Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

# Who Owns the Tank? Governance, Knowledge and Operational Responsibilities for Decentralized Water Systems in Caribbean SIDS

**ALANA SIZAA MAHABIR**

alanasizaa@gmail.com

UNIVERSITY OF THE WEST INDIES, TRINIDAD https://orcid.org/0009-0007-9068-7932

**Allan Edwards**

UNIVERSITY OF THE WEST INDIES, TRINIDAD

**SANDRA SOOKRAM**

UNIVERSITY OF THE WEST INDIES, TRINIDAD

**Hazi Azamatullah**

UNIVERSITY OF THE WEST INDIES, TRINIDAD

**Research Article**

**Keywords:** school rainwater harvesting, water security, KAP survey, readiness index, Trinidad and Tobago

**Posted Date:** November 12th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-10195162/v1

**License:** This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

**Additional Declarations:**
**Author Contributions**

Alana S. Mahabir conceptualized the study, developed the research framework, coordinated the data collection and analysis, interpreted the findings, and prepared the original manuscript draft. Allan Edwards contributed technical data support, institutional knowledge, and review of the water-resources context relevant to the study. Sandra Sookram provided supervisory guidance, contributed to the socio-cultural and policy framing of the study, reviewed the methodology and interpretation of results, and critically revised the manuscript for intellectual content. Hazi Azamathulla provided supervisory guidance on the engineering and water-resources components of the study. All authors reviewed, edited, and approved the final version of the manuscript for submission.

**Conflict of Interest Statement**

The authors declare that there are no conflicts of interest associated with this manuscript.

**Who Owns the Tank? Governance, Knowledge and Operational Responsibilities for Decentralized Water Systems in Caribbean SIDS**


## ABSTRACT

Decentralized rainwater harvesting (RWH) systems are increasingly promoted to improve water security in schools affected by intermittent mains supply. The long-term sustainability of decentralized RWH systems depends on both infrastructure and the institutions that operate and maintain them. This study evaluates the implementation readiness of school-based RWH systems in Trinidad and Tobago using a Knowledge, Attitudes, Practices, and Barriers (KAP-B) survey administered to representatives from 18 schools with installed RWH systems.

We developed the Readiness100 Index, a 0–100 score based on KAP indicators to measure institutional preparedness and guide operational decisions  The overall readiness level was moderate to high (mean = 74.83; SD = 9.42), and reliability was strong across KAP-B domains (Cronbach's $\alpha$ = 0.887–0.976). Readiness was strongly associated with knowledge (Spearman's $\rho$ = 0.830, $p < 0.001$), while schools equipped with solar-powered pumping systems demonstrated significantly higher readiness levels than those without solar pumping ($U = 1.00$, $p = 0.004$).

Qualitative responses highlighted recurring challenges related to financing, maintenance capacity, staff training, technical support, water-quality monitoring, and access to solar-powered pumping. The findings indicate that school RWH systems should be managed as social and operational infrastructure rather than simply as water-storage assets. To support sustainable implementation, a transferable framework is proposed for Caribbean Small Island Developing States (SIDS) and similar contexts. It integrates readiness assessment and targeted training. It funds operation and maintenance, supports solar pumping for delivery, establishes routine water-quality monitoring, and puts contingency plans in place to sustain sanitation during supply disruptions.



Keywords: school rainwater harvesting, water security, KAP survey, readiness index, Trinidad and Tobago

# 1.0. INTRODUCTION

Adequate water is essential for schools: it provides drinking water and enables handwashing, cleaning and sanitation. Where supplies are unreliable, schools can face health risks, service interruptions, and even closures. In water-scarce settings, the education sector has been highlighted as particularly vulnerable; many schools experience insufficient and unreliable water supplies, and associated health concerns can disrupt schooling (Gibberd, 2021).

Although Trinidad and Tobago is not water-scarce by conventional per-capita metrics, the reliability and equity of potable water supply remain persistent challenges. Although national per-person figures look adequate, many communities, and some schools still suffer intermittent supply, which disrupts hygiene and restroom services (Peters et al., 2013). Unreliable school water disrupts teaching, harms hygiene and increases administrators' workloads. Framing school water security in this way positions rainwater harvesting not only as a technical intervention, but also as an investment in educational continuity, student wellbeing and basic service resilience.

Against this backdrop, rainwater harvesting (RWH) is widely recognised as a practical coping strategy for improving water security at household and institutional scales, especially where public supply is intermittent or coverage is uneven. Peters et al. (2013) report that communities in Trinidad adopt RWH when conventional supplies are unreliable; Dean et al. (2012) link household uptake to gaps in water infrastructure.

However, the effectiveness of RWH systems is not determined solely by infrastructure presence (tanks, gutters, pipes), but also by management practices, user knowledge, and routine maintenance. Public health concerns are critical when harvested rainwater is used for handwashing or food preparation. A Trinidad study emphasised that when considering harvested rainwater as a major drinking water source, two critical issues include contamination risks and whether stored water can become a breeding source for mosquitoes (Dean et al., 2012). These concerns are especially salient in tropical contexts, where stored water, if poorly designed or maintained, can unintentionally create vector habitats.

Sustainability requires regular operation and maintenance, a designated responsible person, and basic water-safety measures. Provide schools with hands-on training and simple resources to lower the O&M workload (Dao et al., 2021; Huq et al., 2024). This also raises an institutional and governance question: Who should bear responsibility for recurrent financing, maintenance, water-quality monitoring, and eventual replacement? In practice, the sustainability of school-based RWH depends not simply on ownership of the tank but on clear assignment of accountability, budgetary support, and access to technical oversight.

