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Review Paper

Evaluation of failings in urban water supply and sanitation systems in Sub-Saharan Africa: a systematic review to inform future planning

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ABSTRACT

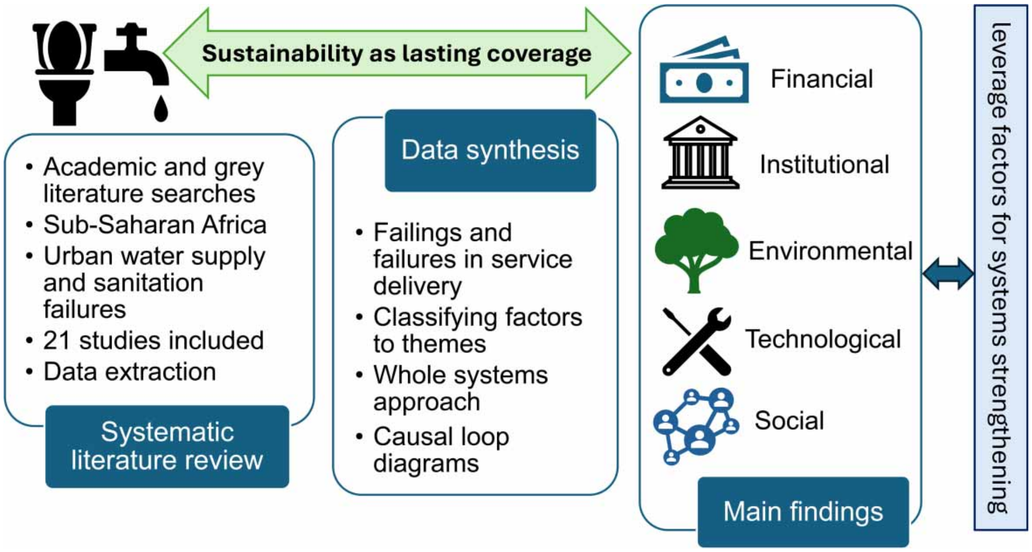
The high failure rate of water supply and sanitation (WSS) systems is a major concern, especially for developing countries. Using the Collaboration for Environmental Evidence guidelines, this study carried out a systematic review of literature on failings in WSS in the urban areas of Sub-Saharan Africa to identify the factors hindering sustainability as lasting coverage. There were 101 full-text articles examined and 21 articles included in the final review. The findings are discussed through the lens of the financial, institutional, environmental, technological and social (FIETS) framework and depicted in a causal loop diagram to visualize the system structure. In total, 37 factors that contribute to the failings of urban WSS systems across 14 Sub-Saharan African countries were identified. The root causes of failed or failing systems included a lack of stakeholder engagement in the planning and implementation; limited human resources capacity; limitations imposed by settlement type (informal settlements); insufficient funds, corruption and mismanagement of funds; and insufficient operation and maintenance of facilities. The study concludes that sustainability in the sector will involve the use of legal instruments, adequate planning techniques, anti-corruption and cost recovery mechanisms to ensure long-term financing.

Key words: failures, sanitation, Sub-Saharan Africa, sustainability, urban systems, water supply

HIGHLIGHTS

- Failings in urban water security are complex, interlinking financial, institutional, environmental, technical and social constraints.
- Removing barriers to sustainability as lasting coverage requires coordinated efforts involving top-down and bottom-up approaches.
- Multiple strategic leverage factors have been identified for planning and mobilizing resources for urban water supply and sanitation systems.

GRAPHICAL ABSTRACT



INTRODUCTION

The lack of sustainability in water supply and sanitation (WSS) systems is a major concern for developing countries. In Africa, a legacy of unsustainable WSS interventions leaves 418 and 779 million people without access to safe drinking water and basic sanitation services, respectively (UNICEF 2022). These numbers are large underestimates because recent JMP data and modeling approach peer-reviewed analysis suggest the amount of people without safe access is much higher (Greenwood *et al.* 2024). Earlier research has identified several factors behind the failings in the WSS sector. For instance, failures of WSS in Africa have been attributed to poor maintenance (Katukiza *et al.* 2010); inappropriate technology (Murphy *et al.* 2009); corruption (Muller 2020); non-participation of stakeholders (Schiedek *et al.* 2021); insufficient capacity, poor coordination, politics and bureaucracy (Barrington *et al.* 2021); inadequate sector financing (World Bank & UNICEF 2017) and little or no revenues for operation and maintenance (Carter *et al.* 2010). Furthermore, 21st-century global challenges of climate change (Howard *et al.* 2016) and population growth (Okello *et al.* 2015) also pose short- and long-term threats to safe and reliable WSS services.

The varying degrees of success in attempts to meet the WSS delivery targets of several Sub-Saharan African countries have raised questions about the impacts of WSS initiatives in Africa (Sambu 2016). Sub-Saharan African countries remain top on the list of nations where the urban WSS coverage is not keeping up with population growth, leading to serious concerns about meeting the targets of Sustainable Development Goal 6 by 2030 (UNICEF 2020).

With 2030 rapidly approaching, it is evident that one major obstacle to achieving universal water and sanitation coverage is the reoccurring failings and premature failure of urban WSS systems (UNDP/UNICEF 2015). There are multiple examples where WSS systems fail to provide lasting benefits to their users. It is estimated that of the 245 million liters of water produced in the city of Dar es Salaam, only about 51% gets to the users, the rest is lost due to dilapidated infrastructure and illegal connections (United Republic of Tanzania 2013). A report on the piped water supply utility of Old Town, Mombasa, revealed a major water quality scare due to the cross-contamination of the piped water by sewage effluent from the city's broken sewer system (Kinya 2010). In other failures, a water utility performance index analysis of 15 urban water supply utilities in Mozambique shows that all the utilities investigated were economically unsustainable, raising concern over the medium- to long-term functionality of these facilities (Farolfi & Gallego-Ayala 2014; Gallego-Ayala *et al.* 2014). These findings are consistent with evidence from Kenya where the financial sustainability of the water sector is threatened by high levels of non-revenue water (NRW) use (WASREB 2013).

Similarly, high rates of failings have been documented for sanitation facilities. It is estimated that within 2 years of construction, 70% of the sanitation systems in resource-limited communities fail (WHO & UNICEF JMP 2017). In the urban area of Kenya, only about 60% of the wastewater that enters the sewerage reaches the treatment plants which have a current operational rate of 16% of the design capacity (Institute of Economic Affairs 2007; Republic of Kenya Ministry of Health 2016).

In Accra, partially functional treatment plants combined with inadequate treatment processes result in 92% of the fecal sludge that has already reached the treatment plant being released back into the environment, with only 18% of the treatment capacity being operational (Nikiema 2015; Koppelaar *et al.* 2018). These well-documented examples capture the frequent failure of water and sanitation investments to meet the needs of the residents even after significant resources have been committed.

