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Research Paper

Scenario-based life-cycle cost assessment to support sustainable investment in rural communal sanitation facilities: application to a school-based sanitation facility

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ABSTRACT

Despite decades of investment in widening access to improved sanitation, much of the world still lacks access to functional sanitation facilities. Through much of the Global South, toilets are inoperable and often abandoned. Failure to understand and account for the whole-life cost of sanitation infrastructure, as well as the interplay between context-specific socio-economic determinants, is one explanation for this reduction in the service life of shared sanitation infrastructure. This issue is especially salient in school-based and communal facilities in middle- to low-income countries. Drawing on a case study of a sanitation facility in a government school in rural south India, we explore the relationship between user value, community-based capacity, and external support in determining the costs of operating and maintaining sanitation facilities over their lifetime. We develop a scenario-based life-cycle cost assessment methodology to examine the relational impact of these determinants on the 'real' cost of shared sanitation infrastructure. The analysis concludes that investment and interventions that stimulate demand and enhance the capacity of a community are the most cost-effective options for ensuring the sustainability of sanitation facilities in our case study site. We then reflect on the applicability and limitations of these findings for a wider range of communal sanitation facilities.

Key words: decentralised WASH, functionality, governance, India, rural sanitation, socio-economic determinants

HIGHLIGHTS

- Communal sanitation infrastructure's long-term functionality depends on its value to the community, the capacity of the community to contribute, and the availability of external support.
- We develop a framework to explore the effects of these determinants on the life-cycle cost of communal sanitation infrastructure.
- Results suggest that investment in capacity building and demand stimulation reduce the life-cycle cost.

INTRODUCTION

Despite significant efforts and investment towards wider provision of water, sanitation and hygiene (WASH) services in the last 50 years, in 2020 the WHO reported that the world remained 'alarmingly off track' for meeting targets of universal access to improved sanitation (UNICEF & WHO 2020). The Joint Monitoring Programme of WHO/UNICEF estimates that over half of the world's population do not have access to sanitation facilities that safely treat wastewater (UNICEF & WHO 2020). This shortfall in both sanitation access and wastewater treatment undermines the public health goals of WASH interventions. Explanations for the poor performance of sanitation assert that sanitation has been a low priority for both donors and national policy-makers, resulting in low levels of investment and poor capacity in the sector. At the country level, evidence of these shortcomings is most evident in examples of toilet abandonment and reversion to open defecation (Hueso & Bell 2013; Improve International 2014; Orgill-Meyer *et al.* 2019), what Kwiringira *et al.* (2014) describe as 'descending the sanitation ladder'.

A broad review of the literature on sanitation adoption suggests a lack of emphasis on and evidence about 'post-project' sustainability of sanitation interventions, and a failure to consider the different variables that influence sustained adoption as opposed to initial adoption (Martin *et al.* 2018). Evidentially, there are very few examples of long-term monitoring and

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evaluation of the sustainability of sanitation interventions, followed up with reflection on the factors that influenced these outcomes. One notable exception to this is research in the state of Odisha in India, which revealed that despite a sustained sanitation behaviour change campaign and the availability of public funds for toilet construction, a huge number of toilets built under the Community-Led Total Sanitation Campaign were abandoned within a decade. The analysis of data from Odisha suggested that a lack of durable maintenance arrangements and a failure to stimulate and sustain demand resulted in only short-term reductions in open defecation (Orgill-Meyer *et al.* 2019). Similarly, research in Uganda highlighted capacity and resources challenges for the maintenance and upkeep of communal sanitation facilities, leading to toilet misuse, abandonment, and the continuation of open defecation (Kwiringira *et al.* 2014).

A key component of any maintenance arrangement is an accurate assessment of the maintenance costs. Current budgeting paradigms for communal sanitation interventions account for construction costs but allocate negligible resources and funds for the costs arising from operation and maintenance. Interventions are designed with the consideration of costs during the active project years alone, with the implicit assumption that communities will manage the rest by contributing some combination of labour and capital (Burr & Fonseca 2011). However, lack of surplus capital, technical skills, and/or capacity, along with more complicated social dynamics (such as caste inequalities or social norms around sanitation), present a challenge to the long-term functionality of sanitation infrastructure. These challenges are often amplified by a lack of sustained community participation before and during such projects (Ananga 2015; Alexander *et al.* 2016a).

The sanitation financing literature has adopted different methods for the socio-economic analysis of WASH projects. The focus of these analyses has not been on removing the barriers to achieve long-term impact (Roma & Jeffrey 2011) but on estimating the immediate outcomes either in terms of cost-effectiveness and cost-efficiency of providing access (Briceño & Chase 2016; Reese *et al.* 2017) or creating additional income streams from improved or innovative sanitation solutions, also referred to as the sanitation value chain approach (van Welie *et al.* 2019; Furlong *et al.* 2020). Although cost-effectiveness is undoubtedly important for securing near-term sustainability, this focus fails to address some of the aforementioned issues of longer-term functionality (Kwiringira *et al.* 2014; Orgill-Meyer *et al.* 2019).

