The Use of Qualitative Comparative Analysis to Identify Pathways to Successful and Failed Sanitation Systems

Allie Davis[1], Amy Javernick-Will[1*], Sherri Cook[1]

*Corresponding author email: amy.javernick@colorado.edu
[1]Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder, Boulder, CO 80309

Abstract

Sanitation systems globally fail at high rates. Researchers and practitioners attribute the causes of both sanitation success and failure to numerous factors that include technical and non-technical issues. A comprehensive understanding of what leads to sanitation failure and how to achieve sanitation success is imperative to prioritize the use of limited resources. To determine which combinations of causal conditions led to successful and failed sanitation systems, we applied fuzzy-set qualitative comparative analysis to 20 cases in Karnataka and Tamil Nadu, India with small-scale sanitation systems. Two pathways led to successful sanitation systems, and four pathways led to failed sanitation systems. All successful systems required *Sufficient O&M Funds,* a *Clear O&M Plan,* and *Technical Support* in addition to either *Addressed Sanitation Priorities* and *Community Participation in Planning* or *Behavior Change Education* and *Municipality Involved in Planning.* All failed systems had *Lack of Municipality in Planning, Unaddressed Sanitation Priorities,* and *No Technical Support.* Most failed systems also had *No Clear O&M Plan, Poor Construction Quality, Lack of Community Participation in Planning,* and *Insufficient O&M Funds*. Two failed cases had unique pathways because *Government Barriers* permanently disrupted use and maintenance. Overall, implementing organizations who initiate sanitation projects in resource-limited communities should ensure that (1) communities have adequate technical and financial resources for maintenance; (2) community and municipality stakeholders are engaged in planning and know their maintenance responsibilities; and (3) appropriate technologies are selected that meet community needs and achieve community buy-in.

Keywords

Sanitation, success, failure, qualitative comparative analysis, developing communities

1.0 Introduction

Sanitation systems fail at high rates, with up to 70% of sanitation systems in resource-limited communities failing within two years of construction (WHO and UNICEF, 2017). Sanitation failure is a major problem because it leads to human and environmental health risks (WHO and UNICEF, 2017). Despite the importance of and need for universal access to safe sanitation, sanitation systems continue to fail. Therefore, there is a need to comprehensively and systematically understand why systems are still failing to avoid negative outcomes and achieve sanitation success.

Previous research has identified many factors that influence sanitation success and failure. For example, sanitation failure has been attributed to supply-driven approaches (Starkl et al., 2013), lack of maintenance (Katukiza et al., 2010), faulty designs (Sujaritpong and Nitivattananon, 2009), high operation and maintenance (O&M) costs (Cronin et al., 2014), lack of ongoing support (Eales et al., 2013), lack of user acceptance (Bao et al., 2013), inadequate technical knowledge (Kaminsky and Javernick-Will, 2012), or inappropriate technologies (Murphy et al., 2009). However, persistent sanitation failure suggests that these factors may not fully explain the causes of failure and/or these factors could be better addressed in the sanitation sector. Sanitation success has been attributed to community participation (Roma and Jeffrey, 2010), user satisfaction (Seymour, 2014), affordability (Mwirigi et al., 2014), appropriate technologies (Black, 1998; Bouabid and Louis, 2015; Murphy et al., 2009; Palaniappan et al., 2008), maintenance support (Sansom, 2011), and low maintenance complexity (Brikké and Bredero, 2003). Despite this knowledge, studies have found contrary results for the same factor. For example, in a study of sanitation in India, Battacharyya (2015) found that community participation, good quality construction, and water supply were each positively correlated with success, but Banerjee (2013) found that these same factors are present in failed systems in India. Also, in a literature review by

Mansuri (2004), community participation had either positive, negative, or no impacts on sanitation outcomes; thus, those authors suggested that participation may not be the only driver of success or failure. Overall, analyzing factors in isolation has been insufficient to characterize the complex causes of sanitation success and failure.

While most research has analyzed individual factors associated with success or failure of sanitation systems, a few studies have focused on identifying combinations of factors. For example, one study found that poor quality construction of school toilets could be overcome by the simultaneous presence of multiple other factors, such as a maintenance plan, a sanitation champion, and government support (Chatterley et al., 2014). Another study, of rural water supply systems, found that success could still be achieved, despite the absence of post-construction support, if good financial management and community participation were both present (Marks et al., 2018). Comprehensive evaluations that identify which combinations of factors, including the integration of social, institutional, technical, and economic factors (Tilley et al., 2014; Törnqvist et al., 2008; WaterAid, 2011), are needed to better understand sanitation systems' outcomes.

A common method to holistically examine how factors combine together to produce an outcome is qualitative comparative analysis (QCA). QCA has been used extensively in the social sciences (Fischer and Maggetti, 2017; Nair and Howlett, 2015) and is being used increasingly in engineering (Jordan et al., 2016; Kunz et al., 2015; Opdyke et al., 2018). QCA results in both in-depth case knowledge and generalizable results (Ragin, 1987) by using set theory and Boolean algebra to analyze combinations of factors (i.e., pathways) that lead to an outcome of interest (Ragin, 2008). There can be multiple pathways identified for a given outcome, allowing for a better understanding of the complex causes of success and failure and to highlight alternative pathways to success. QCA has been successfully used to evaluate pathways to success in resource-limited communities for water supply systems (Marks et al., 2018) and for management of school toilets (Chatterley et al., 2014), and this method may be useful to investigate sanitation systems to improve success and universal access.

To this end, this study used fuzzy-set QCA (fsQCA) to investigate the causes of success or failure of 20 small, community-based sanitation systems in India. Specifically, we aimed to determine which factors, in combination, led to sanitation system success or failure in order to provide recommendations for implementing organizations, municipalities, and communities to improve sanitation use, maintenance, and performance. The participating communities were in India, which has the world's fastest growing population and faces significant challenges for sanitation: more than 50% of sanitation systems in India have failed (Chaplin, 2011) and 60% of the population lacks access to safely managed sanitation (WHO and UNICEF, 2017). These issues of failure and lack of sanitation access are also present globally, thus it is important to understand strategies to reduce failure. We selected ten successful and ten failed systems and completed in-depth case studies in each community. Next, we used fsQCA to determine combinations of factors that led to success or failure of sanitation systems (Figure 1). Finally, by comparing the resulting pathways, we identified holistic strategies that lead to successful sanitation systems. Identifying sanitation success pathways can guide implementing organizations, communities, and governments to focus their limited resources to avoid failure-prone scenarios and promote success.

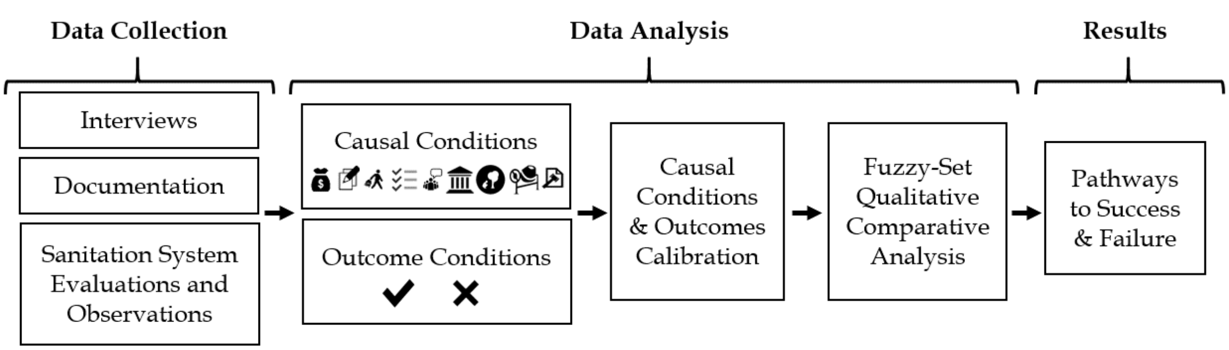


Figure 1. Overview of data collection and analysis methods used to identify pathways to success and failure of sanitation systems.