It has been argued that the customary indicator for progress in the WSS sector, defined as the number of beneficiaries provided for through a scheme or intervention, should be replaced with the goal of sustainability as lasting coverage (Breslin 2010). Lasting coverage will involve moving from low levels of coverage to full coverage and establishing supporting financing, technical and management systems that prevail. By focusing on a simple metric (failings in scheme performance) and rejecting both pre and immediate post project ambitions such as population served or numbers of connections, offers an alternative perspective on interventions - thus challenging the fit and forget approach and emphasizing the lived experience of the project. However, 'failure' is often a contentious and non-binary feature of WSS systems. What is a failure to one party may be seen as conditional or partial success to another. Given the multi-attribute nature of WSS provision, the question is which outputs and outcomes are to be included in an assessment of success or failure, and at what point should failure be declared, and for what reason(s)?

Regionally specific cohort studies of WSS scheme failures are rare and only one of these has formally considered lasting coverage as a success measure. Using a sample of 23 urban and rural projects across six Sub-Saharan African countries, the European Court of Auditors (ECA) found that fewer than half of the projects examined delivered results meeting the beneficiaries' needs and that for a majority of projects, results and benefits were unlikely to be long lasting unless non-tariff revenue could be ensured; or because of weak capacity of the operators to run the installed equipment (European Court of Auditors 2012).

Since publication of the ECA report there has been a welcome increase in the number of published studies which report urban WSS scheme challenges and failings. However, what is often lacking in the existing research on drivers of urban WSS failings is the whole systems approach of understanding the interconnectedness of a complex problem. In this paper, we focus on urban schemes and report findings from a systematic literature review (SLR) of the failure of WSS systems in Sub-Saharan Africa and apply a whole systems approach to better understand the nature and causes of scheme failings and proffer solutions. The specific research question guiding our analysis is: What are the reasons for the failings of WSS systems in the urban areas of Sub-Saharan Africa? and What learnings can we extract from this to inform future planning?

METHODS

Protocol

In a world where success indicators are often the indicators that are measurable, rather than indicators of something that is critical but not so easily measured, careful thought about what can be determined as success or failure is important. For this study, we designated a water supply or sanitation system as failing or a failure only if the data source (report, paper, etc.) provided substantiated evidence of such. In determining this criterion, we looked for verifiable data or information which reflected previously well-reported features of failing schemes, for example, poor infrastructure functionality (Starkl *et al.* 2013) and ineffective supporting policies (Mansour & Esseku 2017). As part of the development of the SLR protocol, we carried out a scoping review to estimate the volume of literature in the field and develop and test our search strategy. In order to synthesize the scientific evidence from a range of sources, we adopted the guidelines developed by the Collaboration for Environmental Evidence (CEE 2013). The CEE guidelines were preferred for this study because of the high-quality reporting style and methodological approach of the method designed to provide the best available evidence (Roberts *et al.* 2006). We developed the research question following the CEE convention to include the PICO components: (i) the Population (urban areas of Sub-Saharan Africa), (ii) Interventions (WSS projects and systems), (iii) Comparison (which will only be applicable if the review is comparing an alternative intervention(s), which in this case is not) and (iv) Outcomes (failing scheme or project). We considered only literature published in the English language between January 2000 and December 2022 with complete information referring to failings on urban WSS projects. Studies that did not inform a response to the research question were excluded.

Information sources and search strategy

We searched the bibliographic databases of Scopus, ISI Web of Science and Science Direct. For grey literature, we used the Google search engine in addition to organizational databases: World Bank and WHO/UNICEF JMP reports. The search strategy was divided into two components: water and sanitation. Articles were searched for a combination of three terms: region of interest (Africa), water and sanitation technologies and a failure term. The search included a date range cutoff date of 2000 to focus on studies accurately reflecting contemporary schemes. To increase search sensitivity, we used the 'OR'/'AND' operators to combine the various PICO components and wildcards to increase flexibility and efficiency. The entry terms were modified to suit the preferred method of the search database. Full search terms for each database are presented in Table 1. The search was performed between 31/5/2022 and 14/6/2022 and repeated between 04/01/2023 and 27/01/2023. We also carried out advanced Google searches for literature and other newspaper articles, which returned thousands of candidate data sources whose relevance declined as we progressed through the list. For simplicity and consistency with the CEE recommendation, the first 100 hits were viewed for each component of the search (CEE 2013).

Data selection and extraction process

Our initial search generated 4,563 articles which were all uploaded to Mendeley reference manager. Duplicates were removed leaving 3,673 to be screened by titles and abstracts. Title-level screening was carried out and 3,392 articles were eliminated because the topics were not specific to our study. For example, articles whose title was about the impact of lack of water on disease outbreaks were excluded at this stage. The abstracts of the remaining papers were then read, and papers that were not relevant to the research were subsequently eliminated, leaving 101 papers to be read in detail.

Inclusion and exclusion criteria

We excluded studies on countries in the North African region because they were outside the scope of this review. Likewise, studies on rural areas were excluded. We found that a higher number of the literature is on failures on rural WASH in Africa, which we excluded because they were outside the scope of this review. We found that many studies on the topic of failings on urban WSS cut across all low- and middle-income (LMIC) countries and not specific to Sub-Saharan Africa's unique context and hence were excluded. Articles on failings related to or due to the impact of climate induced disasters of floods and droughts on urban water supply systems and service delivery are very important. Aspects of sustainability due to systems challenges of directly coping with the impacts of day-to-day and prolonged reduced availability of water sources from drought

Table 1 | Search terms for each database

Database	Search strings	Searched within
Scopus	(i) Water: Africa AND (water* OR wash OR tap* OR handpump* OR 'hand pump*') AND (schemes OR projects OR interventions OR facilities) AND (decline* OR fail* OR damage* OR decrease* OR breakdown OR inefficient OR 'poor maintenance') (ii) Sanitation: Africa* AND (sanitation OR wastewater OR 'waste water' OR toilet* OR latrine* OR pit OR 'septic tank' OR sewage* OR sewer* OR 'fecal sludge') AND (schemes OR projects OR interventions OR facilities) AND (decline* OR fail* OR damage* OR decrease* OR breakdown OR inefficient OR 'poor maintenance')	Title, abstract or keywords
Web of Science	(i) Water: Africa AND (water* OR wash OR tap* OR handpump* OR 'hand pump*') AND (schemes OR projects OR interventions OR facilities) AND (decline* OR fail* OR damage* OR decrease* OR breakdown OR inefficient OR 'poor maintenance') (ii) Sanitation: Africa* AND (sanitation OR wastewater OR 'waste water' OR toilet* OR latrine* OR pit OR 'septic tank' OR sewage* OR sewer* OR 'fecal sludge') AND (schemes OR projects OR interventions OR facilities) AND (decline* OR fail* OR damage* OR decrease* OR breakdown OR inefficient OR 'poor maintenance')	All fields
Science Direct	(i) Water: Africa AND (water OR wash OR handpump OR tap) AND (decline OR fail OR damage OR inefficient) (ii) Sanitation: Africa AND (sanitation OR toilet OR sewage OR sewer OR latrine) AND (decline OR fail OR damage)	Title, abstract or author-specified keywords
Google	(i) Water: failed problem water projects urban Africa (ii) Sanitation: failed problem sanitation projects urban Africa	Advanced search
JMP database	The monitoring category was set to water and sanitation, and data from 2000 to 2022 were scanned	Reports
World Bank	Water supply and sanitation	Browse by topic

conditions were evident and included. There were very limited studies informing the unique environmental circumstances affecting daily operation due to flooding which is often considered a one-off event. However, flooding is no longer a one-off natural disaster but is becoming a regular occurrence of the impact of climate change and as constant as drought as a risk factor in some areas. In any case, strengthened systems are precursors to achieving aspects of climate resilience and adaptation. Finally, 21 papers were included in the systematic review. Of the 4,563 articles identified in database searches, only 21 met all the inclusion criteria and were accepted for analysis. The details of the data selection process are presented in Figure 1. Data collected were stored in Mendeley reference manager and exported to Microsoft Excel 2016 for data extraction and analysis.