To better address issues of long-term sustainability, we highlight the utility of life-cycle cost assessment (LCCA) methodology, a method borrowed from business accounting and adapted to the budgeting of WASH infrastructure (Moriarty *et al.* 2011; Snehalatha *et al.* 2015). Such an approach enables a comparison of potential future costs beyond the costs acquired before and during the construction phase to support an estimate and plan for meeting the full costs of owning and operating a fully operational WASH infrastructure. For example, Burr & Fonseca (2011) set the framework for separate budgeting of capital expenditure and recurrent costs associated with sanitation infrastructure when reporting the total cost estimation of the sanitation infrastructure in Ghana, Mozambique, India and Burkina Faso and demonstrated how costs and service delivery vary across the projects. In later studies, Reddy & Batchelor (2012) applied the LCCA to the WASH projects in households in several rural settlements in the Andhra Pradesh region of India and found that infrastructure investments were prioritised in the budgeting and the annual operation and repair costs vary significantly across communities. Alexander *et al.* (2016a) applied the LCCA to sanitation projects in Kenya and found that the annual expenditure required for the recurrent costs of operation and maintenance could be afforded within the limits of the Government of Kenya allocation to school and these infrastructures can be kept functional if the available resources were allocated accordingly.

Although the need for life-cycle thinking in WASH budgeting has already been identified (Burr & Fonseca 2011), existing applications primarily concentrate on financial capital and its interchangeable derivates (labour, materials, and energy) without accounting for the effect of human capital along the full life cycle of sanitation projects (OECD 2007; Jones & Silva 2009). The 'real' lifetime costs of any communal sanitation infrastructure will be influenced by a complex interplay of social and economic variables which will vary significantly across contexts. Thus, there is a need to develop tools to enable a consideration of these variables as part of the 'whole life cost of sanitation infrastructure', but also to help target investments and interventions around demand stimulation and capacity-building efforts, and to ensure that community-based management arrangements are cognizant of local context. One way to accommodate these socio-economic factors is by developing a range of scenarios against which LCCA estimates can be formulated.

In this paper, we develop and apply a new methodology to assess the relational significance of socio-economic determinants for the long-term functionality of a school-based sanitation facility and construct possible scenarios to demonstrate how this methodology can determine the 'real' costs of delivering sanitation services. While we recognise that a school-based sanitation facility is not a perfect corollary for communal sanitation, we emphasise the wider applicability to communal

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sanitation (Heijnen *et al*. 2015)[1] for the following important reasons. First, the WHO does not consider shared sanitation to be 'improved' sanitation, primarily because of the poor maintenance which plagues so many shared facilities. Yet, scholars and practitioners have argued that well-managed shared sanitation can offer significant improvements to existing WASH conditions (Mara 2016). Similarly, research exploring the impacts of WASH interventions in schools has highlighted the importance of quality over quantity in terms of achieving positive educational and public health outcomes (Dreibelbis *et al*. 2013). What all this research suggests is that high quality, well-managed, and maintained shared facilities are important components of a wider improved WASH landscape. This further underscores the importance of a focus on sustainable management arrangements for shared facilities, particularly in contexts where funding is limited and facilities are under some form of public ownership. By focusing on the sanitation facilities in a village government school, we consider these facilities, like other shared sanitation infrastructures, as a common-pool resource for communities where governance and management arrangements are crucially important. The terms governance and management refer to the long-term decision-making processes and the execution of these decisions in daily operations and ongoing maintenance. We expect the methodology developed here, and the findings from this paper will be of use to a wide audience of WASH researchers, policy-makers and practitioners.

SOCIO-ECONOMIC DETERMINANTS OF LONG-TERM FUNCTIONALITY

While there has been significant focus on new technologies and innovative funding models in WASH infrastructure construction, the role of governance processes and collective action (Shiras *et al*. 2018), long-term management arrangements (Kwiringira 2017), socio-cultural preferences (Nelson *et al*. 2014; Routray *et al*. 2015; Caruso *et al*. 2019), and power relations (Chipungu *et al*. 2019) in keeping sanitation infrastructure functional in the post-construction phase has received relatively less attention by donors, governments, and development agencies (Whaley & Cleaver 2017). However, understanding the determinants of community demand as a key factor influencing the long-term functionality of sanitation infrastructure is essential to achieve the intended benefits of sanitation investment.

Sustainable community-based management of sanitation infrastructure requires a type of community engagement that comes with three distinct yet synergetic components. The first one is the value placed by the individuals and the community on the proposed sanitation infrastructure (Seymour & Hughes 2014; Alexander *et al*. 2016b). The second is the technical and social capacity of the community to maintain and manage a fully functional sanitation system until the end of its intended life cycle (Bouabid & Louis 2015; Whaley & Cleaver 2017). And the third is the availability of external support, including but not limited to financial resources (Foster 2013; Calzada *et al*. 2017; Etongo *et al*. 2018; Hutchings 2018).