2.0 Methods

2.1 Research Context

The 20 communities (i.e., cases) in Karnataka or Tamil Nadu, India were selected to ensure variability between outcomes and factors (i.e., causal conditions). Specific case details and additional methods details are included in the Supporting Information (SI). Major variations between cases included sanitation technologies, implementing organizations, and current system outcomes (SI Table S1). To reduce the total number of causal conditions analyzed, we ensured each case had the following similarities: had one small-scale sanitation system, which was implemented by an external non-governmental organization (i.e., implementing organization) between 2008 and 2010; served 800 to 1000 users; and required community members help maintain the system. Each case was a peri-urban slum resettlement in southern India where local municipalities were responsible for infrastructure and service provision and most residents were from India's lowest caste, were employed as day laborers, and had low incomes (5,000 rupees ($70)/household/month, on average).

2.2 Data Collection

We collected extensive empirical evidence from interviews, documentation, and sanitation system evaluations and observations to thoroughly understand the causal mechanisms for each sanitation system's outcome, to generate case knowledge (Figure 1). We collected data from June to August 2016 and from January to May 2017.

Interviews. Semi-structured interviews were conducted with community members, community leaders, sanitation system operators (a male operator or women's self-help group (WSHG) members), implementing organizations, and local municipalities. Interviews explored system use, maintenance, and history; technology selection; and stakeholder roles in planning and maintenance. Examples of interview questions included: *Can you describe how the sanitation system was planned?* and *What support does your organization provide to the community regarding the sanitation system?* In total, 507 participants were interviewed (SI Table S2). Interviews with community members aimed to achieve balanced gender, age, and geographical representation. Participants were selected using door-to-door sampling in the morning, midday, and evening to capture perspectives from domestic, employed, and unemployed individuals. Interviews concluded in each case when theoretical saturation was reached (i.e., when no new themes or topics were mentioned in a subsequent interview). Interviews with community members, leaders, and sanitation system operators were conducted using local translators who had experience with sanitation fieldwork and were trained to follow the Institutional Review Board-approved protocol (#16-0026). Interviews with implementing organizations and municipalities were conducted in English.

Documentation. We collected documentation from implementing organizations and municipalities that included: standard operating procedures describing planning and implementation strategies; feasibility studies describing decision-making and project goals; planning meeting notes summarizing stakeholder roles in technology selection, construction, and maintenance; detailed project reports describing final system designs, cost information, and material quantities and quality; and sanitation system monitoring and evaluation reports describing historical performance data, system damage, number and type of maintenance tasks performed, user fees collected (where applicable), resource recovery profits, and ongoing technical and financial assistance from implementing organizations or municipalities.

Sanitation System Evaluations and Observations. Sanitation system performance was evaluated using the three regulated parameters for domestic wastewater in India: chemical oxygen demand (COD), biochemical oxygen demand (BOD), and pH (SI Table S3) (Central Pollution Control Board, 2017). Influent and effluent wastewater samples were taken from fourteen of the twenty cases; for the remaining six cases, effluent samples could not be taken because of system damage or lack of wastewater. We also evaluated construction quality based on damage, design errors, and material type. To estimate the percentage of community members who were using the sanitation system, we triangulated data on frequency of use from interviews and researcher observations of the number of individuals using the toilets for two hours in the morning and evening on two separate days, the amount of open defecation at community-reported open defecation sites, the wastewater levels in the treatment tanks, and the cleanliness of at least one-third of a case's toilets, selected randomly, to help evaluate proper use or misuse.

2.3 Data Analysis

Interview transcriptions, observation notes, and documentation were uploaded into QSR NVivo, a qualitative coding software (QSR International, 2015). Qualitative data were coded using both deductive and inductive methods (Saldana, 2009). In deductive coding, researchers use theory to hypothesize important themes related to system success or failure. For example, the theme *Community Participation in Planning* was identified prior to the start of coding because literature states that community involvement may increase willingness to use and maintain the sanitation system (Chatterley et al., 2013; Eales et al., 2013; Marks et al., 2014). In inductive coding, researchers remain open to new themes related to success or failure that emerge from the case knowledge. For example, the theme *Formal Sanitation System Handover* was identified during coding because participants described how handover was important to reinforce O&M responsibility. To ensure internal validity, a coding dictionary was developed iteratively between two coders. Inter-coder agreement was measured using Cohen's Kappa coefficient (Bazeley and Jackson, 2013); the final coefficient was 0.59, which reflects acceptable coding agreement.

Conflicting statements between participants were resolved by triangulating answers with documentation and observations (Basurto and Speer, 2012).

2.4 Fuzzy-set Qualitative Comparative Analysis

A variant of QCA that uses fuzzy logic is fsQCA (Ragin, 2008), which is useful when cases do not dichotomously fall fully in or fully out of a set, such as when implementing organizations involve community members in planning to varying extents. In fsQCA, fuzzy sets for the causal conditions and outcomes were defined through an iterative process called calibration, which ensures that fuzzy set definitions provide a consistent measure for meaningful differences between cases (Basurto and Speer, 2012).

Domain and Causal Conditions Identification. Causal conditions are factors hypothesized to influence an outcome, identified from theory or case knowledge. In total, we analyzed nine causal conditions for all 20 cases (Table 1). First, we identified an initial list of causal conditions from literature (SI Table S4). For example, Eales et al. (2013) asserts that sanitation systems with *Technical Support* are more likely to meet regulations, based on case studies from decentralized sanitation systems in Indonesia. Second, we identified which of those causal conditions were domain conditions, which are conditions that do not vary across the cases and are therefore removed from the analysis (Ragin, 2008). The domain conditions included: regulations (Hawkins et al., 2013), sanitation system age (Sabogal et al., 2014), system size (Brikké, 2000), technology complexity (Brikké, 2000), community socio-economic status (Mwirigi et al., 2009), culture (Mwirigi et al., 2009), capital costs (Eales et al., 2013), community financial contributions to capital costs (Marks and Davis, 2012), and community participation in construction activities (Roma and Jeffrey, 2010). Third, we identified additional causal conditions from case knowledge. For example, interviews uncovered *Government Barriers* because some municipalities had taken deliberate actions to disrupt a sanitation system. Finally, the full list of causal conditions was evaluated to remove conditions if they had low necessity scores (i.e., less than 0.3, a conventional cutoff for condition inclusion (Opdyke et al., 2018)), and case knowledge indicated that the condition was not an important driver of success or failure; if they were too similar to another condition (i.e., those conditions were combined into one); and if they were found to be least-important during the QCA minimization process (discussed below).

Table 1. Causal conditions hypothesized to influence sanitation system success and failure.