Data analysis

We analyzed the included studies to extract those factors mentioned as being responsible for the failings and/or failure of the WSS systems. Identified factors were categorized using the financial, institutional, environmental, technological and social (FIETS) sustainability framework (Dutch WASH Alliance 2013). The FIETS framework was selected because of its comprehensiveness in covering a range of identified components of sustainability (Ajroud *et al.* 2020; Daniel *et al.* 2021; Akbar Chinna Mohideen *et al.* 2022). A whole systems approach involves the understanding of interconnected parts of a complex problem to proffer solutions and prioritize actions. Drawing on the argument that a whole systems approach to WSS analysis can advance progress toward sustainable access to WSS services (Kimbugwea *et al.* 2022), systems diagraming was used to explore causes and effects across the identified factors. The relationship between the identified factors was evaluated based on the interactions identified in the different articles included in the review. We analyzed the interactions between the various identified factors responsible for the failings of WSS systems to identify leverage points. Leverage points constitute opportunities to target interventions that produce effective change in the system (Kimbugwea *et al.* 2022). Using the Vensim® software program, the failure factors we identified from the systematic review were used to create a causal loop diagram (CLD) that represents relationships between elements of the problem and the system dynamics (Williams & Hummelbrunner 2010). CLDs have been useful in studying the dynamics of various systems including urban water distribution (Mbavarira &

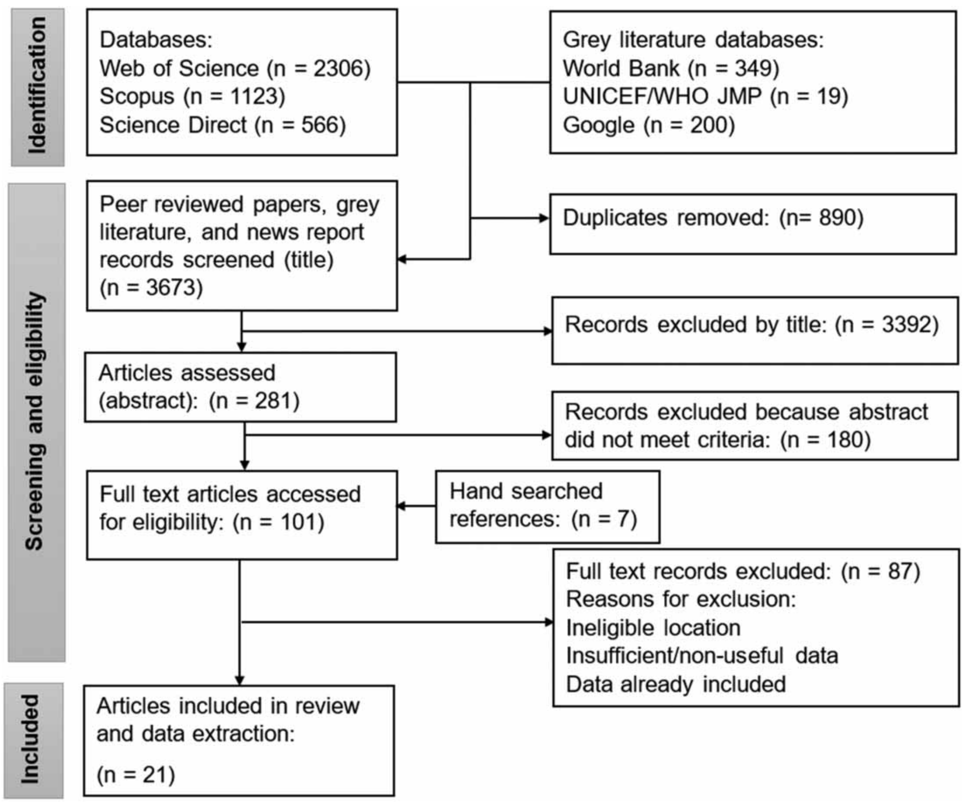


Figure 1 | Flow chart for the study selection.

Grimm 2021), groundwater management (Noor *et al.* 2022) and climate change impact (Khairulbahri 2022). When a group of causal relationships forms a closed circuit, a feedback loop is created (Sterman 2000) which we identified as either reinforcing (R) or balancing (B). We identified feedback loops in the CLD by observing where the output of one identified factor fed back into another factor in the system as input and created a causal flow pattern in a closed circuit. A factor with a high influence on the system, less affected by other factors and common in dominant feedback loops, has a high potential of being an effective leverage point (Kimbugwea *et al.* 2022). However, such leverage points could present risks as well because many system components are sensitive to an intervention at that point. For clarity, the failure factors and links were drawn in different colors, representing the components of the FIETS element each one represents.

RESULTS

Description of studies

Identified studies were spread across all regions of Sub-Saharan Africa including Western, Eastern and Southern Africa. Data were collected relating to projects in Nigeria, Ghana, Senegal, Benin, Burkina Faso, Tanzania, Uganda, Mozambique, Kenya, Ethiopia, Zambia, Angola, South Africa and Namibia. Figure 2 shows the years of publication of the included articles. No useful data was found for articles published before 2007. A summary of included studies showing the study ID and details of included studies is presented in Table 2.

From factors to themes

In total, 37 factors that contributed to the failings of WSS systems across 14 African countries were analyzed from the 21 studies. The identified factors were grouped into five FIETS themes: financial, institutional, environmental/contextual, technical and social factors as shown in Supplementary Figure S1. The financial aspect relates to commerce and the costs associated with the WSS service; the institutional theme focuses on overall institutions and government performance in the WSS sector, including policies, laws and regulations; environmental and contextual aspects are related to the interaction between WSS and the natural environment or the unique environmental circumstances affecting the daily operation; technical factors primarily relate to the technology or service infrastructure used for the delivery of WSS service; social factors are the social conditions involving served community culture, behaviors and attitudes. Institutional factors were identified as the leading cause of WSS systems failure with 12 (32%), followed by technical: 10 (27%), financial: 6 (16%), social: 5 (14%) and environmental/contextual having the least number of factors 4 (11%). The 37 factors contributing to the failings in sustainability as lasting coverage of WSS systems with the corresponding studies are highlighted in Figure 3.