**Conceptual Framework and Research Gap**

This study adopts the practical logic that knowledge, attitudes, and practices (KAP) shape the quality and consistency of RWH operation and maintenance in schools and therefore influence implementation readiness and longer-term sustainability outcomes. Knowledge of system components, water-quality risks, and routine controls supports correct operation and prevention of public-health risks in stored rainwater systems (Dean et al., 2012). Attitudes such as perceived usefulness, perceived safety, and perceived manageability shape willingness to prioritise RWH and allocate effort/resources, consistent with acceptance-oriented framing in the RWH literature (Suni et al., 2025). Routine cleaning, safe storage and other operational controls shape system performance and affect ongoing acceptance and use (Dean et al., 2012). Figure 1 shows the conceptual link between KAP, readiness and sustainability:




*Figure 1. Conceptual Framework (KAP => Readiness => Sustainability)*

Two gaps motivate the study. First, while RWH is widely promoted as a practical institutional solution, school-specific evidence and guidance remain limited in many contexts (Gibberd, 2021). Second, Trinidad-focused evidence raises explicit concerns about contamination and mosquito breeding risks and the underlying question of whether system owners possess the knowledge and skills to manage these risks adequately (Dean et al., 2012), yet the literature provides limited empirical quantification of how KAP levels within institutions translate into readiness and sustained performance in school settings.

Beyond describing KAP patterns, the central contribution of this study is the operationalization of school-based RWH sustainability as a measurable readiness problem. We turn institutional knowledge, attitudes, and practices into a 0–100 Readiness100 score that school managers, water agencies and education-sector decision-makers can use. This is important because decentralized water systems often fail because of unclear responsibility, weak operational knowledge, insufficient maintenance funds, poor water-quality oversight, and low user confidence. Readiness100 therefore provides a practical screening tool for identifying where installed RWH systems are more likely to function as dependable school water services, and where targeted support is required before sustainability risks become operational failures.

The index supplements technical assessments (engineering audits, rainfall yield modelling, water-quality tests) by measuring the institutional and behavioural factors that affect whether staff understand, maintain,

and trust RWH systems. In this sense, the study fills a gap in the RWH literature by linking decentralized water infrastructure to implementation readiness, operational responsibility and service continuity on small islands.

### 1.1. Aims and Objectives

Accordingly, this paper empirically examines KAP relating to school-based RWH in Trinidad and Tobago and summarises implementation readiness using a composite index. Specifically, the study: (i) assesses KAP levels across Knowledge, Attitudes, Practices, and Barriers; (ii) constructs and reports a Readiness100 (0–100) index derived from composite Knowledge, Attitudes, and Practices; (iii) tests differences in readiness and KAP by operational category (solar-powered pumping vs. non-solar) and region using non-parametric methods; and (iv) examines associations among readiness, KAP domains, and selected operational indicators to identify practical leverage points for strengthening sustainable school-based RWH.

## 2.0. Study Design and Sample

This study uses a cross-sectional, descriptive-analytical design to assess knowledge, attitudes, and practices (KAP) relating to school-based rainwater harvesting (RWH) systems in Trinidad and Tobago. Data were collected at the school level using a structured questionnaire administered in person (paper-based). The unit of analysis was the school, represented by one designated respondent (e.g., principal, vice principal, senior teacher, or staff member with responsibility for school operations and/or the RWH system).

Schools were selected from a sampling frame of institutions reported to possess RWH systems, obtained from National Institute of Higher Education, Research, Science and Technology (NIHERST). Eligible schools were contacted and invited for participation. The final sample included 18 schools (n = 18), with one questionnaire completed per school.

### 2.1. Instrument and measures

The questionnaire comprised four KAP domains, each with eight items: Knowledge (K1–K8), Attitudes (A1–A8), Practices (P1–P8), and Barriers (B1–B8). Responses were recorded using 5-point ordinal scales: For Knowledge and Attitudes use an agreement scale (1 = Strongly disagree to 5 = Strongly agree); for Practices use a frequency scale (1 = Never to 5 = Always); for Barriers use a severity scale (1 = Not a barrier to 5 = Major barrier).

Four composite scores were computed to summarise each domain: K_score, A_score, P_score, and B_score. Each composite score was calculated as the mean of its corresponding eight items (e.g., K_score as the mean of K1–K8). Higher scores indicate increased knowledge, more positive attitudes, and more frequent RWH practices and stronger perceived barriers.

To provide a single interpretable implementation-readiness measure, a Readiness100 index (0–100) was derived from the Knowledge, Attitudes, and Practices composite scores. First, each composite was transformed onto a 0–100 scale using:

**K100 = ((K_score − 1) / 4) × 100; A100 = ((A_score − 1) / 4) × 100; P100 = ((P_score − 1) / 4) × 100.**

Readiness100 was then computed as the average of the domain indices using MEAN.2(K100, A100, P100). This function requires at least two non-missing domain values.

Three criteria guided the construction: interpretability, operational relevance and transferability. A 0-100 scale was chosen as it allowed readiness to be communicated clearly to non-specialist decision-makers while retaining the underlying KAP structure. Knowledge was included because school personnel must understand system components, contamination pathways, mosquito-breeding risks and basic operational controls. Attitudes were included because perceived usefulness, safety and manageability influence whether RWH is prioritized as a legitimate school water-security asset. Practices were included because routine cleaning, safe storage, inspection and use behaviours determine whether the system can provide reliable support during interruptions in mains supply.

Perceived barriers were analysed separately rather than incorporated into the Readiness100 score because barriers represent external or systemic pressures that may constrain readiness even when school-level knowledge and practices are positive. This separation allows the index to distinguish between internal preparedness and external implementation constraints such as financing, procurement, technical support, water-quality testing and security. The resulting structure makes Readiness100 a diagnostic tool: schools with low readiness require capacity-building and operational support, while schools with high readiness but high barriers require institutional, financial or technical interventions.

