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Review Paper

Comparative economic analysis of urban sanitation interventions in low- and middle-income countries: a systematic review

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ABSTRACT

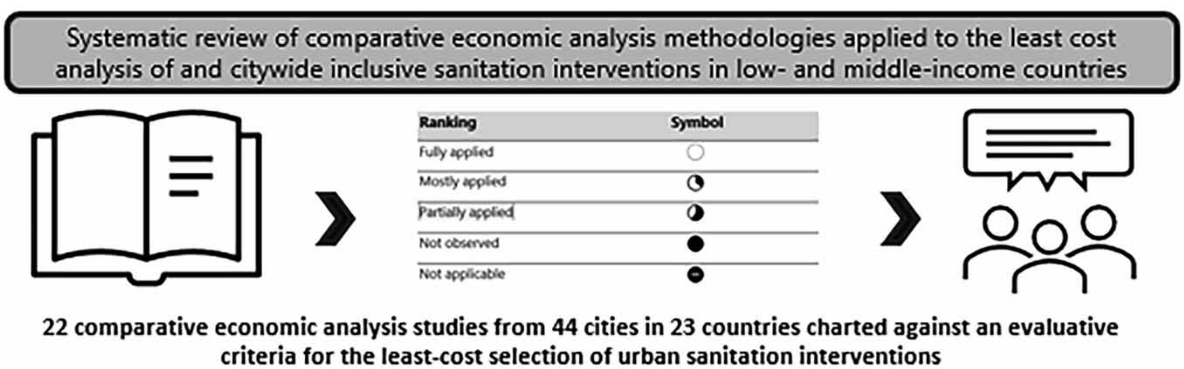
This review assesses evaluative criteria for least-cost economic analyses of citywide inclusive sanitation (CWIS) interventions, focusing on their alignment with the practical needs for decision support in low- and middle-income countries. We examined the literature from 2003 to 2022 that compares the costs and benefits of urban sanitation interventions to analyse their capacity to select cost-efficient and equitable urban sanitation options. The analysis revealed that finer disaggregation of cost perspectives could better articulate the diverse demands for services. Furthermore, options for comparison should be framed in addition to the diverse service provision models already existing within a context to ensure these perspectives are included. Developing the capacity to forecast a context-specific without-project scenario, using locally derived cost data as a basis of comparison, will be essential for adhering to CWIS planning principles. In addition, involving marginalised users more effectively in decision-making processes within economic analyses is essential for advancing equitable service provision. Future comparative economic analysis studies should embrace the complexities of CWIS contexts by supplementing broad-scale comparisons with detailed, context-sensitive evaluations to support more inclusive urban sanitation planning.

Key words: cost analysis, cost-effectiveness, economic principles, social equity, sustainability

HIGHLIGHTS

- Related literature studies are collated on the comparative economic analysis of urban sanitation interventions.
- Gaps in existing practices were appraised when applied to heterogeneous urban sanitation configurations in low- and middle-income countries.
- This study highlights how economic principles may be used to adapt methods for prioritising the selection of citywide inclusive sanitation interventions.
- Assumptions within existing planning approaches are challenged and what this means for best practice is discussed.

GRAPHICAL ABSTRACT



INTRODUCTION

Sustainable Development Goal (SDG) Target 6.2 aims to achieve access to adequate and equitable sanitation and hygiene for all and end open defecation by 2030. It also pays particular attention to the needs of women, girls, and vulnerable populations (United Nations 2015). Achieving SDG Target 6.2 requires cost-effective decisions about sanitation investments. Estimated annual investments range from $6.1 to $22.6 billion for basic services and $26.1 to $72.7 billion for safely managed services in low- and middle-income countries (LMICs) from 2020 to 2030 (Hutton & Varughese 2016). Requirements for urban sanitation financing are increasing and are estimated to be double than that needed for rural areas until 2030 (WHO & UNICEF 2021). Of urban investments, 50% need to target low-cost services for the two poorest quintiles of populations in LMICs (Hutton & Varughese 2016). The scale of these investment decisions is immense. The supply rate of basic sanitation services must double by 2030. For safely managed services, it needs to be quadrupled to meet SDG 6.2 (UN Water 2021).

At present, cost-effectiveness data for sanitation options in LMICs are limited to order-of-magnitude estimates (Hutton 2013). Such data are insufficient for making municipal-level decisions about urban sanitation standards (Hutton & Chase 2016). Inclusive selection of least-cost sanitation options and standards must account for the heterogeneity of cost determinants in LMICs. These include population density, topography, existing service models, sociodemographic profiles, and household practices and behaviours (Daudey 2018). Existing data only partially reflect user experiences (Hutton *et al.* 2014). Evidence-based decisions often overlook unknown costs associated with informal service provision in cities in LMICs. This includes services not provided by utilities, especially self-supplied systems (Danert & Hutton 2020). This limitation leads to fragmented service outcomes and an uneven distribution of investment benefits (Lawhon *et al.* 2017; Lüthi *et al.* 2020). Such outcomes are challenging to characterise (Hutton & Chase 2016; van Welie *et al.* 2018).

Current best practices use a heuristic model to simplify comparing the urban sanitation options at the municipal level (Sainati *et al.* 2020). However, the assumptions facilitating comparisons in cities in LMICs are limited. These include (i) using existing service provision models to characterise infrastructure configurations, (ii) assuming the outcomes of these models are acceptable and equivalent, (iii) that lifecycle costs can be reported in a standardised format, and (iv) that equitable decisions can arise from a single cost perspective. Such assumptions are limited in their capacity to account for the complexities within urban sanitation contexts in LMICs. These assumptions aligned with a generalised comparison of the feasibility of existing alternatives (Sainati *et al.* 2020), rather than fully embodying citywide inclusive sanitation (CWIS) principles (Lüthi *et al.* 2020).

Complementary approaches are needed to address the complex urban contexts in LMICs, where diverse service provision models coexist (Lawhon *et al.* 2017; van Welie *et al.* 2018). Deliberating trade-offs between multiple competing priorities for CWIS interventions is also necessary in these situations (Lüthi *et al.* 2020). It is important to clarify how heuristic rules of thumb about selecting sanitation options are integrated with detailed analytical decision support to address issues in complex, evolving local systems (Lawhon *et al.* 2017; van Welie *et al.* 2018). Such integration is vital for comparative economic analysis to foster a transition to more inclusive outcomes (Sainati *et al.* 2020). Therefore, it is important to discuss how effectively comparative economic analysis studies embody CWIS principles.

Recently, evaluative criteria aimed at enhancing the quality of least-cost economic analyses of CWIS interventions were devised from a scoping review (Ross *et al.* under review). This paper applies these criteria as a charting tool within a *systematic review* (Khalil & Tricco 2022). It appraises the methods used to design, implement, analyse, and interpret comparative economic analysis studies for urban sanitation configurations within LMICs over the past 20 years. The insights from this review will shape fit-for-purpose methodologies that complement more generalised comparisons and work towards achieving CWIS principles. Specifically, the review emphasises the need to enable diverse mixtures of interventions at different scales to be compared, represent the complexity of the existing context as a basis for comparison, enable both tangible and intangible determinants of lifecycle costs and benefits to inform decisions, and accommodate diverse cost perspectives within decisions, particularly for those with marginal access to sanitation services (Lüthi *et al.* 2020).

METHODS

This paper adheres to PRISMA guidelines (Page *et al.* 2021), as outlined in Figure 1.