Financial factors

Several financial factors responsible for failing and in some cases outright failure of WSS systems were identified, as shown in Figure 3(a). There were six factors identified which were failings that affected lasting coverage. Eight studies reported a lack of

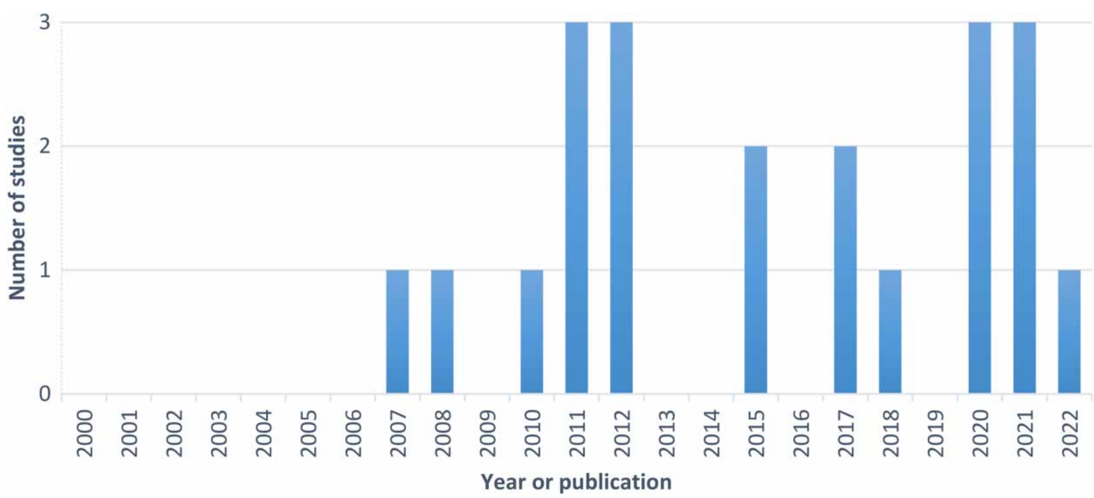


Figure 2 | Timeline of papers included in the review.

Table 2 | Summary of included studies with reference ID number

Study ID	Author(s)	Title	Year	Location/Country
1	Adeyeye *et al.*	Water marginality in rural and peri-urban communities	2020	Limpopo province, South Africa
2	Ashipala *et al.*	Impediments to the adoption of alternative sewerage in South African urban informal settlements	2011	South Africa
3	Birhanu *et al.*	Impact of natural and anthropogenic stresses on surface and groundwater supply sources of the upper Awash sub-basin, central Ethiopia	2021	Addis Ababa, Ethiopia
4	Buckley *et al.*	The Sustainable Development Goal for urban sanitation: Africa's statistical tragedy continues?	2018	Uganda
5	Cirolia *et al.*	Infrastructure governance in the post-networked city: state-led, high-tech sanitation in Addis Ababa's condominium housing	2021	Addis Ababa, Ethiopia
6	Fakoya *et al.*	Improving water pricing decisions through material flow cost accounting model: a case study of the Politsi Water Treatment Scheme in South Africa	2021	Limpopo province, South Africa
7	Fischer *et al.*	Assessment of public-private partnerships in Mozambique	2012	Mozambique
8	Günther *et al.*	When is shared sanitation improved sanitation? The correlation between number of users and toilet hygiene	2012	Kampala, Uganda
9	Mansour & Esseku	Situation analysis of the urban sanitation sector in Ghana	2017	Ghana
10	Mansour & Oyaya	Situation analysis of the urban sanitation sector in Kenya	2017	Kenya
11	Muller	Money down the drain: corruption in South Africa's water sector	2020	South Africa
12	Ndokosho *et al.*	Assessment of management approaches in a public water utility: a case study of the Namibia water corporation (NAMWATER)	2007	Namibia
13	Norman & Pedley	Exploring the negative space: evaluating reasons for the failure of pro-poor targeting in urban sanitation projects	2011	Dakar, Senegal
14	Norman & Scott	The PAQPUD settled sewerage project (Dakar, Senegal): problems arising, lessons learned	2011	Dakar, Senegal
15	Peprah *et al.*	Public toilets and their customers in low-income Accra, Ghana	2015	Accra, Ghana
16	Publications Office of the European Union (POEU)	European Union development assistance for drinking water supply and basic sanitation in Sub-Saharan countries: special report	2012	Angola, Benin, Burkina Faso, Ghana, Nigeria & Tanzania
17	Rugemalila *et al.*	Urban water governance failure and local strategies to overcoming water shortages in Dar es Salaam, Tanzania	2015	Dar es Salaam, Tanzania
18	Trémolet *et al.*	Financing on-site sanitation for the poor: a six country comparative review and analysis	2010	Mozambique, Senegal
19	WaterAid	Why did city water fail? The rise and fall of private sector participation in Dar es Salaam's water supply	2008	Dar es Salaam, Tanzania
20	World Bank	Improving water supply and sanitation in growth centers in Zambia technical efficiency analysis	2022	Zambia
21	World Bank	Zambia water supply and sanitation sector diagnostic: narrowing the gap between policy and practice	2020	Zambia

financial resources for the operation and maintenance (O&M) of the WSS infrastructures. All utilities evaluated had interrupted/intermittent water supply with water utilities in Zambia reporting interrupted supply due to economic reasons (World Bank 2022), while the country's sanitation sector was found to receive limited investment (World Bank 2020). Similar