Causal Conditions*	Definition	Source
Addressed Sanitation Priorities	The sanitation system is an appropriate technology that therefore addresses a majority of the community's (most important) sanitation priorities; quantified using the priority addressment protocol (Davis et al., 2019).	Black, 1998; Davis et al., 2019; Hacker and Kaminsky, 2017; Murphy et al., 2009; Palaniappan et al., 2008; Seymour, 2014; Case Knowledge
Behavior Change Education	Behavior change theory is used to teach community members the benefits of sanitation and to reduce open defecation.	Mosler, 2012; Rosenquist, 2005; Wegelin-Schuringa, 2000; Case Knowledge
Clear O&M Plan	All required maintenance tasks are known, and all stakeholders agree on whose responsibility it is to perform and finance each task.	Brikké and Bredero, 2003; Chatterley et al., 2014; Case Knowledge
Community Participation in Planning	Community members are regularly and meaningfully involved in planning, which includes attending meetings and helping to make decisions such as site selection and appropriate technology selection.	Battacharyya, 2015; Black, 1998; Bouabid and Louis, 2015; Mansuri, 2004; Roma and Jeffrey, 2010; Palaniappan et al., 2008; Case Knowledge
Construction Quality	The sanitation system is well-constructed based on high material quality and correct implementation.	Chatterley et al., 2014, 2013; Case Knowledge
Absence of Government Barriers	The local municipality has not taken deliberate actions that prevent or disrupt sanitation system use, maintenance, or performance.	Case Knowledge
Municipality Involved in Planning	The local municipality is regularly and meaningfully involved in planning, which includes attending meetings and helping to make decisions such as site selection and appropriate technology selection.	Bouabid and Louis, 2015; Harris et al., 2011; Kooy and Harris, 2012; Sansom, 2011; Case Knowledge
Sufficient Funds for O&M	Funds are available from user fees or implementing organization or municipality assistance equal to or in excess of the system's O&M costs.	Bouabid and Louis, 2015; Eales et al., 2013; Starkl et al., 2013; Case Knowledge
Technical Support	Adequate technical capacity for maintenance is available through a	Bouabid and Louis, 2015; Chatterley et al., 2014; Eales et al., 2013; IDECK, 2015;

	skilled operator and external maintenance assistance.	Kooy and Harris, 2012; Sakthivel et al., 2014; Tilley et al., 2014; Case Knowledge

*The presence of causal conditions is hypothesized for success, and the absence is hypothesized for failure.

Causal Condition Calibration. The complete calibration guide for all causal conditions is included in the SI (Table S5, Figures S1 and S2). Seven of the nine causal conditions had mostly qualitative data, so we calibrated these conditions indirectly (i.e., set membership is defined qualitatively, based on case knowledge and theory (Basurto and Speer, 2012)). First, we defined the anchor points for in-set membership (fuzzy set score of 1), out-of-set membership (fuzzy set score of 0), and the crossover point (fuzzy set score of 0.5) for each causal condition based on theory. Next, we adjusted these definitions until meaningful differences between the 20 cases were accurately reflected by the calibrations. For example, out-of-set membership for *Community Participation in Planning* was when community members were entirely uninvolved in planning and learned of the project only after construction began; we added "community members attended exposure visits" to the in-set membership definition because case knowledge indicated that exposure visits (i.e., where nearby successful sanitation systems were visited to learn about technology options and O&M needs) differentiated cases with in-set membership from cases with partial membership. The remaining two of the nine causal conditions were calibrated directly (i.e., set membership is defined by continuously normalizing raw quantitative data within anchor points (0, 0.5, 1) (Ragin, 2008)). For *Addressed Sanitation Priorities,* raw data for each case was a quantitative priority addressment score, which reflects the extent to which priorities were addressed based on importance (i.e., how appropriate the technology was to the local context) (Davis et al., 2019) (SI Figure S1). For *Sufficient O&M Funds,* raw data for each case was the amount of available funds as a percentage of monthly O&M costs (SI Figure S2).

Outcome Classification and Calibration. Each case's sanitation system was classified as being either successful or failed. Success was defined as the presence of three criteria (Davis et al., 2019, 2018): (1) the system is used by at least 75% of the community; (2) at least 90% of maintenance tasks are performed correctly and on time; and (3) the system complies with local regulations for pH, COD, and BOD. Cases were classified as failed if they did not meet at least one of the success criteria. Use was directly calibrated (SI Figure S3). In-set membership was defined as more than 75% of the system's target population using the system correctly, daily, and exclusively (i.e., no open defecation) (Andres et al., 2014; Harris et al., 2017) while out-of-set membership was defined as less than 25% using it correctly, daily, and exclusively. Maintenance was also directly calibrated (SI Figure S4). In-set membership was defined as at least 90% of the total required maintenance tasks were completed correctly and on time (Brikké, 2000; Eales et al., 2013) while out-of-set membership was defined as less than 25% completed correctly and on time. Performance was indirectly calibrated using a three-value fuzzy set (SI Table S6). In-set membership was defined as complying with all applicable pH, BOD, and COD regulations while out-of-set membership was defined as failing to comply with all three regulations; an intermediate value of 0.3 was defined as a system failing to comply with only one regulation. For the fsQCA, success outcome scores were determined by taking the minimum of the fuzzy set scores for use, maintenance, and performance (SI Table S7). The outcome of failure was analyzed using the negated (i.e., absence) of the success outcome scores.

Pathway Identification and Interpretation. Fuzzy set scores for all conditions and outcomes were assigned for every case and summarized in a QCA truth table (Table 2). We used the software fs/QCA (Ragin, 2013) to minimize the truth table and to calculate, using Boolean algebra and fuzzy logic (Ragin, 2008), pathways to success and to failure. Minimization was performed by comparing all possible combinations of causal conditions in a stepwise process to remove least-important causal conditions and identify the simplest combinations of causal conditions needed to produce an outcome. Each pathway is a combination of causal conditions that results in an outcome. To interpret each pathway's validity, we used four main QCA metrics. Consistency evaluates each pathway's reliability; it is the fraction of cases that exhibit the same pathway and outcome, and fractions above 0.8 are required for a pathway to be "consistent" (Ragin, 2006). Necessity evaluates how commonly a causal condition is present with an outcome; it is calculated using the same process as consistency, and fractions above 0.9 are required for a causal condition to be "necessary" (Ragin, 2008). Coverage helps evaluate the generalizability of findings; of cases with the same outcome, it is the fraction explained by the same pathway (Rihoux and Ragin, 2009) such that higher coverage indicates that that pathway explains more cases. Sufficiency evaluates how commonly a causal condition results in a positive outcome; it is calculated the same way as coverage, and fractions above 0.8 are required for a causal condition to be "sufficient" (Ragin, 2008).

Table 2. The truth table summarizes the fuzzy scores for each causal condition and the outcome for all 20 cases.

Case Number	Causal Conditions									Outcomes				
	Addressed Sanitation Priorities	Behavior Change Education	Clear O&M Plan	Community Participation in Planning	Construction Quality	Government Barriers	Municipality Involved in Planning	Sufficient O&M Funds	Technical Support	Maintenance	Performance	Use	Success [min(Use, Maintenance, Performance]	Failure (1-Success)
1	0.22	0.67	1	0.33	1	0	1	1	0.67	0.96	1	1	0.96	0.04
2	0.82	0.33	0.67	0.67	1	0	0.33	1	1	0.92	1	1	0.92	0.08
3	0.62	0.67	0.67	0.33	0.67	0	1	0.88	0.67	0.92	1	0.98	0.92	0.08
4	0.03	0.33	0	0.67	0.33	0	0	0.51	0	0	0	0	0	1
5	0.04	0	0	0	0.33	0	0.33	0.27	0	0	0.3	0.01	0	1
6	0.11	1	0.33	0.33	0.67	0	0	0.21	0.33	0.07	0	0.43	0	1
7	0.96	0.67	1	0.33	1	0	1	1	0.67	1	1	1	1	0
8	0.7	0.67	1	0.33	0.67	0	1	1	1	1	1	0.99	0.99	0.01
9	0.24	1	0.67	0.67	0.67	1	0	0.07	0.33	0.14	0	0.98	0	1
10	0	0	0	0.67	0.33	0	0	0.88	0	0	0.3	0	0	1
11	0.97	0.67	1	0.67	1	0	0.67	1	1	1	1	1	1	0
12	0.33	0.33	0.33	0.33	0.67	0	0.33	0.32	0.33	0.07	0	0.06	0	1
13	0.96	1	1	1	1	0	0.33	0.99	1	1	1	1	1	0
14	0.98	0.67	1	0.67	1	0	0.33	1	0.67	1	1	1	1	0
15	0.66	0.67	1	0.33	0.67	0	1	1	0.67	0.92	1	0.99	0.92	0.08
16	0.01	0	0	0.67	0.33	0	0	0.5	0	0.05	0.3	0.06	0.05	0.95
17	0.02	0.33	0	0.33	0	0	0	0.5	0	0.14	0	0.99	0	1
18	0.98	1	1	1	1	0	0.67	1	1	1	1	1	1	0
19	0.03	0	0	0	0	0	0	0.43	0	0.5	0	0.98	0	1
20	0.01	1	0.67	1	0.33	1	0	1	0	0	0	0	0	1

Note: Scores greater than 0.5 indicate membership in the set for the condition or outcome; scores less than 0.5 indicate non-membership in the set for the condition or outcome. Success outcome scores greater than 0.5 are considered to be successful cases; success outcome scores less than 0.5 are considered to be failed cases.

