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DEVELOPING A COMMUNITY-BASED WATER RESOURCE SECURITY FRAMEWORK FOR RURAL MALAYSIA: INTEGRATING GREEN TECHNOLOGY AND SOCIAL CAPITAL PERSPECTIVES

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Abstract

Access to safe and reliable water remains a persistent challenge for rural communities in Malaysia, where infrastructural limitations, spatial constraints, and governance fragmentation continue to undermine water security. While technological solutions have been widely promoted, their long-term effectiveness in rural contexts is often constrained by limited community ownership and weak institutional coordination. This paper develops a Community-Based Water Resource Security Framework (CBWSF) that integrates social capital, place-responsive green technology, and institutional coordination. This study used a structured integrative synthesis of peer-reviewed scholarship, Malaysian planning evidence, and national policy documents to derive and connect five dimensions: institutional governance, social capital, green technology, spatial and environmental context, and sustainability monitoring. The framework distinguishes four recurring terrain-settlement configurations (interior highland, riverine floodplain, coastal peat-lowland, and island or stilt settlement) and links each to source, technology, and governance choices. It also translates the National Water Resources Policy and Rural Development Policy 2030 into operational community-level planning actions. The paper contributes a policy-connected implementation logic for rural water planning rather than an empirically validated causal model. Its propositions should therefore be tested through comparative case studies and longitudinal performance assessment.

Keywords: Water resource security; community-based planning; social capital; green technology; rural development

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INTRODUCTION

Water resource security is a planning concern because reliable access depends on the interaction of source availability, water quality, infrastructure, affordability, governance, and the capacity to maintain services. Globally, rural populations continue to lag behind urban populations in safely managed drinking-water access (World Health Organization, 2023). In Malaysia, treated piped-water access is high overall but remains uneven between states and between urban and rural strata; this indicator should not be conflated with the more demanding international definition of safely managed drinking water (National Water Services Commission, 2022). The residual deficit is concentrated in places where conventional network extension is difficult and where failures have disproportionate consequences for health, livelihoods, and spatial equity.

Rural Malaysia combines climate exposure with demanding physical geography. Drought and intense rainfall can alter source reliability and turbidity, while dispersed settlements, river dependence, steep interiors, peat lowlands, and islands raise capital and maintenance costs (Fulazzaky et al., 2023; Sarbatly et al., 2023). Institutional fragmentation compounds these constraints: responsibilities for resource governance, service provision, rural development, land, and local planning are distributed across agencies and levels of government (Tuah et al., 2022). A uniform infrastructure response is therefore unlikely to be technically appropriate or institutionally sustainable.

Community-based planning offers a complementary response by combining local knowledge, collective responsibility, and external technical support. Evidence across rural water systems shows that participation can improve source protection, monitoring, maintenance, and legitimacy, but only when communities receive durable institutional backing and when roles are explicit (Aashiq et al., 2020; Lockwood & Smits, 2011; Souter et al., 2024). Green technologies can reduce energy and network dependence, yet their performance remains contingent on siting, water quality, operator capability, and access to parts.

This paper develops a Community-Based Water Resource Security Framework (CBWSF) for rural Malaysia. It asks how social capital, green technology, spatial conditions, and institutional arrangements can be organised within a single planning logic, and how that logic corresponds to Malaysia's National Water Resources Policy (NWRP) and Rural Development Policy (RDP) 2030. The contribution is conceptual and planning-oriented: it specifies dimensions, relationships, and decision points that can guide diagnosis and subsequent empirical testing.

LITERATURE REVIEW

Rural Water Insecurity as a Planning and Development Challenge

Rural water insecurity is produced by interacting environmental, spatial, socio-economic, and institutional conditions. Climate variability affects quantity and raw-water quality, while groundwater availability varies markedly across settings (Hosea & Khalema, 2021; MacDonald et al., 2021). In Malaysia, climate change increases pressure on resource management and demands more adaptive planning (Fulazzaky et al., 2023). Sabah's rural-water experience further demonstrates that terrain and geographical distance are primary barriers to extending conventional systems, strengthening the case for decentralised and context-specific options (Sarbatly et al., 2023).