### 2.2. Data Processing and Analysis

Data was analysed in IBM SPSS Statistics. Reliability was assessed using Cronbach's alpha. Due to small sample size (n = 18) and ordinal scales, we ran nonparametric tests at $\alpha = 0.05$: Mann–Whitney U (two groups), Kruskal–Wallis H (≥3 groups), and Spearman's rho (associations among composites and Readiness100). Categorical associations were assessed using chi-square/Fisher's exact tests as appropriate. Open-ended responses (G1–G3) were thematically coded to identify key themes.

## 3.0. RESULTS AND DISCUSSION

### 3.1. Sample Profile and Overall KAP/Readiness

Eighteen schools with school-based rainwater harvesting (RWH) systems participated. The sample comprised schools from the North (n = 3), South (n = 5), and East (n = 10). Four schools had solar-powered

pumping; fourteen did not. Eleven schools were primary and seven were secondary. These characteristics are summarised in Table 1, and the regional distribution is illustrated in Figure 2.

*Table 1. Sample composition (n=18)*

| Grouping variable | Categories | n |
|---|---|---|
| Region | North/South/East | 3/5/10 |
| Has solar-powered pumping | Yes/No | 4/14 |
| School level | Primary/Secondary | 11/7 |

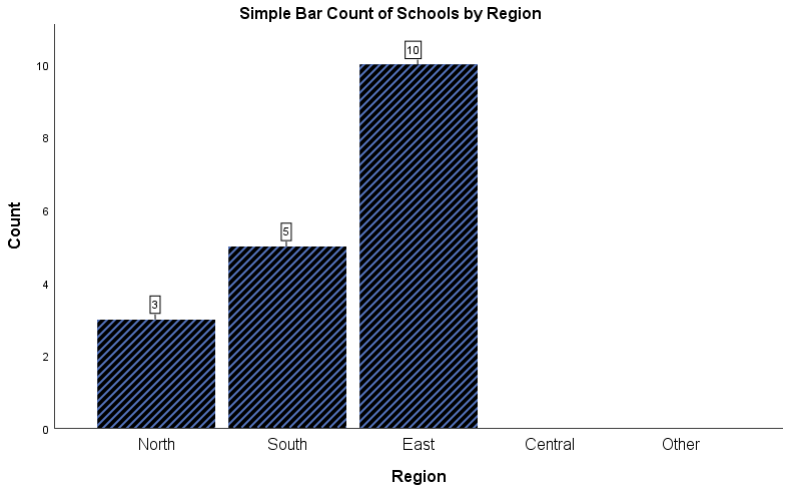



*Figure 2. Bar chart of Schools by Region*

Composite KAP scores, perceived barriers, and the Readiness100 index are presented in Table 2, with a domain comparison shown in Figure 3. Overall, knowledge scores were high (mean = 3.92, SD = 0.77), attitudes were generally favourable (mean = 3.79, SD = 0.61), and practices were strong (mean = 4.26, SD = 0.41). Perceived barriers were moderate (B_score mean = 3.03, SD = 0.50). The overall readiness index indicated moderate-to-high implementation readiness (Readiness100 mean = 74.83, SD = 9.42; range: 51.04–92.71).

*Table 2. Composite KAP scores, barriers and readiness (n=18)*

| Variable | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| K_score | 18 | 2.00 | 5.00 | 3.9236 | 0.77191 |
| A_score | 18 | 2.63 | 5.00 | 3.7917 | 0.60785 |
| P_score | 18 | 3.50 | 5.00 | 4.2639 | 0.40649 |
| B_score | 18 | 2.00 | 3.75 | 3.0347 | 0.50148 |
| Readiness100 | 18 | 51.04 | 92.71 | 74.8264 | 9.42084 |

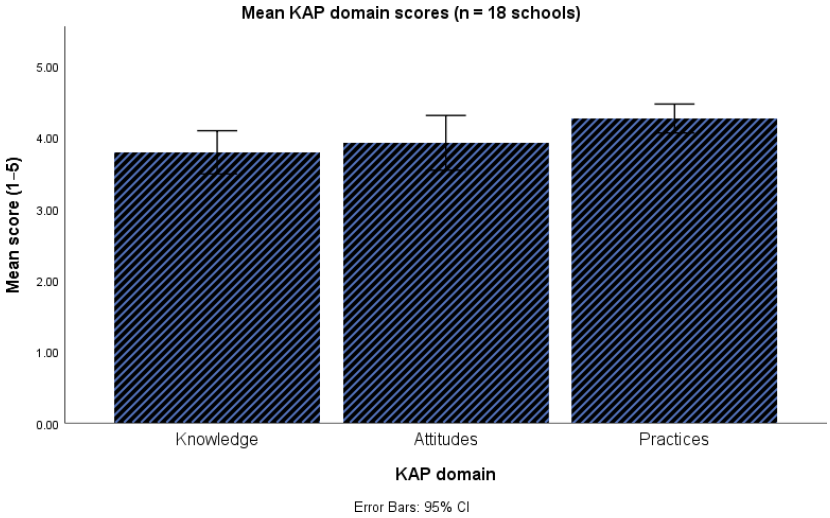



*Figure 3. KAP domain comparison*

The four KAP domains were internally consistent (Knowledge α = 0.976; Attitudes α = 0.948; Practices α = 0.890; Barriers α = 0.887), which justifies using composite scores for analysis (Table 3).

