



# Drivers of Variance in Rural Water Service Sustainability: Evidence from Semi-Arid Tanzania

Lusajo Japhet Kamwela<sup>1,2</sup>, Norbert J. Ngowi<sup>1</sup> & Venosa A. Mushi<sup>1</sup>

<sup>1</sup>Mzumbi University, Tanzania

<sup>2</sup>Tengeru Institute of Community Development, Arusha, Tanzania

## Article History

Received: 2025.11.01

Revised: 2026.04.22

Accepted: 2026.04.30

Published: 2026.05.06

## Keywords

Financing

Hierarchical regression

Institutions

Water service

## How to cite:

Kamwela, L. J., Ngowi, N. J., & Mushi, V. A. (2026). Drivers of Variance in Rural Water Service Sustainability: Evidence from Semi-Arid Tanzania. *Journal of Research and Academic Writing*, 3(1), 123-137.

Copyright © 2026



## Abstract

Despite significant investments in rural water infrastructure, many systems in semi-arid areas such as Chemba District continue to experience declining service levels, frequent breakdowns, and premature failure, raising critical concerns about the long-term sustainability of water service delivery. This study examined rural water service sustainability variation in semi-arid Tanzania using cross-sectional household survey data from 384 respondents in Chemba District. Sustainability was assessed using a composite index of perceived service levels, namely water quality, quantity adequacy, reliability, accessibility, and affordability as proxies for the continued functioning of rural water services. Explanatory conditions were captured as composite indices representing financial conditions, institutional arrangements, technical performance, social organisation, and environmental stressors. Hierarchical multiple regression was used to estimate the incremental contribution of each domain to observed sustainability variation. Sustainability outcomes varied widely (mean 3.02; SD 0.95; range 1.00 to 5.00). The baseline model with socio-demographic controls explained a small and statistically insignificant share of variation ( $R^2$  0.095;  $p$  0.227). Adding financial conditions produced the largest improvement in explanatory power ( $\Delta R^2$  0.223;  $p$  0.001). Institutional arrangements added a modest contribution ( $\Delta R^2$  0.060;  $p$  0.053). Technical performance did not improve model fit once finance and institutions were included ( $\Delta R^2$  0.000;  $p$  0.907), while social organisation and environmental stressors added small, statistically insignificant increments ( $\Delta R^2$  0.017;  $p$  0.306; and  $\Delta R^2$  0.024;  $p$  0.219). The final model was statistically significant and explained 41.9 percent of the variation in sustainability outcomes ( $R^2$  0.419; adjusted  $R^2$  0.297;  $p$  0.005), with low multicollinearity. These results indicate that financial and institutional factors significantly explain variations in sustainability, reflecting the central role of effective management, timely availability of funds, and accountability mechanisms in maintaining service delivery. In contrast, technical performance did not significantly improve the model, suggesting that the mere presence of infrastructure is



insufficient to ensure sustainable services in the absence of strong financial and institutional support. The study highlights the importance of strengthening governance and financing systems to improve rural water service sustainability in resource-constrained settings like Chemba.

---

## **Introduction**

Despite substantial investments in rural water infrastructure over recent decades, a large proportion of systems still experience declining service levels, intermittent functionality, or complete failure within a relatively short period after construction (Lebu et al., 2024; Bazaanah & Mothapo, 2023). This situation has been widely documented across Sub-Saharan Africa and points to a persistent gap between expanding infrastructure coverage and the long-term delivery of reliable water services (George-Williams et al., 2024).

In response to these challenges, national water policy and research have gradually shifted from an infrastructure-focused approach to a service-delivery perspective. Under this perspective, sustainability is not viewed as a static outcome achieved at the point of construction, but rather as the ongoing ability of a water service to deliver acceptable levels of quality, quantity, reliability, accessibility, and affordability over time (Kosoe et al., 2025). Using cross-sectional survey data, we captured the current state of service-delivery, which reflects accumulated system performance and management decisions over time. From this viewpoint, sustainability is shaped by a combination of financial capacity, institutional arrangements, technical performance, social organisation, and environmental conditions that interact throughout the life-cycle of a water service.

A substantial body of empirical research has examined rural water sustainability by identifying factors associated with system functionality or by validating integrated analytical frameworks that combine technical, financial, institutional, social, and environmental dimensions (Al-Hamawi et al., 2025; Avidar, 2024; Murray et al., 2024). While this literature has generated important insights, it has tended to focus on whether particular factors are associated with sustainability, rather than explaining why sustainability outcomes vary across communities operating under broadly similar contextual conditions. As a result, relatively little empirical work has assessed the importance of different service conditions in explaining observed variation in sustainability outcomes.

This gap is particularly relevant in semi-arid environments, where rural water services are subject to shared environmental constraints, including seasonal variability, groundwater stress, and recurrent drought. Under such conditions, differences in sustainability outcomes are unlikely to be explained by environmental exposure alone. Instead, existing evidence suggests that variation in performance often reflects differences in service management capacity, financing arrangements, and governance effectiveness (Morante-Carballo et al., 2022). However, empirical studies that explicitly examine variation in sustainability within a single semi-arid setting remain limited.

