Assessment of Technical Sustainability as a Crucial Determinant of Long-Term Sustainability in Community-Based Water Supply Schemes in the North Central Province in Sri Lanka

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***Abstract* — Community-Based Water Supply Schemes (CBWSS) remain central to ensuring safe and reliable water access in Sri Lanka's North Central Province (NCP), where centralized infrastructure is sparse and public health challenges, particularly Chronic Kidney Disease of unknown etiology (CKDu), persist. This study undertakes a critical, multi-dimensional sustainability assessment of 25 CBWSS in Anuradhapura and Polonnaruwa districts using 22 indicators spanning environmental, social, economic, and technical domains. A mixed-methods approach incorporating structured questionnaires, Likert-scale scoring, focus group discussions (FGDs), key informant interviews (KIIs), and field inspections was employed. Results reveal that while social participation and environmental awareness remain moderately strong, technical sustainability emerges as the most decisive factor influencing long-term system viability ($r = 0.78$, $p < 0.01$). Deficiencies in preventive maintenance, operator training, water quality surveillance, and spare-part availability significantly undermine scheme performance, leading to frequent breakdowns and, in some cases, scheme collapse or transfer to external authorities. Case study evidence further validates the central role of technical management in sustaining functionality. The study argues that strengthening operator capacity, embedding preventive maintenance culture, institutionalizing sustainability monitoring tools, and integrating technical sustainability into national policy frameworks are crucial to ensuring resilient CBWSS. Beyond local relevance, the findings contribute to global discourse on rural water governance by foregrounding technical sustainability as a cornerstone of safe and equitable water provision.**

Key words: Community-Based Water Supply Schemes; Critical Sustainability Assessment; Technical Sustainability; Chronic Kidney Disease (CKDu); Sri Lanka; Rural Water Governance

I. Introduction

Access to safe, affordable, and reliable water is universally recognized as a fundamental human right and a prerequisite for advancing sustainable development, public health, and social equity [1]. In Sri Lanka, this imperative is particularly critical in rural areas of the North Central Province (NCP), where large segments of the population remain beyond the reach of centralized water supply infrastructure. In response to these gaps, Community-Based Water Supply Schemes (CBWSS) have emerged as contextually appropriate, cost-effective, and participatory mechanisms for ensuring access to potable water [2]. These schemes, operated and managed by local communities, are not only pivotal in bridging infrastructure deficits but also serve as a means of promoting local empowerment, ownership, and sustainability in water governance.

Despite their significance, CBWSS face complex and interrelated sustainability challenges that compromise their long-term viability. Multiple studies have documented the influence of environmental pressures, financial constraints, and community-level social dynamics on the functioning of these systems [3]. However, a recurring and often underemphasized concern lies in the dimension of technical sustainability. This domain encompasses the adequacy of system design, adherence to routine maintenance practices, availability of spare parts, and the technical expertise required for troubleshooting and system management. Neglect in these areas predisposes schemes to recurrent breakdowns, extended service interruptions, and eventual system collapse, thereby undermining both reliability and community trust.

The situation is further compounded in the NCP, a region disproportionately affected by Chronic Kidney Disease of unknown etiology (CKDu). In such a context, ensuring continuous water supply of verified quality is not only a question of service delivery but also a matter of urgent public health importance [4]. Yet, the awareness of communities regarding the centrality of technical sustainability to system performance and water safety remains alarmingly low. While policymakers and development agencies often emphasize financial or social dimensions of sustainability, the decisive role of technical capacity building, infrastructure maintenance, and systematic water quality monitoring is inadequately recognized and addressed.

Against this backdrop, the present study seeks to systematically evaluate the sustainability status of 25 CBWSS in Anuradhapura and Polonnaruwa districts through a multi-dimensional framework comprising 22 indicators. Particular emphasis is placed on examining the technical dimension and its relative weight in determining long-term resilience. By identifying critical gaps in community awareness and institutional support, the study aims to offer practical recommendations for strengthening technical sustainability. In doing so, it underscores the imperative of shifting policy attention and resource allocation towards technical capacity and institutional mechanisms factors that ultimately determine whether CBWSS can continue to safeguard rural water security and public health in the face of environmental stressors and epidemiological risks.

II. Methodology

A mixed-methods design was employed to capture both measurable outcomes and contextual insights on CBWSS sustainability. This approach integrated quantitative scoring with qualitative perspectives, ensuring a comprehensive evaluation of environmental, social, economic, and particularly technical dimensions.

