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Review

Towards "Sustainable" Sanitation: Challenges and Opportunities in Urban Areas

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Abstract: While sanitation is fundamental for health and wellbeing, cities of all sizes face growing challenges in providing safe, affordable and functional sanitation systems that are also sustainable. Factors such as limited political will, inadequate technical, financial and institutional capacities and failure to integrate safe sanitation systems into broader urban development have led to a persistence of unsustainable systems and missed opportunities to tackle overlapping and interacting urban challenges. This paper reviews challenges associated with providing sanitation systems in urban areas and explores ways to promote sustainable sanitation in cities. It focuses on opportunities to stimulate sustainable sanitation approaches from a resource recovery perspective, generating added value to society while protecting human and ecosystem health. We show how, if integrated within urban development, sustainable sanitation has great potential to catalyse action and contribute to multiple sustainable development goals.

Keywords: urbanization; sustainable sanitation; resource recovery; urban planning and development; public health

1. Introduction

Sanitation is fundamental to healthy and productive urban life, and the provision of sanitation services for fast-growing urban populations is one of the world's most urgent challenges. Currently, more than 700 million urban residents lack improved sanitation access globally, including 80 million who practise open defecation [1]. More than 80% of the unserved population live in sub-Saharan Africa, South Asia or East Asia. Sanitation gaps are particularly critical in rapidly expanding informal urban areas, exacerbating inequalities and unsustainable development processes [2]. At the same time, aging sanitation systems in the urban centres of some high income countries are starting to deteriorate.

From 2000 to 2030, the urban population in developing countries is expected to double [3]. Large investments will be needed to provide and maintain adequate sanitation systems to serve these growing cities. In addition, most urban growth is projected to occur in small and medium-sized cities (with populations of less than 1 million and 1–5 million, respectively) in developing regions [4,5]. In low- and middle-income countries especially, these smaller cities receive less support for infrastructure investment compared to major cities and capital cities.

Meeting these needs means developing systems that are safe, affordable and functional, as well as sustainable over the long term. This requires a better understanding of the dysfunctions, discontinuities and inequalities in the current models of sanitation provision. This paper reviews key gaps and obstacles that threaten our ability to expand sanitation coverage to meet growing needs in urban areas. In this paper sustainable sanitation is understood as solutions that, apart from protecting and promoting human health, should be "economically viable, socially acceptable, and technically and institutionally appropriate, [they] should also protect the environment and natural resources", as defined by the Sustainable Sanitation Alliance (SuSanA) [6]. SuSanA is a network of major sanitation actors (e.g., practitioners, policy makers, researchers, and academics), aiming to contribute to the achievement of global development goals by promoting a systems approach to sanitation provision, taking into consideration all aspects of sustainability. We apply these sustainability criteria to understand the major challenges facing urban sanitation, and highlight new ways of thinking needed to promote a "sustainable" sanitation approach, focusing on opportunities from a resource recovery perspective.

2. Beyond the Toilet: Complex Challenges Facing Urban Sanitation

2.1. Poor Access and Dysfunctional Systems

Substantial progress has been made in sanitation provision in the past few decades, with the Joint Monitoring Programme (JMP) for Water Supply and Sanitation reporting an increase in "improved" sanitation use globally from 54% to 68% (79% to 82% in urban areas) between 1990 and 2015 [1]. However, the definition of "improved sanitation" only refers to hygienic separation of human excreta from human contact, such as the use of a toilet or latrine, and does not address poorly functioning or malfunctioning systems. Thus these figures should not be taken as representing "adequate" sanitation coverage.

According to one estimate, roughly 1.5 billion people in urban areas use toilets that are connected to a sewerage network that releases sewage without treatment [7]; of this total, 69% are located in Asia, 12% in Europe, 11% in South America, 5% in Central and North America, and 4% in Africa. In particular, many cities in low- and middle-income countries face pressures to expand sewerage, but are not able to provide adequate collection and treatment systems. For example, in India, only one-third of urban households are connected to a sewerage network, and of this more than two-thirds of wastewater generated is released untreated [8]. Untreated wastewater threatens the health of surrounding human communities and ecosystems by spreading infectious diseases and degrading water quality, and thus cannot be considered safe or sustainable—but would be counted as improved sanitation.