Infrastructure alone does not secure service. Rural schemes often deteriorate when financing, spare parts, operator support, water-quality surveillance, or maintenance responsibilities are insufficient (Alvarado et al., 2022; Lockwood & Smits, 2011; Souter et al., 2024). Water-security assessments also show the value of multidimensional indicators rather than a single supply measure (Abdullah et al., 2024; Vieira et al., 2020). The planning problem is consequently one of spatial inequality, lifecycle management, and institutional coordination rather than construction alone.

These conditions require planners to connect settlement form and environmental sensitivity with service standards, implementation capacity, and local governance. A place-based framework should reveal which constraint is binding, who controls the relevant decision, and how performance will be monitored after handover.

Governance, Institutions, and Decentralised Water Management

Centralised and fragmented governance can weaken responsiveness because authority, finance, and operational knowledge are separated. Sarawak's infrastructure-planning experience illustrates coordination and implementation challenges in remote areas (Tuah et al., 2022). Comparative research likewise shows that decentralisation works only when local institutions have recognised authority, clear accountability, technical assistance, and dependable escalation routes (Prachanda Pradhan et al., 2022; Yu, 2014).

Community management should therefore be understood as co-production rather than state withdrawal. Public agencies retain responsibility for standards, capital support, surveillance, and corrective intervention; village institutions contribute contextual knowledge, day-to-day oversight, and collective action. Leadership ethics and accountability are relevant to this allocation of responsibility, while technical education must combine competence with stewardship (Bennett et al., 2018; Ismail et al., 2025; Kahsay et al., 2023; Kamaruding et al., 2026). The practical implication is a nested governance

arrangement: a representative local committee operates the system under a written agreement, district actors provide technical and administrative support, and state agencies maintain regulatory oversight. Such an arrangement reduces ambiguity without transferring unreasonable risk to volunteers.

Community-Based Planning and the Role of Social Capital

Social capital explains why similarly designed schemes can produce different outcomes. Bonding ties support mutual help within a settlement; bridging ties connect groups across communities and organisations; and linking ties provide access to authorities, expertise, and finance (Carmen et al., 2022; Putnam, 1995). Rural-water studies associate these relationships with participation, rule compliance, monitoring, and maintenance (Aashiq et al., 2020; Rasool et al., 2024; Simarmata et al., 2024). Social capital is not automatically inclusive. Dense networks can reproduce exclusion unless committee design, decision records, grievance channels, and representation requirements protect less powerful users. Sabah research on mutual assistance and intergroup harmony indicates that local networks can mobilise support across social boundaries, but these capacities should be translated into transparent institutional rules. Scholarship on local wisdom similarly supports treating community knowledge as a planning resource to be documented and critically assessed rather than romanticised (Muis & Sintang, 2026; Van Huynh et al., 2020).

Green Technology and Sustainable Rural Water Infrastructure

Decentralised green technologies including rainwater harvesting, gravity-fed supply, slow sand or biofiltration, and low-energy treatment can serve settlements for which conventional network extension is costly (Kumar & Choudhury, 2024; Shivaraju et al., 2024). Malaysian evidence on roof-collected rainwater highlights the need for quality control, while research on Sarawak peat water demonstrates that difficult raw-water chemistry requires treatment suited to local conditions rather than generic selection (Frichot et al., 2021; Rahman et al., 2023).

Technology is therefore a socio-technical choice. Source yield, raw-water quality, terrain, energy, storage demand, operator skill, consumables, and replacement parts must be evaluated together. Training and digital documentation may strengthen monitoring, but technology should support, not substitute for, local accountability and human judgement (Beal et al., 2023; Ismail et al., 2025; Li, 2024; Muis et al., 2026).

Existing studies establish the importance of governance, participation, local knowledge, and appropriate technology, but commonly examine them separately. Bennett et al., (2018), Folke et al., (2007) and Muis (2025) advances a local-wisdom-based water-management model; the present paper differs by specifying an integrated planning architecture in which social capital mediates

technology stewardship, spatial diagnosis constrains technology choice, and policy alignment defines institutional support. The unresolved conceptual task is to connect these elements to an operational sequence and explicit monitoring responsibilities.