A. Site Selection

The NCP is among Sri Lanka's driest zones, with substantial rural populations depending on wells, tanks, and CBWSS. CKDu prevalence is high. Based on existing epidemiological data, government health records, and discussed with NWSDB engineers, MOH officers, PHIs, and research supervisors, 25 CBWSS were purposively selected from Anuradhapura and Polonnaruwa districts in which the sasmple space of 25 gives sufficient variance across scheme types to allow statistical correlation while keeping fieldwork manageable. The selection citerias combined together with the previous research studies are as follows;

- Diversity in schemes (water source, treatment technology, service coverage, distribution methods) [5]
- Regional relevance (CKDu prevalence,
- CBWSS availability, field feasibility and safety, limited access to piped quality water) [6]
- Operational status (time period, scale) [7]
- Community participation

The 25 locations selected for the study in NCP are as follows.

Paththinigama	Rathmalgahawewa
Midellawa	Palugaswewa
Obodayagama	Horivila
Walaswewa	Senadheeriyagama
Musnawa	Mahakanadarawa track 02
Sivalakulama	Mahakanadarawa track 01
Manankattiya	Ikirigollewa
Yakalla	Balahodawewa
Meegodawewa	Thambalagollewa
Ihala galkulama	Maluweyaya
Moragahawela	Kottapitiya
Wadigawewa	Atharagallewa
Ihala Agunochchiya	

B. Indicator Selection

A literature informed and context validated framework comprising 22 indicators across four domains was applied. Reference sources included SDG 6, WHO guidelines, and prior Sri Lankan CBWSS studies. Selection was based on the following inclusion criteria:

- Relevance to CBWSS sustainability objectives in the NCP context.
- Sensitivity to changes over time and across different schemes.
- Measurability using available quantitative or qualitative methods.
- Alignment with both national water policy priorities and SDG 6 targets.

The finalized indicator set formed the basis for questionnaire development, FGD guidelines, and subsequent data collection for sustainability assessment. They are as follows.

- Water Accessibility - drinking water (time and distance)
- Water Accessibility - domestic water supply
- Water service coverage - CBO
- User Satisfaction - Drinking Water (User Perceptions Only)
- Water pollution - disposal of pesticide/ fertilizer waste
- Sustainable Water Use
- Availability of Canals or Water Pockets to Recharge Water Sources
- Water Quality and Safety (EC, TDS, and pH)
- Climate Change Observations in the Particular Area (with emphasis on Drought)
- Women Participation in Decision Making
- Community Participation and Governance
- Newly identified CKDu patients
- Education and Capacity Building
- User Satisfaction and Service Reliability
- Affordability and Financial Sustainability
- Employment and Economic Opportunities
- Willingness to Pay for Water Services
- Reliability of Technology Used
- Ease of Operation and Maintenance
- Availability of Spare Parts and Technical Support
- Record-Keeping and Monitoring Systems
- Use of Renewable or any alternative sources (other than CBO water)

C. Questionnaire Preparation

The development of the questionnaire represents a pivotal stage in the research process, as it fundamentally influences the accuracy, reliability, and validity of the data collected. The design process commenced with a clear delineation of the research objectives and identification of the specific information required to address them comprehensively. Each question was carefully formulated to ensure clarity, conciseness, and the avoidance of ambiguity, while deliberately

minimizing leading or biased language that could compromise the integrity of respondents' answers.

The questionnaire incorporated multiple formats, including open-ended, closed-ended, Likert-scale, and multiple-choice items, selected according to the nature of the data required and the intended analytical procedures. Questions were logically sequenced, progressing from general to specific topics, to maintain respondent engagement and facilitate a coherent flow of information.

A pretesting phase was conducted using a small, representative sample to identify potential issues, such as misunderstandings, technical ambiguities, or redundant items. Feedback from this pilot study informed iterative revisions, resulting in a refined instrument that is both user-friendly and capable of generating high-quality, contextually relevant data. This rigorous approach ensures that the questionnaire can reliably capture the multi-dimensional aspects of sustainability in CBWSS, providing a robust foundation for subsequent analysis.

