Governance and Financing Barriers in Scaling Urban Sanitation Infrastructure

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Abstract: *This paper presents an operational conceptual framework that explains why urban sanitation infrastructure scale-up stalls under fragmented governance, constrained finance, and limited monitoring of non-sewered service chains. Existing typologies often reduce the problem to single-cause narratives or generic checklists, leaving decision limits implicit and weakening comparability across cities. The proposed approach defines bounded constructs for governance and financing barriers, links them to causal mechanisms shaping service reliability and equity, and specifies boundary conditions under affordability and operator-capacity constraints. A programmatic cohort design and a structured coding rubric are introduced to convert heterogeneous case material and public aggregate water, sanitation, and hygiene statistics into evaluable indicators, supported by grouped holdouts, leakage controls, and bootstrap uncertainty reporting. The contribution is a compact set of propositions and a validation protocol that makes alternative explanations testable while preserving traceability of evidence and decision rules. The framework is intended to support municipal leaders and sanitation regulators in low- and middle-income cities when selecting feasible remedies under fiscal and institutional constraints.*

Keywords: Urban Sanitation Finance, Fecal Sludge Service Chain, Enabling

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Environment Analysis, Municipal Accountability, Governance Fragmentation, Programmatic Cohort Validation, Grouped Holdout Evaluation, Coding Rubric

Introduction

Urban sanitation scale-up often stalls where rapid urbanization meets fragmented governance, thin finance, and limited monitoring of non-sewered systems (Bose et al., 2024; Strande, 2024). Fig. (1) situates the analysis in a generic low- and middle-income city service chain, where utilities, landlords, and private empties negotiate responsibilities. Evidence from global water, sanitation, and hygiene (WASH) reviews underscores that community engagement and financing arrangements can enable innovation, yet remain unevenly implemented still (Bose et al., 2024).

Service performance is therefore treated as a level on a sanitation ladder rather than a binary outcome, drawing on Joint Monitoring Programme (JMP) categories and ladder-based scoring approaches (Zimmerman et al., 2022). Non-sewered contexts add distinct constraints: stored waste degrades, properties vary, and terminology inconsistencies can obscure feasible interventions (Strande, 2024). Research design transparency is maintained by synthesizing these literatures into an operational model, defining propositions that link governance and financing barriers to decisions, and outlining a coding rubric with a validation plan for observable outcomes.

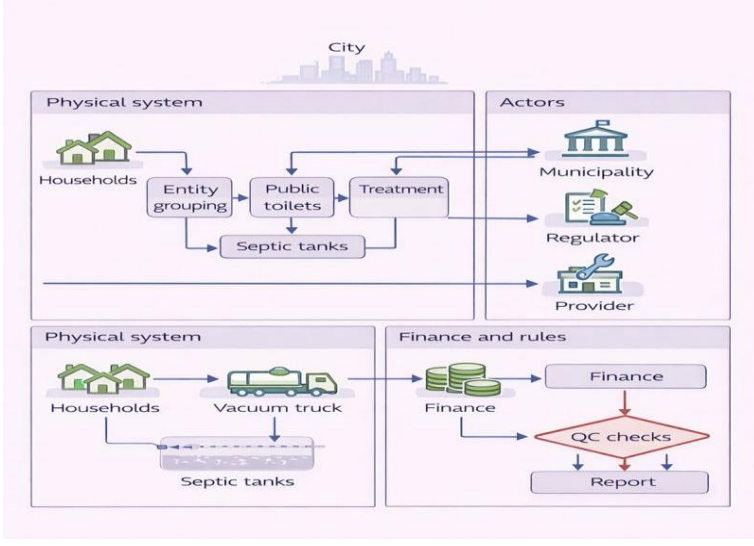

Figure 1. *Urban sanitation governance context scene*

Literature Review

Entrepreneurship-oriented accounts emphasize market shaping and enterprise ecosystems, yet governance frictions often dominate scale-up constraints. A Scopus-based bibliometric and content analysis maps 375 sanitation entrepreneurship papers and highlights the concentration of influence in specific outlets and themes (Kumar et al., 2023). Political economy work on container-based sanitation in Kenya specifies six recurring governance and incentive failures, including fragmented authority and land-tenure politics (Mallory et al., 2022). Baselines for the present model therefore include finance-only narratives and checklist approaches, which under-specify institutions.