The literature stresses the importance of user satisfaction with the sanitation service in the post-construction period of the infrastructure (Seymour & Hughes 2014; Walters & Javernick-Will 2015), in particular to quality, quantity, accessibility, and reliability of the services, features used to measure the service capacity of a sanitation infrastructure (Moriarty *et al*. 2013; Bouabid & Louis 2015; Carter & Ross 2016). The valuation of the community members affects their willingness to contribute disposable income and labour towards maintenance (Alexander *et al*. 2016a). For new sanitation facilities to be valued, owned and voluntarily managed by the community, the facilities must provide services that are perceived as significantly superior to the existing options (Alexander *et al*. 2016a; Whaley & Cleaver 2017). The values attached to the sanitation infrastructure fluctuate depending on its condition. Once quality, quantity, or accessibility of the service starts to deteriorate, the value placed by the community on the infrastructure also goes down.

While the valuation of the sanitation infrastructure by the community is important, socio-economic limitations might dissuade the community from maintaining and adding to this value (Dickin *et al*. 2017). There are two central questions for consideration to retain the initial value placed on the infrastructure: (1) who has the time to keep it functional in the long run and (2) will those with disposable time have the skills to undertake various skilled and unskilled tasks (e.g. cleaning, managing daily operations, performing replacement and repair activities, bookkeeping, collecting money, ordering materials, attending minor repairs, and managing relations with external parties such as local administration) to keep sanitation the infrastructure sustainable in the long run (Dickin *et al*. 2017; Whaley & Cleaver 2017).

A community must have or acquire a certain degree of capacity to successfully maintain and operate sanitation infrastructure. This capacity depends on various social and economic capitals such as administrative and technical skills, as well as ability to pay and contribute in non-monetary means, i.e. labour and time (Bouabid & Louis 2015). A wide systematic

[1] Communal sanitation infrastructure is shared by more than 5 households or 30 individuals (Heijnen *et al*. 2015).

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review of 174 rural water supply facilities in low-income countries concludes that capacity building on technical and management skills has the strongest influence in achieving functional community-operated infrastructures both at the short (0–5 years) and longer (>5 years) term (Hutchings *et al.* 2015).

The third determinant is external support (Foster 2013; Calzada *et al.* 2017; Etongo *et al.* 2018; Hutchings 2018), which is critical in the post-construction phase for sustaining community-led management. External support for community projects comes in different forms and at different levels such as technical and administrative assistance, financial support and provision of materials for undertaking significant repairs and replacements, access to supply chain and spare parts, loans and microfinance (Hutchings *et al.* 2015). Local and central government bodies, NGOs, and other organisations such as foreign aid organisations and local and international research institutions are the external actors that provide these monetary and non-monetary means of support. Rural sanitation infrastructures governed by hybrid arrangements that combine existing bottom-up structures in the community and external support are found to remain functional for longer periods (Hutchings *et al.* 2015).

We note that post-construction measures of help from local government and development officers, the representatives of the state in rural communities, may take various forms in India. The national sanitation programme (Swacch Bharat Abhiyaan) encourages local authorities (panchayat) to provide additional funding for maintenance and operational costs, i.e. topping up school budget for sanitation purposes, paying for janitorial staff to regularly clean the facilities, and subsidising supply of electricity. Alternatively, they also use their authority and influence to support operations, i.e. provide support in obtaining necessary building permits. Regional and local government can also provide support by investing in relevant training programmes to build technical capacity for maintaining sanitation infrastructure within the communities. At the national level, ongoing investments that promote sanitation and hygiene as a public value are important in shoring up local and regional forms of support.

Local and international NGOs and donor agencies can also deliver post-construction support by underpinning sanitation or hygiene behaviour change. For example, a significant amount of funds are being transferred by international organisations, such as the World Health Organization, UNICEF, and World Bank, each year to smaller NGOs to run local campaigns for incorporating sanitation into school curriculums (Ambesh & Ambesh 2016). Yet despite their important role in shoring up WASH investments, third sector organisations may not always be aligned with domestic policy targets or community priorities. NGOs may also be operating under 'project mode' which does not consider the problems related to funding the long-term functionality. Thus, relying on a multi-scale portfolio of institutions from both state and third sector provides a more robust structure of external support over the long term (O'Reilly & Louis 2014).

CASE STUDY OF SCHOOL-BASED SANITATION

The data and analysis presented here were collected throughout the design, construction, and post-construction phase of a decentralised wastewater treatment (DWWT) and sanitation facility in the Berambadi village school located in a part of the Chamarajanagar district that is 5 h away from any major city in the State of Karnataka, India (Figure 1) (Subramanian *et al.* 2020). This project was funded by the Hydronation International Initiative of the Scottish Government as part of a wider effort to support research and innovation that contributes to progress towards SDG6. Notably, this decentralised facility is designed to address the water and energy resource constraints that often undermine the service capacity of sanitation infrastructures by incorporating renewable energy sources and water reuse technologies. In addition to the wastewater treatment objectives, the project aimed to improve access to good quality sanitation facilities for school attendees by co-designing new toilet and handwash facilities. Crucially, the project endeavoured to ensure this quality as well as the effective treatment of wastewater could be sustained beyond the project period. The life expectancy of the infrastructure in Berambadi is limited to 25 years post-construction in the estimations of the design team.