Theoretical Foundations

Putnam's (1995) social capital theory provides the principal explanatory lens. Bonding, bridging, and linking relations are treated as distinct resources that can enable collective action, coordinate users, and connect rural communities to formal institutions. The framework does not assume that social cohesion is sufficient or uniformly beneficial; its effect depends on inclusive rules, accountability, and access to material and technical support. The CBWSF embeds social capital within a socio-technical planning system. Spatial conditions define feasible sources and infrastructure; institutions allocate authority and resources; green technology provides a service mechanism; and social relationships influence selection, operation, maintenance, and adaptation. Water security is the outcome of these interactions, assessed through reliability, quality, accessibility, and institutional sustainability.

RESEARCH METHODOLOGY

Conceptual Framework Development

This study uses a structured integrative conceptual synthesis to develop a planning framework rather than to estimate an empirical effect. The design follows guidance for theory-synthesis conceptual articles and integrative literature reviews, in which previously separate constructs are connected through explicit organising logic (Jaakkola, 2020; Snyder, 2019). The unit of analysis is the conceptual proposition linking a planning condition, an enabling mechanism, and a water-security implication. The evidence corpus was assembled purposively from peer-reviewed research and official Malaysian documents cited throughout the paper; it was not a preregistered or exhaustive systematic review and no claim of comprehensive coverage is made. This boundary is important because the method supports conceptual integration and analytical transferability, not bibliometric inference or population-level generalisation.

First, sources were retained when they informed at least one of four domains: rural water security outcomes; community governance and social capital; decentralised or green water technology; or rural spatial planning. Priority was given to peer-reviewed empirical or review studies, authoritative policy documents, and Malaysian or comparable rural contexts. Sources unrelated to water planning or unable to support the proposition for which they were cited were excluded. For each retained source, the relevant actor, constraint,

mechanism, outcome, and contextual condition were identified. Concepts were then coded deductively into availability, quality, accessibility, reliability, governance, collective capacity, technology fit, spatial constraint, and lifecycle monitoring. Apparent contradictions were treated as conditional differences, for example, community management performing differently depending on the level of technical support, rather than averaged into a universal claim. Relationships among these concepts were compared across the four domains. Recurring dependencies, such as institutional support for community maintenance and terrain constraints on technology choice, were retained as framework linkages, while isolated associations were not treated as causal evidence (Binder et al., 2013; McGinnis & Ostrom, 2014).

Second, the synthesis was grounded in rural Malaysia using water access data, sectoral planning evidence, and national policy. Contextual interpretation considered settlement dispersion, terrain, hydrology, raw water quality, institutional mandates, and rural development priorities. The official policy texts were read for objectives, core areas, thrusts, responsible actors, and implementation implications; the open-data indicator was interpreted according to its stated definition. Documentary interpretation was used to preserve policy meaning and historical context (Blasio & Sorice, 2016; Esa et al., 2025; Nugroho et al., 2015), while local-wisdom research informed the treatment of situated knowledge (Fallys et al., 2022; Muis, 2025; Muis & Sintang, 2026).

Third, the concepts were organised into five interacting dimensions: institutional governance, social capital, green technology, spatial and environmental context, and sustainability monitoring. A proposed linkage was included only when it had a plausible planning mechanism, support in the reviewed literature, and a corresponding diagnostic or implementation question. The dimensions were checked against three design criteria: conceptual distinctness, practical observability, and relevance to a planning decision. Redundant elements were consolidated, and policy correspondence was assessed only where the official wording provided a defensible match (Connell & Daoust-Filiatrault, 2018; Macmillan et al., 2016; Rudolf et al., 2017). **Figure 1** presents the resulting architecture. The procedure yields an analytically transparent framework, not an empirically validated model. It cannot establish effect sizes, causal direction, or relative weights among dimensions. Those questions require comparative field application, stakeholder validation, and longitudinal measurement; the framework's present purpose is to structure that research and planning process.