Urban behaviour change evidence is less consistent than often assumed. A scoping review of urban household interventions reports mixed effects, with gains mainly in latrine quality and handwashing with soap (MacLeod et al., 2025). Enabling-environment frameworks extend beyond sanitation: six-city analyses of inclusive piped water identify progress types and cross-cutting institutional and financing characteristics (Trimmer et al., 2023), while FIETS-based sustainability assessment ranks financial and institutional dimensions as critical (Al-Hamawi et al., 2025). Evidence corpus integrity is constrained by selective cases and database coverage; inclusion rules are not reported here.

Baseline Typologies For Urban Sanitation Finance And Governance Barriers

Urban sanitation finance debates often reduce barriers to a single lens, yet governance constraints shape what funding can buy in practice. Baselines are therefore organized around common typologies drawn from regulatory and Citywide Inclusive Sanitation (CWIS) cases (Lerebours et al., 2022; Saker et al., 2022) and from documented tensions between utilities and private providers (Grisaffi et al., 2022). Table (1) compares these baseline typologies by evidence basis, decision limit, and best use, clarifying why rapid proxies can mislead decisions.

The proposed framework adds an explicit cross-walk between supply-side and demand-side policy logics, which rarely appear jointly in checklist or narrative baselines (Humňalová & Ficek, 2023; Yulianti & Meutia, 2023). In the matrix, each baseline is linked to one evidence basis and one decision limit. Fig. (2) summarizes this value-add by showing where baseline approaches stop short of governance-finance interactions that determine implementability. Evidence corpus

integrity remains bounded by the documented case and policy record; inclusion and exclusion rules for the underlying corpus are not reported here.

Figure 2. *Baseline typologies and gaps matrix*

Table 1. Baseline typologies comparison

Baseline Typology	***Evidence Basis***	***Decision Limit***	***Best Use***
Topic Modeling Proxy	Document corpus	Weak causal trace	Rapid triage
Supervised Text Labels	Labeled barrier texts	Label budget bound	High volume coding
Single-Cause Narrative	Finance-only framing	Misses governance	Advocacy messaging

Generic Checklist	Best-practice list	Low context fit	Quick compliance scan

Evidence Corpus Selection For Programmatic Cohort WASH Statistics

Evidence corpus selection prioritizes public, aggregate water, sanitation, and hygiene (WASH) statistics and a program cases list to support programmatic cohort indicators. Indicator definitions align with Demographic and Health Survey style measures that capture access and disparity patterns (Dhital et al., 2024; Keleb et al., 2024). Macro covariates include inequality and financial inclusion to reflect national enabling conditions (Acheampong et al., 2024). Table (2) specifies inclusion and exclusion rules and lineage checks that rule out individual-level records and ad hoc anecdotes.

Spatial and regional heterogeneity evidence informs sampling strata and grouped holdouts, limiting overgeneralization from single settings (Valencio et al., 2024; Victor et al., 2022). Fig. (3) summarizes cohort provenance from source type screening through split construction and audit checkpoints. Evidence corpus integrity is enforced via manifest hashes, entity ID audits, and split hash checks, with QC blockers triggering a halt when violations occur. Research design transparency is supported by documenting train-only preprocessing and the no-lookahead constraint, although audit pass rates are not reported here.