*Table 3. Internal consistency of KAP and barriers scales*

| Scale | Items | Cronbach's Alpha |
|---|---|---|
| Knowledge (K1-K8) | 8 | 0.976 |
| Attitudes (A1-A8) | 8 | 0.948 |
| Practices (P1-P8) | 8 | 0.890 |
| Barriers (B1-B8) | 8 | 0.887 |

Although item-level tables are not reproduced here (to comply with conference space constraints), responses showed better understanding of core system components and basic functions than of operational and routine risk-management details. This reinforces that sustainability depends not only on infrastructure but on consistent O&M behaviours and basic water-safety controls over time (Gikas, 2012; Gwenzi et al., 2015).

### 3.2. Key group differences: Solar powered pumping and regional patterns

The most practically important quantitative result was the difference by solar-powered pumping status. As shown in Table 4, schools with solar-powered pumping had significantly higher readiness ($U = 1.00$, $Z = -2.888$, $p = 0.004$; large effect $r = 0.681$) and higher knowledge ($U = 8.00$, $Z = -2.141$, $p = 0.032$; $r = 0.505$) compared with non-solar schools. Attitudes, practices, and barriers did not differ significantly by solar status ($p > 0.05$), though attitudes showed a near-significant trend ($p = 0.069$).

*Table 4. Mann-Whitney U results: solar vs non-solar schools (n=18)*

| Outcome | Mean Rank (No solar) | Mean Rank (solar) | U | Z | P (2-tailed) | Effect size r |
|---|---|---|---|---|---|---|
| K_score | 8.07 | 14.50 | 8.000 | -2.141 | 0.032 | 0.505 |
| A_score | 8.29 | 13.75 | 11.000 | -1.816 | 0.069 | 0.428 |
| P_score | 8.61 | 12.63 | 15.500 | -1.347 | 0.178 | 0.317 |
| B_score | 9.00 | 11.25 | 21.000 | -0.759 | 0.448 | 0.179 |
| Readiness100 | 7.57 | 16.25 | 1.000 | -2.888 | 0.004 | 0.681 |

Solar pumping was associated with greater system usability during outages, but the solar subgroup was small (n=4), so the finding is preliminary and best treated as a clear implementation signal for future scale-up evaluation.

Regional differences were also observed. Table 6 shows that readiness differed by region (H(2)=6.043, p=0.049, $\varepsilon^2$=0.27): South schools had lower readiness than North and East. Knowledge differences approached conventional significance (H(2) = 5.721, p = 0.057; $\varepsilon^2$ = 0.25), while attitudes, practices, and barriers did not differ significantly across regions. Exploratory pairwise tests for readiness (Table 5) indicated significant differences between North vs South and South vs East, but these were treated as exploratory due to small subgroup sizes and multiple comparisons. Consistent with broader school water literature, such geographic patterns support the need for tailored support rather than uniform strategies (Khalil and Mahmoud, 2022). From an equity perspective, regional gaps in preparedness can cause inconsistent sanitation and hygiene protection across schools. This suggests that implementation support should not only be context-sensitive, but also deliberately targeted to less prepared regions. Doing so will stop decentralized water systems from reinforcing territorial inequalities in school resilience.

*Table 5. Exploratory pairwise Mann-Whitney U comparisons for Readiness100 by Region (unadjusted p-values)*

| Comparison | U | Z | P (2-tailed) | Exact p | Effect size r |
|---|---|---|---|---|---|
| North vs South | 0.000 | -2.263 | 0.024 | 0.036 | 0.800 |
| North vs East | 14.000 | -0.170 | 0.865 | 0.937 | 0.047 |
| South vs East | 8.000 | -2.101 | 0.036 | 0.040 | 0.542 |

*Table 6. Kruskal-Wallis tests by Region (mean ranks and overall test results)*

| Outcome | North mean rank | South mean rank | East mean rank | H | Df | P | $\varepsilon^2$ |
|---|---|---|---|---|---|---|---|
| K_score | 13.17 | 4.90 | 10.70 | 5.721 | 2 | 0.057 | 0.25 |
| A_score | 9.00 | 6.90 | 11.25 | 2.526 | 2 | 0.283 | - |
| P_score | 9.17 | 8.30 | 10.20 | 0.449 | 2 | 0.799 | - |
| B_score | 10.50 | 8.70 | 9.60 | 0.230 | 2 | 0.891 | - |
| Readiness100 | 12.33 | 4.60 | 11.10 | 6.043 | 2 | 0.049 | 0.27 |

### 3.3. Associations among KAP, readiness and operational reliability indicators

Readiness correlated strongly with knowledge ($\rho = 0.830$, $p < 0.001$); other correlations were positive but not significant; see Table 7 for full values. These results underscore the need for targeted capacity-building that converts knowledge into correct operation, basic safety, and routine maintenance (Barthwal et al., 2014). Water reliability days and mains outage frequency showed a very strong negative correlation ($\rho = -0.884$, $p < 0.001$).

*Table 7. Key Spearman correlations (ρ) among readiness, KAP domains and operational indicators (n=18)*

| **Relationship** | **Spearman ρ** | **p (2-tailed)** | **Interpretation** |
|---|---|---|---|
| Readiness100 ←→ K_score | 0.830 | <0.001 | Strong positive, significant |
| Readiness100 ←→ A_score | 0.434 | 0.072 | Moderate positive, not significant |
| Readiness100 ←→ P_score | 0.384 | 0.116 | Moderate positive, not significant |
| Readiness100 ←→ B_score | -0.121 | 0.633 | Very weak, not significant |
| Water_Reliability_Days ←→ Mains_Outages_Freq | -0.884 | <0.001 | Very strong negative, significant |
| B_score ←→ Water_Reliability_Days | 0.427 | 0.077 | Moderate positive, borderline |
| B_score ←→ Mains_Outages_Freq | -0.424 | 0.079 | Moderate negative, borderline |

A categorical check found no evidence that solar-powered pumping was concentrated in either primary or secondary schools (Fisher's exact two-sided $p = 1.000$), implying that solar pumping may be feasible across school levels rather than being confined to one type of institution.