While several locations in the south Indian state of Karnataka were considered as potential pilot sites, the Berambadi village school was chosen for the population density of the local community, the number of students attending the school (180 students between ages 5 and 14) and the willingness of school staff and management committee to engage with the project (Ellis *et al.* 2020). The school is typical of the 40% of the schools in India that have non-functioning or absent sanitation facilities (Comptroller and Auditor General of India 2018; UNICEF & WHO 2020). Existing toilets had become inoperable due to poor maintenance, failed septic tanks, and unreliable supply of fresh water. Baseline data collection revealed that as a result

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Figure 1 | Location of Berambadi Village, Karnataka, India taken from Google Maps in April 2021.

of discontinuous water supply and lack of privacy, female students, in particular, refrained from using the toilets, and many students preferred open defecation to using the school toilet (see Supplementary Material, Appendix 1).

Because of the innovative design of the system at the Berambadi school, special consideration was given to the potential challenges of maintaining this system and to the arrangements that would govern and manage the system. Early data collection highlighted a lack of technical skills and capacity in the community to manage and maintain both the more complex wastewater treatment components of the system, as well as to ensure routine maintenance of the toilet and handwash facilities (see Supplementary Material, Appendix 1). Also, there was not an obvious link between the primary beneficiaries, i.e. school children and indirectly their parents, and those who potentially have time to contribute, i.e. unemployed young people. In response, the project undertook capacity-building activities, in particular, the development of a 2-month technical training and wastewater management programme which actively incentivised participation from young men (3) and women (2) by providing them additional practical benefits such as a stipend and basic technical and soft skills training. Despite these direct interventions in capacity building, it became clear that ensuring the long-term functionality of the sanitation facilities and wastewater treatment system required a more careful consideration of the factors that shape and sustain capacity, not least, the value placed on the system and the wider supporting environment. The research questions and methodologies presented here emerged out of these more sustained discussions and activities surrounding the maintenance and management of the system. All work was completed with the approval of the James Hutton Institute's Research Ethics committee.

METHODS

In this paper, we develop a scenario-based LCCA methodology. To do so we conduct a review and analysis of existing evidence about the determinants of long-term sanitation functionality. We then explore the relationship between these determinants through empirically grounded qualitative data derived from our case study location. We utilise these to construct a range of scenarios that combine determinants in a way that might plausibly impact the lifetime costs and thereby functionality of school-based sanitation facilities. Against these scenarios, we conduct the LCCA. The intention of this paper is not to report on the functionality or outcomes of sanitation interventions in the case study locations, but rather to demonstrate how LCCA methodologies can be utilised to determine the likely cost of a facility in a given location. As such, we include the primary data derived from the case study location in an accompanying appendix (Supplementary Material, Appendix 1).

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Life-cycle cost assessment

We utilise LCCA to identify the impact of a range of determinants on the 'lifetime' cost of communal sanitation infrastructure. In the LCCA methodology, there are two major categories of costs: capital expenditure and recurrent expenditure. Capital expenditure is related to the pre-construction and construction stages. These are mostly one-off cost items such as excavation, lining, slabs, superstructures and pipes. On the other hand, recurrent costs are incurred as a result of ongoing operations and maintenance. These cost items are responsive repairs rising from unexpected breakdowns, damages resulting from vandalism and misuse: any scheduled repair and daily operation costs such as electricity consumption and cleaning (Fonseca *et al.* 2010). In cases where the projects are funded with loans, the costs of capital as well as the costs associated with any monitoring activities by an external funder should also be considered as a part of the operational costs (Fonseca *et al.* 2010).

Applying LCCA to the budgeting of sanitation interventions projects enables a comprehensive and replicable estimation of costs that can be expected to accrue over the life cycle of a facility or infrastructure. But LCCA alone does not account for the interaction of dynamic socio-economic processes, which have the potential to significantly influence these costs and which change over time. One way to accommodate these is to develop a range of scenarios against which LCCA estimates can be formulated and the full cost of sanitation alternatives can be compared.

To address this need, the LCCA framework here is informed by three critical determinants of long-term functionality and use discussed above, i.e. value placed on the sanitation infrastructure, capacity of the community, and the availability of external support. Although previous applications of LCCA for sanitation have demonstrated the variance in life-cycle cost figures of similar WASH infrastructure in different communities (Burr & Fonseca 2011; Reddy & Batchelor 2012), there have been few if any attempts to anticipate and account for the socio-economic processes that underpin this variance. In our methodology, we complement the application of LCCA to sanitation projects by developing metrics that qualitatively assess the key factors for the long-term functionality of communal sanitation infrastructure. We demonstrate how these aspects can affect the life-cycle cost of the infrastructure and accurately project the scale of the economic burden on the community or a potential funder.

Analysis of determinants

We conducted a review and content analysis of evidence about the functionality of small-scale sanitation facilities in rural India. Out of this analysis, we identified a core set of determinants for their long-term functionality. A matrix of factors that contribute to each determinant was developed to systematically assess their relative strength within a community. We qualitatively ranked these factors as essential, intermediate, or advanced factors. The achievement of essential factors is assumed to be necessary for the consideration of intermediate factors, and the achievement of intermediate factors is assumed to be necessary for the consideration of the advanced ones. The factors (Table 1) are compiled from the qualitative comparative analysis of Davis *et al.* (2019) based on 20 small-scale sanitation systems in the Indian states of Karnataka and Tamil Nadu, and the systematic reviews of case studies in rural India by O'Reilly and Louis (2014) and Hutchings *et al.* (2015).