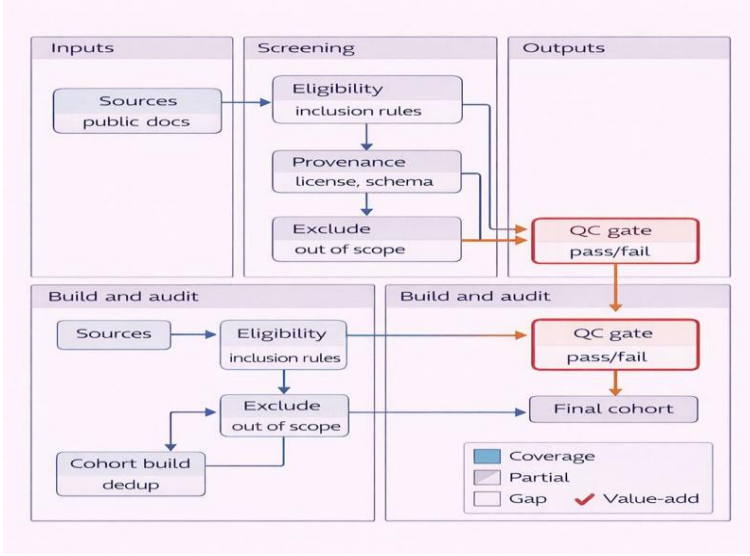

Figure 3. *Cohort selection and provenance flow*

Table 2. Corpus criteria and lineage

Element	*Include Rule*	*Exclude Rule*	*Lineage Check*
Source Type	Public aggregate WASH stats	Individual level records	No individual data
Cohort Records	Program cases list	Ad hoc anecdotes	Manifest hashes
Splits	Grouped holdouts design	Cross-split entity reuse	Entity ID audit
Preprocessing	Fit on train only	Any lookahead fit	Split hash check
Quality Control	QC blockers enforced	Release on blockers	QC halt rules

Conceptual Framework

Urban sanitation scale-up is modelled as governance choices under constrained finance and fragmented authority. The causal structure follows a governance capability framing in which knowing, wanting, and enabling conditions determine whether actors coordinate mandates, monitor performance, and mobilize resources (Ejigu & Yeshitela, 2023). Enabling-environment constructs from comparative urban service delivery are adapted to represent institutional and policy features that translate capability into inclusive provider action (Trimmer et al., 2023). Causal logic and mechanisms are conditional: capability activates the environment, which shapes decision consistency and equity.

To prevent single-factor explanations, the framework treats financial, institutional, technical, social, and environmental constraints as interacting rather than additive, consistent with the FIETS lens used for WASH sustainability assessments (Al-Hamawi et al., 2025). Context enters through lived infrastructure configurations, where households combine on- and off-grid sanitation to manage water scarcity and risk (Alda-Vidal et al., 2024). These contextual mechanisms can offset short-term service failure yet weaken accountability when responsibilities diffuse. Observable implications include shifts in remedy-match consistency when monitoring and mandate clarity improve.

Key Constructs And Definitions For Governance And Financing Barriers

Clear construct boundaries are required to code governance and financing barriers consistently across urban sanitation cases. Terminology is aligned with non-sewered sanitation scholarship that highlights how imprecise categories hinder learning (Strande, 2024), and service progress is interpreted using ladder-based service levels rather than binary coverage (Zimmerman et al., 2022). Table (3) specifies Governance Fragmentation, Financing Sustainability, and related constructs through operational definitions, observable indicators, and decision relevance, supporting conceptual precision in subsequent coding.

To connect institutional and financial barriers to sustainability assessment, the constructs are mapped to the FIETS dimensions, emphasizing financial and institutional drivers of performance (Al-Hamawi et al., 2025). Equation (1) defines typology coverage as the share of cases that can be assigned a typed barrier category among all cases under review. This metric provides a direct evaluability check on whether the construct set is sufficiently complete, while leaving causal attribution and remedy effectiveness tests to later analyses.

$$Coverage = \frac{N_{typed}}{N_{total}} \quad (1)$$

Table 3. Constructs and indicators

Construct	***Operational Definition***	***Observable Indicator***	***Decision Relevance***
Governance Fragmentation	Overlapping mandates	Conflicting actor roles	Accountability breakdown
Financing Sustainability	Opex funding adequacy	Revenue covers O&M	Service continuity risk
Regulatory Implement ability	Rules plus process	Monitoring and enforcement	Compliance feasibility
Service Reliability	Consistent service delivery	Frequent service outages	User trust impact
Equity In Access	Pro-poor service reach	Coverage gap by subgroup	Disparity mitigation

Boundary Conditions Across LMIC Cities Service Level And Affordability

Boundary conditions govern when the proposed framework can credibly compare service-level and affordability trade-offs across LMIC cities. Table (4) enumerates four binding conditions and their stress-test cues, emphasizing affordability caps and operations-and-maintenance constraints grounded in bottom-up costing evidence (Chettry et al., 2024). Applicability is further bounded by subnational disparities and the need for localization, which limits transfer of parameter choices across jurisdictions (Biswas et al., 2024). When projected costs exceed the cap, conclusions are treated as non-applicable within the tested range.