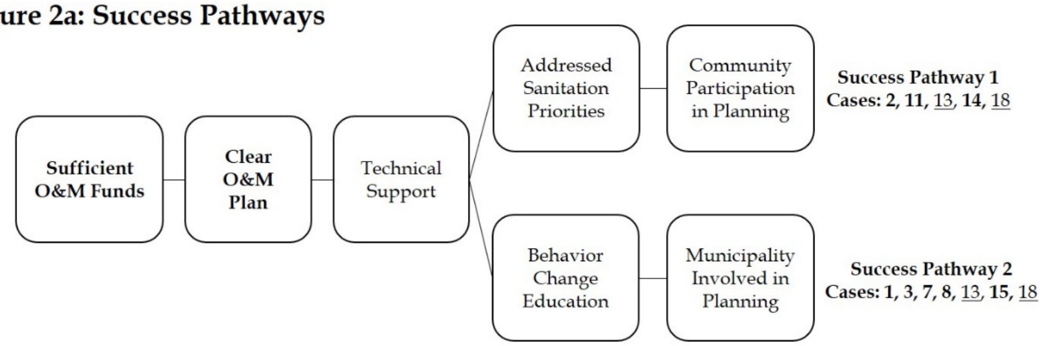
3.0 Results

Two pathways to success were identified (Figure 2a) and demonstrate alternative ways to achieve the same outcome of success. Together, they described all ten successful cases. Each success pathway had five causal conditions, of which three were shared: *Sufficient O&M Funds, Clear O&M Plan,* and *Technical Support.* The first success pathway, which described five of the ten successful cases, also had *Addressed Sanitation Priorities* and *Community Participation in Planning* causal conditions. The second success pathway, which described seven of the ten successful cases, also had *Behavior Change Education* and *Municipality Involved in Planning* causal conditions. Two cases, Cases 13 and 18, had all eight causal conditions present and were thus described by both pathways. Both success pathways highlight the importance of leveraging local knowledge to incentivize system buy-in and of establishing adequate resources and clear responsibilities for maintenance.

Four pathways led to failure (Figure 2b). All four, which together described all ten failed cases, shared three common causal conditions: *Lack of Municipality in Planning, No Technical Support,* and *Unaddressed Sanitation Priorities.* The first failure pathway described six of the ten failed cases and also included *No Clear O&M Plan* and *Poor Construction Quality*; the second described four of the ten failed cases and also included *No Clear O&M Plan, Lack of Community Participation in Planning,* and *Insufficient O&M Funds*; the third described one unique case (Case 20) and also included *Government Barriers* and *Poor Construction Quality*; the fourth described another unique case (Case 9) and also included *Government Barriers* and *Insufficient O&M Funds*. Cases 5 and 19 were described by both the first and second failure pathways. Overall, the failure pathways each highlight that failed systems were unable to overcome inadequate maintenance resources, especially when municipalities and communities were uninvolved in planning.

While the high consistency and coverage of the success and failure pathways highlight the strength of the results, the number of cases and the focused context limit our ability to evaluate and consider all possible combinations of causal conditions that could influence sanitation outcomes. Additionally, pathways represent the combinations of conditions that together were sufficient to produce the outcome of success or failure. Causal conditions in a pathway are presented in order of decreasing necessity scores; the order is not chronological. Finally, the results demonstrate alternative combinations of conditions. For a given outcome, each pathway was sufficient to produce that outcome; one is not necessarily better than the either.

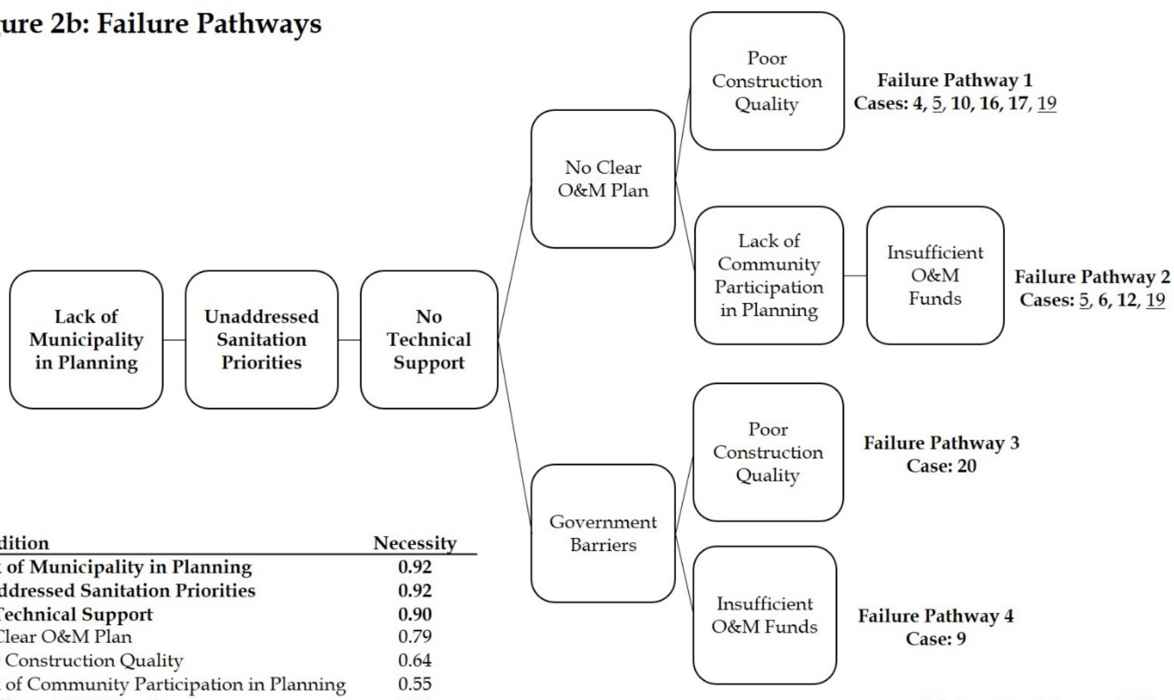
Figure 2a: Success Pathways



Condition	Necessity
Sufficient O&M Funds	**0.99**
Clear O&M Plan	**0.94**
Technical Support	0.85
Addressed Sanitation Priorities	0.81
Municipality Involved in Planning	0.73
Behavior Change Education	0.72
Community Participation in Planning	0.59

Solution Consistency = 0.93
Solution Coverage = 0.75

Figure 2b: Failure Pathways



Condition	Necessity
Lack of Municipality in Planning	**0.92**
Unaddressed Sanitation Priorities	**0.92**
No Technical Support	**0.90**
No Clear O&M Plan	0.79
Poor Construction Quality	0.64
Lack of Community Participation in Planning	0.55
Insufficient O&M Funds	0.53
Government Barriers	0.36

Solution Consistency = 1.00
Solution Coverage = 0.70

Figure 2. Results of the combinations of conditions that led to (a) success and (b) failure. **Bold** conditions have necessity scores greater than or equal to 0.90. **Bold** case numbers indicate cases that are uniquely explained by one combination of conditions; Underlined case numbers indicate cases that are explained by more than one combination of conditions. The causal conditions in the pathways are not chronological or linear; causal conditions are presented based on necessity scores, with the exception of *Government Barriers* in failure pathways 3 and 4, which is presented first to differentiate these two pathways. Case numbering matches cases from Davis et al., 2019, 2018.