The strong link between Readiness100 and knowledge shows the index reflects practical preparedness, not just positive attitudes toward RWH. This matters for environmental management because decentralized water systems are often installed as climate or water-security interventions, but their long-term performance depends on whether local institutions can operate, maintain and monitor them. In this study, Readiness100 functions as an implementation-readiness screen that can help agencies prioritize support. Lower-readiness schools can be targeted for training, simplified O&M guidance and closer follow-up, while higher-readiness schools can be supported through maintenance financing, water-quality testing and resilience upgrades such as solar pumping.

Use Readiness100 as a screening tool to guide support; not as a direct measure of system performance. It identifies where the social, institutional and operational factors enhance or undermine sustained RWH systems. For journal publication, this distinction is important: Readiness100 is not presented as a universal

performance score, but as a replicable screening approach that helps connect school-level behaviour and governance capacity with environmental service continuity.

Although the empirical data are drawn from Trinidad and Tobago, the decision problem examined in this study is highly transferable to Caribbean SIDS and other small-island school systems. Many islands experience a mismatch between aggregate water availability and reliable access at the point of use, particularly where rainfall seasonality, drought, ageing distribution networks, energy interruptions and uneven maintenance capacity affect service continuity. Schools are especially sensitive to these disruptions because water availability underpins sanitation, handwashing, cleaning, food preparation, and core functions that keep schools operating safely.

The transferability of the study lies in the readiness logic rather than in the exact numerical thresholds observed in this small sample. Readiness100 can be adapted across island settings by retaining the core domains of knowledge, attitudes and practices. This should be coupled with local rainfall regimes, governance arrangements, school infrastructure, public health requirements and water quality standards. This makes the approach useful for ministries of education, water utilities, water-resources agencies and disaster-risk or climate-adaptation programmes seeking to move beyond one-off infrastructure installation toward managed, monitored and equitable decentralized water services.

For small-island systems, this framing is particularly important because school RWH sits at the intersection of climate adaptation, public health, infrastructure governance and social equity. Without a readiness assessment, decentralized systems may reproduce existing territorial inequalities: schools with better leadership, technical support or financing may sustain functional systems, while lower-capacity schools may inherit assets that deteriorate, create water quality risks or fail during the very outages they were designed to mitigate. A transferable readiness framework helps schools fairly prioritize training, fund routine maintenance, track system performance, and plan resilience upgrades.

### 3.4. Qualitative findings and implications

Qualitative responses (G1–G3) provide direct explanation for the quantitative patterns. Schools reported water interruptions that hurt sanitation and handwashing. Many said rainwater harvesting served as a backup, and solar pumps were needed to keep water flowing to taps during outages. Across responses, RWH was described as an operational buffer during outages, and many schools explicitly identified solar pumping as a practical requirement to maintain water delivery to use points during outages.

The dominant constraints and requested supports were also clear. Fifteen of 18 schools cited funding limitations; twelve reported limited maintenance/O&M capacity; thirteen requested training and technical

guidance; and eight raised water-quality monitoring and treatment needs. When asked what would improve sustainability, schools most often requested practical O&M support (15/18), training/technical support (15/18), and basic water-quality testing/treatment resources (13/18), with solar pump support packages also commonly requested (12/18). These theme frequencies are summarised in Table 8 and visualised in Figure 4. A key implication is that policymakers must account for full lifecycle costs, not just installation; including maintenance, water-quality testing, pumping and repairs and eventual replacement. Recurring O&M expenses are offset by costs avoided when water is reliable; fewer sanitation interruptions, less lost class time and lower administrative effort.

*Table 8. Frequency of dominant themes in open-ended responses (n=18)*

| **Theme** | **G1 count** | **G2 count** | **G3 count** |
|---|---|---|---|
| Water outages / intermittent supply | 18 | 5 | 0 |
| Sanitation (washrooms/toilets/handwashing) | 18 | 4 | 8 |
| Solar pumping/energy backup | 18 | 15 | 12 |
| Maintenance and O&M capacity | 8 | 12 | 15 |
| Water quality / treatment / monitoring | 0 | 8 | 13 |
| Funding / budget constraints | 4 | 15 | 11 |
| Policy / approvals / procurement | 0 | 5 | 6 |
| Need for training / technical support | 0 | 13 | 15 |
| Security / vandalism | 0 | 3 | 3 |