In addition, many urban residents use on-site sanitation, such as pit latrines or pour-flush toilets and septic tanks [9]. These systems must be periodically emptied (or replaced, in the case of some pit latrines), and safe disposal and treatment of waste may be costly for users and difficult to carry out in high-density informal settlements. This often leads to poor management of pit latrines and septic tanks, which can contribute to contamination of the surrounding environment (e.g., groundwater), particularly during high rainfall events [10,11]. Small and medium-sized cities face particular constraints in providing adequate wastewater treatment and faecal sludge management capacities due to more limited urban management capacity and lower revenues. Even in higher-income countries, such as Sweden, smaller urban centres are closing down their sewage treatment plants and building costly pipelines to neighbouring larger cities [12].

2.2. Inequitable Sanitation Systems

Sanitation coverage in many urban areas is characterized by unequal access to these services. While the JMP maintains coverage data disaggregated by wealth quintile, information is lacking on the distribution of large gaps in access among the most marginalized groups, such as migrants to informal (peri-urban) areas. Around a quarter of the world's urban population lives in slums, where an increasing number of people do not have access to sanitation due to the inability or unwillingness of decision-makers to provide adequate services [13,14]. Thus, the urban poor, and particularly children, are disproportionately exposed to the impacts of poor sanitation, including high disease burdens, which reinforces existing processes of inequitable urban development [15].

Many of the challenges in providing sustainable sanitation systems are linked to traditional approaches to water supply and sanitation development [16,17]. In both high- and low-income countries there tends to be a narrow focus on providing conventional sanitation "hardware": latrines or toilets on the user side, and waterborne sewerage on the public/municipal side. Less thought has been given to ensuring that the systems are correctly used, operated and maintained over the long term (e.g., when septic tanks or sewer channels fill up), or to incorporating other crucial aspects for sustainability, such as user-friendliness, affordability, protection of public and ecosystem health and equitable access that meets diverse needs. The Millennium Development Goals (MDGs) target for sanitation access partly reinforced this by keeping the focus on the number of toilets.

2.3. Health Risks Along the Entire Sanitation Chain

From the sanitary revolution in the 19th century—which led to the widespread adoption of the waterborne sewerage systems in many areas—to the present day, urban sanitation has been seen almost exclusively as a means to protect public health by containing and disposing of dangerous human waste—in many cases meaning simply carrying wastewater away from cities as quickly as possible (see e.g., [18]). The connections between pathogens found in human excreta and diseases such as chronic diarrhoea and infection with intestinal parasites like helminths are well known. Diarrhoea is one of the leading causes of death among children globally, with 842,000 deaths per year directly associated with lack of adequate water supply, sanitation and hygiene practices [19]. These diseases also exacerbate undernutrition, which can impact cognitive and physical development. However, these serious health risks associated with open defecation and dysfunctional sanitation systems have not yet provided a strong enough motivation to address growing urban sanitation needs in many areas. This may be due in part to the overlooked but critical role urban planners play in designing sanitation systems that can promote public health [20].

In urban areas, sanitation-related health risks extend far beyond basic access to household sanitation and include a number of exposure points. Safe collection, transport and disposal of sanitation waste is often a neglected health challenge in cities. For instance, in informal settlements in Nairobi, 85% of latrine pit emptying is done by hand rather than by safer practices such as vacuum trucks [21]. Waste that is collected is often released directly into drainage systems or open water bodies without treatment. While treatment systems have sometimes been built with support from donor countries, low-income countries may lack operations and maintenance capacities to keep them operating safely [22].

In addition, the practice of irrigating vegetables with untreated or partially treated wastewater is prevalent in urban areas in many low- and middle-income countries [23]. One study found that in West Africa 60%–100% of vegetables consumed by urban residents were grown within the city, where irrigation water was generally contaminated. For example, in Accra 280,000 residents were found to consume vegetables from urban farming irrigated with wastewater [24]. While urban agriculture constitutes an important element of food security in many cities, high pathogen and chemical content in untreated wastewater presents serious health risks for consumers of irrigated produce, urban farmers and their families [25].