Eligibility criteria

The review builds on previous work that examined the costs of urban sanitation interventions in LMICs (Daudey 2018). This earlier work highlighted the scarcity of relevant lifecycle cost data with equivalent objectives, timeframes, and scales of

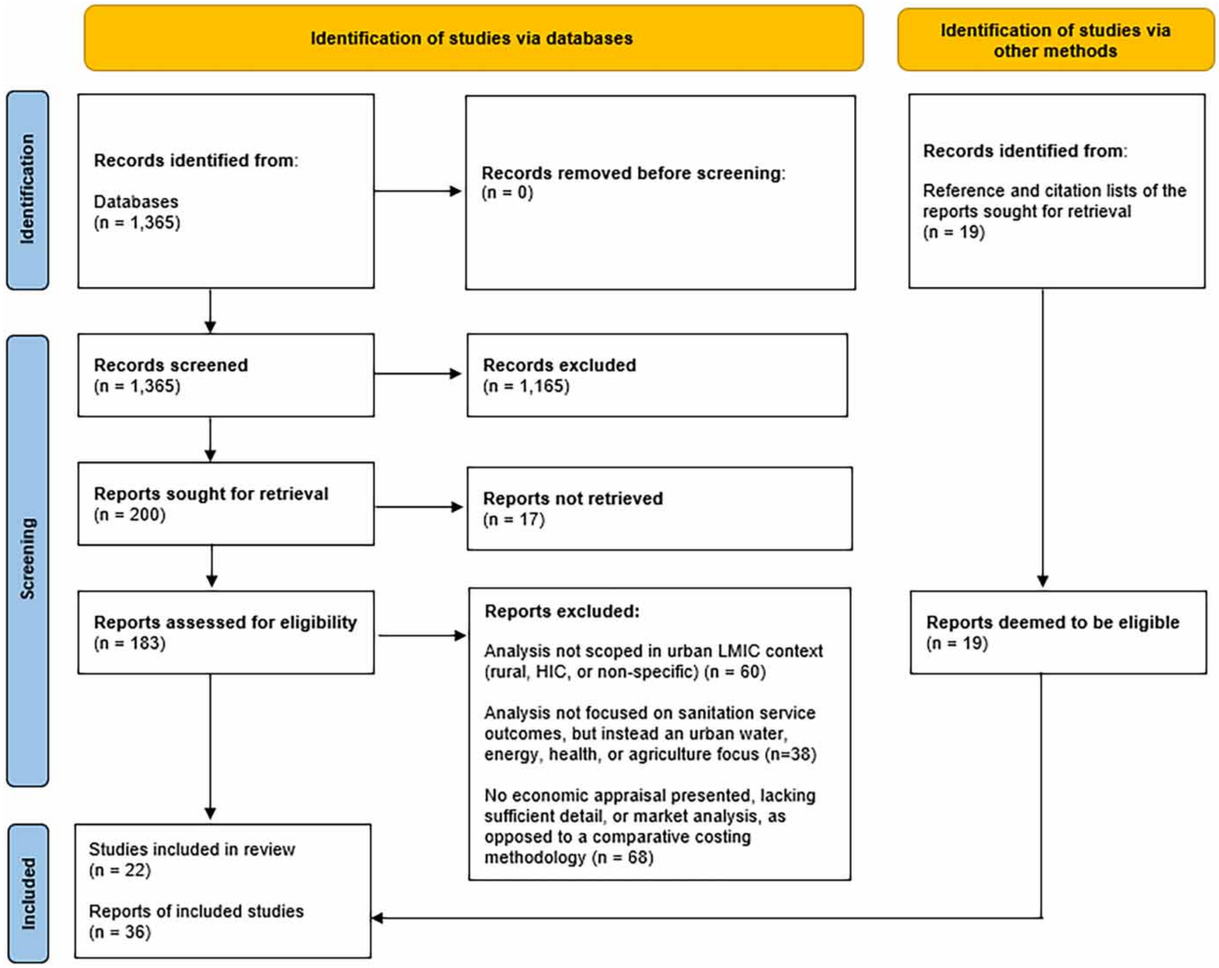


Figure 1 | PRISMA flowchart (Page *et al.* 2021) for the systematic review of comparative economic analysis studies applied to urban sanitation intervention.

analysis (Whittington *et al.* 2012). The eligibility criteria are structured using the participant, comparator, intervention, outcome (PICO) format (Khalil & Tricco 2022). We defined the participant as the economic analysis methodologies and the intervention as comparing cost-effectiveness data for urban sanitation options in cities in LMICs. The comparator was the evaluative criteria from Ross *et al.* (under review), and the outcome focused on how well the methodologies embodied CWIS principles.

Information sources and search strategy

We defined search terms to identify and expand on comparative cost analysis studies identified by Daudey (2018) that aligned with our criteria. We searched the *Scopus* database, using combinations of the search terms 'urban', 'sanitation', 'cost*', 'economic', 'financial', 'appraisal', and 'method*' to find English-language literature from 2003 to 2022. Broader terms resulted in many irrelevant results, so we refined our terms to 'sanitation', 'cost*', and 'method*', yielding 1,365 records.

Screening

We scanned the titles and abstracts of 1,365 records, yielding 200 results. Of these, 17 were inaccessible or not in English. After reviewing 183 reports, 17 were found to have met the criteria. Studies were excluded for several reasons. Some focused on high-income countries or rural contexts ($n = 60$). Others had objectives not aligned with sanitation outcomes ($n = 38$) or lacked detailed economic analyses ($n = 68$). We included 19 additional studies identified via reference and citation lists of the 183 retrieved studies.

Evaluation

We conducted a detailed review of each study (see Table 1) using evaluative criteria from a previous scoping review (Ross *et al.* under review). Refer to Table 2 and Supplementary Table S1 for details. We ranked criteria responses on a four-point scale: fully applied, mostly applied, partially applied, and not present, considering the study context, methodology, and supplementary material without seeking additional author insights. No attempt was made to weigh each criterion or evaluate the overall quality of each study retrospectively.

RESULTS

Our search strategy and screening method identified 36 diverse and comprehensive ranges of economic analysis methodologies. These papers encompass 22 different economic appraisal methodologies for urban sanitation interventions. They span 44 cities across 23 countries, covering developments over the past 20 years.

DISCUSSION

In this section, we analyse the extent to which each study's methodology responds to each evaluative criterion for CWIS interventions.

A research question balances economic efficiency and equity outcomes

Criterion 1.1 assesses whether the methodology balances the selection of the most economically efficient option with the equitable distribution of financial costs and benefits of that option. Table 2 demonstrates that three studies *partially apply* this criterion. These methodologies adjust each option's net financial costs to partially account for their net economic costs. For example, Manga *et al.* (2020) calculated the economic value of options using shadow pricing for capital, land, and water. Prihandrijanti *et al.* (2008) and Ross *et al.* (2016) considered *averted health costs*, i.e. costs no longer incurred because of a sanitation intervention, in their analysis. Shi *et al.* (2018) traded off the financial value of different interventions against a measure of their environmental impact. However, these studies are limited as they only consider how costs are perceived from a single institutional perspective, not how they are distributed.

Studies that *mostly apply* this criterion analyse the economic efficiency of each option and how each option distributes financial costs and benefits to different parties. For example, Meddings *et al.* (2004) and Schuen & Parkinson (2009) considered the benefits of reducing child mortality and the net economic per capita costs of providing sanitation services in Africa, respectively. They also analysed how the financial costs of each option are distributed to a project and household perspective. Similarly, Delaire *et al.* (2020) compared the economic efficiency by which different options may achieve adequate citywide, safely managed urban sanitation by 2030. Then, they used a *willingness-to-pay* survey to analyse how users and government subsidies may cover the financial costs of each option.