In Tanzania, water services are predominantly managed through community-based arrangements operating within a decentralised governance framework. Although national water policies emphasise sustainability, cost-recovery, and community participation, empirical studies continue to report high rates of non-functionality and declining service performance, particularly in semi-arid districts (Ugulumu et al., 2024). Much of the existing research in Tanzania (Yamlinga & Kiwia, 2025; Bazaanah & Mothapo, 2023; Ngusa, 2022) has focused on identifying determinants of sustainability or assessing compliance with technical and institutional standards, with less attention given to explaining why some services perform better than others under comparable policy and environmental conditions.



This study addresses this gap by examining why rural water service sustainability varies in semi-arid Tanzania. Rather than validating an integrated framework, the study adopts an outcome-oriented explanatory approach that focuses on the relative contribution of key service conditions to observed variation in sustainability outcomes. Using cross-sectional household survey data from Chemba District, sustainability is operationalised as a composite index capturing core service attributes, while financial conditions, institutional arrangements, technical performance, social organisation, capturing community-level factors such as user participation in water management, trust in local management bodies, transparency and accountability in fee use, gender representation in committees, and mechanisms for conflict resolution and environmental stressors are analysed as distinct explanatory domains.

Hierarchical multiple regression is employed to assess the incremental explanatory power of each domain, allowing for a direct comparison of their relative importance in explaining variation in sustainability. This approach moves beyond binary assessments of statistical significance and provides a clearer, more policy-relevant basis for identifying where interventions are likely to have the greatest impact. The hierarchical regression model was structured based on theoretical considerations from the service-delivery perspective and the FIETS framework. Financial conditions were entered first, as they provide the basic resources necessary to sustain water services, followed by institutional arrangements, which depend on financial capacity to function effectively. Technical, social, and environmental factors were subsequently included to capture additional dimensions influencing sustainability.

The study is guided by the following research question: 'Why does rural water service sustainability vary?' By addressing this question in Chemba District, semi-arid Tanzania, the paper makes two specific contributions. Empirically, the findings show that financial and institutional conditions are more influential than technical performance in explaining variations in sustainability, indicating that infrastructure alone is insufficient without reliable financing and effective local management. From a policy perspective, the results challenge approaches that prioritise technical upgrades (such as infrastructure expansion or technology-focused solutions) without addressing underlying governance and financing constraints. Instead, the findings support a shift toward strengthening district-level maintenance financing mechanisms, improving the capacity and accountability of local management bodies such as CBWSOs, and ensuring timely access to funds for operations and repairs. These insights suggest that improving sustainability requires rebalancing investments from hardware-focused interventions toward service-delivery systems.

## **Literature**

Rural water supply sustainability has long been a central concern in water service research and practice, yet its interpretation has evolved significantly over time. Early studies tended to equate sustainability with the continued physical functionality of water infrastructure, often focusing on whether systems were operational or broken at a given point in time (Asbetsadik et al., 2025). While such measures provided useful snapshots, they proved inadequate for capturing the quality and reliability of services users experience over time.

In response, a growing body of research has reframed sustainability as a service-delivery outcome rather than a purely technical condition. From this perspective, sustainability refers to the sustained provision of water services that meet acceptable standards of quality, quantity, reliability, accessibility, and affordability over time (Murray et al., 2024). This shift reflects recognition that infrastructure alone does not deliver water services. Instead, sustainability depends on ongoing management, financing, institutional support, and the capacity to respond to operational and



environmental challenges throughout the life-cycle of a water service. This service-delivery perspective now underpins much contemporary water supply research and policy, particularly in low and middle-income countries where system failure rates remain high despite continued investment.

### **Conceptual foundations of the service-delivery perspective**

The service-delivery perspective in water supply research is not derived from a single formal theory but has emerged from cumulative empirical evidence and sector learning. It reflects a convergence of scholarship and policy experience, showing that infrastructure-focused approaches have systematically failed to ensure long-term service performance.

Key contributions to this perspective emphasise that sustainability depends on life-cycle financing, effective governance arrangements, post-construction support, and institutional capacity at multiple levels (Kosoe et al., 2025). Rather than asking whether water points function immediately after construction, this body of work focuses on whether services continue to deliver acceptable outcomes over time.

Subsequent studies have reinforced this view by demonstrating that many causes of system failure are organisational and financial rather than technical (Machado et al., 2023). Authoritative sector institutions, including the World Bank and the Rural Water Supply Network, have further operationalised this perspective through policy guidance and empirical assessments that prioritise service-delivery performance over infrastructure counts (World Bank, 2017; RWSN, 2010).

Within this conceptual framing, sustainability is understood as the product of interacting service conditions rather than a single outcome attributable to a single factor. This provides a suitable analytical basis for examining variation in sustainability outcomes across communities.

### **Financial conditions and sustainability outcomes**

Financial conditions are consistently identified in the literature as a critical determinant water supply sustainability. Numerous studies document that inadequate cost-recovery, weak financial management, and the absence of reliable funding for operation and maintenance are among the most common causes of service failure (Machado et al., 2023; Mohanty & Rout, 2022).

Evidence from Sub-Saharan Africa shows that community-managed water systems often struggle to mobilise sufficient financial resources, particularly in low-income and semi-arid contexts where households face competing livelihood demands (Jiménez-Redal et al., 2024). Where tariffs are set unrealistically low, collection rates are poor, or financial records are inadequately maintained, systems become vulnerable to prolonged breakdowns and declining service quality.

Recent service-delivery research further emphasises that financial sustainability depends not only on revenue generation but also on transparency, accountability, and access to external support mechanisms when major repairs are required (Chimphero et al., 2025). These findings suggest that differences in financial capacity and management effectiveness are likely to play a central role in explaining variation in sustainability outcomes.