Emerging Health Risks

An emerging urban health concern is associated with antimicrobial resistance (AMR) spread from wastewater treatment systems [26,27]. Surveys in Delhi have shown that AMR traits (New Delhi metallo-beta-lactamase, or NDM-1 enzyme) can be found in enterobacteriaceae such as *E. coli*, *Shigella*, and *Enterobacter*. This enzyme mutation renders the bacteria resistant to multiple antibiotics. In one study, NDM-1 was detected in 2 of 50 drinking water samples and 51 of 171 seepage samples in Delhi [28]. NDM-1-positive traits were first found in Delhi in 2006 and are now already widespread in the intestinal bacteria of people living in South Asia, and have continued to spread to other regions. Open sewer systems in urban areas pose obvious transmission risks, and globally, more than 80% of all wastewater is discharged untreated [29]. However, even in well-maintained and leak-free systems, there is still a risk of transmission if effluents are released without specific treatment steps. For instance, standard biological treatment steps in conventional wastewater treatment plants may cause a selective increase of the antibiotic resistant bacteria population by facilitating mixing of antibiotics, antibiotic resistance genes, and antibiotic resistant bacteria [30]. AMR is emerging as a top public health concern, but it is being addressed largely as a medical problem centred on improper use of antibiotics, with sophisticated antibiotics and vaccines considered the primary solution. An integrated preventative approach led by water, sanitation and hygiene experts and practitioners as part of a sustainable sanitation strategy would provide a much more effective first line of defence.

2.4. Low Prioritization of Sanitation: A Barrier to Achieving Sustainable Systems

Unsustainable sanitation systems can often be linked to a range of institutional factors and governance failures [20]. One key barrier to sustainability is the way sanitation has often been overlooked in favour of other types of development by urban decision-makers, national governments and users themselves. For instance, water and sanitation together comprise just 6.1% of total development aid commitments, putting them behind health, education, transport, energy, government and civil society, and agriculture sectors [31]. Lack of financial, human and technical capacity, of political attention, and of champions willing to help catalyse change has contributed to the persistence of unsustainable systems that cannot ensure excreta is properly contained and sanitized.

2.4.1. Urban Populations Lack a Vital Link with Nature

One reason for the low priority given to sanitation by users is that urbanization has largely disconnected humans from the hydrological, energy and other resource cycles around them. In cities with centralised infrastructure, this has resulted in alienation and separation of urban residents from waste management systems [32]. Hence, many people have little knowledge and awareness of the health risks associated with poor sanitation systems [17], compared with other health challenges such as air pollution. With the advent of the flush toilet in countries with conventional sewage systems that brought significant improvements in hygiene and health, odour control, collection and transport, a new behaviour called “flush and forget” was established. This situation is worsened by taboos surrounding human excreta, as other health challenges often generate greater attention [33]. In addition, global vaccination programmes (e.g., against polio) and use of antibiotics to combat life-threatening infections have left citizens less aware of other possible diseases that can occur from faecal-oral pathways [34]. In countries with low sanitation coverage, households and communities may consider sanitation to be of lower importance compared with other concerns, particularly for the poor who must prioritize other expenditures. Thus, creating demand for sanitation services and overcoming behaviour barriers is critically important to ensure that infrastructure that is installed is used.

A lack of consumer knowledge and participation may extend beyond health risks and include a lack of understanding of how sanitation systems are operated [35]. People may not know how their waste is treated, dispose of inappropriate types of waste that may damage treatment systems or the environment, or they may assume that wastewater is adequately treated before release into the environment even when it is not. Users may also value the perceived status of a particular system, such as a flush toilet, over interest in sustainability of the systems [17]. Consumers in developing and developed countries need to be educated on the risks, as well as the range of choices for providing sustainable sanitation systems and their associated costs.

In some cases there is growing public awareness of dysfunctional systems [36], such as the significant media coverage of the occurrence of contaminated drinking water in Flint, Michigan, USA [37]. In addition, urban residents may actually be more supportive of sustainable systems than perceived by local authorities. This is evidenced in a study of Australian cities that showed public support for reusing wastewater [32]. As people’s values and aspirations for urban areas influence decision-making, greater public awareness of the importance of, and participation in establishing sustainable sanitation systems is critical.

2.4.2. Sanitation Requires Political Will and Dedicated Resources

Limited decision-maker attention and associated investments to meet critical sanitation needs in urban areas have contributed to unsustainable systems in many cities. The need for dedicated resources, including financial, human and technical capacity to support sustainable sanitation is a global challenge. This includes repairing and rebuilding aging infrastructure in cities in middle- and high-income countries, and providing universal access to urban sanitation services in poor countries. Political will is additionally needed to put in place adequate policies and regulations to ensure sustainable systems [17], as there is poor compliance in many areas where there are existing sector regulations, and a lack of sanitation safety plans where local regulations are not in place.