Studies that *fully apply* this criterion analyse how the financial costs of an economically preferred option are perceived by subgroups, such as women, girls, or those living in informal settlements. For example, the *Economics of Sanitation Initiative* (ESI) in Southeast Asia (Hutton *et al.* 2014) comprehensively measured the economic efficiency of different options and then determined how the financial costs of these interventions are distributed to households from different income quintiles. Willetts *et al.* (2010, 2013) demonstrated an alternative approach to fully applying this criterion by integrating a financial cost–benefit analysis for different options into a deliberative economic appraisal. In this case, options are prioritised based on broader economic criteria, including financial and non-financial costs and benefits. Both of these studies respond effectively to CWIS principles (Lüthi *et al.* 2020) by explicitly accounting for the distribution of costs to marginal groups.

A societal cost perspective is disaggregated by subgroup perspectives

Criterion 1.2 complements Criterion 1.1 and assesses whether a study adopts a *societal cost perspective* that includes all relevant costs, irrespective of who incurs them. This perspective helps one to consider whether the measure of economic efficiency used to prioritise options is comprehensive, which is key to defining a *least-cost-to-society* ranking. An example of a study that *fully applies* this criterion is Hutton *et al.* (2014). They account for the tangible and intangible economic costs and benefits of various options, from multiple financial cost and subgroup perspectives. However, although the net costs were derived from municipal data, they aimed for national comparisons, making the data less context-specific than in other studies.

Table 1 | Summary of the included literature

Study	Methodology and study location	Cost perspective(s)	Outcome measure(s)
Meddings *et al.* (2004)	Economic CEA for a latrine construction and rehabilitation program (Kabul, Afghanistan)	Societal (disaggregated by NGO perspective)	Costs per death averted
Dahiya *et al.* (2006)	Financial cost comparison of HH hygiene improvement and traditional vs ventilated pit latrine options (Ulaanbaatar, Mongolia)	HH	Costs per household
von Münch & Mayumbelo (2007)	Financial CEA of a VIP latrine vs UDDT option (Lusaka, Zambia)	HH and utility	TACC, 10-year NPV
Prihandrijanti *et al.* (2008)	Economic CBA of two decentralised options vs a simplified sewer option (Surabaya, Indonesia)	Societal (defined by an institution)	B-C ratio, 20-year NPV
Kerstens *et al.* (2009)	Financial cost comparison of four innovative, resource-oriented sanitation alternatives for a greenfield site (Changzhou, China)	Institutional	20-year NPV
Schuen & Parkinson (2009)	Financial and economic cost comparison of UDDT vs VIP and centralised sewerage options (Kabala, Uganda; eThekwini, South Africa; and Ouagadougou, Burkina Faso)	Societal (disaggregated by low and high-income HHs and projects)	10-year NPV
Willetts *et al.* (2010); Retamal *et al.* (2011); and Willetts *et al.* (2013)	Financial CEA for four hybrid (centralised and decentralised component) options (Can Tho, Vietnam)	HH, utility, developer and government	30-year NPV, TACC, TACH
Hutton *et al.* (2014)	Economic CBA, CUA, and CEA for sanitation options in 17 urban contexts in Cambodia, Indonesia, Laos PDR, the Philippines, Vietnam, and Yunnan, China.	Societal (disaggregated by HH income levels, government, private sector)	B-C ratios, Cost per DALY, case, death, 20–25-year NPV and TACH
Dodane *et al.* (2012)	Financial CEA for a sewer-based and FSM system within the same geographical area (Dakar, Senegal)	HH, service provider (PS), utility, and government	TACC
Mburu *et al.* (2013)	Financial CEA for a waste stabilisation pond (WSP) and constructed wetland (Juja, Kenya)	Institutional	TACPE
Peal & Georges (2013)	Financial CEA for four hybrid CWIS scenarios (Dhaka, Bangladesh)	Institutional; and low and non-low-income HHs	30-year NPV and TMCH
Tilmans *et al.* (2015)	Financial CEA for a public eco-san latrine and CBS option (Cap Haitien, Haiti)	Institutional (NGO)	Total cost per kg of faeces per 13 weeks
Ketema *et al.* (2015); Ketema & Langergraber (2015; 2016)	Financial CEA for four diverse, hypothetical urban sanitation interventions, defined by cost functions (Arba Minch and Bahir Dar, Ethiopia)	Societal (user, service provider, and externalities)	25-year NPV
Kennedy-Walker *et al.* (2016)	Financial CEA for seven FSM transportation and treatment configurations (Lusaka, Zambia)	Utility/community water trust	TMCH and 25-year NPV
Ross *et al.* (2016)	Economic CUA and Financial CEA for four hypothetical low-cost off-site urban sanitation configurations (Dhaka, Bangladesh)	Societal (low-income HHs and institutional	Cost per death and illness and DALY averted; TACH
Jung *et al.* (2018)	Financial cost comparison of centralised vs decentralised waste water management (WWM) systems (Alibag, India)	Fixed and floating HHs, Institutional	30-year NPV
Shi *et al.* (2018)	Economic cost comparison of four resource-oriented public toilet options (Beijing, China)	Societal (institutional and environment)	20-year NPV
McConville *et al.* (2019)	Financial CEA sewer and FSM service regimes. (Kampala, Uganda)	HH, utility, informal businesses	TACC

(*Continued.*)

Table 1 | Continued

Study	Methodology and study location	Cost perspective(s)	Outcome measure(s)
Furlong *et al.* (2020)	Financial CEA of four hybrid urban sanitation FFMs (Pokhara, Nepal)	Various (dependent on FFM)	30-year NPV
Manga *et al.* (2020)	Financial and economic CEA of three simplified sewer scenarios, with VIP and UDDT options (Soweto, South Africa)	HH and institutional (all costs attributed to HHs)	TACH, TACC, and 25-year NPV
Delaire *et al.* (2020)	Economic cost comparison for options meeting SDG 6.2 targets by 2030 and the economic value users are willing to pay (Kisumu, Nakuru, and Malindi, Kenya; Rangpur, Bangladesh; and Kumasi, Ghana)	Societal (low-income HHs and service providers)	10-year NPV
Carrard *et al.* (2021)	Financial CEA of resource-oriented sanitation option (Balangoda, Sri Lanka)	HHs; local authorities; and government	10-year NPV and TACC

CBA = cost–benefit analysis; CEA = cost-effectiveness analysis; CUA = cost-utility analysis; FFM = financial flow model; FSM = faecal sludge management; VIP = ventilated improved pit latrine; UDDT = urine dry diverting toilet; CBS = container-based sanitation; HH = household; NPV = net present value; DALY = disability affected life-year; B-C ratio = benefit–cost ratio; TACH = total annual cost per household; TMCH = total monthly cost per household; TACC = total annual cost per capita; TACPE = total annual cost per person equivalent; WSP = waste stabilisation pond and WWM = waste water management to the list of acronyms.

Studies that *mostly apply* the criterion limit the scope of a societal cost perspective. The scope may be limited to particular urban areas. For example, Ross *et al.* (2016) and Delaire *et al.* (2020) compared the economic efficiency of options for a 'slum' and 'low-income' context, respectively. However, this analysis is also limited to this cost perspective, so financial trade-offs with other parties in an urban population cannot be considered. An alternative method limits the societal cost perspective by focusing solely on financial efficiency. This approach assumes that economic outcomes for each option are equivalent. For example, Peal & Georges (2013) and Willetts *et al.* (2010) compared hybrid mixtures of sanitation interventions aimed at providing services to all cost perspectives within a specific population. These approaches required detailed forecasting of each option's financial costs and benefits to test assumptions over the time horizon of each study. Another method of applying this assumption is to divide an urban area into different *service regimes* (van Welie *et al.* 2018) or characteristic service provision models, thus enabling different cost perspectives to be disaggregated from a broader societal cost lens. Proponents assume that a *service regime* that exists in the same geographical area will have the same economic determinants of costs justifying a financial comparison. Both Dodane *et al.* (2012) and McConville *et al.* (2019) applied this approach. However, in both examples, it is unlikely that costs are spatially or temporally homogenous across the study context. This variability limits how meaningful a financial comparison is in practice. This limitation persists even when McConville *et al.* (2019) attempted to optimise the comparison by scaling options to full capacity. Cost determinants in this case are unlikely to be consistent even within the same service regime. Carrard *et al.* (2021) further demonstrated how even the boundaries of a single service configuration are challenging to define in terms of geography or population.