### **Institutional arrangements and governance capacity**

Institutional arrangements shape how water supply services are managed, financed, and supported. Governance structures determine decision-making processes, accountability relationships, and the enforcement of rules related to tariff collection and maintenance responsibilities. Empirical studies consistently show that weak institutional capacity undermines sustainability, even where communities express willingness to contribute financially (Angmor et al., 2024).



In community-based management systems, which dominate rural water provision in many developing countries, sustainability outcomes depend heavily on the effectiveness of local water committees, clarity of roles, and leadership capacity (Lema, 2025). Where institutional arrangements are poorly defined, or accountability mechanisms are weak, financial resources are often misused or insufficiently allocated to maintenance.

At the same time, the literature highlights that institutions do not operate independently of financial conditions. Governance arrangements tend to matter most when they enable effective mobilisations and use of financial resources, reinforcing the interdependence between institutional capacity and financial sustainability (Angmor et al., 2024).

### **Technical performance and infrastructure characteristics**

Technical performance has traditionally occupied a central place in rural water sustainability research, with attention given to technology choice, construction quality, and system design. While these factors influence initial functionality, growing evidence suggests that they are insufficient to ensure long-term sustainability.

Comparative studies show that systems constructed to similar technical standards often experience very different performance trajectories over time, largely due to differences in maintenance practices, financing, and management capacity (Angmor et al., 2024). As a result, technical factors tend to explain early system performance but lose explanatory power once services enter the operational phase.

This has led to increasing recognition that technical performance is often an outcome of financial and institutional conditions rather than an independent driver of sustainability. Where adequate resources and management capacity exist, technical problems can usually be addressed. In their absence, even technically sound systems are prone to failure.

### **Social organisation and community participation**

Social organisation and community participation have long been regarded as important elements of water supply sustainability, particularly within community-based management models. Early assumptions held that strong social cohesion would naturally translate into sustained service performance. However, empirical evidence presents a more nuanced picture.

Studies indicate that social organisation contributes to sustainability primarily by supporting tariff compliance, accountability among service providers, and collective decision-making (Golfinopoulos & Koumparou, 2024). Where these mechanisms are weak, participation alone is insufficient to sustain services. In some contexts, strong social ties may even inhibit the enforcement of rules or mask governance failures. Consequently, recent literature treats social organisation as a facilitating condition that interacts with financial and institutional arrangements, rather than as a standalone determinant of sustainability.

### **Environmental stressors and semi-arid contexts**

Environmental stressors such as drought, seasonal variability, and groundwater depletion are widely recognised as challenges to the sustainability of water supplies, particularly in semi-arid regions. Climate variability can reduce source reliability and increase operational demands, placing additional pressure on service providers.

However, empirical studies show that environmental stress alone does not fully explain variation in sustainability outcomes within the same geographic area. Communities exposed to similar climatic conditions often experience markedly different service trajectories (Verma, 2025). This suggests that



environmental stressors influence sustainability primarily through their interaction with financial and institutional response capacity.

In semi-arid settings, the ability to adapt to environmental stress depends on access to resources, effective management, and external support. Where these conditions are weak, environmental shocks are more likely to result in prolonged service failure.

### **Synthesis and research gap**

The reviewed literature demonstrates a broad consensus that the sustainability of water supply services is shaped by financial, institutional, technical, social, and environmental conditions. However, much of the existing empirical work focuses on identifying determinants or validating integrated frameworks, with limited attention given to explaining why sustainability outcomes vary across communities facing similar challenges like Chemba.

In particular, there are inadequate empirical studies that explicitly assess the relative explanatory importance of different service conditions within a single semi-arid setting. This limits policymakers' ability to prioritise interventions based on evidence of which factors contribute most to observed variation in sustainability outcomes. In a semi-arid region like Chemba, "variation" in sustainability isn't just an academic curiosity; it's a matter of survival during drought. If one village survives a drought and the next one doesn't, despite having the same pump, this study addresses this gap by adopting an outcome-oriented explanatory approach that examines the incremental contribution of key service conditions to variation in sustainability in semi-arid Tanzania. Communities face similar contextual constraints in the Tanzanian rural water sector, including low and seasonal household incomes, climate variability and recurrent drought, dependence on groundwater sources, weak local management capacity within Community-Based Water Supply Organisations (CBWSOs), delays in accessing maintenance funds (often centralised through agencies such as Rural Water Supply and Sanitation Agency), and varying levels of community participation and accountability

### **Methods**

The study adopted a quantitative, cross-sectional explanatory design to examine why water supply sustainability varies within a semi-arid context. The design is appropriate for estimating associations between service conditions and sustainability outcomes at a single point in time, while focusing on comparative explanatory contribution rather than causal identification. The study is conceptually grounded in the rural water service-delivery perspective, which frames sustainability as sustained service performance over time and emphasises post-construction financing, governance, and management capacity beyond infrastructure provision (Toan et al., 2023)

The empirical strategy uses hierarchical (block-entry) multiple regression, where predictors are entered in conceptually defined blocks specified a priori, and incremental explanatory power is assessed after each block is added (Jeger et al., 2014).

The study was conducted in Chemba District, located in central Tanzania. The district is characterised by semi-arid conditions, seasonal rainfall variability, and recurrent drought exposure. These shared constraints make the area suitable for analysing why sustainability outcomes differ across communities facing broadly similar environmental conditions.