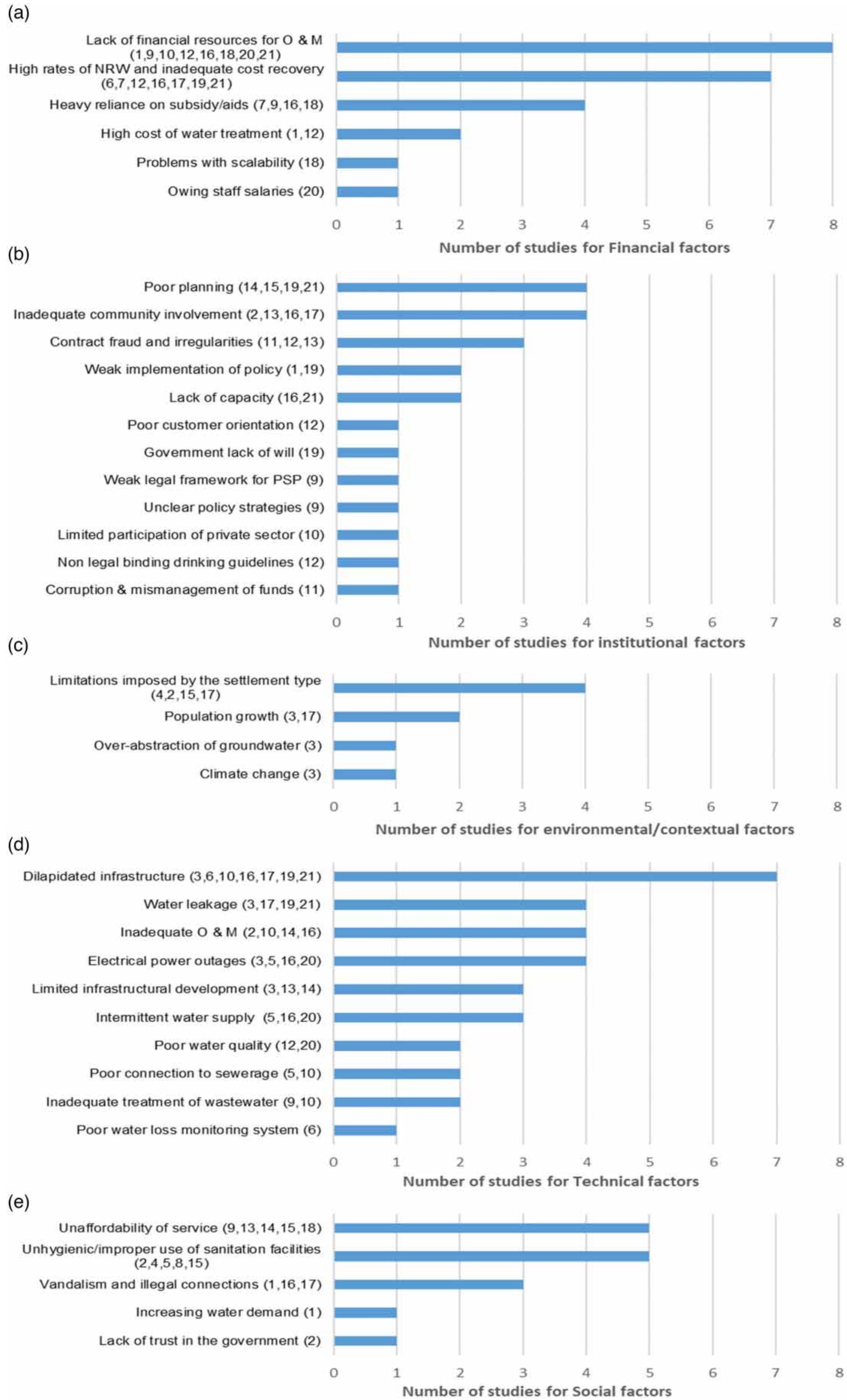


Figure 3 | (a) Financial, (b) institutional, (c) environmental/contextual, (d) technical and (e) social factors with corresponding study ID numbers from Table 2.

financial pressures in the sanitation sector were reported in Ghana (Günther *et al.* 2012) and in Limpopo province, South Africa (Adeyeye *et al.* 2020). In Senegal and Mozambique, the inability of sanitation interventions to be up-scaled was linked to the lack of adequate financing (Trémolet *et al.* 2010). Furthermore, NRW and inadequate cost recovery were reported as major hindrances to sustainability, with water utilities recording varying amounts of NRW due to inefficiency (World Bank 2020), leakages (WaterAid 2008; Rugemalila & Gibbs 2015) and ineffective billing or payment monitoring systems (POEU 2012; Rugemalila & Gibbs 2015; Fakoya & Imuezerua 2021). In parts of Limpopo province, the high cost of treatment interventions was reported to be due to high nitrate and fluoride content in the catchment water which made service provision expensive and the water agency receiving only about 16% of the OPEX budget needed per annum to maintain existing infrastructure (Adeyeye *et al.* 2020). A similar situation was also observed in Namibia where the cost of removing some inorganic contaminants partly put the state-owned water corporation, Namibia water corporation (NAMWATER) into experiencing poor financial performance indicated by its high losses estimated at US$14 million (N$100 million) in 2004 (Ndokosho *et al.* 2007). The impact of limited local financing and inadequate cost recovery led to the WSS sector being dependent on donor funding (Trémolet *et al.* 2010; Fischer & Nhabinde 2012; POEU 2012; Mansour & Esseku 2017) with some utilities unable to pay their staff full salaries (World Bank 2022), which is indicative of a failing system and not financially sustainable in the long-term.

Institutional factors

Twelve institutional factors were revealed as being responsible for failings in lasting coverage of WSS systems, as shown in Figure 3(b). Poor planning was observed by four articles as one of the reasons the studied project failed (WaterAid 2008; Norman *et al.* 2011; Peprah *et al.* 2015; World Bank 2020). In Zambia, weak institutional capacity for planning, implementation, monitoring and evaluation led to high levels of NRW with most of the increased production lost in leaky networks and accompanied by inefficient bill collection which created a fiscal burden and hindered the progress of the 2011 National Urban Water Supply and Sanitation Program (World Bank 2020). Inadequate community involvement was witnessed in urban water projects implemented in Angola (POEU 2012) and Dar es Salaam (Rugemalila & Gibbs 2015) and sanitation projects in Dakar (Norman & Pedley 2011) and South Africa (Ashipala & Armitage 2011). Communities lacked the capacity to maintain and repair water networks or implement behavioral changes which led to the vandalism of pipe networks in Angola (POEU 2012). Furthermore, limited private sector participation in the sanitation sector was observed as an element of the failure of urban sanitation projects in Ghana (Mansour & Esseku 2017) and Kenya (Mansour *et al.* 2017). An investigative study of South Africa's WSS sector exposed significant and multiple cases of abuse of power, bribery, corruption, mismanagement of funds and contract fraud (Muller 2020). In Dakar, Senegal, an evaluation of the World Bank-funded sewerage project (PAQPUD) revealed failings mainly due to contract management issues, resulting in only five of the projected 11 schemes being operational after all the money had been spent (Norman & Pedley 2011). A culture of an absence of performance contracts or service level agreements in Namibia's water sector promoted unaccountability and poor customer service (Ndokosho *et al.* 2007). Similarly, the lack of legally binding drinking water guidelines made it difficult for the government to enforce drinking water quality guidelines (Ndokosho *et al.* 2007).

Environmental/contextual factors

Four environmental or contextual factors were found to threaten the lasting coverage of WSS systems in Sub-Saharan Africa. For example, large areas of unplanned settlements in Temeke municipality, Dar es Salaam were not connected to communal water and sanitation infrastructure (Rugemalila & Gibbs 2015). However, sanitation projects were most affected by settlement-imposed constraints. A lack of space in the low-income neighborhoods in Accra was a limiting factor in the ownership of a private toilet by the residents (Peprah *et al.* 2015). Similarly, in the Durban Simplified Sewerage pilot study in South Africa, the informal settlement type predominant in the area presented a major challenge in the adoption of the proposed sanitation technology (Ashipala & Armitage 2011). Kampala slums were also reported to present challenges of hygiene and difficulty in the maintenance of sanitation facilities (Buckley & Kallergis 2019). Rapid population increase in Temeke municipality without a corresponding increase in WSS infrastructure threatened the long-term and short-term sustainability of WSS services in the municipality (Rugemalila & Gibbs 2015). Research on the Awash Sub-Basin, a basin that supplies water to the urban areas of Addis Ababa, projected that the water availability in the Awash basin will be severely affected by 2030 due to population growth, water loss and climate change (Birhanu *et al.* 2021). The same study expressed concern over declining groundwater levels resulting from over-abstraction to meet the water demand of Addis Ababa city (Birhanu *et al.* 2021). Figure 3(c) shows the environmental factors identified by the SLR process and the number of studies it appeared on.