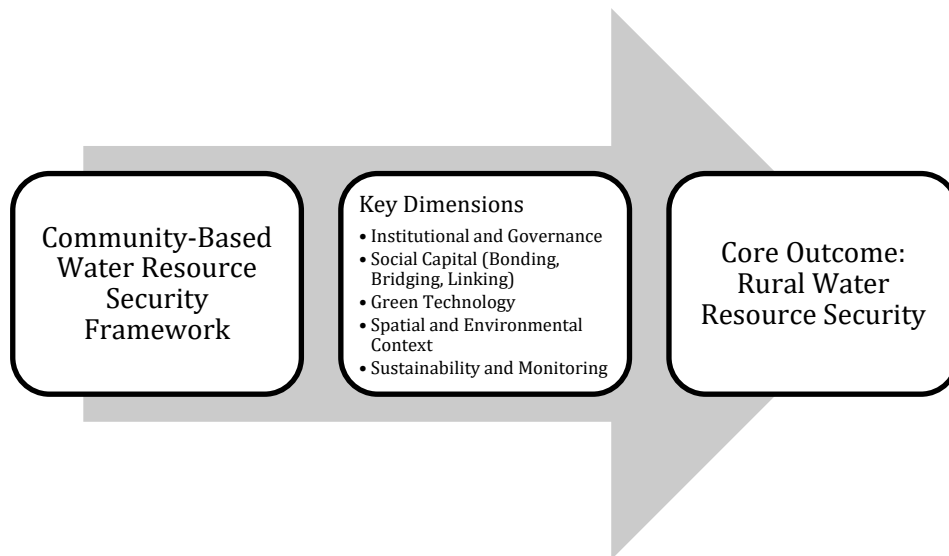


Figure 1: Community-Based Water Resource Security Framework (CBWSF).

ANALYSIS AND DISCUSSION

The Community-Based Water Resource Security Framework (CBWSF)

The CBWSF treats rural water security as an outcome of five interacting dimensions. It begins with a spatial and service diagnosis, selects a feasible source and technology, assigns institutional and community responsibilities, and establishes monitoring and escalation. No dimension is sufficient by itself: technically sound infrastructure may fail without maintenance, strong local cooperation may be ineffective without formal support, and policy alignment may remain symbolic without place-specific design. The framework is iterative because performance evidence can require redesign of technology, rules, finance, or support arrangements.

Core Dimensions of the CBWSF

Institutional and Governance Dimension

Institutional effectiveness requires an explicit division of responsibilities among water authorities, rural development agencies, district and local actors, and village organisations. Each scheme should identify the asset owner, operator, funding source, water-quality surveillance body, maintenance schedule, and escalation route. This converts participation from consultation into accountable co-production (Lockwood & Smits, 2011; Souter et al., 2024; Tuah et al., 2022).

Social Capital Dimension

Bonding capital supports routine cooperation; bridging capital broadens representation and exchange; and linking capital connects communities to technical, financial, and regulatory resources. The planning task is to cultivate all three through inclusive committee rules, recorded decisions, transparent contributions, and scheduled contact with external agencies (Carmen et al., 2022; Prachanda Pradhan et al., 2022).

Green Technology Dimension

Green technology is selected through fitness for context rather than novelty. Rainwater harvesting may suit islands or peat lowlands, gravity-fed systems may suit protected upland catchments, and modular treatment may suit riverine settlements, provided storage, quality control, energy, operator competence, and supply chains are adequate (Frichot et al., 2021; Kumar & Choudhury, 2024; Sarbatly et al., 2023).

Spatial and Environmental Dimension

Settlement dispersion, slope, flood exposure, peat conditions, salinity, catchment size, and access routes determine the feasibility and lifecycle cost of water options. These variables should be mapped before design because they shape source yield, treatment demand, construction logistics, maintenance access, and vulnerability to disruption. The assessment scale should match the decision: district mapping can screen settlement types and hazards, whereas scheme design requires site-level source, elevation, access, and water-quality data. Figure 2 is therefore an analytical transect, not a georeferenced inventory of all rural settlements.

Sustainability and Monitoring Dimension

Monitoring should combine service indicators (downtime, quantity, basic quality, user access, maintenance completion, and expenditure) with community feedback. Simple records can support adaptive management and district-level escalation; digital tools may improve continuity where connectivity and data governance are adequate (Muis et al., 2026). Monitoring remains a shared public-community responsibility rather than an unfunded local obligation.

Spatial and Topographical Constraints of Distantly Located Rural Settlements

In this paper, 'distantly located' refers not only to kilometres from an urban centre but to functional remoteness created by terrain, hydrology, access conditions, and weak network connectivity. **Figure 2** distinguishes four idealised but recurring configurations. Sabah evidence identifies terrain variation and geographical

distance as major rural-supply constraints, supporting decentralised solutions where network expansion is impractical (Sarbatly et al., 2023).

