). However, there are is a paucity of data on the relative costs of different options for providing sanitation services in urban areas, as analyses are generally confined to capital cost comparisons rather than life-cycle costs (Daudey, 2018). Consequently, there is a shortage of data to inform decision-making about possible service scenarios to achieve citywide sanitation.

While several recent studies have provided critical financial perspectives for urban sanitation, they have focused on discrete aspects of the issue. These include: studies of willingness to pay (for example, Vásquez and Alicea-Planas, 2018; Acey et al., 2019; Tidwell et al., 2019); the business case and cost recovery for fecal sludge management (e.g., Andersson et al., 2017; Blackett and Hawkins, 2017; Otoo and Drechsel, 2018); and analysis of the pro-poor reach of infrastructure investments (Hutchings et al., 2018). Analyses comparing sewer and onsite technologies exist (Dodane et al., 2012; McConville et al., 2019) but can be limited by inconsistent analytical boundaries due to the exclusion of costs borne by households (for example Stantec, 2019). These types of analyses do not address the fundamental need for cost comparisons and decisions across different scales, technologies and service options. Such comparisons are needed to broaden the suite of options considered beyond the dominant investment focus on large-scale wastewater treatment and sewerage systems (Hutchings et al., 2018) that typically serve better-off socio-economic groups (McGranahan, 2015). This section outlines the evidence base to date, and points to important areas which need to be included in the robust consideration of costs in citywide sanitation decision-making.

A recent review (Daudey, 2018) confirmed that available contextualized data on the costs of urban sanitation solutions is surprisingly limited and of variable quality. However, the body of literature does identify some typical cost characteristics for urban sanitation systems. In general, "lower tech" (typically onsite or simplified sewer) solutions are considered less costly than "higher tech" (conventional centralized) systems. However, the systems under consideration typically do not offer equivalent levels of service or treatment (Daudey, 2018; Rozenberg and Fay, 2019) and as such are not directly comparable. This is of concern given the above sections discussing contamination and public health risks, including the exacerbation of these with climate change. In addition, across the lifecycle of sanitation infrastructure, the expenditure required for operation and maintenance (compared with capital expenditure) is highly variable. Daudey (2018) found that operations and maintenance expenditure ranged from 6% to more than 60% of total expenditure, with a lower proportion in the case of centralized sewerage systems (given their high capital costs) and a higher share for FSM-based systems (Dodane et al., 2012; Daudey, 2018; Stantec, 2019). However, such comparisons are not useful for informing investment decisions, since they do not provide a basis of comparison between options with a consistent metric. In addition, the costs of sanitation systems are highly contextual, with determinants related to technical, topographic, demographic, socio-economic and material factors (Daudey, 2018). For example, when modeling the costs of onsite and offsite options for the delivery of sanitation in Soweto, South Africa, Manga et al. (2019) found that population density and rates of connection to sewers had a significant impact on the relative costs of systems, with sewers becoming attractive from a cost point of view once population densities exceed a threshold value that varies depending on the extent of pumping and treatment options.

The challenges associated with defining typical cost characteristics of sanitation options are compounded by limitations in the available evidence. Daudey (2018) identified three main limitations in the literature on urban sanitation costs: inconsistent inclusion of life-cycle costs; failure to include costs for the whole service chain; and a lack of transparent reporting on the costing methodology. Few analyses transparently include life-cycle costs, with many focusing on only one or two cost types or neglecting to disclose which costs are included. Only six of the 50 studies reviewed in Daudey's (2018) analysis included at least capital, recurrent and capital maintenance costs. The review itself also excluded expenditure on direct and indirect support, two cost components identified in the WASHCost costing approach (Fonseca et al., 2011) that are critical for the sector to move toward professionalized management arrangements for service provision. Exploring the costs associated with direct and indirect support activities would be a valuable contribution from future cost analyses seeking to inform citywide inclusive sanitation. Analyzing these costs requires an assessment of the costs associated with economic and environmental regulation, inter-sectoral coordination, monitoring and IT systems (Fonseca et al., 2011). Full life-cycle costing in cost-effectiveness analyses must also acknowledge the different expected life spans of infrastructure alternatives in order to compare options on an equal footing. Such comparisons need to take into account anticipated phasing of investment and differences in asset capital and operating cost profiles over time (Mitchell et al., 2007).

The second limitation Daudey (2018) found in the literature was that many studies fail to include costs across the whole sanitation chain (containment, emptying and transfer, treatment, reuse/disposal), with fewer than half the reviewed studies (19 of 50) addressing at least containment, emptying and transfer. Studies which focus only on parts of the service chain risk misrepresenting the true costs of services, limiting their usefulness in investment decision-making for citywide services. Potential benefits or revenue streams can also be missed if the full chain is not included (Willetts et al., 2010; Andersson et al., 2016; Lazurko, 2019; Trimmer et al., 2019). It is also necessary to consider the potential increased demand for some resources such as nutrients for fertilizers, with scarcity increasing chemical fertilizer prices and demand for alternatives such as treated sludge expected to increase, attracting investment (Hutton and Chase, 2016).