Primary data were collected through a structured household questionnaire administered to water users. The instrument captured perceived water service outcomes and service conditions across financial, institutional, technical, social, and environmental domains, consistent with established rural water sustainability research and sector guidance (Dominguez et al., 2019). Likert-type response scales



were used to support the construction of composite indices. Ethical procedures were followed during data-collection, including voluntary participation and informed consent.

A multistage sampling procedure was applied. In the first stage, four wards were purposively selected to represent the study area, two from the Sandawe community and another two from the Rangi community. In the second stage, two villages were selected from each ward, resulting in a total of eight villages included in the study. In the third stage, households were selected within each village using simple random sampling to represent rural water service users. A total of 384 households were surveyed, with approximately 48 households selected from each village, ensuring balanced representation across the study area. In each village, households relied on shared communal water points (e.g., boreholes or public taps), meaning that multiple households accessed the same water source. As a result, the data exhibit a clustered structure at the village/water point level rather than representing independent observations.

Water supply sustainability was operationalised as a composite Sustainability Index reflecting five user-reported service attributes: perceived water quality, quantity adequacy, reliability, accessibility, and affordability. For the household  $i$ , the index was computed as the arithmetic mean of the item scores:

$$SI_i = \frac{1}{K} \sum_{k=1}^K s_{ik}, K = 5$$

where  $s_{ik}$  denotes the response of the household  $i$  to the service attribute  $k$ . Internal consistency of multi-item indices was assessed using Cronbach's alpha, following standard reliability practice, while recognising that reliability statistics are reported in the results section rather than in the Methods section (Tavakol & Dennick, 2011).

Five explanatory domains were operationalised as composite indices derived from questionnaire items: financial conditions ( $FIN_i$ ), institutional arrangements ( $INST_i$ ), technical performance ( $TECH_i$ ), social organisation ( $SOC_i$ ), and environmental stressors ( $ENV_i$ ). For each domain, items were coded in the same direction so that higher values indicate more favourable conditions for sustaining water supply services. Negatively worded items were reverse-coded prior to aggregation. Each domain index was computed as the mean of its respective item scores for the household  $i$ ,

$$D_i = \frac{1}{M} \sum_{m=1}^M d_{im}$$

where  $D_i$  represents any of the domain indices and  $d_{im}$  represents the  $m$ -th item contributing to that domain.

Household socio-demographic controls included gender, age, and household size. Education was initially considered a control; however, it was excluded from the final regression due to diagnostic issues during model estimation, indicating insufficient usable correlations for inclusion in the block-entry procedure. This exclusion is reported transparently in the results section.

The association between sustainability and service conditions was estimated using ordinary least squares multiple regression:

$$SI_i = \beta_0 + Z_i^T \gamma + D_i^T \beta + \varepsilon_i$$

where  $SI_i$  the Sustainability Index for household  $i$   $Z_i$  is a vector of control variables,  $D_i$  is a vector of the domain indices,  $\beta_0$  is the intercept,  $\gamma$  and  $\beta$  are parameter vectors, and  $\varepsilon_i$  is the disturbance term.



Hierarchical regression evaluates incremental explanatory contribution by adding predictors in blocks defined prior to estimation (Almonroeder, 2022). In this study, controls were entered first to account for household characteristics. Domain indices were then entered sequentially, beginning with financial condition, whereas we measured using household-level perceptions of the affordability, payment practices, and financial management of rural water services. followed by institutional arrangements, technical performance, social organisation, and environmental stressors. This ordering reflects service-delivery logic in which financing and governance conditions are commonly positioned as upstream capacities that shape the feasibility of operation, maintenance, and adaptation, while technical and contextual constraints are assessed after these foundational capacities are accounted for (Lockwood & Smits, 2011; Smits et al., 2017).

Incremental explanatory contribution was assessed using the change in explained variance between successive block-entry specifications:

$$\Delta R_t^2 = R_t^2 - R_{t-1}^2$$

where  $t$  denotes the specification after adding a new block, and the statistical significance of  $\Delta R^2$  was assessed using the standard  $F$  change test provided by the regression output (Field, 2018).

To support valid interpretation of estimates, standard diagnostic checks were conducted. Multicollinearity was assessed using variance inflation factors. Residual-based diagnostics were examined to evaluate major departures from linearity and constant variance. In line with common reporting practice, numerical diagnostic outputs are summarised in the results section, while the present section documents the procedures used (Ammon, 2022; Bhandari, 2021).

This study employed a cross-sectional household survey design to examine variations in the sustainability of rural water services in Chemba District. A cross-sectional approach was appropriate as it allows data to be collected from a large number of respondents at a single point in time, enabling analysis of relationships between sustainability outcomes and explanatory factors (Creswell & Creswell, 2018). The study involved 384 households selected through a multistage sampling procedure, where four wards were first selected, followed by eight villages (two from each ward), and 48 households were randomly sampled from each village, ensuring adequate statistical power and representativeness (Krejcie & Morgan, 1970). Data were collected using a structured household questionnaire administered via mobile data-collection tools (KoboCollect/KoBoToolbox), which improved data quality and minimised data entry errors. The questionnaire was developed in English and translated into Swahili to ensure respondent understanding, with the translated version reviewed for consistency. Data-collection was conducted by trained enumerators familiar with the local context, who received prior training on study objectives, ethical considerations, and administration procedures to ensure reliability. The instrument captured sustainability indicators (water quality, quantity, reliability, accessibility, and affordability) and explanatory variables (financial, institutional, technical, social, and environmental conditions) based on established approaches (Lockwood & Smits, 2011; Smits et al., 2017). In addition, field observations and focus group discussions were conducted to provide contextual insights into water service-delivery. Participation was voluntary, and respondents were informed of the study's purpose, with verbal consent obtained prior to data-collection.