As boundary conditions, operator capacity and service-demand stability constrain implementation: backlog breaches indicate that the assumed service level is infeasible and motivate reduced-capacity stress tests. Evidence from container-based sanitation highlights demand heterogeneity and attrition driven by economic pressure, implying that subscription-based service may fail even when technical performance is adequate (VanRiper, Russel, Cramer, et al., 2022; VanRiper, Russel, Tillias, et al., 2022). Over longer horizons, sustainability and slippage remain credible failure modes, so inferences should be revisited when governance or financing conditions shift (Sakas et al., 2022). Grouped holdouts guard against leakage; aggregate data require proxies.

Table 4. Boundary conditions and bounds

Boundary	***Applies When***	***Fails When***	***Stress Test Cue***
Affordability Caps	Cost fields capped	Costs exceed cap	Tighten cap range
Operator Capacity	Limited response capacity	Backlogs breach SLA	Reduce capacity level
Grouped Holdouts	Split by context	Entity leakage occurs	Leave-group-out
Public Aggregate Data	No individual records	Fine-grain needed	Shift to proxies

Causal Mechanisms Linking Municipal Accountability To Service Reliability

Municipal accountability is treated as the capacity to demand justification and enforce correction across the regulatory cycle, from rule initiation to routine enforcement. Causal logic and mechanisms posit that stronger accountability

improves implementability by aligning stakeholder knowledge, motivation, and resources with enforceable rules in fecal sludge service regulation (Lerebours et al., 2022). This channel weakens when governance is fragmented and decisions reflect personal power rather than institutions, which destabilizes service delivery (Mallory et al., 2022). Fig. (4) makes the proposed causal chain and propositions explicit.

Conceptual precision requires separating accountability from capacity: accountability operates through who can sanction, while reliability is defined as consistent, safe service performance for households, including low-income areas. Provider function and explicit pro-poor policy can mediate this link by shifting incentives and removing access barriers, but only when institutional arrangements support sustained operations (Trimmer et al., 2023). Evidence from utilities attempting to scale pit emptying suggests that commercial-social role conflicts and political viability of private delivery can still limit reliability even under formal mandates (Grisaffi et al., 2022).