We construct scenarios combining different levels of achievement in each determinant, i.e. value placed on the sanitation infrastructure (valuation), capacity of community, and availability of external support. Scenarios 1–8 combine different levels of each determinant as indicated in Figure 2.

Understanding determinants

To better understand how the previously identified determinants of long-term sanitation functionality interact empirically, we draw on data collected through a series of semi-structured qualitative interviews, focus groups, and participant observations. It is important to note that qualitative data collection activities spanned 2 years and were often designed to collect data in support of the multiple research objectives of the wider collaboration that delivered the sanitation infrastructure at the Berambadi school. As such, data about sanitation preferences and practices, willingness to contribute financially or in-kind to maintenance, as well as wider issues of social capital and relationships were collected in the pre- and post-construction phases of the school sanitation facility. Further evidence can be found in Supplementary Material, Appendix 1.

Multiple focus group discussions with all major stakeholders were conducted at different stages of the project period. Three separate focus group discussions were conducted with school attending boys (participants from grades 6, 7, and 8), school attending girls (18 participants from grades 6, 7, and 8), and teachers (2 female and 2 male teachers). These group discussions were conducted to understand the stakeholders' views on school and village sanitation before and after the project, their requirements from the school sanitation system, and the barriers to sustained maintenance and operations of the sanitation

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Table 1 | Matrix of factors affecting different determinants of long-term success in sustaining sanitation infrastructures

	Valuation	Capacity	External support
Advanced factors	Quality of the materials and aesthetics of the design	Soft skills, leadership and transparency in governance	Political and policy priorities of the national government
Intermediate factors	Accessibility	Disposable time and willingness Intermediate technical skills	Access to the support of NGOs and foreign aid organisations
	Cleanliness		Availability of in-kind (e.g. staff time) contributions from the local administration
Essential factors	Privacy	Basic technical skills	Availability of monetary contributions from the local administration (i.e. panchayat)
	Functionality	Disposable funds in the community	Geographical and social isolation of the community

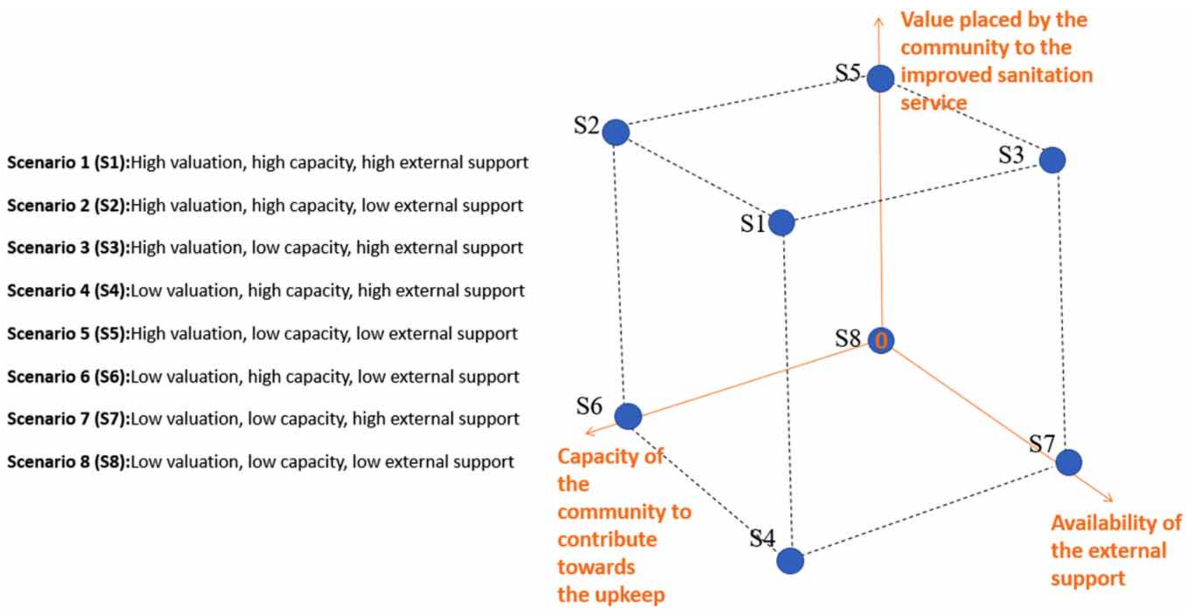

Figure 2 | Representation of possible scenarios.

system. Toilet usage data were also collected through a self-reporting survey. The combination of focus group and toilet use data allowed us to better understand the factors shaping the value placed on sanitation infrastructure. During the project period, we also conducted transect walks, passive observations, unstructured, and semi-structured interviews to better understand the sanitary conditions at the village level in general and at the school level. We observed and recorded levels of maintenance, vandalism, and toilet abandonment.

Three focus groups were conducted with purposive samples of elderly residents, young adults (16–25), and school parents with the aim of discussing and identifying opportunities for capacity and skills development. We also conducted several informal semi-structured interviews with school staff and members of the school management committee to help better understand issues of access to material inputs and resourcing for maintenance requirements. Finally, we organised a school meeting and several stakeholder meetings with local authorities to discuss potential avenues for securing funding for ongoing maintenance of sanitation. The year after inauguration of the facility in 2018, the satisfaction and the use of the school children, schoolteachers and staff were explored in three focus groups that took place in 2019. Further details of the stakeholder engagements can be found in Supplementary Material, Appendix 1.