Studies that best apply Criterion 1.2 are those that balance the inclusion of all costs to the society and how meaningfully they can be disaggregated and analysed (Lüthi *et al.* 2020). The examples above illustrate how challenging accounting for heterogeneity within the context of studies of CWIS options can be.

Options are compared against a least-cost, without-project standard

Criterion 2.1 evaluates whether urban sanitation options are compared against meaningful and realistic without-project standards. These standards represent cost-effective situations that would likely occur without any intervention, according to the context of the study. To facilitate compelling decisions, options should be defined in addition to this standard (Willetts *et al.* 2010). Each option should be mutually exclusive, meaning selecting one precludes the selection of others. Table 2 indicates that no studies *fully apply* Criterion 2.1. This result reflects the challenges discussed in response to Criterion 1.2 of framing an objective and meaningful basis of comparison.

To illustrate these challenges, we consider Willetts *et al.* (2010). They *mostly apply* this criterion by systematically defining a *reference case* using an *end-use model* (see Criterion 7.1) (Retamal *et al.* 2011). They compare costed sanitation service provision scenarios based on detailed concept designs aligned with local policies for new greenfield developments. However,

Table 2 | Abridged evaluative criteria (Ross *et al.* under review) and analysis of the included literature

1.1	A research question balances economic efficiency and equity outcomes	4.1	The source of effectiveness data is specific to the study context.	8.1	The time horizon and discount rate applied are stated and justified.
1.2	A societal cost perspective is disaggregated by subgroup perspectives.	4.2	A justification for comparisons of cost effectiveness across different contexts is provided		
2.1	Options are compared against a least-cost *without-project standard*	5.1	An incremental analysis in units of TACH/TACC is presented as a primary outcome measure.	9.1	Confidence intervals are presented for stochastic data.
2.2	Consistent and appropriate system boundaries are applied	5.2	Benefit valuation methods are described and justified for the study population.	9.2	Sensitivity and scenario analyses are used to enhance the use of modelled data.
		5.3	Intangible benefits are reported separately and interpreted within the analysis.	9.3	Deliberative methods are used to allow for epistemic uncertainty.
3.1	A comprehensive economic analysis methodology is adopted	6.1	Average incremental costing is used to structure life cycle costs over time.	10.1	Reported outcome measures (TACH/TACC) align with the basis of comparison.
		6.2	Adjustments for inflation and currency conversion are made explicit.	10.2	Outcome measures are presented in an aggregated and disaggregated format.
		7.1	Assumptions within the costing model are justified and contextually relevant.	10.3	Conclusions arise from multiple cost perspectives informed by multiple criteria.

Fully applied ○ Mostly applied ◔ Partially applied ◑ Not observed ● Not applicable ⊖

Study / Criteria	1.1	1.2	2.1	2.2	3.1	4.1	4.2	5.1	5.2	5.3	6.1	6.2	7.1	8.1	9.1	9.2	9.3	10.1	10.2	10.3
Meddings et al. (2004)	◔	◑	◑	◔	◑	○	◔	◔	○	◔	◑	○	◑	⊖	◔	●	●	◑	◑	◑
Dahiya et al. (2006)	●	●	◔	◔	○	○	⊖	◔	⊖	○	◑	○	◑	⊖	●	●	◔	◑	◑	◔
von Münch & Mayumbelo (2007)	●	◑	●	◑	◑	◔	⊖	◔	⊖	●	◑	○	◑	○	●	●	●	◑	◔	●
Prihandrijanti *et al.* (2008)	◑	●	●	◑	◑	◑	⊖	●	◑	◑	◑	◑	◑	◔	●	◔	●	●	◑	●
Kerstens *et al.* (2009)	●	●	◑	●	◑	◔	⊖	●	●	◔	◑	●	◑	○	●	○	●	●	◑	●
Schuen & Parkinson (2009)	◔	◔	●	●	◑	◑	◑	●	◑	◑	◑	○	◑	◔	●	○	●	●	◑	◑
Willetts *et al.* (2010 ; 2013) ; Retamal *et al.* (2011)	○	◔	◔	○	◔	○	⊖	○	⊖	○	○	○	○	○	●	◔	◔	◔	◑	◔
Hutton *et al.* (2014)	○	○	◔	◑	◑	◔	◔	◔	○	◔	◑	○	◑	○	●	○	●	◑	○	○
Dodane *et al.* (2012)	●	◔	●	◔	◑	◔	◑	◔	⊖	◔	◑	○	◑	○	●	◑	◑	◑	○	◑
Mburu *et al.* (2013)	●	●	●	◔	◑	◔	◑	◑	⊖	●	◑	●	◔	●	●	●	●	◑	◑	●
Peal (2013)	●	◔	●	○	◑	◔	⊖	◔	⊖	●	◑	○	◔	○	●	◔	◑	◑	◑	◔
Tilmans *et al.* (2015)	●	◑	◑	◑	◑	◔	◑	◑	⊖	◑	●	●	◔	⊖	◑	●	●	◑	◑	◑
Ketema *et al.* (2015)	●	●	●	◔	◑	◔	●	●	⊖	●	●	○	◑	◔	●	◔	●	●	◑	●
Kennedy-Walker *et al.* (2016)	●	●	◔	○	◑	◔	⊖	○	⊖	●	○	◑	◑	○	●	○	●	○	◑	●
Ross *et al.* (2016);	◑	◔	●	◑	◑	◑	⊖	◔	◑	◔	●	○	◑	●	●	●	◑	◑	◔	◑
Jung *et al.* (2018)	●	●	●	◑	◑	○	◑	●	⊖	◑	●	○	◔	○	○	○	●	●	◑	●
Shi *et al.* (2018)	◑	●	◑	◔	◑	◔	◑	●	⊖	◔	◑	○	◔	○	●	◔	●	●	◑	●
McConville *et al.* (2019)	●	◔	●	●	◑	◔	⊖	◔	⊖	◑	●	◑	◑	○	●	◔	◑	◑	○	◑
Furlong *et al.* (2020)	●	◑	◔	○	◔	◔	⊖	●	⊖	●	●	◑	◑	○	●	◔	◑	●	◔	◔
Manga *et al.* (2020)	◑	●	●	◔	◑	○	◑	○	⊖	◑	○	○	◔	○	●	○	●	◑	◑	●
Delaire *et al.* (2020)	◔	◔	◔	○	◔	○	●	●	◔	◔	◑	○	◑	○	◑	○	◑	●	○	◔
Carrard *et al.* (2021)	●	◑	◔	◔	◑	○	◔	◔	⊖	◑	◔	○	◑	◔	◑	◑	◑	◔	○	◔

Note: These criteria are presented in full in Ross *et al.* (under review) and Supplementary Table S1.

they neglected to include the cost perspectives of existing urban users. This omission makes it less certain whether a least-cost without-project standard (see Criterion 1.2) was fully defined. The local status quo likely included a mix of informal service provision, as well as plans for developing conventional centralised services. This definition is crucial because it affects the inclusivity and relevance of the options compared in the analysis. When faced with the challenges of collecting data to represent a least-cost *without-project standard* (see Criterion 2.1), many studies define a *do-nothing scenario*. This assumes that the existing context remains the same over time. The difference in these definitions is nuanced but significant. Defining a do-nothing scenario excludes the opportunity costs of forgoing existing practices from consideration.