## **Results**

### **Presentation of findings**

Table 1 presents descriptive statistics for the Sustainability Index and the composite explanatory variables included in the analysis. The Sustainability Index has a mean of 3.02 and a standard



deviation of 0.95, indicating moderate average sustainability levels alongside substantial variation across households.

The explanatory indices for financial conditions, institutional arrangements, technical performance, social organisation, and environmental stressors display similar mean values, ranging from 3.03 to 3.05. The correlations among the explanatory variables were generally weak to moderate, indicating limited overlap between the constructs. Most correlation coefficients were below 0.50, suggesting that the variables capture distinct dimensions of rural water service sustainability. No strong correlations were observed, and all values were within acceptable thresholds, indicating that multicollinearity is unlikely to be a concern in the analysis. Standard deviations close to one indicate considerable dispersion for all constructs. Minimum and maximum values span most of the five-point scale, confirming that the data capture wide variation in both sustainability outcomes and service conditions.

No evidence of extreme skewness or scale compression is observed at the descriptive level, supporting the suitability of the composite indices for inclusion in linear regression models.

*Table 1: Descriptive statistics of study variables (N = 384)*

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Sustainability Index (SI)	384	1.00	5.00	3.0193	0.94890
Financial conditions (FIN)	384	1.00	5.00	3.0324	0.93514
Institutional arrangements (INST)	384	1.00	5.00	3.0420	0.94868
Technical performance (TECH)	384	1.00	5.00	3.0512	0.91557
Social organisation (SOC)	384	1.00	5.00	3.0448	0.96154
Environmental stressors (ENV)	384	1.00	5.00	3.0479	0.95373

*Source: Authors owns compilation (2026)*

All variables are composite indices measured on a five-point Likert scale. Descriptive statistics are based on all valid observations.

### Reliability analysis

As reported in Table 2, both the Sustainability Index and the Social Organisation Index demonstrate satisfactory internal consistency, with Cronbach’s alpha values exceeding the commonly accepted threshold of 0.70. These results indicate that the items used to construct each index reliably capture the intended service outcome and social organisation dimensions, supporting their use in subsequent regression analysis (Usubiaga-Liaño & Ekins, 2024).

Reliability coefficients are not reported for the remaining explanatory variables because these constructs were operationalised as composite indices rather than reflective scales. Financial conditions, institutional arrangements, technical performance, and environmental stressors represent analytically distinct and complementary attributes of rural water service-delivery, for which high inter-item correlation is neither theoretically required nor methodologically expected. For such composite measures, internal consistency metrics such as Cronbach’s alpha are not appropriate indicators of measurement quality. Instead, validity is established through conceptual grounding and careful indicator selection based on prior empirical and sector-based literature (Muñoz, 2025).

*Table 2: Reliability statistics for reflective composite indices*

Construct	Items	Cronbach’s $\alpha$
Sustainability Index (SI)	5	0.778
Social organisation (SOC)	9	0.899

*Source: Authors’ own compilation (2026)*



### **Relative Contribution of Service Conditions to Sustainability Variation**

Hierarchical multiple regression was employed to explain variation in rural water service sustainability. Results are presented in Table 3.

Model 1 includes only socio-demographic control variables (gender, age, and household size). The model explains a small proportion of the variation in sustainability outcomes ( $R^2 = 0.095$ ) and is not statistically significant ( $F = 1.506$ ,  $p = 0.227$ ). None of the control variables exhibits statistically significant independent effects, indicating that sustainability differences are not primarily driven by household demographic characteristics.

The inclusion of financial conditions in Model 2 substantially improves model performance. Explained variance increases by 22.3 percentage points ( $\Delta R^2 = 0.223$ ,  $p < 0.001$ ), raising the total  $R^2$  to 0.318, representing the largest incremental contribution across all explanatory domains. Financial conditions exhibit a strong, statistically significant positive association with sustainability ( $\beta = 0.473$ ,  $p = 0.001$ ), underscoring their central role in explaining variation in observed service outcomes.

Model 3 introduces institutional arrangements, resulting in a further increase in explained variance ( $\Delta R^2 = 0.060$ ,  $p = 0.053$ ), bringing the total  $R^2$  to 0.378. Although the contribution is more modest than that of financial conditions, institutional arrangements demonstrate a positive and borderline statistically significant association with sustainability ( $\beta \approx 0.30$ ,  $p \approx 0.05$ ). This suggests that governance, participation, and accountability mechanisms contribute meaningfully to differences in service performance.

The addition of technical performance in Model 4 does not improve explanatory power ( $\Delta R^2 = 0.000$ ,  $p = 0.907$ ). Technical performance indicators show no statistically significant association with sustainability after accounting for financial and institutional factors. This indicates that variation in sustainability is not primarily driven by differences in physical infrastructure or maintenance capacity alone.

Model 5 adds social organisation variables, yielding a small increase in explained variance ( $\Delta R^2 = 0.017$ ,  $p = 0.306$ ). However, social organisation does not remain statistically significant in the presence of financial and institutional factors, suggesting that its influence may operate indirectly or be contingent on financial and governance conditions.