For instance, in a European context, despite the adoption of the EU Urban Wastewater Directive in 1991 only 14 of the 28 EU capital cities were fully compliant in 2012. Still, many countries in Europe lag behind in wastewater treatment, as many have no or low tertiary (full) treatment coverage [38]. On top of this, many of the more established and advanced sewerage systems are in urgent need of new investment for repair and upgrading, such as London's sewer network, which is grossly under-dimensioned for the city's current size, so raw sewage is bypassed into the Thames River during heavy rains. In high income countries, there has been a reliance on conventional systems, such as large centralized sewage systems, that can lead to a lack of ability to adapt to changing conditions [17,18], such as changes to the concentration and temperature of effluent, which affects treatment performance. To reduce these risks there is a need for political will to develop more innovative measures, such as ways to retain or locally infiltrate stormwater [39,40].

In Asia, the situation in Indian cities is typified by Hyderabad, where only 40% of the roughly 1800 million litres per day (MLD) of wastewater generated can be treated due to lack of operation and maintenance capacity, as well as frequent power cuts. As a result, most of the wastewater is discharged into lakes or the dry bed of the Musi River, without phosphorus or heavy metal removal [41], and this pollutant export can result in damage to downstream ecosystems. To address these challenges investments are needed to increase plant capacity, and improve operation and maintenance capacities.

Due to population growth, the urban population in Africa without improved sanitation services increased from 80 million in 1990 to 215 million in 2015 [1]. Sanitation in sub-Saharan African cities is dominated by pit latrines, septic tanks and other on-site solutions, many of which require attention to develop better systems for faecal sludge management. When it comes to sewer systems, infrastructure is lacking in most sub-Saharan African countries and sewer connections are limited [42]. For instance, in Addis Ababa the Kaliti treatment plant built in 1983 was designed to serve 50,000 people, but after 30 years serves only 13,000. In addition, many technology options, such as installed sewage treatment plants, break down or do not adequately meet sanitation needs because they were not appropriate for a city's local context.

2.4.3. Raising Global Awareness of Sanitation Challenges

Limited attention to sanitation has even extended to the global decision-making level, and the MDGs initially lacked any sanitation target. However, a target (halving the share of people without access to improved sanitation by 2015) was eventually added in 2002. In addition, leading up to the adoption of the Sustainable Development Goals (SDGs), discussion within the sanitation sector acknowledged the limitations of the hardware-focused MDG target, particularly with regards to sustainability. This discussion also recognized that ensuring universal access would require more attention to equity to address priorities of different user groups (especially women, girls, and people with disabilities)—a greater acknowledgement of social dimensions of sustainability. This has shifted focus onto providing sustainably managed sanitation services within the SDG 6.1 and 6.2 (Clean water and sanitation), an ambitious agenda that advances the sanitation target far beyond minimum coverage with basic services. This also includes the added environmental dimension linked to sanitation, where the SDG Target 6.3 aims for improved water quality by reducing discharge of untreated wastewater and increasing recycling and safe reuse. While there has been growing interest (primarily in higher-income countries) in going beyond health targets to ensure the environmental protection of receiving waters, this has mainly led to further promotion of end-of-pipe or technology-only solutions, such as dependence on advanced wastewater treatment, rather than expansion of sustainable systems [43].

2.5. Growing Pressure on Urban Environments

Cities are facing rapid social and environmental changes that must be considered to ensure the future health and wellbeing of urban populations and surrounding ecosystems. As noted by the Organisation for Economic Co-operation and Development (OECD), "global challenges are more complex and interconnected than ever before: growing inequalities, changing consumption patterns and population dynamics, increasing natural resource scarcity, and climate change require greater policy coherence and the involvement of all key actors and stakeholders" [44]. These changes include rapid growth and concentration of populations in urban centres, a trend that is particularly strong in lower-income countries where an increase of 2.5 billion urban dwellers is expected by 2050 [45]. Due to lack of available land and associated land-rights barriers, a significant part of this increase is predicted to occur in expanding slums. For example, in Africa, people living in slums will make up about 50% of the projected increase in the urban population, where sanitation service levels are often already low or non-existent [46]. Thus, ensuring the sustainability of cities will require special attention to upgrade and provide sustainable sanitation services for the poor.