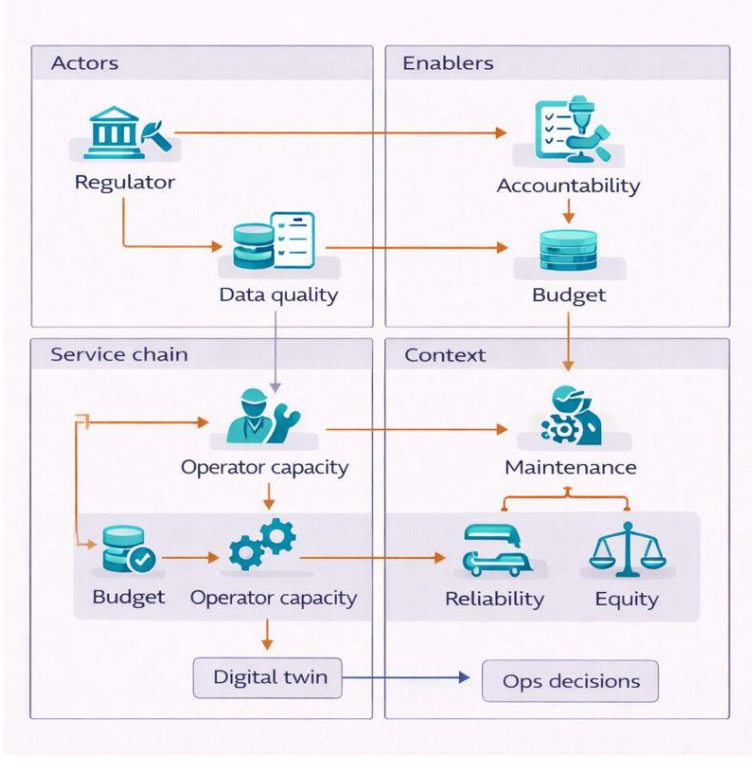

Figure 4. *Mechanism DAG from accountability to reliability*

Materials and Methods

A structured index-and-typology design was adopted to convert heterogeneous governance and finance case material into evaluable indicators. Index construction followed an evaluable precedent that aggregates maintenance-related indicators into a composite score, adapted here for barrier and remedy coding (Joe et al., 2023). Validation logic was organized around a Process-Outcomes-Context chain, enabling alignment between implementation processes, service outcomes, and enabling conditions (Novotný et al., 2024). Qualitative case narratives and quantitative public WASH statistics were jointly coded under a single rubric (Joe et al., 2023; Novotný et al., 2024).

Research design transparency was ensured by specifying units of analysis (case, barrier, and remedy), coding steps, and an explicit validation plan on the programmatic cohort. Evaluability was operationalized through measurable acceptance criteria for inter_rater_kappa, typology_coverage_percent, and remedy_match_consistency, and through predefined grouped holdouts by entity, geography, and context. Uncertainty reporting followed BCa bootstrap confidence intervals with 2000 resamples, and hypothesis screening used FDR correction with alpha 0.05 (Joe et al., 2023; Novotný et al., 2024).

Coding Rubric And Inter Rater Kappa Workflow For Barrier Labels

Barrier coding relied on a structured rubric that maps each case excerpt to barrier labels and a remedy match, aligning with index-based measurement practice in sanitation performance research (Joe et al., 2023). Table (5) specifies the rubric elements and inter-rater agreement workflow, including two annotators who coded a 15% sample and adjudicated disagreements with an adjudication log. For research design transparency, the protocol preserves traceable artifacts (rubric codebook, split_hashes.json) and halts if cross-split ids are detected.

Inter-rater reliability (IRR) was quantified using inter-rater kappa with acceptance criterion AC1: kappa >= 0.75 and a 95% confidence interval reported from a BCa bootstrap with 2000 resamples (kappa_report.csv; ci_bootstrap.json). Equation (2) defines inter-rater agreement beyond chance. Evaluability follows from explicit decision rules for agreement, uncertainty, and leakage control; the leakage audit required no cross-split ids (split_hashes.json). Adjudication and consistency targets reflect prior management-performance coding in sanitation settings (Joe et al., 2023).

$$\kappa = \frac{p_o - p_e}{1 - p_e} \tag{2}$$

Table 5. Rubric and IRR protocol

Element	*Specification*	*Acceptance*
Annotator Setup	Two annotators; 15% sample	Adjudicate disagreements
Rubric Output	Barrier labels; remedy match	Coverage and consistency
IRR Metric	Inter-rater kappa	AC1: kappa >= 0.75
Uncertainty	BCa bootstrap; 2000 resamples	95% CI reported
Leakage Audit	No cross-split ids	Halt if leakage

Grouped Holdouts And Leakage Controls By Entity And Context

Grouped evaluation was organized around entity and context to avoid optimistic estimates when observations cluster in space and governance setting, a pattern documented in urban WASH studies (Valencio et al., 2024; Victor et al., 2022). Endogeneity and cross-sectional dependence are treated as primary threats to validity in this cohort design (Acheampong et al., 2024). Fig. (5) specifies grouped splits and leakage control checks. Research design transparency is maintained by defining leave-group-out and context-stratified holdouts before model comparison.