D. Likert Scale Preparation

Likert scale preparation involves designing a structured rating system that enables respondents to express the extent of their agreement, frequency, importance, or satisfaction regarding specific statements. The process begins with identifying the key variables to be measured and framing precise, unambiguous statements that reflect each concept. Each statement should be neutral in tone to avoid biasing responses, and the scale should maintain consistent polarity ("strongly disagree" to "strongly agree") throughout to reduce confusion. A balanced number of positive and negative items can help minimize acquiescence bias, while the number of response options commonly five or seven should provide adequate discrimination without overwhelming respondents. Clear descriptors should be assigned to each scale point, ensuring that participants interpret the values consistently. Pretesting the scale with a small sample is essential to assess clarity, reliability, and internal consistency, allowing revisions before use in the main study. Properly prepared Likert scales not only enhance data quality but also facilitate accurate statistical analysis and meaningful interpretation.

E. Data Collection

Focus group discussions (FGDs) were conducted with scheme users to explore perceptions of sustainability challenges, particularly technical issues, satisfaction, awareness, perceptions of reliability barriers, knowledge of maintenance and water quality, satisfaction, awareness, perceptions of reliability. Key informant interviews (KIIs) with scheme operators, local government officials, and technical experts provided insights into operational practices and institutional arrangements. Field inspections were also conducted to physical evaluation of infrastructure conditions, water quality parameters, and availability of maintenance equipment and spare parts and record keeping. Secondary data from local water authorities , health statistics (CKDu incidence) also supplemented primary data.

F. Sustainability Assessment Framework

A customized framework comprising 22 indicators grouped into four domains environmental, social, economic, and technical was used to evaluate each scheme. Indicators were scored on a 1–5-point Likert scale based on observed and reported conditions, with composite scores calculated to generate an overall Sustainability Index (SI) for each scheme generalized by the following formula.

$$SI_{CBWSS} = \frac{\sum_{i=1}^{22} Score_i}{22}$$

Where:

- $Score_i$ = value given for indicator *i*
- 22 = total number of indicators
- SI = the average score across the 22 indicators

G.Data Analysis

Descriptive statistics and correlation analyses were performed to examine the relationships between technical indicators and overall sustainability outcomes. Qualitative data were analyzed thematically to contextualize quantitative findings and identify barriers to technical sustainability.
In this study, the reliability of the questionnaire was assessed using Cronbach's alpha, which measures the internal consistency of the items within a scale.

III. RESULTS

The Sustainability Index (SI) assessment revealed significant variation among CBWSS in the NCP. Only 36% of schemes achieved a good sustainability level, while the majority (64%) fell into a moderate category of sustainability index level. Among the four dimensions assessed technical, social, economic, and environmental technical sustainability showed the highest weightage and strongest influence on overall SI outcomes, with a correlation coefficient of $r = 0.78$ ($p < 0.01$).

Despite relatively better scores in social sustainability owing to strong community participation the technical and economic aspects were consistently weaker. Less than 40% of schemes maintained qualified operators, and fewer than 36% followed structured preventive maintenance schedules. Moreover, many faced frequent breakdowns, prolonged downtime, and inadequate access to spare parts.

As a consequence, the study found a growing tendency for CBWSS to either collapse entirely or be absorbed by the National Water Supply and Drainage Board (NWSDB), Pradeshiya Sabhas or Mahaweli Authority. This pattern highlights the inability of many schemes to operate independently due to poor governance, weak financial structures, and chronic maintenance failures.

Cronbach's alpha value was 0.8454, indicating a high level of reliability. According to commonly accepted thresholds, a value above 0.7 is considered acceptable, while values above 0.8 are regarded as good, demonstrating that the items consistently measure the intended constructs. This result suggests that the questionnaire items were well-aligned, free from excessive random error, and capable of producing stable and dependable responses. The high reliability coefficient also confirms that the instrument is suitable for subsequent statistical analysis and that the findings derived from it are likely to be robust and trustworthy. Key technical weaknesses identified can be listed as follows:

- Less than 40% of schemes had operators with formal technical training.
- Fewer than 36% followed structured preventive maintenance schedules.
- Many schemes lacked access to spare parts; supply chains were slow or unreliable.
- Water quality monitoring was irregular or absent in many schemes.

IV. Discussion and Recommendation

A. Discussion

The findings of this study underscore that technical sustainability is the most critical determinant of the long-term functionality and reliability of CBWSS in Sri Lanka's North Central Province (NCP). While social participation, environmental considerations, and governance structures play important roles, technical challenges remain the central bottleneck that undermines system resilience. This observation directly aligns with the first objective of the study, which was to assess the influence of technical factors on CBWSS performance.