A changing climate exacerbates many of these challenges, and has costly impacts on basic services, infrastructure, housing, and health [47]. Limited attention has been paid in many regions to designing water and sanitation systems that are resilient to natural hazards, which become more extreme in some areas due to climate change. Extreme events such as floods and droughts can cause existing sanitation systems to overflow or break down, creating major health risks from pathogen and pollutant exposure during disasters [18] and putting vulnerable groups, such as poor people living in unplanned urban areas prone to flooding, at even greater risk.

In addition, cities require efficient management of natural resources in the face of growing demands and changing environmental conditions. For instance, the hard-hitting 2014–2015 drought in Sao Paulo, Brazil, is a recent warning call evidencing this increasing vulnerability [48]. Inhabitants of Sao Paulo suffered severe water shortages, which also impacted numerous industries and farms, causing productivity to go down. An indirect consequence was a dengue disease outbreak caused by mosquito breeding in water tanks that households used for storing up water. This also shows how natural resource scarcity needs to be more strategically addressed, where key measures must include improved resilience and resource efficiency.

3. Sustainable Sanitation a Catalyst for Urban Development

In the face of these wide-ranging challenges, the need for a more sustainable approach to sanitation is increasingly recognized [49,50], which must address economic, social, technical, institutional, environment and natural resource dimensions in an integrated way. Sustainable sanitation is not a single technology or specific limited sanitation system design, but rather an approach where a broad set of criteria needs to be taken into consideration in order to achieve universal and equitable access to services over the long-term in a particular context. For instance, this includes recognizing and engaging users and institutions responsible for service provision and operation and maintenance in the development of more sustainable systems [16]. This could mean different efforts to address user needs, consider behavioural factors, and assess available financial and technical capacities. Figure 1 describes cross-cutting entry points for addressing sanitation in urban development.

This is very much in line with current thinking on sustainable cities and sustainable urban development (see e.g., UN-Habitat's guidelines for urban development planning [51]), which stresses that sustainability cannot be confined to physical infrastructure, but rather needs to consider the environmental, social, political and economic contexts and that achieving a balance between these dimensions is critical [51,52]. On this basis, it seems logical that sustainable sanitation must be centrally integrated within sustainable urban development [16].

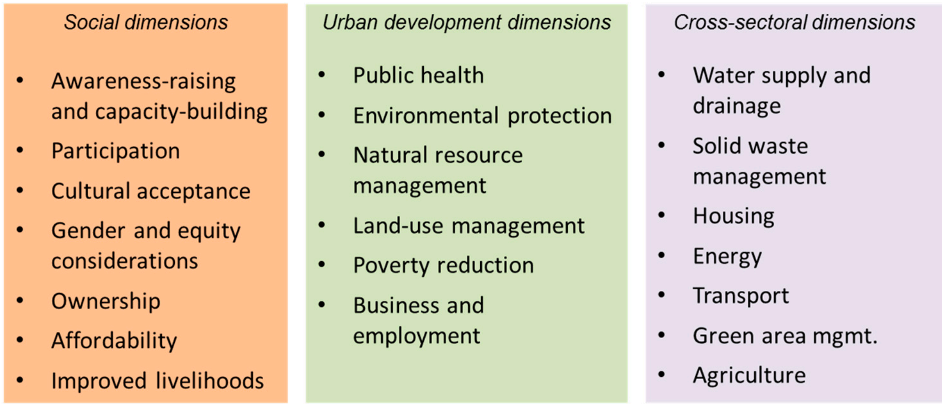

Figure 1. Cross-cutting entry points for addressing sanitation in urban development (after [52]).

The idea that cross-sectoral integration is needed to achieve wide-ranging sustainability benefits in development is not new, even if progress in putting it into practice has been slow. In 2002 the European Commission developed guidelines for sustainable urban development where they stated that "co-operation in sectoral projects, such as transport, water and sanitation, within towns and cities can have a greater impact on a wider scale than just one of the sectors" [52]. Such co-operation is important not only to exploit synergies between development goals, but also to manage emerging challenges and conflicts of interest between different sectors.

To progress towards sustainable urban sanitation, the continued development and application of broader systems frameworks is imperative. Holistic frameworks can break down barriers that traditionally confine sanitation infrastructure and service provision to the water sector, barriers that also impact how we think about and perceive system boundaries [16]. In particular, a focus on linear rather than circular thinking has overlooked opportunities for resource governance perspectives that present key opportunities to catalyse urban development, by contributing to economic, social and environmental aims. In the following section, we examine opportunities to advance sustainable sanitation from a resource recovery perspective, by generating added value to society while protecting human and ecosystem health.