The third limitation identified by Daudey (2018) was that reporting of cost analyses was often opaque in terms of methodology and specification of the options considered. This limits the extent to which included data can be interpreted as relevant (or not) for planning in different contexts. This illustrates a sector-wide challenge that cost information is not commonly presented in a form suitable for informing decision-making (Hutton and Chase, 2016), and there is no widely accepted and agreed cost-effectiveness methodology. Another challenge for citywide service planning is that the costs of ensuring inclusive services for the hardest-to-reach populations are not well understood and are easily underestimated (Hutton and Varughese, 2016).

A critical consideration for improving our evidence base is comparing system costs for options that meet an equivalent, specific objective (Mitchell et al., 2007). In the case of sanitation, the specific objective is to choose a service level that protects public health and the environment and addresses the contamination issues discussed in the section 2 of this paper. Clarifying this objective is necessary to prevent the inappropriate direct comparison of options with different service levels, such as comparing onsite systems without secondary treatment to sewered systems. To achieve a similar level of service, the costs of reducing the hazard or exposure associated with onsite systems (for example through secondary treatment) should be included in order to provide a more appropriate assessment of relative costs (Mitchell et al., 2016). Similarly, costing any system, whether it is an offsite, onsite or container-based system, without costing the relevant required management, for instance the costs of regular desludging or maintenance, is also misleading, since the required service level cannot be maintained without incurring these costs. To support defensible cost comparisons on a level playing field, options should be required to reach a minimum tolerable level of public health risk. This will require an approach to risk assessment that can inform costing analyses.

The costs of climate change adaptation measures to ensure a minimum ongoing service level and tolerable contamination risk should also be considered. Predictions are needed for expected performance in different climate scenarios, such that maintenance and repair costs for adaptation and response can be integrated into the cost analysis (World Bank, 2011). This is likely to be challenging, given the uncertainties associated with climate change, but also cannot be ignored. The various climate hazards associated with urban sanitation discussed above will increase maintenance costs, as repairs and replacement expenses are expected to become more significant and frequent. Floods are among the most costly types of disaster, especially as they increase in frequency and severity (Cissé, 2012 in Sherpa et al., 2014). The costs of adaptation measures should therefore also be considered. Examples of adaptation measures include increasing the resilience of infrastructure by providing additional flood protection for latrines or treatment plants, increasing the capacity of sewers, and sealing pit latrines. Equally, decisions about whether to prioritize more robust or easily rebuilt low-cost infrastructure must be made. For example, the Char communities in Bangladesh, who have a history of exposure to rainfall variability and adapting their lifestyle (e.g., through migration) build more temporary low-cost structures that can be rebuilt rather than expensive permanent structures that would regularly be abandoned (Charles et al., 2009).

Climate change will also increase operational costs, particularly for centralized sewerage systems. This is due to the increased cost of energy as well as the pumping and treatment costs associated with increased volumes of wastewater and stormwater due to precipitation increases (Major et al., 2011). In addition to the costs of repairing and replacing damaged infrastructure as sea levels rise, cities may no longer be able to rely on gravity to discharge combined sewer overflow and wastewater effluent, and this will increase pumping costs (World Bank, 2018). Adaptive management can increase operational costs, for example due to increased human resources and training costs, asset management systems, and monitoring and warning systems. While these are necessary in non-climate change conditions, addressing the specifics of climate change adds another layer of complexity to evaluation and decision-making processes for city planning that is already challenged by incomplete information about the range of future costs (World Bank, 2011).

As a way forward to inform decision-making, cost-effectiveness comparisons should ensure system-wide, consistent boundaries of analysis such that different infrastructure configurations, considering the whole service chain, can be appropriately compared. This requires taking a whole-of-society perspective which considers all costs over time and identifies which options represent the least cost to society to achieve the specified service level (Mitchell et al., 2007; Willetts et al., 2010). Including all cost perspectives (e.g., user, operator, initial investor) is particularly critical when comparing options with substantially different cost profiles in terms of their distribution and timing (Mitchell et al., 2007).

Once a sanitation option is decided upon that incurs the least cost to society, decision-makers can then develop mechanisms for financing the selected option and determine an appropriate distribution of costs across different stakeholders to ensure affordability for low-income households (Mitchell et al., 2007). Transfer payments may be required, for example an appropriate household payment to a service provider, or a subsidy from a municipality to a service provider. This is critical when considering equity in citywide sanitation, particularly as low-income areas may require higher cost solutions due to their hard-to-reach locations or higher-cost-to-user solutions such as onsite systems. Decision-makers could also change the way costs are distributed, as households who pay for FSM-based onsite systems and emptying services typically incur a greater portion of costs than those with centralized systems for which a larger share of costs is borne by utilities and other service providers (Daudey, 2018; Dodane et al., 2012). With the complexity of the sanitation chain and its multiple actors and institutions, it remains a significant challenge to conduct robust costing analyses at the 'system' level. However, without this, there is potential for chosen service systems to burden governments and society with expensive solutions, or to inadvertently disadvantage the poorest and most vulnerable, for instance by only costing and examining one part of the sanitation chain in isolation.