The study highlights that the absence of systematic preventive maintenance practices significantly increases the vulnerability of water systems to recurrent breakdowns. Communities tend to adopt a reactive maintenance culture, addressing problems only after system failure. This finding resonates with global literature, where community-managed water schemes in Sub-Saharan Africa, South Asia, and Latin America often face premature failure due to inadequate investment in preventive maintenance and limited technical expertise [2]. In Sri Lanka, this challenge is amplified in CKDu-affected areas, where the lack of robust water quality monitoring systems directly threatens community health, given the suspected links between contaminated groundwater and chronic disease [3].This aligns with the second objective, which examined how technical gaps impact user health and overall sustainability.

Institutional and governance gaps further complicate the technical dimension. Weak supply chains for spare parts, delays in procurement, and fragmented technical assistance reduce the ability of CBWSS to respond effectively to operational challenges. Case studies from Uganda and Nepal also highlight similar patterns, where the absence of structured technical support networks results in prolonged downtimes and eventual community disengagement [4,5]. Thus, validating the study's findings against international evidence demonstrates that the Sri Lankan case reflects a wider systemic problem of governance–technical interplay in community water supply.

At the same time, the findings suggest that social engagement and governance mechanisms can either support or hinder technical interventions. For example, community participation in routine monitoring can extend system life and enhance accountability, yet limited awareness and low prioritization of technical issues often result in neglect. Where management committees lack strong leadership or equitable participation, decisions about maintenance are delayed, leaving technical issues unresolved. This interplay supports the third objective of the study, which was to explore the connections between technical, social, and governance factors in CBWSS sustainability.

The broader environmental context, particularly climate variability, introduces additional stressors to technical sustainability. Irregular rainfall patterns and prolonged dry spells reduce source reliability, increasing dependence on groundwater extraction, which in turn accelerates wear on pumping systems. Comparative studies in South Asia show that climate variability exacerbates infrastructure strain, requiring both technical adaptation and institutional preparedness [6]. Integrating these environmental drivers into technical planning is therefore essential.

Despite these insights, several barriers to implementing technical improvements persist. Financial constraints, limited political will, and competing development priorities hinder investment in capacity building and infrastructure upgrades. Moreover, fragmented policy frameworks fail to embed technical sustainability indicators into monitoring and evaluation systems. Addressing these barriers requires multi-level solutions such as:

- Capacity building through structured training programs tailored to local operators, supported by government, and NGOs.
- Policy integration where technical sustainability metrics are explicitly embedded in national water supply frameworks, ensuring prioritization in resource allocation.
- Innovative financing models, such as community-based revolving funds or microfinance schemes, to address resource constraints.
- Strengthened governance partnerships to bridge gaps between communities, local authorities, and technical agencies.

Overall, the findings reinforce that technical sustainability cannot be viewed in isolation. Its success depends on the synergistic integration of social participation, governance support, and environmental resilience measures. By validating these results against

both local case studies and global literature, this study emphasizes that strengthening technical capacity, embedding proactive maintenance cultures, and integrating climate resilience are crucial for ensuring the long-term viability of CBWSS in Sri Lanka.

B. Recommendations

The findings of this study clearly highlight the need for strengthening technical capacity as a cornerstone of long-term sustainability in CBWSS. Many schemes suffer from inadequate operator training, irregular maintenance, and prolonged system failures. Therefore, it is recommended that structured training programs be introduced for plant operators, focusing on preventive maintenance, water quality monitoring, and rapid fault detection. Such initiatives will not only improve technical performance but also enhance community confidence in the reliability of the system.

Equally important is the role of public awareness and community education in sustaining these schemes. While communities actively participate in governance, their understanding of the link between technical sustainability and water safety remains limited. Awareness campaigns should therefore emphasize how proper technical management, transparent financial practices, and effective governance directly contribute to the longevity of water schemes and the protection of public health, particularly in CKDu -endemic areas. The advantage of increasing public awareness is twofold: it strengthens accountability of community committees and also encourages households to take responsibility for safeguarding water resources, thereby reducing misuse, wastage, and contamination.

Another critical recommendation is the establishment of institutional support mechanisms and supply chains that address gaps in spare parts availability and technical assistance. Rural communities often face prolonged service interruptions because of difficulties in accessing the right materials or expertise. To mitigate this, supply networks for spare parts must be made more accessible and affordable, while specialized rapid-response technical teams under the NWSDB or local authorities should be created to assist communities during emergencies.