Other studies that *mostly apply* Criterion 2.1 comprise various attempts to define a meaningful without-project context. For instance, Kennedy-Walker *et al.* (2016) compared various modelled scenarios of faecal sludge collection and transportation with results from an existing pilot study. Dahiya *et al.* (2006) and Hutton *et al.* (2014) compared iterative improvements in sanitation service levels against a sanitation service ladder. Delaire *et al.* (2020) defined investments that would have been made by households and institutions *without a project*, based on results from a willingness-to-pay survey. Furlong *et al.* (2020) attempted to contextualise *financial flow model*s validated in a comparable city. At the same time, Carrard *et al.* (2021) defined a without-project case without comparing it to alternative interventions. Any approach may introduce subjective biases, making a critical evaluation of whether a meaningful basis of comparison has been selected necessary (see Criterion 9.3).

Consistent and appropriate system boundaries are applied

Criterion 2.2 assesses whether the system boundary of comparative economic analysis is clearly defined and consistently applied (Willetts *et al.* 2010). This idea aligns with the standard, generalisable system boundary proposed by Sainati *et al.* (2020) for comparing unit costs across different urban sanitation contexts. This system boundary specifies the cost perspectives (Criterion 1.2), lifecycle cost components (Criterion 6.1), and components of a sanitation service chain (Criterion 7.1) relevant to analysis.

Some studies that *fully apply* Criterion 2.2 such as Peal & Georges (2013), Delaire *et al.* (2020), and Furlong *et al.* (2020) adopt comprehensive system boundaries. Others like Kennedy-Walker *et al.* (2016) may adopt more discrete boundaries specific to a context, such as the collection and treatment of faecal waste for low-income users. Carrard *et al.* (2021) demonstrated that system maps are valuable for visually depicting the costs and benefits within a system boundary, as well as external factors that might influence a study's results.

A comprehensive economic analysis methodology is adopted

Criterion 3.1 evaluates a study's adherence to three required elements of a comparative economic appraisal. These include conducting a cost-effectiveness analysis, optimising each alternative towards a defined service outcome, and engaging end users in the final cost–benefit determination. All studies meeting the review's eligibility criteria fulfil the first two requirements of Criterion 3.1. Therefore, our analysis focuses on how effectively studies engage end users in decision-making processes. Based on this criterion, only the study by Dahiya *et al.* (2006) fully applied Criterion 3.1. They adopted an informed choice approach, enabling service users to trade off perceived benefits of various household containment options against their financial cost.

Other studies *mostly apply* Criterion 3.1 by demonstrating methods that engage institutions in a decision using approaches that may also be used to engage service users. For example, Furlong *et al.* (2020) conducted workshops with local service providers to contextualise how different *financial flow models* may accurately represent the study context. Willetts *et al.* (2013) engaged local authorities in deliberating a least-cost option. Delaire *et al.* (2020) indirectly engaged low-income households in a least-cost determination via a willingness-to-pay survey. Studies fully meeting this criterion should consider how these approaches engage service users in decision-making. Such engagement builds demand for safely managed sanitation, aligning with CWIS principles (see Criterion 10.3).

The source of effectiveness data is specific to the study context

Criterion 4.1 assesses how specific data sources deriving cost-effectiveness measures, to a context, focus on the relevance of input variables, models, and assumptions. Table 2 indicates that the extent to which different studies describe caveats associated with their data sources varies.

A justification for comparisons across different urban contexts is provided

Criterion 4.2 assesses how meaningful cost-effectiveness comparisons across diverse urban sanitation contexts are. In general, urban sanitation interventions in LMICs feature heterogeneous cost determinants, making direct comparisons difficult to justify (Carrard *et al.* 2021). For instance, Sainati *et al.* (2020) recommended using generalised estimates with a minimal error of $\pm$25% for broad comparisons. Standardised comparisons, like those in case–control studies, pose challenges for urban sanitation. They require specifying a single cost-effectiveness measure that encompasses all relevant costs and benefits (Ross *et al.* 2022). Table 2 indicates that no stud fully applies this criterion. However, several acknowledge the limitations of these comparisons (Meddings *et al.* 2004; Hutton *et al.* 2014; Carrard *et al.* 2021). Hutton *et al.* (2014) suggested using generalised comparisons mainly in broad national contexts. In contrast, the heterogeneous contexts of cities in LMICs demand more detailed analyses.

An incremental analysis in units of TACH/TACC is presented

Criterion 5.1 assesses if studies use standardised unit costs, specifically total annualised cost per household (TACH) or per capita (TACC), to compare sanitation options. This method is advocated by Sainati *et al.* (2020). These units facilitate an incremental comparison of the *lifecycle costs* of relevant options in addition to a without-project case (see Criterion 2.1). In this case, instead of assuming a linear change, the net present value of each option varies as households or individual users gain access to water-related services (see Criterion 6.1). This approach enables more meaningful comparisons of diverse urban sanitation interventions, from capital-intensive infrastructure projects to lower-cost, intermediate options with more intermediate service outcomes. Incremental analysis also aids in evaluating demand-side management options and the potential for avoided costs from delaying infrastructure-led options.

Studies that *fully apply* Criterion 5.1 include Kennedy-Walker *et al.* (2016), who analysed different faecal sludge collection and transport options for urban poor communities. Manga *et al.* (2020) compared simplified sewer configurations against onsite options. In addition, Retamal *et al.* (2011) modelled the financial performance of various hybrid sanitation interventions. These studies exemplify the application of average incremental costing (AIC) (see Criterion 6.1) for projecting detailed lifecycle costs to inform future service provision models.

Benefit valuation methods are described and justified for the study population

Criterion 5.2 assesses whether benefit valuation methods for economic efficiency are clearly defined and appropriate for the study context. Benefit valuation for urban sanitation can be contentious due to the potential for bias by only partially including all relevant outcomes of an intervention. The *ESI methodology* (Hutton *et al.* 2014) is an example that *comprehensively applies* Criterion 5.2 via the range of benefits it attempts to quantify using rigorous methods. Typically, benefit valuation methods are most effective in homogeneous settings where they can be applied consistently to yield reproducible results. In heterogeneous urban contexts in LMICs, justifying benefit valuation methods is more difficult, as demonstrated in Table 2, where few studies attempt this. For example, Meddings *et al.* (2004) conducted a case–control study, Prihandrijanti *et al.* (2008) estimated averted health expenditures, Delaire *et al.* (2020) utilised a willingness-to-pay survey, and Schuen & Parkinson (2009) assumed a generic health benefit for sub-Saharan Africa.

Intangible benefits are reported separately

Criterion 5.3 evaluates whether studies distinguish between intangible costs and benefits and economic efficiency measures in reported results. Urban sanitation systems often include diverse intangible benefits that are difficult to define and measure. Studies that *fully apply* Criterion 5.3 systematically differentiate between factors that can and cannot be quantified to support clearer decisions. For instance, Hutton *et al.* (2014) effectively categorised benefits as valued, quantified, and tangible. Another example is Willetts *et al.* (2010, 2013), who embedded a quantitative measure of cost-effectiveness within a deliberative sustainability assessment of sanitation options conducted with local authorities. The latter approach further exemplified Criterion 5.3 by transparently aligning their approach for defining and handling externalities with global sustainability frameworks.