Interior highland settlements in the Crocker Range, interior Sabah, and upper Sarawak face steep slopes, difficult road access, and turbidity at upland intakes; gravity-fed systems may be feasible where catchments are protected. Riverine and floodplain settlements along corridors such as the Rajang, Baram, Kinabatangan, and Segama have accessible surface water but experience variable quality, inundation, and linear dispersion, favouring raised intakes, elevated storage, and modular treatment.

Coastal peat-lowland settlements confront acidic, highly coloured raw water, saline intrusion, and unstable ground; Sarawak treatment research confirms that peat-water chemistry materially affects technology choice (Rahman et al., 2023). Island and stilt settlements have limited catchment and groundwater options and may depend on communal rainwater storage or transported supply. These types can overlap; their purpose is diagnostic, linking the dominant spatial constraint to source choice, treatment, storage, access, and the CBWSF governance leverage point.

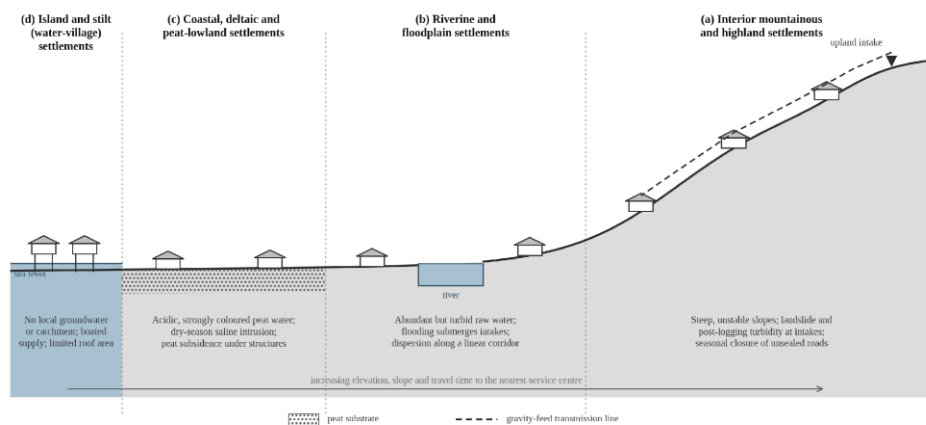


Figure 2: Idealised terrain transects of rural Malaysia.

Operational Logic of the Framework

Operationally, planners apply the CBWSF in six linked steps: (1) diagnose service deficits and terrain-settlement conditions; (2) identify feasible sources and risks; (3) assess community networks, representation, and capability; (4) select technology using lifecycle and operator criteria; (5) formalise roles, finance, maintenance, and escalation; and (6) monitor service and adapt. **Table 1** converts the five dimensions into planning questions and outputs.

Table 1: Key Dimensions of the CBWSF and Planning Relevance.

Framework Dimension	Key Elements	Planning Relevance
Institutional and Governance	Local authorities, water agencies, coordination mechanisms	Infrastructure planning, service delivery, policy alignment
Social Capital	Trust, networks, community participation	Community-based planning and governance
Green Technology	Rainwater harvesting, biofiltration, low-energy systems	Sustainable infrastructure solutions
Spatial and Environmental Context	Settlement pattern, land use, topography	Place-based and rural planning
Sustainability and Monitoring	Maintenance systems, feedback mechanisms	Long-term resilience and adaptive planning

Discussion: Planning, Policy, and Theoretical Implications

Implications for Rural Planning Practice

The CBWSF reframes rural-water planning from a standard asset-delivery exercise to a place-based service system. Its diagnostic sequence helps planners avoid two recurrent errors: selecting technology before understanding terrain and water quality and transferring facilities before defining support and maintenance. Application should produce a spatial diagnosis, technology options appraisal, inclusive governance agreement, lifecycle plan, and monitoring protocol.

Institutional and Policy Relevance

The framework complements the Water Sector Transformation agenda and national development planning by specifying a community-scale delivery mechanism. Its most direct policy anchors are the National Water Resources Policy and the Rural Development Policy 2030, launched in 2019. The CBWSF does not replace statutory mandates; it connects their principles to scheme-level decisions.