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Data and assumptions in the scenarios

A list of major replacements, minor repairs, and operational tasks and their expected frequencies are compiled using the maintenance tasks and materials document prepared for the School Management Committee for guidance and in consultation with the researchers that designed each module in the project and the chief engineer who developed this document. Material costs for each task involving replacements and costs related to different skilled labourers (e.g. plumber and electrician) are taken from the itemised list of material costs collected at construction. For other small operational items (e.g. bulbs, door handles, and chemicals) whose cost information was not documented, estimates were drawn using prices from online outlets such as IndiaMART that delivers to the location and the insights of the designing researchers. Similarly, frequency and quantity of use and unit prices (e.g. piece, bottle, and package) of the consumables required for repairs and daily maintenance were estimated in consultation with the researchers and checked online in online outlets.

According to the observations of the current employee at the school, the regular unskilled tasks related to operations and minor repairs take around 1.5 h per day, adding up to a total of 6–7 h per week. These activities do not require expert supervision or further instructions if a manual with adequate descriptions and schedules is provided to the employee. To arrange for the numerous transactions and to pay hourly wages are complicated, as there is no organisation, group, or individual that could allocate and oversee the minor tasks every day. We assumed that the current position continues, and an unskilled local employee is employed. The monthly expense for unskilled labour for the position is set at £44 (Rs 4,000), the exact wage of the person employed during the research project.

In all the scenarios, applicable costs are broken into its three different components: materials, labour, and energy. As the energy for running the decentralised water treatment and toilet facility at the Berambadi school is obtained from PV solar panels, the energy cost is zero in all the scenarios. According to the expert opinion of the chief engineer, to build the same infrastructure would be 30% cheaper in a less isolated location where material and labour provision would cost less. Except for the materials that could directly be sourced at the village such as chlorine in the form of household bleach, acquiring materials, in general, is assumed to be more expensive than it would be in a central location. Therefore, the cost of materials is assumed at least medium in all scenarios. The specific assumptions in material and labour cost made in relation to the varying degrees of achievement in three key determinants are listed below:

- We assumed a link between the need for repairs and the valuation. When the valuation of the infrastructure is low, repairs due to vandalism and misuse are expected. Therefore, costs of repair materials are predicted to go up due to their increased frequency in scenarios in which infrastructure is poorly valued by the local community, i.e. S4, S6, S7, S8.
- We assumed the materials used in operations such as cleaning products will need to be sourced equally under any scenario, and these materials could be sourced locally in the village.
- High achievement in valuation by the local community and high human capital are assumed as conditions for sustaining the low-cost provision of labour. If the infrastructure is partly or fully looked after by the former and the current interns of the Youth Training Programme (YTP), then the labour costs will be reduced accordingly.
- If the community valued the system but did not have the necessary skills (e.g. electrical wiring, and plumbing), then the skilled labour needs to be imported from the town. Due to the isolated location of the village, importing the skilled labour would cost approximately 30% higher than sourcing it within the village. Making the skilled labour cost is ranked as medium in scenarios with low capacity.
- The high-capacity scenarios assume that the community retains the technical capacity built by the YTP. In these scenarios, technical tasks are carried out by the former or current interns of the YTP and they are paid per task. This outcome removes the premium logistic cost of acquiring skilled labour and reduces the total cost of skilled labour by 30%.
- A common form of external support is monetary aid, especially in isolated locations (Miller *et al*. 2019). On a case-by-case basis, local governments or other organisations might meet a part of maintenance and operational costs (Reddy & Batchelor 2012). In scenarios where the external support is high, we assumed that the external sources contribute towards the fixed expenses. Unskilled employee's monthly wage as a fixed cost is assumed a reasonable expense to be subsidised externally without many arrangements and intermediaries.

RESULTS AND DISCUSSION

This section focuses on the results that underpin the life-cycle cost of the sanitation infrastructure at DWWT project in Berambadi primary school. We found the average monthly cost to keep the existing infrastructure functional ranges between £52

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and £128/year, corresponding to £624 and £1536/year, considering inflation over 25 years (Ellis *et al.* 2020). We also found that investing in capacity through training and programmes is likely to reduce the cost by 45% when controlling for value between S1 and S3. Similarly, investing in valuation through continuous maintenance and funding would reduce the costs by over 35% when controlling only for capacity between S1 and S4 (Ellis *et al.* 2020). Table 2 compares the different cost outcomes of the scenarios in a heat map colour-coded in a way that the greens indicate low average annual cost, while the reds indicate high average annual cost and shades of orange indicate medium cost level.