4.0 Discussion

4.1 The Importance of Operation & Maintenance for Success

Adequate managerial, technical, and financial resources for maintenance were imperative for success, while their absence was a major driver of failure. All successful cases had a *Clear O&M Plan*, where technical and financial responsibility for each well-specified maintenance task was assigned and agreed upon by the implementing organization and community, and eight of the ten failed cases lacked an O&M plan. Implementing organizations should focus their efforts on reducing O&M vulnerabilities by creating clear and comprehensive O&M plans, bolstering operator skills and reliability, and securing ongoing financial, technical, and managerial support for the duration of the systems' lifetimes.

Clear responsibility meant that all successful cases also had *Technical Support*, where technical maintenance assistance from the implementing organization or municipality and a skilled operator were both regularly present. Skilled operators were essential for daily maintenance and recognizing larger system issues that would require technical assistance (e.g., pump failure). Two systems were operated by well-organized community WSHGs; six had male operators from the community; two were operated by male employees from the municipality or implementing organization. In the successful cases, the WSHGs and male operators from the communities did not previously have experience as operators but received effective training that provided them the knowledge and skills to diagnose problems, perform corrective action, and complete regular maintenance tasks correctly. The male operators from the implementing organizations or municipalities were professional operators with formal education in sanitation (e.g., sanitary engineering degrees). Technical maintenance assistance was important to train new operators and assist with maintenance during operator changes and transitions. Overall, technical maintenance assistance provided accountability and redundancy to community maintenance efforts, which aligns with existing literature that found that communities are often unable to adequately perform maintenance independently (Bouabid and Louis, 2015; Chowns, 2015; Marks et al., 2014). Since sanitation system size and the number of required O&M tasks were similar across all 20 cases, both conditions are domain conditions and their influence on success or failure could not be analyzed (Ragin, 2008).

When technical support was not provided, systems failed. All ten failed cases had *No Technical Support*, where no technical maintenance assistance was provided by the implementing organization or the municipality, and operators did not exist (four cases) or were unskilled (four cases). As a result, communities were not prepared to take responsibility for the sanitation system and unable to perform essential maintenance like desludging, subsequently leading to poor system performance. Additionally, eight failed cases had *No Clear O&M Plan* (failure pathways 1 and 2, Figure 2b), where technical and financial responsibilities were not clearly assigned, and communities or municipalities claimed that maintenance was not their responsibility.

All successful cases also had *Sufficient O&M Funds*, where O&M funds came from user fees and/or funds provided by the implementing organization or municipality. Five cases (Cases 7, 11, 13, 15, and 18) generated equal to or more than 100% of O&M costs; four cases (Cases 2, 3, 8, and 14) generated an average of 67% of O&M costs; one case (Case 1) did not generate income. Income was generated primarily through user fees, and in four of the ten successful cases, additional O&M income was generated by selling resources recovered from the sanitation system: vegetables grown using recycled water (Case 11), compost sales (Cases 13 and 14), and biogas for cooking fuel (Cases 13 and 18). In these four cases, this income provided additional benefits beyond sanitation. For example, excess system income was lent as micro-loans to women (Cases 11 and 18) or used to improve other community infrastructure (e.g., community hall (Case 18)).

These non-sanitation benefits may have contributed to these cases' strong commitment to using and maintaining the systems. All successful cases also had external financial assistance, where the implementing organization (Case 2) or the municipality (Cases 1, 3, 7, 8, 11, 13, 14, 15, and 18) agreed to and consistently paid for large O&M costs (e.g., desludging) and/or covered all costs that were not covered by system income generation. Case knowledge indicates that successful systems still required this financial redundancy and external assistance (i.e., subsidies) particularly when large, unexpected O&M costs arose or when community members irregularly paid user fees. Literature supports the finding that adequate O&M funds are essential for success and are particularly important to be secured prior to system implementation (Bouabid and Louis, 2015; Eales et al., 2013; Palaniappan et al., 2008; Starkl et al., 2013). While these systems were successful, there is still progress to be made towards sustainability. Additionally, system capital costs from all 20 cases were almost entirely subsidized (i.e., negligible community contributions) by the implementing organization (ten cases), municipality (six cases), or by both (four cases); since capital costs and community contributions did not vary across the 20 cases, the effects of these conditions were not analyzed.

In contrast, five of the ten failed cases had *Insufficient O&M Funds* (failure pathways 2 and 4), where income generation and financial assistance were less than 50% of O&M costs. As a result, operators were un-paid or under-paid, and maintenance tasks that significantly impacted performance (e.g., desludging) were not done. The lack of funds were because (i) community members did not pay user fees, because they could not afford to, did not see the benefit of sanitation, or were unsatisfied (e.g., "why should I pay to use the toilet when the toilet is never clean?"); (ii) there were no funds provided by the implementing organization because they did not intend to support maintenance long-term; or (iii) there were no funds provided by the municipality, because the implementing organizations did not include the municipality in planning or the municipality did not have the resources to pay for sanitation. Four failed systems (Cases 4, 10, 16, and 17) generated 71% of O&M costs on average but received no external financial assistance and were therefore unable to pay for costly maintenance (e.g., desludging). One failed system (Case 20) generated over 100% of O&M costs, but *Government Barriers* ultimately disrupted maintenance (described further below). Overall, implementing organizations must ensure that adequate funds are available for O&M long-term, especially to incentivize operator retention.

4.2 The Importance of Local Stakeholder Engagement and Community Buy-In for Success

Local Stakeholder Engagement**.** Engagement of local stakeholders was important in both pathways to leverage local knowledge for appropriate technology selection and define maintenance responsibilities. For successful cases, implementing organizations either involved the community *or* the municipality in planning; two successful cases (Cases 13, 18) had both involved. Local stakeholder engagement also better supported long-term relationships with the implementing organizations, which helped ensure ongoing technical and financial assistance. The success pathways also demonstrate that local engagement needed to be combined with *Addressed Sanitation Priorities* if the community was engaged or with *Behavior Change Education* if the municipality was engaged to help achieve community acceptance and willingness to use and maintain the system. All failed cases lacked the engagement of local stakeholders, which meant that implementing organizations were unfamiliar with local norms and sanitation priorities and thus implemented inappropriate systems or ineffective management strategies. Local stakeholder engagement is considered essential for community buy-in (Roma and Jeffrey, 2010), appropriate technology selection (Palaniappan et al., 2008), and ongoing maintenance (Battacharyya, 2015).

One particularly effective approach of local engagement was *Community Participation in Planning*. In the first success pathway, implementing organizations recognized the importance of engaging the community in planning, especially when the municipality did not have the resources to participate in planning. This helped to create a strong O&M plan and encourage system use and maintenance. *Community Participation in Planning* positively influenced success when community members had moderate to high citizen power, meaning they were well-informed of the project, attended meetings, co-identified project goals, and provided input for how the sanitation system should be designed and managed. Case knowledge further indicates that *Community Participation in Planning* in all cases in the first success pathway increased community buy-in and the likelihood that priorities were incorporated into appropriate technology selection and design. In contrast, *Lack of Community Participation in Planning* in the second failure pathway meant community members were uninformed of the sanitation project and were not bought into the goals of sanitation system and that the sanitation technologies may have been inappropriate for the local context. A common theme expressed by these failed cases, as summarized by one community member, was: "the first time we learned about the sanitation system was when the contractor came and started building." Implementing organizations that did not engage the community typically thought that community members lacked the technical skills to be involved in the planning of a sanitation system. This exacerbated unclear O&M responsibilities, left the communities unprepared to independently perform maintenance, and meant that sanitation priorities were unknown and therefore unaddressed.