Technical factors

Ten technical factors were found to limit the sustainability of WSS systems, as shown in Figure 3(d). Old and dilapidated infrastructure was the most recurrent technical issue in the sustained delivery and lasting coverage of WSS services, as shown in Figure 3(d). Damaged infrastructure has led to water leakages as identified in Central Ethiopia (Birhanu *et al.* 2021), Dar es Salaam (WaterAid 2008; Rugemalila & Gibbs 2015) and Zambia (World Bank 2020). Similarly, aging infrastructure was associated with excessive overhead costs leading to financial losses as seen in the Politsi Water Treatment Scheme in Limpopo province, South Africa (Fakoya & Imuezerua 2021). In sanitation services, burst sewers and non-functional treatment plants were observed in the urban areas of Kenya which created pressure on lasting coverage (Mansour *et al.* 2017). The reasons for prevalence of damaged WSS infrastructure in the urban areas of Sub-Sahara Africa were attributed to inadequate repair and maintenance culture (Ashipala & Armitage 2011; Norman *et al.* 2011; POEU 2012; Mansour *et al.* 2017), social issues such as vandalism (POEU 2012; Rugemalila & Gibbs 2015; Adeyeye *et al.* 2020) and informal settlement (Ashipala & Armitage 2011; Peprah *et al.* 2015; Rugemalila & Gibbs 2015; Buckley & Kallergis 2019). There were repeated cases of intermittent water supply (POEU 2012; Cirolia *et al.* 2021; World Bank 2022). In the city-led high-tech sanitation in Addis Ababa's condominium housing project, interrupted water and electricity supply was reported to severely limit the potential of the project (Cirolia *et al.* 2021). In Zambia, interrupted supply was majorly attributed to financial reasons and electricity outages (World Bank 2022). Similarly, in Nigeria (POEU 2012) and Addis Ababa (Birhanu *et al.* 2021), utilities can only pump water for a limited time due to non-existent or interrupted electricity.

Social factors

Five social factors were identified to contribute to the failings of WSS systems, as shown in Figure 3(e). For instance, in the urban areas of Accra, the cost of improved household sanitation facilities or desludging services was unaffordable for many residents which led to open defecation (Mansour & Esseku 2017). Findings from another study in Accra described the cost of public toilets as the major reason for open defecation (Peprah *et al.* 2015). The PAQPUD sewerage project in Dakar, which targeted the poor, did not achieve its aim because coverage among low-income residents was low (Norman & Pedley 2011). Also, about 70–75% of the residents in some districts could not connect to the sewerage because they cannot afford the fees (Norman & Pedley 2011). Furthermore, some of the toilets observed were found to be dirty with the presence of flies and odor. Unhygienic toilets were prevalent in informal and low-income settlements (Ashipala & Armitage 2011; Günther *et al.* 2012; Peprah *et al.* 2015; Buckley & Kallergis 2019). Improper use of toilets was also observed in Addis Ababa where Kotari residents used the toilets for general disposal of waste products including disposable nappies, menstrual pads and kitchen waste, resulting in blockages of the sanitation system of the households (Cirolia *et al.* 2021). Illegal diversions of water or vandalism of water infrastructure were observed in Limpopo province (Adeyeye *et al.* 2020), Dar es Salaam (Rugemalila & Gibbs 2015) and Angola (POEU 2012). Finally, a lack of trust in the government was seen in South Africa mainly due to the government's history of failed projects (Ashipala & Armitage 2011).

Factor interactions providing a system level picture

The findings described above are summarized in the CLDs shown in Figure 4(a) (water supply) and 4b (sanitation), illustrating the interconnections between the identified factors influencing WSS systems in Africa. The CLD shows that some of the identified elements have common root causes. For example, the lack of financial resources for O&M is the root cause of inadequate O&M, intermittent water supply, dilapidated infrastructure, poor water quality, owing of staff salaries and reliance on aid (Figure 4(a)).

Feedback loops

The key feedback loops identified from the CLDs are isolated, as shown in Figure 5. The water supply systems loop in Figure 5(a) highlights that 'community participation' variable is linked to 'adequate planning' and 'human resource

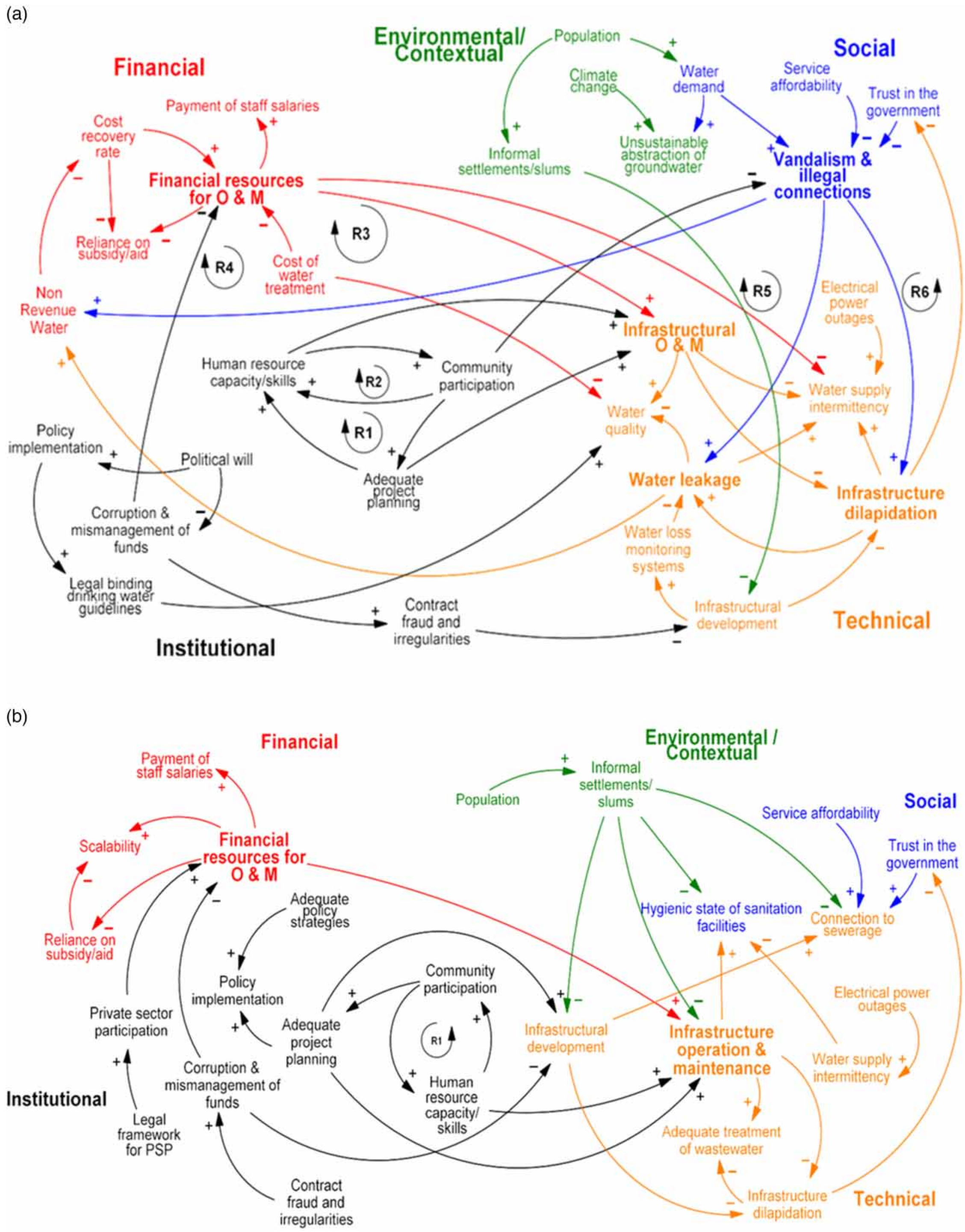


Figure 4 | Causal loop diagram representing the factors affecting (a) urban water supply systems and (b) urban sanitation systems in Sub-Saharan Africa clustered into the five FIETS themes.