Alignment with the National Water Resources Policy and the Rural Development Policy

NWRP organises national action around water resource security, sustainability, partnerships, and capacity building. The CBWSF translates these areas into source integrity and risk diagnosis, stakeholder role allocation, community-agency partnerships, operator capability, and monitoring. Its spatial dimension supports NWRP's concern with resource integrity and disaster risk, while the institutional and social capital dimensions operationalise inclusive shared governance (Ministry of Natural Resources and Environment, 2012).

RDP envisions prosperous, inclusive, sustainable, and holistic rural development by 2030. The CBWSF contributes through comprehensive infrastructure, effective delivery and governance, human capital development, environmental stewardship, and integrated settlement planning (Ministry of Rural

Development, 2019). **Table 2** makes the correspondence explicit and identifies a practical output for each framework dimension.

The policies create a clear planning mandate but do not by themselves prescribe how a remote settlement should match terrain, technology, community capability, and inter-agency support. The CBWSF addresses that operational gap. Its place-based and adaptive logic also aligns with the Thirteenth Malaysia Plan 2026-2030's emphasis on resilient infrastructure and more balanced territorial development (Economic Planning Unit, 2025).

Table 2: Correspondence between the CBWSF, National Water Resources Policy, and Rural Development Policy

CBWSF dimension	Corresponding NWRP core area and thrust	Corresponding RDP thrust	Operational planning implication
Institutional and governance	Core Area 3 (Partnership): Thrust 7, stakeholder inclusiveness and engagement; Thrust 8, shared water resources governance	Effective delivery system and governance	Formal allocation of roles between state water authorities, district offices, and village institutions, recorded in a written operation and maintenance agreement
Social capital	Core Area 4: Thrust 9, capacity building and awareness, including joint programmes with higher learning institutions and non-governmental organisations; Core Area 3: Thrust 7	Quality human capital; prosperous rural living	Constitution of a village water committee with inclusive membership, supported by a recurring training cycle rather than a single handover briefing
Green technology	Core Area 1: Thrust 3, use of alternative water resources and sources	Comprehensive and advanced infrastructure	Technology selected against the terrain-settlement typology in Figure 2, with spare parts obtainable within the district
Spatial and environmental	Core Area 1: Thrust 2, water resources integrity; Core Area 2: Thrust 6, conservation and protection, including sensitivity mapping in physical planning	Sustainable biodiversity and environment; integrated housing, regional development, and rural settlement planning	Catchment sensitivity mapping and siting rules incorporated into district and local plans before scheme design
Sustainability and monitoring	Core Area 1: Thrust 1, water intelligence; Thrust 4, water-related disaster risk reduction, preparedness, and response	Effective delivery system and governance	Simple community-recorded indicators reported to district level, with a defined escalation route when performance falls

Theoretical Contributions

The theoretical contribution is a conditional account of social capital in rural infrastructure planning. Social capital is positioned neither as a substitute for public capacity nor as an inherently positive community attribute. It becomes productive when institutional support, inclusive rules, and technically appropriate assets convert relationships into reliable collective action. The framework's further contribution is to make spatial context a boundary condition: the same

social and institutional capacity may require different technologies and support arrangements across highland, riverine, peat-lowland, and island settings. Three propositions follow for empirical testing. First, bonding capital should improve routine operation only when rules and responsibilities are explicit. Second, bridging and linking capital should be more strongly associated with recovery from technical or climate disruption because they provide access to external resources. Third, the relationship between participation and service reliability should be mediated by technology-terrain fit and maintenance support. These propositions distinguish the framework from a descriptive list of desirable factors.

CONCLUSION

This paper develops a Community-Based Water Resource Security Framework that connects institutional governance, social capital, green technology, spatial context, and sustainability monitoring. The framework makes explicit that durable rural service depends on relationships among these dimensions rather than on infrastructure provision alone. For planning practice, the CBWSF provides a sequence for diagnosing terrain-settlement constraints, appraising sources and technology, allocating roles, and monitoring service. Its mapping to NWRP and RDP 2030 demonstrates how national principles can be translated into community-scale outputs while preserving public accountability. Figure 2 and Tables 1-2 provide concise tools for initial application. The framework remains conceptual. Future research should test its propositions across contrasting Malaysian settlement types using comparative case studies, participatory validation, and longitudinal indicators of water quality, reliability, access, cost, maintenance, inclusion, and institutional response. Such evidence is necessary before causal or performance claims can be made.

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