The final model incorporates environmental stressors. Although the inclusion of environmental factors increases explained variance marginally ( $\Delta R^2 = 0.024$ ,  $p = 0.219$ ), these factors do not exert a statistically significant independent effect on sustainability in the full model. This implies that while environmental pressures are relevant, their explanatory power is limited relative to financial and institutional conditions.

### **Explanatory Power and Diagnostic Checks**

The full model (Model 6) explains 41.9% of the variation in rural water service sustainability ( $R^2 = 0.419$ ; Adjusted  $R^2 = 0.297$ ) and is statistically significant ( $F = 3.427$ ,  $p = 0.005$ ). Multicollinearity diagnostics indicate no concern, with all variance inflation factor (VIF) values well below commonly accepted thresholds (maximum VIF  $\approx 1.56$ ). Residual plots reveal no systematic patterns, supporting the adequacy of model assumptions.



Table 3: Hierarchical regression explaining variation in rural water service sustainability (Dependent variable: Sustainability Index)

Variables	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Gender	-0.135	-0.123	-0.113	-0.112	-0.099	-0.039
Age	-0.195	-0.177	-0.144	-0.142	-0.135	-0.118
Household size	0.225	0.223	0.275*	0.277*	0.286*	0.285*
Financial conditions (FIN)	–	0.473***	0.322*	0.313	0.269	0.285*
Institutional arrangements (INST)	–	–	0.298†	0.300†	0.225	0.211
Technical performance (TECH)	–	–	–	0.017	0.042	0.047
Social organisation (SOC)	–	–	–	–	0.166	0.184
Environmental stressors (ENV)	–	–	–	–	–	0.193
R <sup>2</sup>	0.095	0.318	0.378	0.379	0.395	0.419
ΔR <sup>2</sup>	–	0.223	0.060	0.000	0.017	0.024
F-change	1.506	13.754***	3.956†	0.014	1.076	1.563

Notes: Standardised coefficients reported.

†  $p < 0.10$ , \*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Regression estimates are based on valid observations used in the hierarchical models.

Source: Authors' own compilation (2026) Regression Diagnostics

Variance inflation factor values for all explanatory variables remained below conventional thresholds, indicating no evidence of multicollinearity. Examination of standardised residuals shows no systematic patterns or extreme outliers. Coefficient signs and magnitudes remain stable across hierarchical steps.

## Discussion

### Financial factors in explaining sustainability variation

The strongest finding of the analysis is the dominant role of financial conditions in explaining variation in the sustainability of rural water services. The introduction of financial variables produces the largest increase in explained variance, and financial conditions remain positively associated with sustainability across all subsequent model specifications. This finding aligns with a substantial body of rural water research that identifies financial capacity as a central constraint on the continuity of service-delivery, particularly in resource-constrained and climate-stressed settings (Poudel & Adhikari, 2024).

From a service-delivery perspective, financial conditions influence sustainability through multiple channels, including the ability to fund routine operations and maintenance, to mobilise timely repairs, and to retain technical and managerial capacity. The present results suggest that, even when other aspects of service-delivery are considered, differences in financial capacity remain a key factor distinguishing more sustainable from less sustainable services within the study area.

### Institutional arrangements and their contribution to sustainability variation

Institutional arrangements add explanatory power to the model, although their statistical significance diminishes once additional service dimensions are included. This pattern suggests that governance and management structures matter for sustainability, but their effects may be mediated through or constrained by financial capacity.

This finding is consistent with prior studies showing that institutional effectiveness in rural water systems is often contingent on the availability of adequate financial resources. Formal management structures and rules alone may be insufficient to sustain services in the absence of reliable financing mechanisms (Angmor et al., 2024). The attenuation of institutional effects in the full model does not



imply irrelevance; rather, it highlights the interdependence between governance arrangements and financial viability.

### **Independent effects of technical, social, and environmental factors**

Technical performance, social organisation, and environmental stressors do not exhibit statistically significant independent associations with sustainability once financial and institutional conditions are accounted for. This result contrasts with infrastructure-centred narratives that emphasise technical design or environmental exposure as primary determinants of sustainability. Instead, the findings support arguments in the literature that technical and environmental challenges become critical primarily when financial and managerial capacities are insufficient to respond to them. In semi-arid contexts, exposure to environmental stress is widespread, but the ability of services to cope with such stress appears to depend more on institutional and financial preparedness than on environmental conditions alone (Daniel et al., 2021).

Similarly, while social organisation is often highlighted as a cornerstone of community-managed systems, its independent explanatory power appears limited once broader service conditions are considered. This suggests that social cohesion and participation may play a supportive role rather than acting as a primary driver of sustainability outcomes in isolation.

### **Implications for understanding sustainability variation**

Taken together, the results suggest that variation in rural water service sustainability within semi-arid Tanzania is driven less by differences in environmental exposure or technical characteristics and more by differences in service capacity, particularly financial capacity. This finding reinforces the shift in rural water research away from infrastructure-focused explanations toward service-oriented perspectives that emphasise financing, governance, and long-term management. Importantly, this study differs from framework validation approaches by focusing on the relative explanatory contribution rather than on a comprehensive system representation. By examining how much each service dimension contributes to explaining observed variation, the analysis provides empirical insight into priority areas for strengthening rural water services under resource constraints.