capacity/skills' through the R1 reinforcing loop. The R2 reinforcing feedback loop implies that an increase (or decrease) in the 'community participation' would generate an increase (or decrease) in 'human resources capacity/skills'. The R3 reinforcing feedback loop provides information on the interaction between 'cost recovery rate', 'financial resources for O&M',

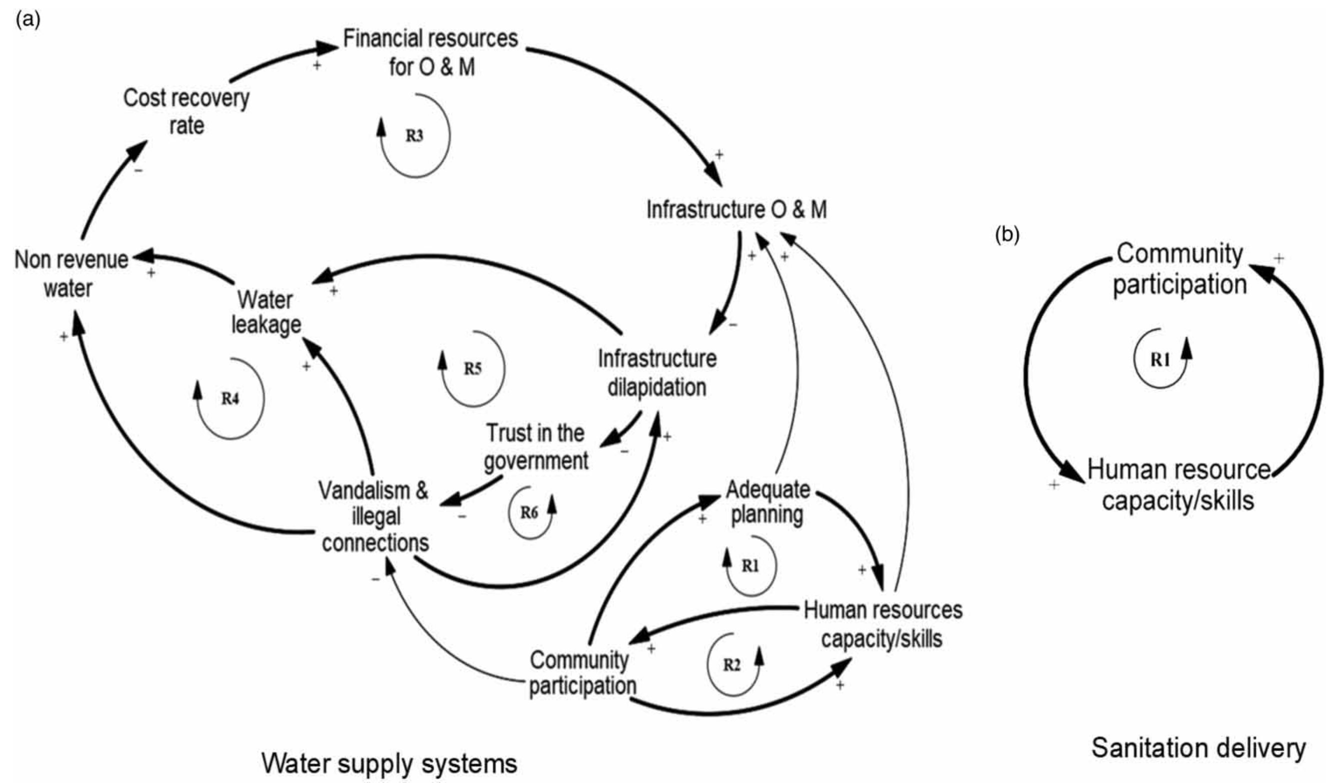


Figure 5 | Feedback loops for (a) water supply systems and (b) sanitation delivery.

'infrastructure O&M', 'dilapidated infrastructure', 'water leakage' and 'non-revenue water'. Furthermore, the R4 and R5 reinforcing feedback loops are similar in that they show how the linkages between cost recovery, financial resources for O&M, infrastructure O&M, dilapidated infrastructure, trust in government, vandalism & illegal connections and NRW (R4), and vandalism & illegal connections, NRW and water leakage cause cycles of deterioration (R5). The R6 reinforcing feedback loop shows the cycle between trust in government, vandalism & illegal connections and dilapidated infrastructure. In Figure 5(b) for sanitation delivery, community participation is linked with human resource capacity/skills through a reinforcing feedback loop R1. There are fewer feedback loops in sanitation delivery because there were fewer studies identified in the review that analyzed urban sanitation failures in the same way as urban water delivery. The feedback loops identified in water are likely to be relevant in sanitation too.

Leverage factors evaluation

Further analysis of the CLD and the feedback loops reveals potential leverage points for enhancing lasting coverage. The leverage factors were evaluated by considering the factors with high influence, low dependency and presence of significant feedback loops. Community participation has strategic significance on the system because it influences multiple factors and is present in two major feedback loops. Similarly, adequate planning, human resource capacity, cost recovery rate and corruption/mismanagement of funds have a tactical influence on other institutional, social, technical, environmental and financial factors that are vital for the sustainability of water and sanitation systems. Finally, the prevalence of informal settlements is influenced by population growth but plays a major role in the WSS system. The identified factors with their system characteristics arranged in the order of influence are shown in Supplementary Table S1 for water supply and in Supplementary Table S2 for sanitation.

DISCUSSION

The sustainable delivery of WSS services is a complex issue and encompasses many factors. Special attention to the strategic leverage factors that can contribute to a more sustainable WSS sector is important. Failing WSS systems put huge pressures on lasting coverage. To achieve sustainability as lasting coverage, the FIETS themes and the interrelationships as highlighted from the pattern of failures from different factors in the CLD are crucial to inform future planning. Most of the crucial elements that contribute to system failings were raised in both the WSS systems; hence, this section combines the two sectors when discussing the factors.

Financial resources are required for WSS systems to deliver effective and efficient lasting coverage as shown in the CLDs. The commercial vicious cycle was highlighted by the reinforcing feedback loops R3, R4 and R5 in the results. Adequate financing in the sector from improving cost recovery rate from taxes and tariffs and reducing NRW will allow sufficient financial resources for O&M and staff salary payments and will reduce reliance on subsidy/aid. Apart from increased budgetary allocation to the sector, closing the financing gaps through a combination of institutional measures will improve sustainability and deliver lasting coverage. This is important because institutional factors were seen to have significant influence on the system and minimum dependence on other factors as shown by the arrows in the CLD. The elimination of corruption and mismanagement of funds and maximizing the use of existing resources will help improve WSS systems and improve coverage in the sector. Strategic corruption control measures are therefore necessary for an overall improvement of financing in the WSS sector. Proven anti-corruption measures include transparency in the dealings in the sector, fair competition for contracts, accountability of stakeholders, strengthened monitoring/oversight and strict punishment for offenders (Jenkins 2017). The huge institutional influence observed is further supported by other studies which acknowledge the controlling influence of institutional factors over the other four FIETS themes affecting the WSS sector (Machado *et al.* 2019; Hamer *et al.* 2020; Daniel *et al.* 2021). The presence of strong institutions and governance provides the legal and regulatory incentives that will motivate stakeholders and create an enabling environment for sustained access to WSS services (Kennedy-Walker *et al.* 2015). Furthermore, limited private sector participation may not be indicative of a failure unless if seen as a solution, which is not always the case. It may be that the identified failures are rather failures of a particular discourse with respect to water and sanitation systems or how we imagine the system should deliver services and hence the problem could be limited private sector participation, or that the role of private sector participation is unclear/unsupported/only relevant to particular aspects of service delivery.