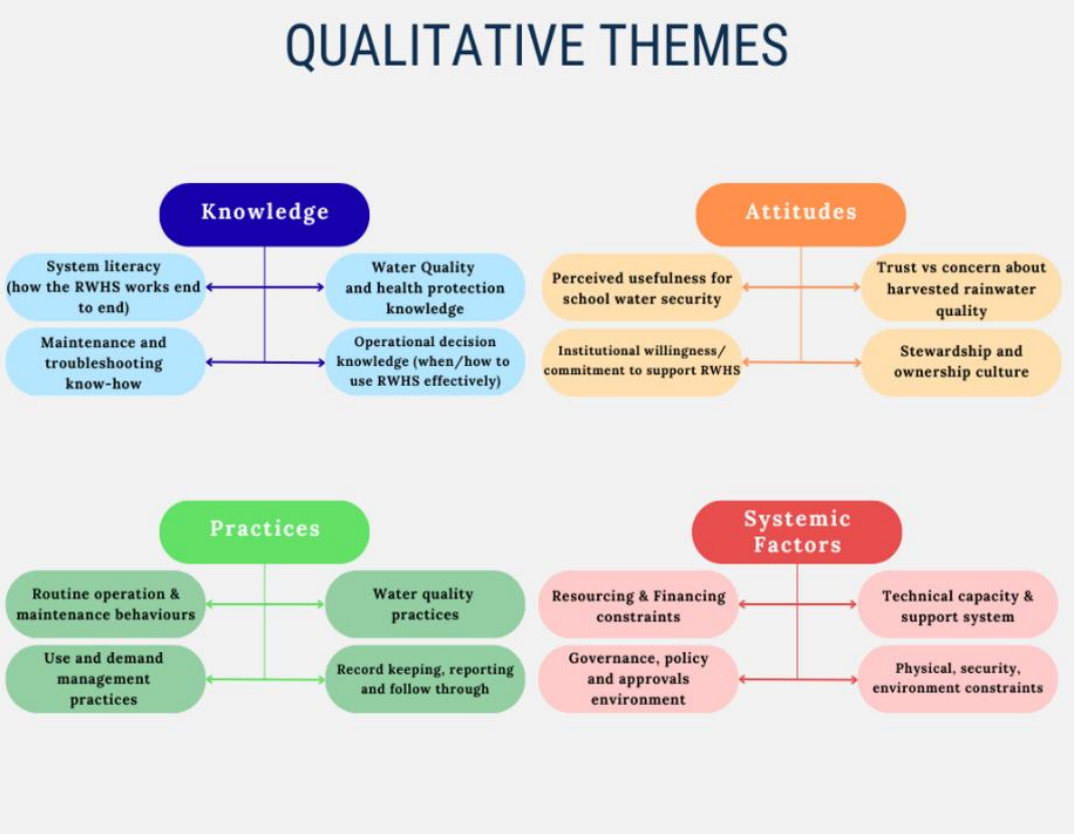



*Figure 4. Qualitative Themes Map*

The findings point to a pragmatic implementation pathway: sustainability is most likely to improve when schools receive not only infrastructure but also structured operational supports such as simple O&M routines (gutters, first flush, tank hygiene), assignment of responsibility within schools, accessible technical guidance/training, and (where appropriate) solar-powered pumping as a resilience upgrade.

On this basis, adopting a managed service is recommended: each school appoints an RWH custodian, uses a one-page O&M checklist, and follows a defined repair escalation route; consider solar pumping where appropriate. The second step is practical training: school personnel should receive brief, regular refresher sessions (e.g., quarterly) with simple checklists and a named technical contact. Training should be treated as recurrent capacity-building rather than a one-time handover activity.

The third step is recurrent O&M financing. Sustainable RWH requires a budget line for cleaning, minor repairs, replacement fittings, pump servicing, water-quality testing, mosquito-proofing and eventual component replacement. Without recurrent financing, the system remains a capital asset without a service model. The fourth step is resilience-oriented upgrades, particularly solar pumping when gravity-fed supply is inadequate or power outages make stored rainwater unreliable. In this study, solar pumping increased readiness by sustaining water delivery and boosting schools' confidence in their rainwater-harvesting systems.

The fifth step is routine water-quality and vector-risk management. Schools should have access to basic

testing protocols, periodic microbiological screening where water is used near human contact, treatment guidance where appropriate, and clear procedures for managing tank covers, screens, overflows and stagnant water. The sixth step is monitoring and feedback. Readiness100 can be used together with days of water reliability, pump functionality, cleaning schedule completion and reported disruptions to spot when a system shifts from stable operation to at-risk. This creates a practical feedback loop linking readiness assessment to school sanitation continuity, allowing agencies to identify when a system is moving from functional resilience toward unmanaged risk.

### 3.5. Policy and Management Implications

School RWH should be treated as a service: Ministries, school boards and water agencies should budget for both installation and ongoing O&M, assign clear ownership, train staff, schedule regular water-quality checks and establish a rapid technical-response protocol. Where these supports are absent, schools may technically "own" a tank but lack the capacity, budget or authority to ensure that it delivers safe and reliable water when needed.

## 4.0 CONCLUSION

This study assessed knowledge, attitudes, and practices (KAP) related to school-based rainwater harvesting (RWH) systems in Trinidad and Tobago using school-level responses from 18 schools (n = 18), grouped by region, school level, and solar-powered pumping status. Overall, participating schools demonstrated positive knowledge ($\bar{K}$ = 3.92, SD = 0.77), generally favourable attitudes ($\bar{A}$ = 3.79, SD = 0.61), and strong reported practices ($\bar{P}$ = 4.26, SD = 0.41), alongside moderate barriers ($\bar{B}$ = 3.03, SD = 0.50) and moderate-to-high readiness (Readiness100 mean = 74.83, SD = 9.42). Importantly, the KAP and barriers scales showed acceptable-to-excellent internal consistency ($\alpha$ = 0.887-0.976), supporting the reliability of the composite measures used for interpretation and comparison.

Across domains, practices scored highest, indicating that many schools reported routine operational actions aligned with sustaining RWH use (e.g., use for hygiene needs and periodic checks). Nevertheless, sustainability risks persist because the main obstacles are water quality and safety, policy restrictions, initial cost, vandalism, and limited space; issues that can undermine long-term success unless RWH is managed with clear accountability and basic water-safety measures.

The inferential findings highlight two practical implications for improving school RWH sustainability. Two practical points: readiness strongly correlates with knowledge (Spearman $\rho$ = 0.830, $p < 0.001$), underscoring the value of capacity building. Schools with solar pumps showed higher readiness and knowledge (readiness U = 1.00, p = 0.004; knowledge U = 8.00, p = 0.032), though the solar subgroup is small, so this should be interpreted cautiously.