Our qualitative data suggest that the most likely scenarios for the case study site in Berambadi will be either S2 (HV-HC-LES), S3 (HV-LC-HES), or S5 (HV-LC-LES). We also consider S1 (HV-HC-HES) as a potential, but less likely scenario, which we discuss in further detail below. Data collected in the post-construction phase reveal that an important component of value for the primary beneficiaries was the high quality of the material used and the appropriateness of design. A certain element of pride and ownership has been established by having a toilet that is comfortable and that caters to more than meeting basic needs such as privacy and functionality. These analyses also indicate that the toilet use by the children has increased after the instalment of the new facilities in the village school and all parents expressed satisfaction about the infrastructure design that was in line with the social and the cultural norms of the community as well as offering improved access (see Supplementary Material, Appendix 1). The valuation of the community members affects their willingness to contribute disposable income and labour towards their maintenance (Alexander *et al.* 2016b).

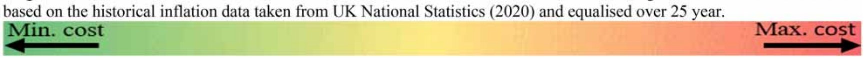
While no willingness or ability-to-pay information prior to the construction is available, high valuation might not necessarily translate into monetary or in-kind contribution in terms of labour or other resources towards the upkeep of the infrastructure in Berambadi due to multiple reasons. First, collecting monetary contributions from the parents is complicated not only because it can introduce discrimination among children as their families are observed to have varying abilities to pay but also the collection of money at school via existing organisations, such as School Development and Management

Table 2 | Cost of each scenario in the Berambadi village school case study

Scenarios[1]	Repairs' material cost	Operational material cost	Skilled staff	Unskilled staff	Total costs of use and repairs*
Scenario1 (S1) (HV-HC-HES)					
Scenario2 (S2) (HV-HC-LES)					
Scenario3 (S3) (HV-LC-HES)					
Scenario4 (S4) (LV-HC-HES)					
Scenario5 (S5) (HV-LC-LES)					
Scenario6 (S6) (LV-HC-LES)					
Scenario7 (S7) (LV-LC-HES)					
Scenario8 (S8) (LV-LC-LES)					

[1]S1: High valuation-high capacity-high external support; S2: High valuation-high capacity-low external support; S3: High valuation-low capacity-high external support; S4: Low valuation-high capacity-high external support; S5: High valuation-low capacity-low external support; S6: Low valuation-high capacity-low external support; S7: Low valuation-low capacity-high external support; S8: Low valuation-low capacity-low external support.

*Figures are first converted at 0.011 rate from Rs to £. The total cost in £ is fixed with an average annual inflation rate of 0.02 based on the historical inflation data taken from UK National Statistics (2020) and equalised over 25 year.



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Committee (SDMC), is not allowed. Therefore, the initial idea of collecting monetary contribution, even of a symbolic amount, was abandoned. Second, ability for in-kind contribution in terms of labour is also limited, as parents are engaged in domestic and farm chores throughout the day. Therefore, the villagers' limited ability to contribute time and money, the basic and intermediate level factors in achieving capacity, is not readily available.

Leadership roles, for example, head teacher, are critical in leading and organising the parents and wider community and to communicate with the local officials and organisations to ensure their external support is critical in the current setting. The teacher positions in the school are time-bound and transferable every few years. Therefore, the teachers may not have any personal incentive to go beyond their remit and take on additional responsibilities. Even when some of them might support the maintenance of the infrastructure voluntarily, there is no guarantee that all will be equally capable, benevolent, and generous with their time taking on an extra task. In an ideal scenario, there would be a more durable structure of leadership that does not rely on the motivation of the individuals and builds on the current set-up of the village workforce and distributes and prescribes responsibilities. Currently, such a mechanism does not exist.

Technical and social skills are the critical factors for assessing the available capacity in the community. Focus group data indicated that prior to the project the village had few if any people with basic technical skills required to manage a sanitation system, such as diagnosing the source of more complicated problems, nor the necessary networks and contact with authorities and other external organisations that may be able to undertake more complex repairs. Focus group participants expressed a desire to develop capacity in these areas (see Supplementary Material, Appendix 1). In response to this, project researchers designed and conducted follow-up workshops to inform the development and implementation of the Youth Training Programme (YTP) to create a critical mass of young people with basic technical and soft skills, as well as fostering new links with local institutions that may marshal resources and expertise needed.

The training programme was designed such that outgoing interns would provide orientation to the incoming interns under the guidance and supervision from the project team. There are multiple purposes of having interns who train future interns: to assess how well the interns have understood the system and its requirements, to revise training material accordingly, to develop the communication skills among the interns, and to create ownership of the system among the programme participants so that they would engage in the operation and maintenance of the infrastructure and of the training programme after the community take-over.

While the YTP has succeeded in demonstrating how this approach to training and capacity building can support the longer-term functionality of facilities, it also provides the skills necessary for future employability for village youth and created a feeling of ownership in the community. The success is evidenced by the reduced incidents of infrastructure vandalism. However, it cannot be guaranteed that trainees will remain in the village, voluntarily pass the skills they acquired onto others or attend to repairs and daily tasks related to the operation of the infrastructure without receiving compensation as they are not direct beneficiaries of the improved sanitation at the village school. Therefore, maintaining this capacity once the system is taken over by the community is not certain.