IMPLICATIONS

While the interlinkages between contamination, climate change and costs for sanitation options and investment decisions were noted at the end of each section, there are three key cross-cutting challenges which are important to draw out.

Firstly, the burden of contamination, climate change and costs associated with sanitation is unequal. To date, reducing inequalities has mostly focused on access to services. However, inequalities in exposure to fecal contamination, particularly in the face of climate change (notably flooding) also warrant attention and are under consideration in the evolution of monitoring of SDG 6.2. The cost burden of living with elevated risk of contamination and climate change effects such as flooding falls disproportionately on the poor. To date there has been limited work on how costs of building resilience should be equitably shared.

Second, inadequate data and evidence gaps limit informed decision making across each of these three areas. Research on the fate of different types of pathogens in dense urban living environments is urgently needed to address contamination (Amin et al., 2020; Foster et al., 2020). For climate change we require cohesive ways to bring together disparate climate science, engineering, public health and social science knowledge. As noted earlier, accumulation and analysis of cost data across different sanitation options for the full sanitation service chain is only recently emerging.

Third, whilst this paper primarily tackles the technical inputs needed for improved decision making, in reality we recognize the significant role of politics and power dynamics in real-life decision-making. That is, sanitation investment decisions rarely follow a rational planning process, as there are many additional factors that intervene, such as politics, ideologies, implicit beliefs and assumptions, restrictive policies or standards, and insufficient confidence to deviate from traditional approaches (Abeysuriya et al., 2019). The top-down influence from politicians, funding agencies or other investors may also shift focus to capital and/or large investments rather than the ongoing expenses or consideration of progressive improvements that are important for sustainability.

This said, a risk-based approach to decision making will remain important to identify and target interventions which address inequalities; such an approach is vital to ensure that incremental investments are selected based on their comparative cost effectiveness in terms of their broader benefit to society. A stronger understanding of pathogen flows and climate hazards is essential to enable decision makers to determine the highest priority risks and the real costs of their mitigation. Attention to these risks can also inform appropriate sequencing and prioritization of investment, and the effective delivery of incremental improvements. An incremental approach promotes a gradual build-up of capacity and allows feedback and incorporation of new information, which is particularly important in the context of climate change and rapid city level development. A key ingredient is therefore increased monitoring to understand the operation of sanitation systems, including from a financial perspective, as well as real time data to identify and manage risks. Critical for sustainability across all areas is an increased priority on operation and maintenance, without which the benefit of any investment will be effectively lost with consequent further downward pressures on both equity and resilience in the city.

Putting these approaches and research into practice requires new capacities to be built. Optimizing urban sanitation investment decisions is a complex challenge, and it requires high levels of expertise and technical know-how at the city level. The skills required go well beyond the 'technical' engineering focus that has tended to dominate historically. Many of these skills may exist but are rarely brought together to facilitate a multi-dimensional planning process that balances positive health outcomes, sustainable services and cost effectiveness.

CONCLUSION

Contamination, climate change and costs are three aspects of sanitation that require critical attention in decision-making to ensure that sanitation solutions are chosen that achieve the public health, sustainability and economic objectives integral to inclusive citywide sanitation. Bringing a contamination and climate adaptation and mitigation focus to decision-making requires risk-based thinking and will emphasize the importance of addressing inequalities and prioritizing vulnerable communities, not just for equity but for citywide public health. Operation and maintenance are cross cutting challenges that must be considered upfront when investigating sanitation options, particularly how these options are to be resourced and financed. Analysis of cost effectiveness against consistent service objectives will permit improved comparison of the mix of sanitation options likely to be appropriate to different contexts across a city. This will create an opportunity to then separately consider how costs may be fairly distributed across different actors. Research and data gaps need to be addressed, particularly in relation to fecal contamination risks and climate change, and particularly as relevant for the conditions found in dense low-income areas. With the large investment needed to achieve citywide sanitation for all, consideration of the three areas of cost, climate and contamination can enhance recognition of sanitation's importance for a sustainable healthy city and important contribution to health, sustainability and economic outcomes.

AUTHOR CONTRIBUTIONS

JW, NC, JK, and FM conceived the objective of the manuscript and conducted background research. FM and JW refined framing and structure. FM took the lead in drafting the manuscript with contributions by JW (all sections), BE (contamination, abstract, introduction, and conclusion), NC (costing), and JK (climate). FM addressed reviewers' comments. All authors reviewed the final version.

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