Regional results further indicate that context matters: readiness differed significantly by region (Kruskal-Wallis $H(2) = 6.043$, $p = 0.049$; $\varepsilon^2 = 0.27$), with South schools showing lower readiness ranks than North and East in this dataset. These differences point to the value of targeted support where readiness appears comparatively weaker, especially when the goal is to ensure equitable functionality and benefits of RWH across schools. The findings suggest that school-based RWH functions as both water and social infrastructure: it increases supply during outages, maintains sanitation, and keeps schools operating. Its value lies not only in augmenting supply during outages, but in supporting safe sanitation, preserving school functionality, and strengthening institution resilience; accordingly, sustainable scale-up will require recurrent financing, clear assignment of responsibility and targeted support to lower-readiness schools.

Given that the sample is small and self-reported, this should be treated as an implementation-readiness pilot; not a definitive performance evaluation of all school RWH systems in Trinidad and Tobago. The Readiness100 index provides a structured and transparent way to summarize preparedness, but it should be validated in larger samples and combined with engineering condition assessments, rainfall-yield analysis and independent water-quality testing. This limitation does not diminish the study's practical value. It clarifies that the index is best used for early screening and prioritization in environmental management and school water security planning.

The main contribution of this study is the reframing of school rainwater harvesting as an implementation-readiness challenge. The index identifies whether schools have the knowledge, attitudes and practices needed to use RWH reliably. In the Trinidad and Tobago sample, readiness was moderate to high overall, but the results also showed that knowledge, solar-powered pumping and regional context had a measurable influence on readiness. These findings indicate that decentralized school water systems require structured support, not only installation.

For Caribbean SIDS and other small-island school systems, the findings support a practical shift from "install and hand over" approaches toward managed-service models for decentralized water infrastructure. Sustainable school RWH requires assigning of clear responsibility; set up recurrent financing, train staff, provide technical support, install solar pumps where needed, run routine water-quality tests and control mosquito breeding sites. When these elements are linked through a readiness-based monitoring framework, RWH can contribute not only to water supply augmentation, but also to safer sanitation, educational continuity and climate-resilient public service delivery. Future research should validate the Readiness100 index across larger samples, integrate objective water-quality and engineering performance data, and test whether targeted training and O&M support measurably improve school water reliability over time.

## 5.0 DECLARATIONS

**Funding**

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

**Availability of Data and Materials**

The data are available from the corresponding author upon reasonable request.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

## 6.0 REFERENCES

Ahmed, W., T. Gardner, and S. Toze. "Microbiological Quality of Roof-Harvested Rainwater and Health Risks: A Review." Journal of Environmental Quality 40 (2011): 13-21. https://doi.org/10.2134/jeq2010.0345.

Asmuni, Shahariah, Ruzita Baah, Sabariah Yusoff, and Fatin Nabilah Sofea Ahmad Ridzuan. "Public Acceptance and Preference Towards Rainwater Harvesting in Klang Valley, Malaysia." Journal of Emerging Economies and Islamic Research 4 (2016), Special Issue.

Ayog, Janice Lynn, Salinah Dullah, and Rosdianah Ramli. "Harvested Rainwater Quality Assessment on the Effects of Roof Materials to the First Flush Runoff." Transactions on Science and Technology 3, no. 1-2 (2016): 271-276.

Barthwal, Sonali, Sanchit Bansal, Puneet Soni, and Satinder S. Randhawa. "Socio-economic acceptance and willingness to pay for rooftop rainwater harvesting: A case study of the city of Chandigarh, India." Urban Water Journal 11, no. 3 (2014): 231-239. https://doi.org/10.1080/1573062X.2013.765494.

Dao, Dung A., Son H. Tran, Huyen T. T. Dang, Viet-Anh Nguyen, Cuong V. Do, and Mooyoung Han. "Assessment of rainwater harvesting and maintenance practice for better drinking water quality in rural areas." AQUA—Water Infrastructure, Ecosystems and Society (2021). https://doi.org/10.2166/aqua.2021.076.

Dean, Jonathan M. E., Fredericka Deare, Keizel Kydd, Jennie Ward-Robinson, and Paul R. Hunter. "Rainwater harvesting in rural Trinidad; a cross sectional, observational study." Journal of Water,

Sanitation and Hygiene for Development 2, no. 4 (2012): 241-249. https://doi.org/10.2166/washdev.2012.102.

Dobbie, Mark F., Robert R. Brown, Ataur Rahman, and Timothy Werner. “Independent roof-harvested rainwater supply systems: An evaluation of the social, environmental and economic benefits.” npj Clean Water 2 (2019): 7. https://doi.org/10.1038/s41545-019-0030-5.

Gibberd, Jeremy. “Designing School Rainwater Harvesting Systems in Water-Scarce Developing Countries.” In Rainwater Harvesting for the 21st Century, 153-170. CRC Press, n.d. [Early working draft].

Gikas, Georgios D., and Vassilios A. Tsihrintzis. “Assessment of water quality of first-flush roof runoff and harvested rainwater.” Journal of Hydrology 466-467 (2012): 115-126. https://doi.org/10.1016/j.jhydrol.2012.08.020.

Gwenzi, Willis, Nothando Dunjana, Charity Pisa, Tonny Tauro, and George Nyamadzawo. “Water quality and public health risks associated with roof rainwater harvesting systems for potable supply: Review and perspectives.” Sustainability of Water Quality and Ecology (2015). https://doi.org/10.1016/j.swaqe.2015.01.006.