### **Conclusion**

This study examined why rural water service sustainability varies within a semi-arid context, using hierarchical regression to assess the relative contribution of financial, institutional, technical, social, and environmental service conditions. The results show that variation in sustainability is explained primarily by differences in financial conditions, with institutional arrangements playing a secondary role. Other service dimensions contribute little additional explanatory power once financial capacity is considered. These findings reinforce the view that sustaining rural water services depends less on infrastructure characteristics or environmental exposure alone and more on the capacity of services to mobilise and manage financial resources over time. In contexts where environmental stress is broadly shared, differences in sustainability appear to reflect differences in service capacity rather than differences in physical conditions.

By focusing on relative explanatory contribution rather than framework validation, this study offers a complementary empirical perspective to existing rural water sustainability research. The results highlight the importance of prioritising financial mechanisms and management capacity when addressing sustainability challenges in semi-arid rural settings, as reliable funding ensures timely maintenance and repairs, while strong local management, such as CBWSOs, enhances accountability, efficient resource use, and service continuity.



The study is subject to limitations, including reliance on cross-sectional data and a smaller sample for the regression analysis. These constraints limit causal inference and generalizability. Future research could build on this work by employing longitudinal designs and examining interactions between financial capacity and environmental stress over time.

The results have several important implications for rural water policy and practice in Tanzania and similar semi-arid settings.

First, strengthening financial sustainability should be treated as a central policy priority. At the community-level, Community-Based Water Supply Organisations (CBWSOs) must ensure consistent tariff collection and transparent financial management to support routine operations and minor maintenance. While the government should play an oversight and co-financing role, ensuring accountability and providing technical backstopping to CBWSOs, development partners may complement these efforts through conditional financing and capacity building.

Investments in new infrastructure are unlikely to yield sustained benefits unless accompanied by effective cost-recovery mechanisms, transparent financial management, and reliable access to funds for operations and maintenance. Policies that support life-cycle cost financing and predictable maintenance funding are likely to produce greater sustainability gains than construction-focused interventions alone.

Second, institutional capacity building remains critical, particularly regarding governance, accountability, and financial oversight. The modest but meaningful contribution of institutional arrangements indicates that financial resources must be embedded within functional management structures to be used effectively. Strengthening the roles, responsibilities, and accountability of local water service providers can enhance the impact of financial reforms.

Third, the limited explanatory role of technical performance suggests that continued emphasis on hardware upgrades, without parallel investments in financing and governance, may yield diminishing returns. Technical interventions should be integrated within broader service-delivery strategies that address management and financial constraints.

Fourth, while social organisation and environmental stressors are relevant to rural water sustainability, their influence appears to be largely through financial and institutional mechanisms. Policies aimed at enhancing community participation or adapting to environmental stress are therefore most likely to be effective when they reinforce financial compliance, accountability, and adaptive management capacity.

### References

- Al-Hamawi, H., Davies, P., Mayouf, M., & Nikologianni, A. (2025). Sustainability of Water, Sanitation, and Hygiene (WASH) in Post-Emergency Contexts: A Conceptual Framework. *Water*. 10.3390/w17020280
- Almonroeder, T. (2022). Multiple regression. *Advanced Statistics for Physical and Occupational Therapy*. doi: 10.4324/9781003179757-10
- Ammon, J. (2022). Water governance and service sustainability in rural contexts. *Water Policy*, 24(5), 789–803. <https://doi.org/10.2166/wp.2022.123>
- Angmor, E., Frimpong, L., Mensah, S. L., & Okyere, S. (2024). Exploring the Institutional Barriers to Rural Water Management in Ghana. *Water Policy*. 10.2166/wp.2024.130
- Asbetsadik, T., Alemayehu, A., Wolde, D., & Derib, G. (2025). Enhancing the Sustainability of Rural Water Supply Schemes in Emegua Kebele: The Role of Community Participation and Key Challenges. *Discover Sustainability*, 6. 10.1007/s43621-025-01098-9