The technical aspects of WSS systems are the most dependent factors as depicted in the CLD. The WSS infrastructure is expected to perform effectively and efficiently in the long-term to meet the targets set on coverage, capacity, operation and maintenance (O&M) plans. To deliver lasting coverage, the technology suitability (Murphy *et al.* 2009), maintenance process (Katukiza *et al.* 2010) and condition of WSS infrastructures (United Republic of Tanzania 2013) must be considered. Routine operation and maintenance of the installed infrastructure must be carried out as expected and within the appropriate maintenance timeline and schedule. This will reduce the rate of infrastructure dilapidation, improve water quality, reduce water intermittency and increase adequate treatment of wastewater. The adequate planning and human resources capacity/skills required to achieve this must be available. Likewise, the required electricity for operating WSS treatment plants needs to be reasonably available and affordable to make the system cost-effective. This will ensure that there is reduced negative impact from incessant electrical power outages which have an influence on the treatment efficiency. Nevertheless, the use of expensive electricity will increase the cost of WSS treatment which can equally lead to reduced or short-lived coverage. For example, the Wupa sewage treatment plant in Abuja Nigeria has been running on diesel generators at reduced efficiency since its inception over 13 years ago, which raises concerns about high operational costs and the probability of the system collapsing at any time (Ujah 2021). Because of the unsustainable electricity model of operation of this facility, it can be considered a failing system. Effective and efficient WSS systems are expected to deliver expected services at acceptable risk with a performance data that relies on a sustainable model of operation. Overall, the heavy dependence of technical factors on other FIETS factors implies that the technical performance of the WSS system will be improved if successful attempts are made at improving the influencing factors.

Government actions in the form of policies for social and environmental or contextual factors are also needed for lasting coverage. Vandalism and illegal connections had strong links to water demand, trust in government and service affordability in the CLD. This is in addition to community participation, NRW and infrastructure dilapidation. Policy and implementation must be determined to avoid failings in WSS systems. For instance, unclear or rigid policy strategies for improving sanitation services, especially in urban areas, can lead to policy implementation failure even though it recognizes the importance of safely managed sanitation services (Mansour & Esseku 2017). Informal settlements/slums have an influence in WSS systems as shown in the CLD. The limitation of informal settlements is a critical environmental barrier to WSS sustainability in urban

Sub-Saharan Africa. Constraints imposed by informal settlements have proven to be a major barrier to policy development and implementation and infrastructural development (Sinharoy *et al.* 2019; Daniel *et al.* 2021). More than half of Sub-Saharan Africa's urban population resides in informal settlements and/or slums and the number continues to increase (Shulla & Kőszeghy 2021). These settlements are characterized by high population density, limited space for infrastructural development, limited finances and vandalism of infrastructures (Peprah *et al.* 2015). This means that the conditions in informal settlements make it more difficult to ensure the long-term sustainability of WSS systems. Urban informal settlements are often classified as illegal and are therefore not incorporated into national policies (Matamanda *et al.* 2020). An urgent policy re-strategising around WSS in informal urban settlements is required to improve this critical environmental barrier and improve sustainability through lasting coverage.

The failure of the sanitation system can be due to a failure elsewhere and this highlights that some of what needs to change to improve water and sanitation delivery may need to be done outside the sector, particularly around cultures of corruption. Financing and integrity remain a huge problem in the water sector with corruption being a barrier to progress. Notably, sanitation used to be seen as a public service necessary for public health, and the State was expected to heavily contribute to it (Nilsson 2006). The expectation that it is now to be paid for through 'cost recovery' could be another example of how failings may have been exacerbated (Nilsson 2006) and highlights the need for innovative and forward-thinking measures in our current discourse on sanitation delivery.

LIMITATIONS

The inclusion and exclusion criteria limited the number of the final review set. We found that there are few relevant papers on failures and failings in the urban WSS systems in Sub-Saharan Africa which indicates a research gap. The definitions of what can be described as failure also depend on what is seen as success, and from whose perspective. In some cases, a failure can only be described as such if there is a clear definition of what is deemed to be successful. The lack of sufficient articles indicates a huge gap in the sector and perhaps this is due to the lack of clear sector-wide definitions.

The papers we selected for this review were limited to those published in English language. Hence, we may have missed important experiences of francophone Sub-Saharan African countries considering that French is the official or second official language of 21 of these Sub-Saharan African countries.

The relationships between factors including the CLDs were evaluated based on the interactions we identified in the different articles included in the review. Some of these interactions may have been possibly missed out in the CLD. In interpreting the CLDs, feedback loops and leverage analysis, careful thought should be given to how the relationships hold true across all types of urban WSS systems.

In our analysis of the factors, the relationships and interactions depicting Sub-Saharan Africa did not consider geographic/country differences. In using these results, careful context-specific interpretation will be required.

We performed a test run of the search with a few specific country names and found nearly all hits had a mention of Africa, Sub-Saharan Africa or an Africa region somewhere in the article. By not running all 48 Sub-Saharan African countries separately, we may have left out some otherwise eligible studies.

CONCLUSIONS

The factors hindering sustainability as lasting coverage in the WSS sector in urban areas of Sub-Saharan Africa were discussed through the scope of the FIETS framework and depicted in a CLD to visualize the WSS system structure. From a systems viewpoint, this study gave a detailed look into failings in Sub-Saharan Africa's urban WSS sector, identifying the key elements causing poor performance in effectiveness and efficiency. The causes of these failings are complex, interlinking FIETS constraints. However, most interventions in the sector erroneously continue to adopt a linear view rather than a whole systems thinking in their approach to the design of WSS delivery. Therefore, to remove these barriers to sustainability as lasting coverage, this review recommends a coordinated effort involving both top-down and bottom-up approaches including the use of legal instruments of the state to implement regulations and policies that will drive reforms and mobilize the resources needed to ensure the sustainable delivery of services. Therefore, a clear and uniform long-term plan of action should be enacted to address infrastructural development in the sector, operation and maintenance and longer-term financing of

WSS services in urban Sub-Saharan Africa. Finally, the WSS sector is dynamic. As situations continue to change, the drivers of sustainability in the WSS system are expected to change over time, which may impact the prospects of the plans already in progress. This paper, therefore, recommends continual updates and greater use of system dynamics to enable more holistic thinking about the long-term potential of WSS system strategies.

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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.

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