3.1. Sustainable Sanitation Offers Opportunites for Resource Recovery

While the crucial health and environmental protection benefits of sanitation are generally understood among urban decision-makers and planners, most miss out on the fact that many components of sanitation waste streams are potentially recoverable and reusable, for example in the agriculture or energy sectors. Doing so can provide opportunities for new businesses and job creation, as well as making urban systems more resource-efficient. Figure 2 shows typical sanitation waste streams, their resource content, and how these resources might be utilized. The availability and marketability of the resources in a given city requires a context-specific analysis, but the figure communicates the diverse opportunities. Some of these resource recovery schemes are already being implemented in several cases (e.g., irrigation with wastewater), while others are less common (e.g., excreta-based fertilizers) or still at the experimental level (e.g., protein feed production from insect larvae grown on human faeces).

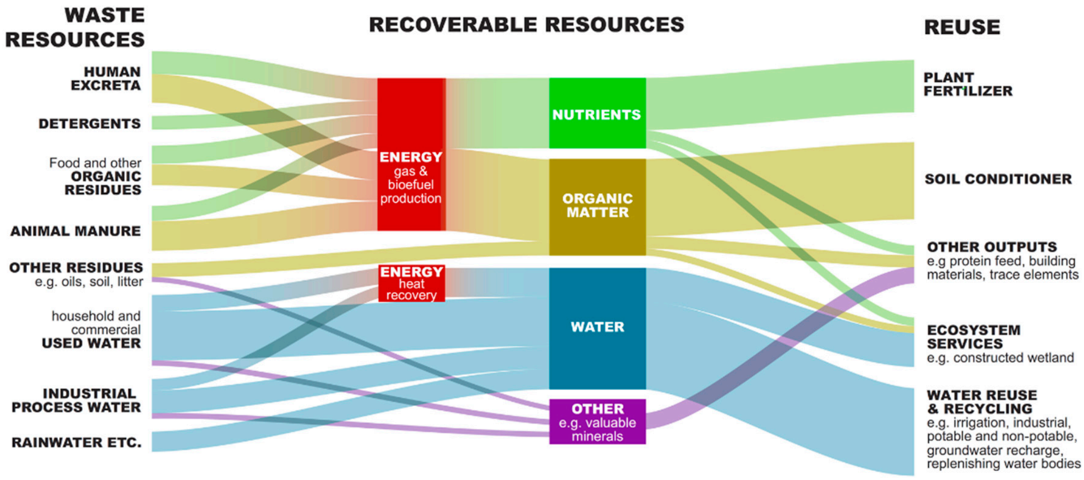

Figure 2. Conceptual overview of waste resources, resource content and potential for recovery (after [53]).

In particular, human excreta as an alternative fertilizer source shows great potential. An adult on average produces 500 L of urine and 50 L of faeces per year, containing nutrients equivalent to about 10 kg of synthetic fertilizer. As a fertilizer its value is about USD 10, but its application represents an increase in agricultural yield of approximately USD 50, compared to not adding any fertilizer at all [54]. For poor smallholder farmers this may represent an important addition to income. For example, in Dakar, safe reuse of nutrients contained in urine and faecal sludge from on-site systems (from 76% of the 2.5 million inhabitants) and organic municipal waste is estimated to be enough to fertilize 50,000 hectares of cultivated rice. This yields approximately 200,000 tons of rice per year, corresponding to a quarter of the annual rice imports for Senegal, significantly contributing to national food security and food sovereignty [53]. In addition, the faecal sludge together with other organic solid waste (e.g., kitchen waste) can be pre-treated through anaerobic digestion generating biogas, with an annual net value in the case of Dakar corresponding to about 3000 m^3 of diesel or 16,000 km/day of bus journeys, also contributing to a more sustainable urban transport sector. There are many other emerging reuse cases to learn from around the world [53]. Processed sewer and faecal sludge is being reused at various scales in different countries around the world [55,56]; likewise, biogas production through anaerobic digestion has become a widespread method in sludge processing in urban wastewater management, especially in high-income settings [57]. To ensure sustainability, it is crucial to recognize potential health risks based on an understanding of potential exposure pathways [53,58]. Mitigating risks to human health can be achieved both through treatment of waste and non-technical measures (e.g., improved hygiene habits) in combination.