AIC is used to structure lifecycle costs over time

Criterion 6.1 assesses whether AIC has been applied to structure lifecycle costs within a study. Table 2 shows that Kennedy-Walker *et al.* (2016), Manga *et al.* (2020), Retamal *et al.* (2011), and Willetts *et al.* (2010) fully applied this method. These studies determined the cost of the next additional unit of service provision for either households or users (see Criterion 5.1).

Adjustments for inflation and currency conversion are made explicit

Criterion 6.2 evaluates whether a study adjusts prices to a common year and currency, explicitly citing conversion factors. As indicated in Table 2, this *criterion fully applied* to most of the included literature.

A contextually relevant resource flow model is used to estimate economic costs

Criterion 7.1 assesses the effectiveness of economic models in representing the specific contexts of urban sanitation interventions within cities of LMICs. Models that fully apply this criterion need to scale and integrate data accurately to forecast cost and benefit changes over time. This will require reconciling fragmented data and ensuring assumptions align closely with real-world behaviours and their impact on demand for urban water resources.

Table 2 indicates that resource flow models most effectively apply Criterion 7.1, as they more closely determine the broader economic impacts of urban sanitation interventions. Six reviewed studies utilised water balance models to estimate economic costs in alignment with this intention. Retamal *et al.* (2011) and Willetts *et al.* (2010) demonstrated a rigorous approach to meeting this criterion by conducting a residential water end-use analysis model based on representative household surveys. This method enables the bottom-up prediction of wastewater flows over the entire timeframe of their analysis, derived from end-use practices within households, such as bathing or flushing. This approach allows the model to test the impact of context-specific assumptions on urban sanitation interventions from diverse perspectives (Retamal *et al.* 2011) (see Criterion 1.2).

Other studies either *mostly* or *partially apply* this criterion, depending on the rigour of the model applied. For instance, studies may represent resource flows using generalised per capita assumptions about total residential wastewater production (Jung *et al.* 2018; Manga *et al.* 2020), empirical cost functions (Peal & Georges 2013), or existing standard design parameters (Mburu *et al.* 2013; Shi *et al.* 2018) to predict the future costs of urban sanitation interventions. Studies that evaluate non-sewered urban sanitation options adopt resource flow models that estimate volumes of faecal sludge, as opposed to wastewater. For example, Tilmans *et al.* (2015) evaluated a container-based sanitation option using a model derived from empirical measurements. In contrast, Furlong *et al.* (2020), Kennedy-Walker *et al.* (2016), and von Münch & Mayumbelo (2007) determined resource flows based on per capita faecal sludge generation rate estimates derived from other contexts.

An alternative method of modelling the costs of urban sanitation interventions that partially applies Criterion 7.1 is financial flow modelling, as adopted by Carrard *et al.* (2021), Dodane *et al.* (2012), and McConville *et al.* (2019). These studies utilise historical financial data from the records of utilities, local authorities, and other service providers to project future costs. However, while the analysis facilitates a valuable financial comparison, the approach does not meaningfully account for the physical impacts of resource flows from changes to populations over time. This impacts how accurately they represent the actual context of the study.

The time horizon and discount rate applied are stated and justified

Criterion 8.1 assesses whether studies clearly define and justify the applied discount rates and time horizons. Most studies *fully applied* this criterion, typically applying discount rates of 4–12% across time horizons of 10–30 years.

Confidence intervals are presented for stochastic data

Criterion 9.1 evaluates whether confidence intervals are included for stochastic data used as model inputs in comparisons of urban sanitation interventions. Although this was not common in the reviewed literature, this criterion helps decision-makers to clearly understand the level of certainty of the results of an economic analysis. Confidence intervals indicate the variability parameters such as unit costs and resource quantities, which can vary widely across different urban settings and result in significant errors and poor decision outcomes.

An example that *fully applies* Criterion 9.1 is Jung *et al.* (2018), who defined confidence intervals for various input variables, including the discount rate, cost of electricity, and the degree to which modelled wastewater treatment configurations were decentralised. These intervals inform more certain decisions about the planning of wastewater treatment configurations in this context. Other examples partially apply Criterion 9.1 by providing confidence intervals only for critical variables with uncertain values, for example the sale price of reuse products (Carrard *et al.* 2021), the mass of faecal waste produced per day (Tilmans *et al.* 2015), the willingness to pay for sanitation services, Delaire *et al.* (2020), and an overall outcome measure of cost per death averted (Meddings *et al.* 2004).

Sensitivity and scenario analyses are used to enhance the use of modelled data

Criterion 9.2 evaluates how sensitivity and scenario analyses enhance the use of modelled data to address uncertainties. Seven studies fully apply this criterion, as detailed in Supplementary Table S1, although they apply these tools in varied ways.

Sensitivity analysis tests assumptions about significant input parameters over a defined range. Some analyses focus on a key parameter, such as the discount rate or time horizon of a study (Prihandrijanti *et al.* 2008; Dodane *et al.* 2012; Willetts *et al.* 2010), the cost of fuel or electricity (Jung *et al.* 2018; Manga *et al.* 2020), the level of subsidy provided (Delaire *et al.* 2020), the sale of reuse products (Schuen & Parkinson 2009; Carrard *et al.* 2021), or non-monetary benefits, such as averted health costs (Hutton *et al.* 2014). Other analyses are more comprehensive and are used to determine the parameters with the most potential to impact a decision (Hutton *et al.* 2014; Jung *et al.* 2018; Ketema & Langergraber 2015).

Scenario analysis poses *what-if* questions to a model to consider the impact of assumptions on a model over time and how this scenario may impact multiple parameters at the same time. This method is primarily used to appraise the impact of uncertain future scenarios when comparing sanitation service options (Prihandrijanti *et al.* 2008; Kerstens *et al.* 2009; Schuen & Parkinson 2009; Kennedy-Walker *et al.* 2016; Jung *et al.* 2018; Furlong *et al.* 2020). Other applications are more specific, seeking to validate a cost function model (Ketema & Langergraber 2015), test and optimise assumptions about the population assumed to be serviced by a service provision model (Carrard *et al.* 2021; McConville *et al.* 2019), or structure lifecycle costs over time with greater certainty (Willetts *et al.* 2010).

Deliberative methods are used to address aspects of epistemic uncertainty

Criterion 9.3 assesses the use of deliberative methods in urban sanitation studies to address uncertainties from diverse perspectives. This criterion highlights the importance of incorporating a broad range of viewpoints to enhance the equity of economic analyses and prevent biased decisions in service provision. Intentionally including these perspectives helps align studies with CWIS principles (Lüthi *et al.* 2020), fostering deeper reflection on and addressing the root causes of disparities in service access.

While no studies have *fully applied* Criterion 9.3, some enabling practices with the capacity to enhance the participation of traditionally excluded groups in economic appraisals were identified. For example, Willetts *et al.* (2013) implemented a sustainability assessment that brought together various stakeholders to discuss complex issues of social equity and environmental sustainability, prompting discussions about challenges in reaching consensus. Similarly, Dahiya *et al.* (2006) employed an informed choice approach, enabling informal households to actively evaluate trade-offs between costs and the intangible benefits of different service options. Future methodologies should further these practices, ensuring comparative economic analysis shapes inclusion in urban sanitation planning decisions.

Outcome measures (TACH/TACC) are reported against a least-cost standard

Criterion 10.1 assesses whether an economic analysis measures outcomes in incremental units of TACH or TACC (see Criterion 5.1) and compares these against an existing least-cost without-project standard (see Criterion 2.1). Among the studies reviewed, only Kennedy-Walker *et al.* (2016) *fully applied* Criterion 10.1 by conducting an incremental analysis. This study compared faecal waste transportation and treatment costs to those of a least-cost pilot study in comparable units of total monthly cost per household.