However, *Lack of Community Participation in Planning* did not always contribute to failure if the municipality was involved. Five successful cases (1, 3, 7, 8, and 15) in the second success pathway had limited community participation in planning where communities were only informed of the project and had no decision-making input, but the municipality was involved and dedicated to the sanitation system's success. Implementing organizations recognized the importance of *Municipality Involved in Planning* because a national policy in India places the responsibility for the provision and management of sanitation infrastructure on the local municipality (Ministry of Urban Development, 2008). Thus, implementing organizations made significant efforts to accommodate the limited time and resources of municipalities. One implementing organization's engineer stated, "We know that government is important. We must do more than just ask for permission for the project to be successful. We must ask them for help in the planning." Therefore, the municipalities in the second success pathway attended planning meetings, helped define maintenance responsibilities, made financial contributions for capital costs, provided oversight during construction, assisted with training of operators, and committed to providing financial and technical maintenance assistance.

In all failed cases, there was a *Lack of Municipality in Planning*. In three cases, the municipality was not informed of the project and thus was not given a chance to be involved in planning. In seven cases, the municipality was asked to participate in planning but was uninterested, unable, or unwilling to be involved. Community members and implementing organizations still expected the municipality to support maintenance despite the municipality never agreeing to do so, and as a result, failed cases struggled with uncertain O&M responsibilities. For example, in Case 16, formal handover to the municipality did not occur, so the municipality stated, "We cannot interfere with a project until it no longer belongs to the [implementing organization]." Since most implementing organizations did not intend to provide long-term technical or financial assistance and because municipalities also did not commit these resources, all failed cases had *No Technical Support,* eight had *No Clear O&M Plan,* seven had *Poor Quality Construction,* five had *Insufficient O&M Funds,* and two had *Government Barriers*. Engaging the municipality in the early planning stages could have potentially mitigated these challenges. Implementing organizations need to prioritize engagement of municipalities, and municipalities need to budget time and resources to provide technical and financial assistance for sanitation.

Community Buy-In**.** Beyond local engagement, efforts to incentivize community buy-in were also important in both success pathways. In the first success pathway, community members cited *Addressed Sanitation Priorities* as an important reason why they continued to use and maintain the sanitation system. In these five successful cases, community members were more involved in decision-making and implementing organizations were familiar with the communities, so more priorities were addressed by the sanitation systems. In successful Cases 11 and 18, implementing organizations also conducted extensive priority assessments that focused on identifying sanitation-specific priorities, which informed technology selection and design; as a result, priorities were extremely well-addressed in these two cases. In successful Cases 2, 13, and 14, implementing organizations did not conduct priority assessments, but priorities were still well-addressed because those organizations were already familiar with the communities (through previous projects such as water supply). In contrast, all ten failed systems had *Unaddressed Sanitation Priorities*, likely due to a combination of the lack of local stakeholder engagement, the lack of priority assessments, and poor-quality construction (i.e., implemented systems did not match intended designs). Case 20 was the only failed case where the implementing organization identified sanitation priorities; all other implementing organizations for failed cases either did not conduct a priority assessment or only identified priorities unspecific to sanitation. In all ten failed cases, priorities did not influence decision-making and system design, so community buy-in did not occur, suggesting that technologies may not have been appropriate to the local context (Bouabid and Louis, 2015; Palaniappan et al., 2008).

However, unaddressed priorities did not always lead to failure; community buy-in could be achieved alternatively through *Behavior Change Education*. In the second success pathway, community members did not participate meaningfully in planning and their sanitation priorities were not well-addressed, but *Behavior Change Education* was used to convince community members of the value of sanitation. Through educational activities that communicated sanitation health benefits such as seminars, street plays, community mapping to identify open defecation sites, or games, community members accepted and used a system that still left some of their priorities unaddressed. For example, priorities were poorly-addressed in successful Case 1, and the community preferred decentralized, individual septic tanks with toilets placed farther from their kitchens, but community members often stated, "We still use the toilets because we know it keeps us from getting sick". Beyond behavior change and addressed priorities, community participation in construction has been theorized to influence buy-in (Roma and Jeffrey, 2010); however, all 20 cases had minimal or no participation in construction, so this condition was not explored in the analysis. Together, the two success pathways demonstrate alternative ways to engage local stakeholders and encourage community buy-in to lead to success, while the failure pathways highlight negative consequences of inadequate stakeholder engagement and buy-in.

4.3 Unique Pathways to Failure: Cases 9 and 20

Two failed cases (9 and 20) were each described by a unique pathway, the third and fourth failure pathways, which shared the three common failure conditions of *Lack of Municipality in Planning, Unaddressed Sanitation Priorities,* and *No Technical Support*. These two pathways diverged from the other two failure pathways because both had *Government Barriers*, which included deliberate actions from the local municipality that permanently disrupted a sanitation system's use, maintenance, and performance.

Case 20, described by failure pathway 3, had strong potential to be successful. Initially, Case 20's sanitation system generated over three times the amount of O&M costs from user fees along with sales of recycled water for use in construction, biogas that was used to run a tea shop, and biogas that was used to heat bathing water. After four years of operation, the municipality revoked the land lease and took control of the system to gain access to the income generation. The municipality did not allow the WSHG to continue to manage the system and instead neglected it and eventually locked the toilets. Since the WSHG has struggled to regain ownership of the system, this *Government Barrier* resulted in permanent system failure (i.e., closure).

Case 9, described by failure pathway 4, also had the potential to be successful. The WSHG managing the system occasionally struggled to perform major maintenance, like desludging or repairs from weather damage due to *No Technical Support* and *Insufficient O&M Funds* but performed enough maintenance to keep the system functional. However, three years after implementation, the municipality resettled another community nearby and overloaded the system by connecting 120 new household toilets to the original sanitation system because the municipality was uninvolved in planning and did not understand the system's intended design. Case 9 did not have sufficient funds to rectify the resulting issues of tank and sewer damage. Also, the municipality was unwilling to repair or expand the system. So, the *Government Barriers* contributed to permanent failure. While difficult to anticipate, these disruptions could be mitigated if implementing organizations engage municipalities in planning and if communities and implementing organizations build strong, long-term relationships with municipalities.

4.4 A Comparison of Top-Down and Bottom-Up Implementation Approaches

Comparing the two success pathways shows that both top-down (organization- and municipality-driven) and bottom-up (community-driven) approaches were able to achieve success. The first success pathway had cases where the implementing organizations were able to employ a bottom-up approach. In these cases, implementing organizations engaged the community in planning and decision-making and addressed local priorities in the design and implementation of the sanitation system. Notably, bottom-up strategies were only effective as long as communities were not expected to maintain sanitation systems without any technical or financial assistance. Despite a strong call in the sanitation sector to move away from top-down implementation strategies (Breslin, 2003; Gabe et al., 2009; Hubbard et al., 2011), most implementing organizations relied on top-down strategies (five successful and eight failed cases). The second success pathway demonstrates that systems implemented with top-down approaches can still achieve success even if there is a lack of community participation and priority assessments. Local engagement and community buy-in were still essential but were achieved with alternative strategies of engaging the municipality and incentivizing community use through extensive behavior change education efforts. In successful top-down approaches, municipalities took ownership of sanitation service delivery and prioritized long-term technical and financial assistance, demonstrating that municipalities are important implementation partners. Top-down strategies resulted in failure (eight cases) when behavior change education was absent and neither communities nor municipalities were engaged.

Finally, successful Cases 13 and 18 employed a combination of top-down and bottom-up strategies in planning. Each implementing organization initiated a sanitation project and each community was actively engaged in determining the sanitation system's technology and design/ability (resource recovery) that would best address their priorities. The communities also had strong relationships with the municipalities, so community members played an active role in engaging the local municipality. This cooperation provided redundant technical and financial resources, which both supported the sanitation system and had additional benefits. For example, both cases generated the most income from sales of resource recovery products, and because the municipalities financially supported O&M, the communities used the extra income to improve solid waste management (Case 13) and water supply (Case 18). In turn, these extra benefits further strengthened community buy-in and the municipalities' understanding of the importance of sanitation. Overall, regardless of the implementation approach, implementing organizations should aim to increase community acceptance and satisfaction for sanitation systems by improving the quality of service delivered, addressing local priorities, and ensuring systems receive maintenance support.