Thus, in planning sustainable sanitation, this approach should not be centred on technology or on the imperative of waste disposal, but could instead start from a focus on resources and their management. Figure 3 shows how this novel order of logic for sanitation planning and design could be framed. Accordingly, the key questions that need to be raised are: (1) what resources are available in the waste streams; (2) what demand there might be for them; and (3) how they could be recovered [53].

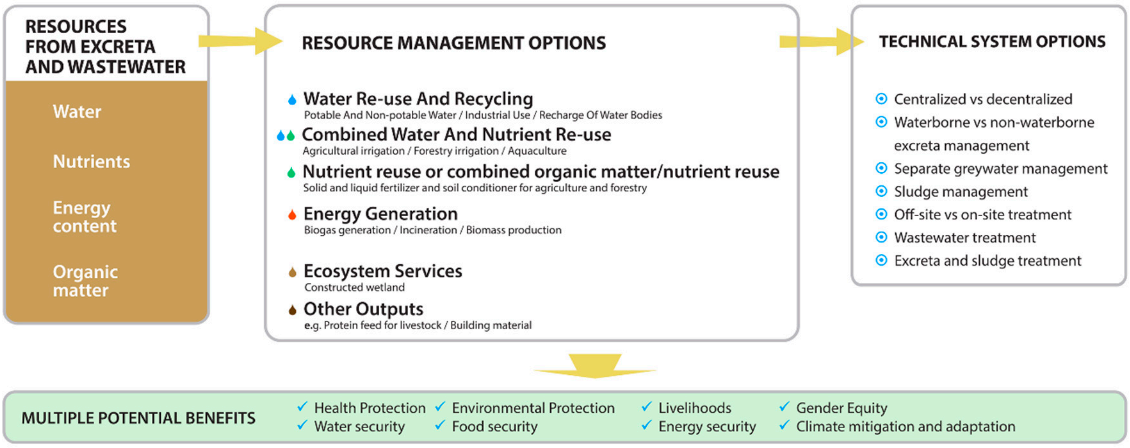

Figure 3. Framing sustainable sanitation from a resource management perspective (after [53]).

3.2. Sustainable Sanitation is a Good Economic, Social and Environmental Investment

Investing in sanitation that effectively protects human health will significantly improve human wellbeing for urban populations, especially those living in slums. From a financial point of view it is also a critical investment, since the cost to the economy of inadequate sanitation has also been shown to be exceptionally high. In India, for example, inadequate sanitation led to the loss of approximately USD 53.8 billion in 2006, equivalent to USD 48 per capita, of which 70% represented direct health-related costs [59]. Every dollar invested in improved water and sanitation has been estimated to generate a fourfold return in the form of reduced health care costs [31]. In the case of India, it has been estimated that the increased investment required to achieve improved sanitation could create new business markets up to an annual value of USD 152 billion [59].

Despite these potential economic gains, there are challenges to convincing decision-makers of the urgent need for up-front investments in order to obtain these long-term benefits. Besides the generally low priority given to sanitation, another important reason is that the economic benefits from conventional sanitation and wastewater management systems (those that include, at best, containment and treatment of sanitation waste but no resource recovery) often take the form of savings in other sectors, such as healthcare, rather than direct monetized returns that can be used to pay off the capital investment or finance on-going operation and maintenance.

Sustainable sanitation with resource recovery, however, can potentially transform the economics of sanitation, producing products with a market value clearly linked to the investment, such as biogas, fertilizers or irrigation water. Quantifying the direct and indirect environmental, social and economic returns of sustainable sanitation requires more comprehensive cost-benefit analyses. These analyses are crucial to comprehend the full range of values to society [60]. For example, a cost-benefit analysis of a Spanish case with agricultural reuse of 13.2 million m^3 per year of treated wastewater from a suburban treatment plant (treatment capacity equivalent to 320,000 persons) calculated the benefits outweighed the costs by 9.5 million euros per year, where the two key factors were cost savings for reducing pumping of irrigation water from rivers and purchasing fertilizer [61]. In Italy, a similar cost-benefit analysis was conducted for a project to reuse wastewater for agriculture in a water scarce area, which included a constructed wetland in a public park. This study showed that the project was financially feasible according to several economic indicators, however, in this case many of the benefits were non-market, e.g., providing improved ecosystem health and associated ecosystem services to the urban population [62].