Table (6) summarizes holdouts and leakage controls, linking each control area to logged audit evidence (split_hashes.json, config.yaml, seed_log.csv) and an explicit failure halt. Preprocessing was fit on training data only, and nested tuning used an embargo to prevent lookahead. Robustness of reasoning is reinforced by stratified BCa bootstrap resampling and a stopping rule when CI overlaps baseline >50%. Equation (3) defines mean improvement over baselines, enabling consistent comparison across grouped splits (Acheampong et al., 2024).

$$\Delta_{holdout} = \overline{m_{model}} - \overline{m_{baseline}} \tag{3}$$

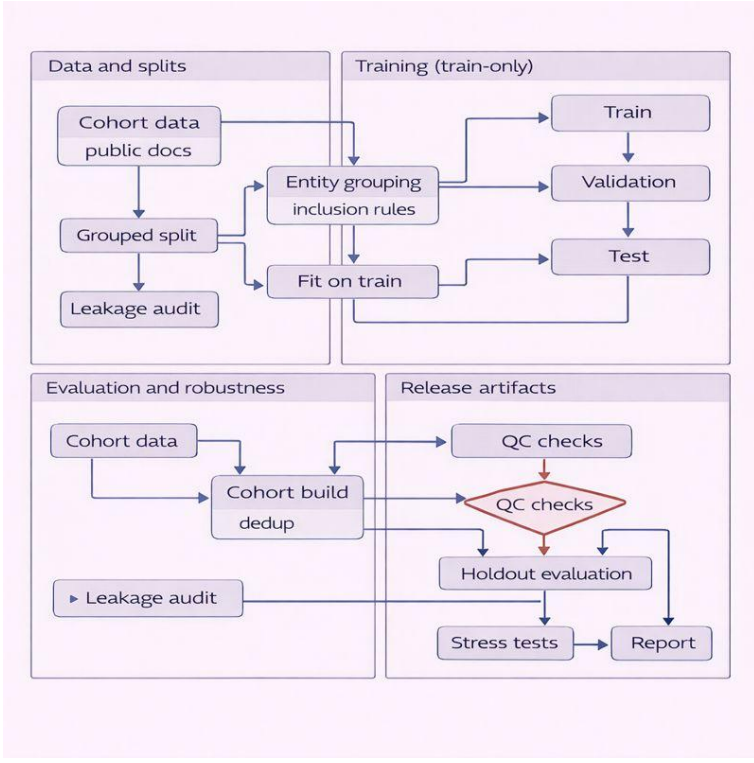

Figure 5. *Grouped holdouts and leakage audits*

Table 6. Holdouts and leakage controls

Control Area	***Implementation***	***Audit Evidence***	***Failure Halt***
Grouped holdouts	Leave-group-out splits	split_hashes.json; entity IDs	Leakage audit fails
Preprocessing fit	Train-only fitting	config.yaml; manifest hash	Split leakage detected
Hyperparam tuning	Nested tuning embargo	seed_log.csv; fixed seeds	QC blockers triggered
Uncertainty resampling	Stratified BCa bootstrap	seed_log.csv; run logs	CI overlaps baseline >50%

Results

Observed affordability constraints aligned most clearly with operations and maintenance (O&M) budgeting, where bottom-up costing translated into explicit municipal policy and recurring funding commitments (Chettry et al., 2024). Evaluability was preserved by framing affordability as an observable gap between required annual O&M resources and documented allocations, with remedy choices judged by subsequent funding adoption. Equation (4) defines the percentile bootstrap confidence interval used to report uncertainty for these indicators within grouped holdouts.

Container-based sanitation (CBS) evidence pointed to demand that is both high and fragile: economic shocks and involuntary terminations were associated with attrition and, in some settings, loss of improved sanitation (VanRiper, Russel, Cramer, et al., 2022), even as CBS targeted resource-insecure residents and reduced untreated excreta handling while creating livelihoods (VanRiper, Russel, Tillias, et al., 2022). These mixed outcomes were consistent with sustainability analyses that link service-delivery system weaknesses to slippage risks over time (Sakas et al., 2022). Evaluability follows by tracking retention, coverage, and remedy-match consistency under external grouped holdouts.

$$CI_{1-\alpha} = \left[q_{\alpha/2}, q_{1-\alpha/2}\right] \tag{4}$$

Discussion

Mixed behavior-change findings in urban sanitation can be consistent with governance-constrained implementation rather than intervention ineffectiveness. A systematic scoping review reports heterogeneous effects across outcomes, with improvements in latrine quality and handwashing but no uniform shifts in practice (MacLeod et al., 2025). Regulatory and financing rules can still disable Citywide Inclusive Sanitation adoption, as documented for Colombia, and may therefore cap achievable household-level change (Saker et al., 2022). Alternative explanations remain plausible: limited ambition, weak service reliability, or measurement error; discriminating evidence requires separating these constraints in comparable settings.