5.0 Conclusion

Two pathways led to successful sanitation systems, and four pathways led to failed sanitation systems. All successful systems required *Sufficient O&M Funds, Clear O&M Plan,* and *Technical Support* in addition to either *Addressed Sanitation Priorities* and *Community Participation in Planning* or *Behavior Change Education* and *Municipality Involved in Planning.* Overall, the pathways to success demonstrate the importance of involving municipalities and communities in all project phases to ensure that appropriate technologies are selected that match the local context. Either pathway can lead to success, therefore implementing organizations should focus on the pathway that best aligns with available resources, expertise, and context-specific needs. Since adequate O&M funds, clear O&M plans, and technical support were in both success pathways, we recommend that implementing organizations should prioritize creating a clear O&M plan that identifies reliable and trained operators, establishes long-term technical support, and secures sufficient local O&M funds to ensure long-term use and maintenance. Failed systems lacked many of these important conditions for success, and these results demonstrate that there are many complex causes of sanitation failure. All failed systems had *Lack of Municipality in Planning, Unaddressed Sanitation Priorities,* and *No Technical Support.* Most failed systems also had *No Clear O&M Plan, Poor Construction Quality, Lack of Community Participation in Planning,* and *Insufficient O&M Funds*. Two failed cases had unique pathways because *Government Barriers* permanently disrupted use and maintenance. The pathways to failure emphasize the importance of engaging local stakeholders—especially the local municipality, as well as establishing clear mechanisms for ongoing technical, managerial, and financial support for resource-limited communities.

Acknowledgements

We thank our research assistants, Vijay Kumar and Sridhar Selvaraj, and all participants in this research for their indispensable time and support.

Funding

This work was completed with financial support from the Mortenson Center in Engineering for Developing Communities at the University of Colorado Boulder.

Conflicts of Interest

The authors have no conflicts of interest.

References

Andres, L.A., Briceno, B., Chase, C., Echenique, J.A., 2014. Sanitation and Externalities: Evidence from Early Childhood Health in Rural India (Policy Research Working Paper). The World Bank, South Asia Region.

Banerjee, A., 2013. Legal and policy framework for wastewater treatment and reuse in India: A background review. GIZ-India.

Bao, P.N., Aramaki, T., Hanaki, K., 2013. Assessment of stakeholders' preferences towards sustainable sanitation scenarios: Assessment on sanitation scenarios. Water Environ. J. 27, 58–70. https://doi.org/10.1111/j.1747-6593.2012.00327.x

Basurto, X., Speer, J., 2012. Structuring the Calibration of Qualitative Data as Sets for Qualitative Comparative Analysis (QCA). Field Methods 24, 155–174. https://doi.org/10.1177/1525822X11433998

Battacharyya, U., 2015. Community participation in water and sanitation services: role of Panchayati Raj in India, in: Water, Sanitation and Hygiene Services beyond 2015: Improving Access and Sustainability. Presented at the 28th WEDC International Conference, Loughborough, England.

Bazeley, P., Jackson, K., 2013. Qualitative Data Analysis with NVivo. Sage Publications.
Black, M., 1998. Learning What Works: A 20 Year Retrospective View on International Water and Sanitation Cooperation. UNDP - World Bank Water and Sanitation Program, Washington, D.C.
Bouabid, A., Louis, G.E., 2015. Capacity factor analysis for evaluating water and sanitation infrastructure choices for developing communities. J. Environ. Manage. 161, 335–343. https://doi.org/10.1016/j.jenvman.2015.07.012
Breslin, E.D., 2003. Demand response approach in practice: why sustainability remains elusive. WaterAid, Mozambique.
Brikké, F., 2000. Operation and Maintenance of rural water supply and sanitation systems. Train. Package Manag. Plan. IRC Int. Water Sanit. Cent. WHO.
Brikké, F., Bredero, M., 2003. Linking technology choice with operation and maintenance in the context of community water supply and sanitation. WHO and IRC WASH, Geneva, Switzerland.
Central Pollution Control Board, 2017. Environmental Standards: Water Quality Criteria [WWW Document]. Cent. Pollut. Control Board. URL http://www.cpcb.nic.in/Water_Quality_Criteria.php (accessed 5.17.16).
Chaplin, S.E., 2011. Indian cities, sanitation and the state: the politics of the failure to provide. Environ. Urban. 23, 57–70. https://doi.org/10.1177/0956247810396277
Chatterley, C., Javernick-Will, A., Linden, K.G., Alam, K., Bottinelli, L., 2014. A qualitative comparative analysis of well-managed school sanitation in Bangladesh. BMC Public Health 14, 1–14.
Chatterley, C., Linden, K.G., Javernick-Will, A., 2013. Identifying pathways to continued maintenance of school sanitation in Belize. J. Water Sanit. Hyg. Dev. 3, 411–422.
Chowns, E., 2015. Is Community Management an Efficient and Effective Model of Public Service Delivery? Lessons from the Rural Water Supply Sector in Malawi: Is Community Management Efficient and Effective? Public Adm. Dev. 35, 263–276. https://doi.org/10.1002/pad.1737
Cronin, A.A., Ohikata, M., Kumar, M., 2014. Social and economic cost-benefit analysis of sanitation in Odisha State, India. J. Water Sanit. Hyg. Dev. 4, 521. https://doi.org/10.2166/washdev.2014.150
Davis, A., Javernick-Will, A., Cook, S., 2019. Priority Addressment Protocol: Understanding the Ability and Potential of Sanitation Systems to Address Priorities. Environ. Sci. Technol. 53, 401–411. https://doi.org/10.1021/acs.est.8b04761
Davis, A., Javernick-Will, A., Cook, S., 2018. A comparison of interviews, focus groups, and photovoice to identify sanitation priorities and increase success of community-based sanitation systems. Environ. Sci. Water Res. Technol. 4, 1451–1463. https://doi.org/10.1039/C8EW00391B
Eales, K., Blackett, I., Siregar, R., Febriani, E., 2013. Review of Community-Managed Decentralized Wastewater Treatment Systems in Indonesia. WSP.
Fischer, M., Maggetti, M., 2017. Qualitative Comparative Analysis and the Study of Policy Processes. J. Comp. Policy Anal. Res. Pract. 19, 345–361. https://doi.org/10.1080/13876988.2016.1149281
Gabe, J., Trowsdale, S., Vale, R., 2009. Achieving integrated urban water management: planning top-down or bottom-up? Water Sci. Technol. 59, 1999–2008. https://doi.org/10.2166/wst.2009.196