There is a need for more research and knowledge sharing to highlight the multiple benefits of sustainable sanitation and to mainstream its implementation within urban sustainable development. One way forward is to extend the World Bank Excreta Flow Diagrams (SFDs) initiative, which currently assesses and visualizes flows of excreta in and through urban systems [63], by adding the potential resources and economic value of productively using the waste streams. A new tool developed at Stockholm Environment Institute can estimate the city-wide value of resource recovery from waste streams [64]. For the Ugandan capital, Kampala, work using the tool calculated that reusing sewage sludge and organic solid waste in the form of solid combustion fuel could replace almost all of the city's current consumption of firewood, a major driver of forest loss in the area. Specifically, 752 tonnes of dry fuel briquettes could be produced per day, meeting the daily household energy needs of 1,108,700 people, currently met by firewood [65]. With the development of new tools and integrated approaches, it is still important to consider the full range of sustainability dimensions. For instance, this may mean identifying "winner" and "losers" associated with promoting certain pathways of development.

3.3. Sustainable Sanitation Contributes to Multiple Sustainable Development Goals

The 2030 Agenda for Sustainable Development provides important impetus for more integrated planning and development of sustainable sanitation. A recent study showed how sustainable sanitation with a resource recovery and reuse focus can make cost-effective contributions to achieving a wide variety of the SDG goals and targets across development sectors [53]. These findings demonstrated particularly high potential within an urban context. Some of the most direct synergies between sustainable sanitation and other SDG targets are described below:

- Goal 6, on clean water and sanitation, calls for access to adequate and equitable sanitation, and for improved wastewater management and, crucially, includes recycling and reuse, which sets sanitation in the context of a circular economy. This could relieve a large burden of infectious diseases within cities and downstream communities (Goal 3, good health and wellbeing). At the same time, equitable access can contribute to social development aims and reduce risks of gender-based violence (Goal 5, gender equity).
- Recovering and reusing the valuable resources present in excreta and wastewater streams also contributes to resource efficiency (Goal 12, sustainable consumption and production) and can help improve food security (Goal 2, zero hunger).
- Making tomorrow's cities liveable (Goal 11, sustainable cities and communities) is not achievable without adequate sanitation and wastewater management. Working with the entire value chain linked to sustainable sanitation can provide new livelihood opportunities (Goal 1, no poverty; Goal 8, decent work and economic growth).

4. Conclusions

This paper explored challenges and opportunities for sustainable urban sanitation, defined as solutions that, apart from protecting and promoting human health, are "economically viable, socially acceptable, and technically and institutionally appropriate, [they] should also protect the environment and natural resources", as defined by the Sustainable Sanitation Alliance (SuSanA) [6]. Ways of applying these critieria and achieving sustainable urban sanitation will vary significantly in different contexts, especially between high and low-income countries. In a high-income context sanitary facilities are generally already in place, protecting local health and environment. But, these systems may have a high degree of infrastructure lock-in, with urban sewerage networks often ill-suited to resource recovery, since they are designed to mix and transport waste flows, normally using huge amounts of energy and water (in most cases treated drinking water). Development in a low-income context often presents opportunities to leapfrog over conventional sewerage, for instance building source-separating systems (which separate out different fractions of excreta and wastewater at the source) optimized for local contexts, and cost-effective resource recovery from the beginning. This requires planning and designing along the entire sanitation cycle (user interface, containment and storage, transport, treatment, disposal or reuse), and addressing key context-specific determinants (e.g., geographical and socio-cultural).

Beyond the sanitation sector, these systems can crucially underpin social, environmental and economic pillars of sustainable urban development. From the environmental perspective, there is an urgent need for urban areas to manage and conserve natural resources more efficiently in order to meet both current and future needs. The reuse of water, nutrients and organic matter can also contribute to improving agricultural productivity, soil quality, and generate energy and mitigate GHG emissions. The negative social impacts from inadequate sanitation are high, including healthcare costs and missed work and school attendance. Having access to sanitation is also a question of personal safety, dignity and human well-being. From an economic angle, achieving sustainable sanitation in urban areas can create new business and employment opportunities. Resource recovery and reuse can change the economics of sanitation investment, by making scarce resources available for society, which can lead to gains in productivity in new sectors such as agriculture, transportation, and forestry, but also provide non-monetized returns in form of environmental benefits.

In conclusion, sanitation could, if developed in an integrated and sustainable manner, play a vital role in realizing the sustainable development 2030 Agenda for urban areas. However, this sustainable sanitation transition needs to start urgently, given the widespread precarious urban sanitation situation, projected rapid population growth, and challenges linked to natural resource scarcities.

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