- Avidar, O. (2024). A Holistic Framework for Evaluating and Planning Sustainable Rural Drinking Water Projects in sub-Saharan Africa. *Journal of Rural Studies*. 10.1016/j.jrurstud.2024.103243
- Bazaanah, P., & Mothapo, R. (2023). Sustainability of Drinking Water and Sanitation Delivery Systems in Rural Communities of the Lepelle Nkumpi Local Municipality, South Africa. *Environment, Development and Sustainability*, 1-33. 10.1007/s10668-023-03190-4
- Bhandari, P. (2021). Correlational research: When & how to use. Scribbr. <https://www.scribbr.com/methodology/correlational-research>
- Chimphero, L., Tembo, M., & Gadama, R. (2025). Community Engagement and Capacity Building as Determinants of Rural Water Supply Functionality: A Case of Traditional Authority Mankhambira in Nkhata Bay District, Malawi. *Journal of Water, Sanitation and Hygiene for Development*. 10.2166/washdev.2025.149
- Creswell, J. W., & Creswell, J. D. (2018). Research design: Qualitative, quantitative, and mixed methods approaches (5th ed.). SAGE Publications
- Daniel, D., Djohan, D., & Nastiti, A. (2021). Interaction of Factors Influencing the Sustainability of Water, Sanitation, and Hygiene (WASH) Services in Rural Indonesia: Evidence from Small Surveys of WASH-Related Stakeholders in Indonesia. *Water*. 10.3390/w13030314
- Dominguez, I., Oviedo-Ocaña, E., Hurtado, K., Barón, A., & Hall, R. (2019). Assessing Sustainability in Rural Water Supply Systems in Developing Countries Using a Novel Tool Based on Multi-Criteria Analysis. *Sustainability*. 10.3390/su11195363
- George-Williams, H., Hunt, D., & Rogers, C. (2024). Sustainable Water Infrastructure: Visions and Options for Sub-Saharan Africa. *Sustainability*. doi: 10.3390/su16041592
- Golfinopoulos, S., & Koumparou, D. (2024). Rural Environmental Governance: A Communal Irrigation System in Greece through the Social-Ecological System Framework. *Sustainability*. 10.3390/su16156416
- Jeger, M., Sušanj, Z., & Mijoč, J. (2014). Entrepreneurial Intention Modeling using Hierarchical Multiple Regression. *Croatian Operational Research Review*, 5, 361-373. 10.17535/crorr.2014.0019
- Jiménez-Redal, R., Arana-Landín, G., Landeta-Manzano, B., & Uriarte-Gallastegi, N. (2024). Understanding Factors Affecting Non-payment Behavior among Rural Water Users in the Democratic Republic of the Congo: An Application of Structural Equation Modelling. *Water Economics and Policy*. 10.1142/s2382624x2450019x
- Kosoe, E., Osumanu, I., & Ogwu, M. (2025). Reimagining Rural and Small-Town Water Supply in Ghana through Inclusive Governance and Sustainable Models. *Journal of Sustainability*. 10.55845/jos-2025-1234
- Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, 30(3), 607-610. <https://doi.org/10.1177/001316447003000308>
- Lebu, S., Lee, A., Salzberg, A., & Bauza, V. (2024). Adaptive Strategies to Enhance Water Security and Resilience in Low- and Middle-income Countries: A critical Review. *The Science of the total environment*, 171520. 10.1016/j.scitotenv.2024.171520
- Lema, M. (2025). Sustaining Rural Livelihoods Through Participatory Water Governance: A Review of Community-Driven Water Resource Management Models in East and Central Africa. *Environmental Quality Management*. 10.1002/tqem.70023
- Lockwood, H., & Smits, S. (2011). *Supporting rural water supply: Moving towards a service delivery approach*. Practical Action Publishing.
- Machado, A., Oliveira, P., Matos, P., & Santos, A. S. P. (2023). Strategies for Achieving Sustainability of Water Supply Systems in Rural Environments with Community Management in Brazil. *Water*. 10.3390/w15122232



- Mohanty, T., & Rout, H. S. (2022). Financial Sustainability of Rural Water Supply: An Analysis of Cost Recovery, Revenue Collection, and Efficiency. *Water and Environment Journal*, 37, 44-57. 10.1111/wej.12816
- Morante-Carballo, F., Montalvan-Burbano, N., Quiñonez-Barzola, X., Jaya-Montalvo, M., & Carrión-Mero, P. (2022). What Do We Know about Water Scarcity in Semi-Arid Zones? A Global Analysis and Research Trends. *Water*. 10.3390/w14172685
- Muñoz, M. D. D. (2025). A formative measurement validation methodology for survey questionnaires.
- Murray, A., Stone, G., Yang, A., Lawrence, N., Matthews, H., & Kayser, G. (2024). Rural Water Point Functionality Estimates and Associations: Evidence From Nine Countries in Sub-Saharan Africa and South Asia. *Water Resources Research*, 60. doi: 10.1029/2023wr034679
- Ngusa, D. (2022). Impact of Key Players in Providing Sustainable Water Services in Busega District, Tanzania. *African Journal of Applied Research*. 10.26437/ajar.31.10.2022.04
- Poudel, A., & Adhikari, S. (2024). Sustainability Analysis of Community-Managed Rural Water Supply Project: A Case Study of Kaski District. *Journal of Engineering and Sciences*. 10.3126/jes2.v3i1.66230
- Smits, S., Lockwood, H., Furey, S., & Fonseca, C. (2017). Service delivery indicators and monitoring to improve sustainability of rural water supplies. *Waterlines*, 36(1), 1-16. <https://doi.org/10.3362/1756-3488.2017.002>
- Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, 2, 53-55. <https://doi.org/10.5116/ijme.4dfb.8dfd>
- Toan, T. D., Hanh, D., & Thu, D. T. (2023). Management Models and the Sustainability of Rural Water Supply Systems: An Analytical Investigation in Ha Nam Province, Vietnam. *Sustainability*. 10.3390/su15129212
- Ugulumu, E., Macha, L., & Fuime, S. (2024). Factors Affecting Borehole Water Project Sustainability in Dodoma, Tanzania: A case of Nghong'onha ward. *Rural Planning Journal*. 10.59557/rpj.26.1.2024.32
- Usubiaga-Liaño, A., & Ekins, P. (2024). Methodological Choices for Reflecting Strong Sustainability in Composite Indices. *Ecological Economics*. 10.1016/j.ecolecon.2024.108192
- Verma, A. (2025). Assessing the Impact of Climate-Induced Water Scarcity on Agricultural Sustainability in Semi-Arid Regions: A Case Study of Western Rajasthan, India. *International Journal For Multidisciplinary Research*. 10.36948/ijfmr.2025.v07i03.49334
- Yamlinga, M., & Kiwia, R. (2025). Factors Contributing to the Sustainability of Water Projects in Mufindi District, Tanzania. *African Journal of Accounting and Social Science Studies*. 10.4314/ajass.v7i1.10