Hacker, M.E., Kaminsky, J.A., 2017. Cultural preferences for the methods and motivation of sanitation infrastructure development. J. Water Sanit. Hyg. Dev. 7, 407–415. https://doi.org/10.2166/washdev.2017.188
Harris, D., Kooy, M., Jones, L., 2011. Analysing the governance and political economy of water and sanitation service delivery. Overseas Development Institute, London, UK.
Harris, M., Alzua, M.L., Osbert, N., Pickering, A., 2017. Community-Level Sanitation Coverage More Strongly Associated with Child Growth and Household Drinking Water Quality than Access to a Private Toilet in Rural Mali. Environ. Sci. Technol. 51, 7219–7227. https://doi.org/10.1021/acs.est.7b00178
Hawkins, P., Blackett, I., Heymans, C., 2013. Poor-inclusive urban sanitation: An overview, Targeting the Urban Poor and Improving Services in Small Towns. WSP, The World Bank, Washington, D.C.
Hubbard, B., Sarisky, J., Gelting, R., Baffigo, V., Seminario, R., Centurion, C., 2011. A community demand-driven approach toward sustainable water and sanitation infrastructure development. Int. J. Hyg. Environ. Health 214, 326–334. https://doi.org/10.1016/j.ijheh.2011.05.005
IDECK, 2015. Strengthening the operation & maintenance sector for servicing decentralised urban sanitation infrastructure in Bangalore: Landscape synthesis report. CDD Society and BORDA, Bangalore, India.
Jordan, E., Javernick-Will, A., Tierney, K., 2016. Post-tsunami recovery in Tamil Nadu, India: combined social and infrastructural outcomes. Nat. Hazards 84, 1327–1347. https://doi.org/10.1007/s11069-016-2489-4
Kaminsky, J., Javernick-Will, A., 2012. Causes for Sustainable Maintenance and Operation of On-Site Sanitation Systems, in: Proceedings of the 2012 Construction Research Congress. pp. 21–23.
Katukiza, A.Y., Ronteltap, M., Oleja, A., Niwagaba, C.B., Kansiime, F., Lens, P.N.L., 2010. Selection of sustainable sanitation technologies for urban slums — A case of Bwaise III in Kampala, Uganda. Sci. Total Environ. 409, 52–62. https://doi.org/10.1016/j.scitotenv.2010.09.032
Kooy, M., Harris, D., 2012. Political economy analysis for water, sanitation and hygiene (WASH) service delivery (Project Briefing). Overseas Development Institute, London, UK.
Kunz, N.C., Fischer, M., Ingold, K., Hering, J.G., 2015. Why Do Some Water Utilities Recycle More than Others? A Qualitative Comparative Analysis in New South Wales, Australia. Environ. Sci. Technol. 49, 8287–8296. https://doi.org/10.1021/acs.est.5b01827
Mansuri, G., 2004. Community-Based and -Driven Development: A Critical Review. World Bank Res. Obs. 19, 1–39. https://doi.org/10.1093/wbro/lkh012
Marks, S.J., Davis, J., 2012. Does User Participation Lead to Sense of Ownership for Rural Water Systems? Evidence from Kenya. World Dev. 40, 1569–1576. https://doi.org/10.1016/j.worlddev.2012.03.011
Marks, S.J., Komives, K., Davis, J., 2014. Community participation and water supply sustainability evidence from handpump projects in rural Ghana. J. Plan. Educ. Res. 34, 276–286.
Marks, S.J., Kumpel, E., Guo, J., Bartram, J., Davis, J., 2018. Pathways to sustainability: A fuzzy-set qualitative comparative analysis of rural water supply programs. J. Clean. Prod. 205, 789–798. https://doi.org/10.1016/j.jclepro.2018.09.029

Ministry of Urban Development, 2008. National Urban Sanitation Policy. Government of India, New Delhi, India.

Mosler, H.-J., 2012. A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. Int. J. Environ. Health Res. 22, 431–449. https://doi.org/10.1080/09603123.2011.650156

Murphy, H.M., McBean, E.A., Farahbakhsh, K., 2009. Appropriate technology – A comprehensive approach for water and sanitation in the developing world. Technol. Soc. 31, 158–167. https://doi.org/10.1016/j.techsoc.2009.03.010

Mwirigi, J., Balana, B.B., Mugisha, J., Walekhwa, P., Melamu, R., Nakami, S., Makenzi, P., 2014. Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. Biomass Bioenergy 70, 17–25. https://doi.org/10.1016/j.biombioe.2014.02.018

Mwirigi, J.W., Makenzi, P.M., Ochola, W.O., 2009. Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. Energy Sustain. Dev. 13, 106–115. https://doi.org/10.1016/j.esd.2009.05.002

Nair, S., Howlett, M., 2015. Scaling up of Policy Experiments and Pilots: A Qualitative Comparative Analysis and Lessons for the Water Sector. Water Resour. Manag. 29, 4945–4961. https://doi.org/10.1007/s11269-015-1081-0

Opdyke, A., Javernick-Will, A., Koschmann, M., 2018. A Comparative Analysis of Coordination, Participation, and Training in Post-Disaster Shelter Projects. Sustainability 10, 4241. https://doi.org/10.3390/su10114241

Palaniappan, M., Lang, M., Gleick, P.H., 2008. A Review of Decsion-Making Support Tools in the Water, Sanitation, and Hygiene Sector. The Pacific Institute, Oakland, California.

QSR International, 2015. NVivo qualitative data analysis software. QSR International Pty Ltd.

Ragin, C.C., 2013. Fuzzy-Set/Qualitative Comparative Analysis. Department of Sociology, University of Arizona, Tuscon Arizona.

Ragin, C.C., 2008. Redesigning social inquiry: fuzzy sets and beyond. University of Chicago Press, Chicago.

Ragin, C.C., 2006. Set Relations in Social Research: Evaluating Their Consistency and Coverage. Polit. Anal. 14, 291–310. https://doi.org/10.1093/pan/mpj019

Ragin, C.C., 1987. The comparative method: moving beyond qualitative and quantitative strategies. University of California Press, Berkeley, Calif.

Rihoux, B., Ragin, C.C., 2009. Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques. Sage Publications, Inc.

Roma, E., Jeffrey, P., 2010. Evaluation of community participation in the implementation of community-based sanitation systems: a case study from Indonesia. Water Sci. Technol. 62, 1028–1036. https://doi.org/10.2166/wst.2010.344

Rosenquist, L.E.D., 2005. A psychosocial analysis of the human-sanitation nexus. J. Environ. Psychol. 25, 335–346. https://doi.org/10.1016/j.jenvp.2005.07.003

Sabogal, R.I., Medlin, E., Aquino, G., Gelting, R.J., 2014. Sustainability of water, sanitation and hygiene interventions in Central America. J. Water Sanit. Hyg. Dev. 4, 89–99. https://doi.org/10.2166/washdev.2013.130

Sakthivel, S.R., Seshadri, A., Rahman, A., Chariar, V.M., 2014. Standardisation of Design and Maintenance of DEWATS Plants in India. India Inst. Technol. Tech. Pap. Ser.

Saldana, J., 2009. The Coding Manual for Qualitative Researchers, 2nd ed. Sage, London.

Sansom, K., 2011. Complementary roles? NGO-Government relations for community-based sanitation in South Asia. Public Adm. Dev. 31, 282–293. https://doi.org/10.1002/pad.609

Seymour, Z., 2014. Sanitation in developing countries: a systematic review of user preferences and motivations. J. Water Sanit. Hyg. Dev. 4, 681–691.

Starkl, M., Brunner, N., Stenström, T.-A., 2013. Why Do Water and Sanitation Systems for the Poor Still Fail? Policy Analysis in Economically Advanced Developing Countries. Environ. Sci. Technol. 47, 6102–6110. https://doi.org/10.1021/es3048416

Sujaritpong, S., Nitivattananon, V., 2009. Factors influencing wastewater management performance: Case study of housing estates in suburban Bangkok, Thailand. J. Environ. Manage. 90, 455–465. https://doi.org/10.1016/j.jenvman.2007.11.006

Tilley, E., Strande, L., Lüthi, C., Mosler, H.-J., Udert, K.M., Gebauer, H., Hering, J.G., 2014. Looking beyond Technology: An Integrated Approach to Water, Sanitation and Hygiene in Low Income Countries. Environ. Sci. Technol. 48, 9965–9970. https://doi.org/10.1021/es501645d

Törnqvist, R., Norström, A., Kärrman, E., Malmqvist, P.-A., 2008. A framework for planning of sustainable water and sanitation systems in peri-urban areas. Water Sci. Technol. 58, 563–570. https://doi.org/10.2166/wst.2008.702

WaterAid, 2011. Sustainability framework (Framework). WaterAid, London, UK.

Wegelin-Schuringa, M., 2000. Public awareness and mobilisation for ecosanitation, in: IRC International Water and Sanitation Center, Delft, Netherlands. Presented at the International Symposium on Ecological Sanitation, IRC International Water and Sanitation Center, Delft, Netherlands, Bonn, Germany.

WHO, UNICEF, 2017. Progress on Drinking Water, Sanitation and Hygiene: Update and SDG Baselines. Joint Monitoring Program, Geneva.