Outcome measures are presented in an aggregated and disaggregated format

Criterion 10.2 evaluates whether economic appraisals of urban sanitation report aggregated outcome measures that are then disaggregated to detail significant cost and subgroup perspectives (see Criterion 1.2), lifecycle cost components (see Criterion 6.1), and stages of a sanitation value chain. Studies that fully apply Criterion 10.2 include Carrard *et al.* (2021), Delaire *et al.* (2020), Dodane *et al.* (2012), Hutton *et al.* (2014), and McConville *et al.* (2019).

Conclusions arise from multiple cost perspectives informed by multiple criteria

Criterion 10.3 extends the principles of Criterion 10.2 by evaluating whether economic analyses support flexible interpretation from diverse urban perspectives and scales. This criterion stresses the importance of transparent and non-prescriptive reporting, avoiding sole reliance on quantitative measures. It advocates for an iterative and collaborative analysis process that adapts to the diverse and evolving economic relationships among various cost and subgroup perspectives.

While current practices often fall short of involving participants directly in analysing results, several studies illustrate emerging approaches that enhance collaborative decision-making. For example, Delaire *et al.* (2020) suggested that considering the spatial heterogeneity of cities could refine economic analyses, optimising sanitation costs for different urban contexts. Schuen & Parkinson (2009) and Peal & Georges (2013) demonstrated how what-if scenarios may be used to explore how changes in urban sanitation configurations might impact different cost perspectives. In addition, Furlong *et al.* (2020) conducted participatory workshops to ensure that a financial flow model adapted from another context resonated with the diverse experiences of users and service providers before its implementation in economic analysis. Future methodologies should develop tools that allow decision-makers across an urban spectrum to relate and interpret results on their own terms. This may facilitate a more inclusive and comprehensive understanding of economic analyses, aligned with CWIS principles.

CONCLUSION

This review examined how methods from costing studies over the past two decades align with evaluative criteria for least-cost comparative economic analysis of CWIS interventions in LMICs. By analysing how each criterion was applied, this paper provides valuable insights for planners aiming to design comparative economic analyses to select equitable and sustainable urban sanitation configurations.

Several challenges emerged from applying these criteria. Local authorities will need practical support to reframe economic analysis from first principles to an inclusive societal cost perspective. This support should facilitate defining a problem that includes all relevant subgroup perspectives in an analysis. It will require negotiating a collaborative definition of an existing without-project standard for sanitation service provision and collecting context-specific data for meaningful comparison. CWIS principles imply the need to take calculated risks to transition from focusing on existing infrastructure options to focusing on a diversity of approaches and outcomes. This will require longer-term economic analysis methodologies to compare context-specific innovations that respond to persistent unmet service demands. Decision support models should aspire to engage service users in this process critically.

The primary contribution of this review is highlighting opportunities to enhance economic analysis methodologies to better address the diverse needs for sanitation in cities in LMICs. The evaluative criteria require broader discussion within the urban water and sanitation sector to improve how they are defined and weighted in an overall evaluation. This activity should be coupled with additional context-specific economic analysis studies aligned with these criteria, complementing more generic heuristic comparisons.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Carrard, N., Jayathilake, N. & Willetts, J. 2021 Lifecycle costs of a resource-oriented sanitation system and implications for advancing a circular economy approach to sanitation. *Journal of Cleaner Production* **307**, 127135. doi:10.1016/j.jclepro.2021.127135.

Dahiya, B., Briones, H., Lahiri, S., Battulga, I., Jenny, H., Kamata, T., Perez, E. & Kolsky, P. 2006 *Manual on Low Cost Sanitation Technologies for Ger Areas (Vol. 3)*. Ulaanbataar, Mongolia. Available from: researchgate.net/publication/313795768.

Danert, K. & Hutton, G. 2020 Shining the spotlight on household investments for water, sanitation and hygiene (WASH): let us talk about HI and the three 'T', *Journal of Water, Sanitation and Hygiene for Development* **10**, 1, pp. 1–4. doi:10.2166/washdev.2020.139.

Daudey, L. 2018 The cost of urban sanitation solutions: A literature review. *Journal of Water Sanitation and Hygiene for Development* **8** (2), 176–195. doi:10.2166/washdev.2017.058.

Delaire, C., Peletz, R., Haji, S., Kones, J., Samuel, E., Easthope-Frazer, A., Charreyron, E., Wang, T., Feng, A. & Mustafiz, R. 2020 How much will safe sanitation for all cost? Evidence from five cities. *Environmental Science & Technology* **55** (1), 767–777. doi:10.1021/acs.est.0c06348.

Dodane, P.-H., Mbéguéré, M., Sow, O. & Strande, L. 2012 Capital and operating costs of full-scale fecal sludge management and wastewater treatment systems in Dakar, Senegal. *Environmental Science & Technology* **46** (7), 3705–3711. doi:10.1021/es2045234.

Furlong, C., Singh, S., Shrestha, N., Sherpa, M. G., Lüthi, C., Zakaria, F. & Brdjanovic, D. 2020 Evaluating financial sustainability along the sanitation value chain using a financial flow simulator (eSOSView™). *Water Science and Technology* **82** (11), 2220–2233. doi:10.2166/wst.2020.456.

Hutton, G. 2013 Global costs and benefits of reaching universal coverage of sanitation and drinking-water supply. *Journal of Water and Health* **11** (1), 1–12. doi:10.2166/wh.2012.105.

Hutton, G. & Chase, C. 2016 The knowledge base for achieving the sustainable development goal targets on water supply, sanitation and hygiene. *International Journal of Environmental Research and Public Health* **13** (6), 536. doi:10.3390/ijerph13060536.

Hutton, G. & Varughese, M. 2016 *The Costs of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygiene*. World Bank, Washington, DC. Available from: documents1.worldbank.org/curated/en/847191468000296045/.

Hutton, G., Rodriguez, U. P., Winara, A., Nguyen, V.-A., Kov, P., Chuan, L., Blackett, I. & Weitz, A. 2014 Economic efficiency of sanitation interventions in Southeast Asia. *Journal of Water Sanitation and Hygiene for Development* **4** (1), 23–36. doi:10.2166/washdev.2013.158.

Jung, Y. T., Narayanan, N. C. & Cheng, Y.-L. 2018 Cost comparison of centralised and decentralised wastewater management systems using optimisation model. *Journal of Environmental Management* **213**, 90–97. doi:10.1016/j.jenvman.2018.01.081.

Kennedy-Walker, R., Holderness, T., Alderson, D., Amezaga, J. M. & Paterson, C. A. 2016 Optimisation and costing of faecal sludge management options for Lusaka's informal settlements. *Environmental Science: Water Research and Technology* **2** (1), 97–106. doi:10.1039/C5EW00179J.

Kerstens, S. M., Mes, T. Z. D. d. & Lue, B. 2009 Designing sustainable sanitation in urban planning proposed for Changzhou, China. *Water Science and Technology* **60** (12), 3165–3172. doi:10.2166/wst.2009.160.

Ketema, A. A. & Langergraber, G. 2015 Sensitivity analysis of the CLARA simplified planning tool using the Morris screening method. *Water Science and Technology* **71** (2), 234–244. doi:10.2166/wst.2014.497.

Ketema, A. A. & Langergraber, G. 2016 Statistical validation of the CLARA simplified planning tool. *Water Science and Technology: Water Supply* **16** (1), 193–201. doi: 10.2166/ws.2015.125.