Planning for non-sewered sanitation requires monitoring that treats wastewater properties and storage degradation as variable drivers of emissions and downstream treatment performance (Strande, 2024). Hybrid infrastructures, where flush toilets and backyard latrines coexist, interact with recurrent drought-related

water shortages and can shift use patterns (Alda-Vidal et al., 2024). Fig. (6) contrasts these alternatives and the evidence that would discriminate among them. Robustness of reasoning is strengthened when propositions are checked under such edge conditions, although those checks are not reported here.

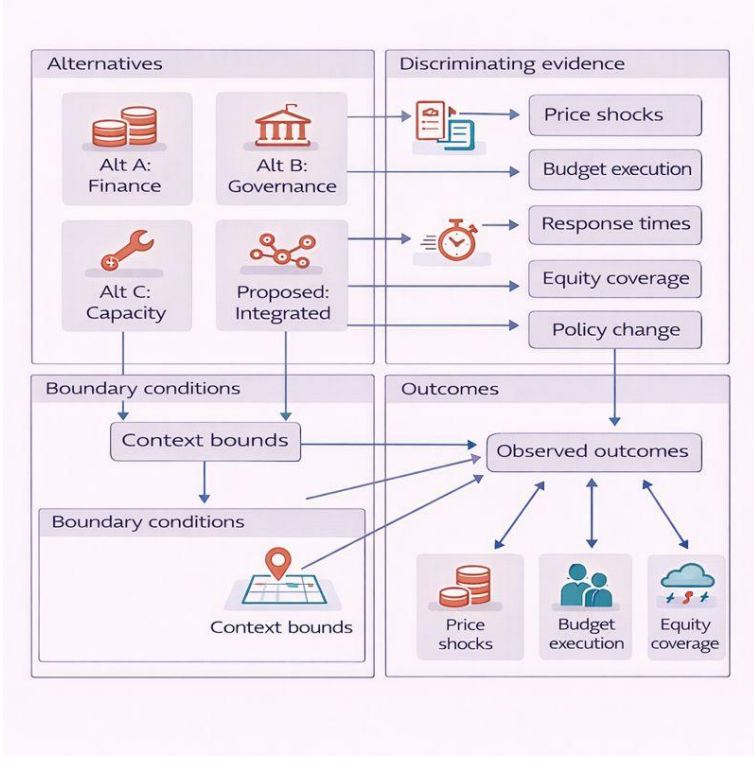

Figure 6. *Alternatives and discriminating evidence map*

Conclusion

This study consolidates governance and financing barriers that impede urban sanitation scale-up and maps them to actionable remedies, extending prior WASH syntheses toward decision support (Bose et al., 2024). The framework links institutional arrangements, financing constraints, and implementation capacity to expected service reliability and equity outcomes, consistent with enabling-environment insights from comparative urban service cases (Trimmer et al., 2023). A compact coding rubric and explicit propositions were specified to support consistent interpretation across heterogeneous programs and to facilitate later empirical validation. For evaluability, outcomes are framed in service-level terms

that can be tracked over time, aligning with ladder-based progress metrics rather than binary coverage measures (Zimmerman et al., 2022). Such tracking supports comparison across grouped contexts and can surface when shared or transitional services mask stagnation. Limitations remain: the programmatic cohort may miss local idiosyncrasies, transfer to new geographies may vary, constructs can be mis-coded, and recommendations risk misapplication (Bose et al., 2024). Decision makers should treat enabling conditions as context-specific (Trimmer et al., 2023).

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