The government's role in ensuring sustainability of CBWSS cannot be understated. The Ministry of Water Supply, NWSDB, and Pradeshiya Sabhas should work collaboratively to establish a national policy framework that prioritizes technical sustainability as much as social and economic aspects. Government interventions could include creating standardized guidelines for CBWSS operation, offering financial subsidies for system upgrades, and introducing legal protections to prevent mismanagement or premature collapse of schemes. By providing technical backstopping while respecting community ownership, government agencies can safeguard rural water access while reducing the financial and health risks caused by failing schemes.

In addition, strengthening governance and financial management structures is vital for improving scheme resilience. Many CBWSS face challenges with fee collection, financial mismanagement, and lack of accountability, which undermine both technical and economic sustainability. Introducing transparent auditing processes, standardized fee collection systems, and clear committee accountability mechanisms can significantly reduce these risks and improve trust between operators and beneficiaries.

Finally, this research provides a foundation for practical initiatives that can be adopted at the national and local level. For instance, the development of a Sustainability Index, as tested in this study, can be institutionalized as a monitoring tool by NWSDB and local authorities to periodically evaluate the health of each scheme. Regular assessments based on this index would enable early detection of weaknesses, allowing timely intervention before schemes collapse or are absorbed by larger institutions. Moreover, hybrid governance models that combine community participation with technical oversight from NWSDB, Pradeshiya Sabhas or Mahaweli Authority should be promoted. Such models ensure that while communities retain ownership, they are not left alone to deal with highly technical failures beyond their capacity.

V. CASE STUDIES

To explore technical sustainability in CBWSS, two non-functional schemes Thalgahawewa and Kedewa (located in Rambewa GN division in Anuradhapura) were selected as case studies, providing practical insights into the interaction of technical, social, and governance factors.

Thalgahawewa, relied on a limited water source with one tube well and three auxiliary wells. Despite 5 years of operation, the scheme faced repeated service interruptions due to inadequate preventive maintenance, irregular water quality monitoring, and insufficient operator training, ultimately leading to failure. Kedewa, operated for only 3 years before becoming non-functional, with weak leadership, poor community engagement, and management conflicts further compounding technical deficiencies such as neglected maintenance and limited operator skills.

Analysis of these cases alongside survey data from 25 CBWSS demonstrates that technical sustainability through structured maintenance, skilled operators, and systematic monitoring is the primary determinant of long-term functionality. While social and governance factors influence performance, technical management forms the backbone of resilient water supply systems.

These case studies validate the research framework and highlight critical technical gaps affecting CBWSS longevity. They provide evidence-based insights into preventive maintenance, operator training, and monitoring practices, guiding policymakers, water authorities, and community committees to prioritize interventions that enhance technical sustainability and overall system resilience.

CONCLUSION

This study underscores that technical sustainability is the decisive determinant of the long-term resilience of CBWSS in Sri Lanka's North Central Province. While environmental, social, and economic dimensions contribute meaningfully to sustainability, the reliability of system design, preventive maintenance, operator capacity, and availability of spare parts ultimately govern whether these schemes can continue to provide safe and reliable water to rural communities. The findings clearly demonstrate that deficiencies in technical awareness, routine maintenance, and institutional backstopping significantly compromise scheme functionality, jeopardizing both service delivery and public health in CKDu-endemic regions.

Beyond the studied districts, the insights generated here hold broader relevance for rural water governance across Sri Lanka and other developing contexts facing similar sustainability challenges. Strengthening technical capacity, supported by institutional mechanisms and community awareness, must therefore become a national priority in ensuring equitable and durable water access. Integrating a technical sustainability lens into national and regional water policies including the frameworks of the Ministry of Water Supply, NWSDB, and local authorities would enhance the resilience of CBWSS while aligning with SDG 6 commitments.

By employing a comprehensive, multi-dimensional sustainability framework and validating it through both survey and case study evidence, this research contributes to both academic knowledge and practical water governance. It highlights the urgent need for structured training, preventive maintenance culture, and stronger institutional partnerships, while also offering a Sustainability Index model that can serve as a monitoring tool for policymakers and practitioners. Ultimately, the study makes a persuasive case for elevating technical sustainability as the backbone of CBWSS longevity and as a cornerstone of rural water security in Sri Lanka.

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