Ketema, A. A., Lechner, M., Tilahun, S. A. & Langergraber, G. 2015 Development of cost functions for water supply and sanitation technologies: Case study of Bahir Dar and Arba Minch, Ethiopia. *Journal of Water Sanitation and Hygiene for Development* **5** (3), 502–511. doi:10.2166/washdev.2015.067.

Ketema, A. A. & Langergraber, G. 2016 Statistical validation of the CLARA simplified planning tool Water Science and Technology: *Water Supply* **16** (1), 193–201. doi: 10.2166/ws.2015.125.

Khalil, H. & Tricco, A. C. 2022 Differentiating between mapping reviews and scoping reviews in the evidence synthesis ecosystem. *Journal of Clinical Epidemiology* **149**, 175–182. doi:10.1016/j.jclinepi.2022.05.012.

Lawhon, M., Nilsson, D., Silver, J., Ernstson, H. & Lwasa, S. 2017 Thinking through heterogeneous infrastructure configurations. *Urban Studies* **55** (4), 720–732. doi:10.1177/0042098017720149.

Lüthi, C., Willetts, J. & Hoffmann, S. 2020 Editorial: Citywide sanitation: The urban sustainability challenge. *Frontiers in Environmental Science* **8**. doi:10.3389/fenvs.2020.585418.

Manga, M., Bartram, J. & Evans, B. E. 2020 Economic cost analysis of low-cost sanitation technology options in informal settlement areas (case study: Soweto, Johannesburg). *International Journal of Hygiene and Environmental Health* **223** (1), 289–298. doi:10.1016/j.ijheh.2019.06.012.

Mburu, N., Tebitendwa, S. M., van Bruggen, J. J. A., Rousseau, D. P. L. & Lens, P. N. L. 2013 Performance comparison and economics analysis of waste stabilisation ponds and horizontal subsurface flow constructed wetlands treating domestic wastewater: A case study of the Juja sewage treatment works. *Journal of Environmental Management* **128**, 220–225. doi:10.1016/j.jenvman.2013.05.031.

McConville, J. R., Kvarnström, E., Maiteki, J. M. & Niwagaba, C. B. 2019 Infrastructure investments and operating costs for fecal sludge and sewage treatment systems in Kampala, Uganda. *Urban Water Journal* **16** (8), 584–593. doi:10.1080/1573062X.2019.1700290.

Meddings, D., Ronald, L., Marion, S., Pinera, J. & Oppliger, A. 2004 Cost-effectiveness of a latrine revision programme in Kabul, Afghanistan. *Bulletin of the World Health Organization* **82**, 281–289.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P. & Moher, D. 2021 The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **10** (1), 89. doi:10.1136/bmj.n71.

Peal, A. & Georges, M. 2013 *Financial Analysis for Sanitation Planning: Lessons From Dhaka*. WSUP. Available from: assets.publishing.service.gov.uk/media/57a08a2ce5274a31e0000476/TB010-A-Financial-Analysis-Tool-for-Dhaka.pdf.

Prihandrijanti, M., Malisie, A. & Otterpohl, R. 2008 Cost-benefit analysis for centralised and decentralised wastewater treatment system (case study in Surabaya-Indonesia). In: *Efficient Management of Wastewater*. Springer, pp. 259–268. doi:10.1007/978-3-540-74492-4_22.

Retamal, M., Willetts, J., Mitchell, C. & Carrard, N. 2011 Modelling costs for water and sanitation infrastructure: Comparing sanitation options for Can Tho, Vietnam. In: *35th WEDC International Conference: The Future of Water, Sanitation, and Hygiene: Innovation, Adaption and Engagement in A Changing World*, Loughborough, United Kingdom. Available from: hdl.handle.net/2134/30004.

Ross, I., Scott, R. & Ravikumar, J. 2016 *Fecal Sludge Management: Diagnostics for Service Delivery in Urban Areas: A Case Study in Dhaka, Bangladesh*, vol. 1. Water and Sanitation Program – World Bank, Washington, DC, p. 106809. Available from: documents1.worldbank.org/curated/en/577961468343135688/.

Ross, I., Greco, G., Opondo, C., Adriano, Z., Nala, R., Brown, J., Dreibelbis, R. & Cumming, O. 2022 Measuring and valuing broader impacts in public health: development of a sanitation-related quality of life instrument in Maputo, Mozambique. *Health Economics* **31** (3), 466–480. doi:10.1002/hec.4462.

Ross, S., Fane, S. & Foster, T. (under review) Evaluative criteria for least-cost economic analysis of citywide inclusive sanitation: a scoping review.

Sainati, T., Zakaria, F., Locatelli, G. & Evans, B. 2020 Understanding the costs of urban sanitation: towards a standard costing model. *Journal of Water, Sanitation and Hygiene for Development* **10** (4), 642–658. doi:10.2166/washdev.2020.093.

Schuen, R. & Parkinson, J. 2009 *Study for Financial and Economic Analysis of Ecological Sanitation in Sub-Saharan Africa, Working Paper*. World Bank, Washington, DC, p. 52235. Available from: documents1.worldbank.org/curated/en/772771468003000076/.

Shi, Y., Zhou, L., Xu, Y., Zhou, H. & Shi, L. 2018 Life cycle cost and environmental assessment for resource-oriented toilet systems. *Journal of Cleaner Production* **196**, 1188–1197. doi:10.1016/j.jclepro.2018.06.129.

Tilmans, S., Russel, K., Sklar, R., Page, L. N., Kramer, S. & Davis, J. 2015 Container-based sanitation: assessing costs and effectiveness of excreta management in Cap Haitien, Haiti. *Environment and Urbanisation* **27** (1), 89–104. doi:10.1177/0956247815572746.

UN Water 2021 *Summary Progress Update 2021: SDG 6 – Water and Sanitation for all*, Geneva, Switzerland. Available from: unwater.org/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf.

United Nations 2015 *Transforming Our World: The 2030 Agenda for Sustainable Development*. Available from: sdgs.un.org/publications/transforming-our-world-2030-agenda-sustainable-development-17981.

van Welie, M. J., Cherunya, P. C., Truffer, B. & Murphy, J. T. 2018 Analysing transition pathways in developing cities: The case of Nairobi's splintered sanitation regime. *Technological Forecasting and Social Change* **137**, 259–271. doi:10.1016/j.techfore.2018.07.059.

von Münch, E. & Mayumbelo, K. M. K. 2007 Methodology to compare costs of sanitation options for low-income peri-urban areas in Lusaka, Zambia. *Water SA* **33** (5), 593–602. doi:10.4314/wsa.v33i5.184017.

Whittington, D., Jeuland, M., Barker, K. & Yuen, Y. 2012 Setting priorities, targeting subsidies among water, sanitation, and preventive health interventions in developing countries. *World Development* **40** (8), 1546–1568. doi:10.1016/j.worlddev.2012.03.004.

WHO & UNICEF. 2021 *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2020: Five Years Into the SDGs, Geneva*. Available from: data.unicef.org/resources/progress-on-household-drinking-water-sanitation-and-hygiene-2000–2020/.

Willetts, J., Carrard, N., Retamal, M., Mitchell, C., Nguyen, H. T. & Nguyen, D. G. T. 2010 Cost-effectiveness analysis as a methodology to compare sanitation options in peri-urban Can Tho, Vietnam. In *IRC Symposium 2010 Pumps, Pipes and Promises*, The Hague, Netherlands. Available from: opus.cloud1.lib.uts.edu.au/handle/10453/35021.

Willetts, J., Paddon, M., Nam, N., Trung, N. & Carrard, N. 2013 Sustainability assessment of sanitation options in Vietnam: planning with the future in mind. *Journal of Water, Sanitation and Hygiene for Development* **3** (2), 7. doi:10.2166/washdev.2013.045.

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