Apart from the community itself, there are external players that might affect the overall fate of a sanitation facility with their (dis)engagement. The local administration's support in Berambadi school case so far has been patchy. This is understandable, as innovative infrastructure projects have to compete with other budgetary priorities or preference for funding more basic infrastructures. While there is significant political support and campaigning for sanitation at a higher level in India, sanitation does not always get prioritised in the local and regional budgets, especially beyond the cost of building basic toilet infrastructure. Local panchayat and politicians as well as the Block Development Officer are critical players in terms of securing current support to pay for small yet regular expenses such as cleaning as well as accessing additional funds and training opportunities such as Skill India Campaign of the Indian Government. Accessing such external support also requires resources such as networks, which may make them less accessible to rural households.

In an effort to lay the foundations for ongoing external support, the research team maintained contact with local panchayat and the Block Development Officer throughout the project in the pre- and post-construction phases. Additionally, several events (i.e. village launch, interactive stakeholder event in Bangalore and a reception at the residence of the British High Commissioner) were organised to promote and facilitate the interest and the support of local and international external stakeholders in the project. The village launch of the facility was attended by local and regional political representatives, the project teams, as well as village residents. The early engagements with the local authorities secured the necessary permissions for the site prior to the construction phase and a commitment for financial support for maintenance of the toilet block in the post-construction phase (Ellis *et al*. 2020).

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An interactive stakeholder event was organised in Bangalore to gain wider recognition and support, and it was attended by Scottish Deputy First Minister, the members of British High Commission, the directors of reputable Indian research institutions like IISc Bangalore and the ATREE, government officials from the Karnataka ministry for education, as well as numerous representatives from civil society and educational organisations. As a result of this event, a network of interested parties was identified for regular correspondence and updates via e-newsletter.

The launch events in both Berambadi and Bangalore received local and national media attention (Ellis *et al.* 2020) and provided visibility to the project and attracted other interested parties in India, including several local authorities requesting documentation to explore the option of replicating the project in rural schools in their region. Later, a reception was held in relation to the DWWT at the British High Commissioner's residence to bring representatives of relevant industries and civil society organisations together to discuss future possibilities (Ellis *et al.* 2020). In June 2018, Marigold Foundation,[2] an NGO working with children and adolescents in India, volunteered to help the project team to train the schoolchildren between grades 1 and 8 in sanitation awareness, practices, and use of the facility.

Based on this evidence, we can assume that the initial endorsement and the basis of support for the DDWT by the external stakeholders exist in the Berambadi case. However, this did not result from an existing governance or institutional mechanism but from the efforts of the interdisciplinary research team. The local community is unlikely to have necessary means, for example, connections and disposable time, to initiate similar contacts or to maintain the initiated conversations with potential external donors and sources of support. While the research team still continues to explore options for helping the community to fund the DWWT facility, in the absence of researchers' efforts, the continuity of external support throughout the lifetime of the facility is uncertain. Therefore, we would caution against making cost estimates on the basis of S1, as it is a less likely scenario and has the potential to result in under costing.

CONCLUSIONS

The operational and maintenance costs of sanitation infrastructure can become prohibitive for rural communities over the infrastructure's life cycle, leading to rising costs, breakdown, and abandonment.

The role of internal and external socio-economic determinants is crucial and yet unexplored topic in the lifetime financing of sanitation infrastructure. We have shown how the application of LCCA to a set of empirically informed scenarios yields a wide range of potential costs accrued over the functional life of a sanitation facility.

The differences in life-cycle costs that are revealed through this methodology make several important contributions to both the practice of budgeting for sanitation infrastructure, as well as to efforts to plan for the sustainability of these systems.

First, early identification of the factors that may increase costs creates the potential for developing interventions to meet capacity gaps or address competing interests and values associated with sanitation facilities. For example, capacity-building efforts like those of the YTP at Berambadi could be institutionalised with support from project donors or NGOs, either as part of the official school curriculum or a separate programme targeting the improvement of wider employability of young people. Such interventions will provide not only support technical skills development but also a form of horizontal leadership in the community around the long-term governance of the infrastructure.

Second, a scenario-based LCCA is a useful way of revealing and interrogating assumptions and expectations about existing and future conditions in a sanitation setting. For example, engagement with the outcomes of this type of LCCA may reveal diverging understandings about the likelihood and duration of external support, which is useful for making informed decisions about how to prioritise and balance activities when budgets are limited. In this example, the LCCA could support an appeal to third sector funders by demonstrating the value-for-money of, for example, capacity-building activities.

Lastly and crucially, the variations in life-cycle costs underscore the importance of durable management arrangements for ensuring the longevity and achieving desired impacts of sanitation interventions. The LCCA developed and presented here has potential to be adopted as a tool to support decision-making around the design of management arrangements in diverse sanitation project contexts. While the factors that influence the state of the determinants for success and the combination of these determinants will theoretically be the same and applicable to other cases, how they translate into actual cost figures will need to be informed by case-specific data. But we see significant potential for the incorporating scenario-based LCCA as a decision support tool for community-based or co-constructed sanitation solutions. In these contexts, where either or both

[2] https://www.mgfindia.org/.

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the sanitation facility and the management responsibilities will be shared, there is a pressing need for life-cycle cost estimates that take account of the interacting determinants that can support or undermine sanitation objectives.

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DATA AVAILABILITY STATEMENT

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

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