Huq, Md. Habibul, Md. Mafizur Rahman, and G. M. Jahid Hasan. “Social perception on rainwater harvesting and wastewater reuse: Opportunities and challenges of a fast-growing township in Dhaka.” Cleaner and Responsible Consumption 12 (2024): 100168. https://doi.org/10.1016/j.clrc.2024.100168.

Igbinosa, I. H., I. T. Aighewi, E. O. Egharevba, and F. A. Eghomwanre. “Assessment of the Quality of Harvested Rainwater Used in Schools and Health Care Facilities in a Rural Community in Benin City.” University of Lagos Journal of Basic Medical Sciences 6, nos. 1-2 (2018): 89-95.

Jamal, A. H. M. Shofiul Islam Molla, Yeasin Arafat Tarek, Md. Abu Bakar Siddique, Md. Aftab Ali Shaikh, Sumon Chandra Debnath, Md. Ripaj Uddin, and Shamim Ahmed, et al. “Development of a fabricated first-flush rainwater harvested technology to meet up the freshwater scarcity in a South Asian megacity, Dhaka, Bangladesh.” Heliyon 9 (2023): e13027. https://doi.org/10.1016/j.heliyon.2023.e13027.

Kassem, Y., H. Gökçekuş, A. Kiraz, and A. H. A. Abdelnaby. “Integrating Rainwater Harvesting and Solar Energy Systems for Sustainable Water and Energy Management in Low Rainfall Agricultural Region: A Case Study from Gönyeli, Northern Cyprus.” Sustainability 17 (2025): 8508. https://doi.org/10.3390/su17188508.

Khalil, Reem. “Assessment of drinking water quality at public schools at Jenin Directorate of Education, Palestine.” Desalination and Water Treatment (2022): 196-206. https://doi.org/10.5004/dwt.2022.28874.

Lay, J. J., J. R. Vogel, J. B. Belden, G. O. Brown, and D. E. Storm. “Water Quality and the First-Flush Effect in Roof-Based Rainwater Harvesting, Part II: First Flush.” Water 16 (2024): 1421. https://doi.org/10.3390/w16101421.

Martinson, D. B., and T. H. Thomas. “Quantifying the First-Flush Phenomenon: Effects of First-Flush on Water Yield and Quality.” In Proceedings of the 12th International Conference on Rain Water Catchment Systems (IRCSA), 2005.

Maykot, J. K., I. C. Martins Vaz, and E. Ghisi. “Characterisation of First Flush for Rainwater Harvesting Purposes in Buildings.” Water 17 (2025): 1772. https://doi.org/10.3390/w17121772.

Memon, Noorani A., Khemchand L. Khatri, Junaid A. Chan, Imtiaz Sohoo, and Jing Zhou. “Public perceptions and perspectives on alternative sources of water for reuse generated at the household level.” Journal of Water Reuse and Desalination 12, no. 1 (2022): 157-174. https://doi.org/10.2166/wrd.2022.002.

Nandi, Santosh, and Vinay Gonela. “Rainwater harvesting for domestic use: A systematic review and outlook from the utility policy and management perspectives.” Utilities Policy 77 (2022): 101383. https://doi.org/10.1016/j.jup.2022.101383.

Peters, Everson J., Daniesh Despot, Kaseima Ragbersingh, and Nikhyl Iyer. “Willingness to pay for improved water services in Trinidad.” Proceedings of the Institution of Civil Engineers - Water Management (2013). https://doi.org/10.1680/wama.12.00128.

Ross, Tara T., Mohammad A. Alim, and Ataur Rahman. “Simple and effective filtration system for drinking water production from harvested rainwater in rural areas.” Journal of Environmental Management 373 (2025): 123887. https://doi.org/10.1016/j.jenvman.2024.123887.

Seo, Eun-Jung, Tae-Yeon Kim, and Tae-Ho Kang. “The Effect of a Rainwater Education Program on South Korean Students’ Awareness and Attitudes.” Environmental Engineering Research 18, no. 2 (2013): 77-84. https://doi.org/10.4491/eer.2013.18.2.077.

Snelling, Andrea M., Jessica Lamond, Glyn Everett, Emily C. O’Donnell, Sangaralingam Ahilan, and Colin Thorne. “Public perceptions of rainwater harvesting (RWH): comparing users and non-users of RWH systems.” Urban Water Journal 21, no. 2 (2024): 181-189. https://doi.org/10.1080/1573062X.2023.2281310.

Suni, S., M. H. Firdaous, F. F. Zailani, S. Gödeke, R. Mohd Raffi, and P. E. Abas. “Urban Water Management and Public Acceptance of Rainwater Harvesting Systems: Insights from Young and Educated Respondents in Muslim Communities.” Sustainability 17 (2025): 3046. https://doi.org/10.3390/su17073046.

Vele, Livhuwani, Eunice Ubomba-Jaswa, and Joshua Nosa Edokpayi. “Perception and acceptability of the public towards the use of harvested rainwater in water scarce regions.” Water and Environment Journal 38 (2024): 500-508. https://doi.org/10.1111/wej.12944.

Verma, Shrey, Shubham Mishra, Subhankar Chowdhury, Ambar Gaur, Subhashree Mohapatra, Archana Soni, and Puneet Verma. “Solar PV powered water pumping system - A review.” Materials Today: Proceedings (2020). https://doi.org/10.1016/j.matpr.2020.09.434. (Corrected proof; volume/issue/pages not assigned in the PDF.)

Vidal, P., A. M. Leiva, G. Gómez, M. Salgado, and G. Vidal. “Water Quality of Rainwater Harvesting Systems: A Review of Physical-Chemical and Microbiological Standards.” Resources 13 (2024): 159. https://doi.org/10.3390/resources13110159.