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Sustainability Dimensions of Rural Water Services in Semi-Arid Tanzania: The FIETS Framework Lens

Sustainability Dimensions of Rural Water Services in Semi-Arid Tanzania: The FIETS Framework Lens

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Abstract

Sustaining rural water supply services remains a persistent challenge in sub-Saharan Africa despite infrastructure investment and various sector reforms, this is particularly pronounced in rural settings where functionality and continuity are vulnerable to institutional capacity constraints, affordability, maintenance, and environmental stress. Drawing on the Financial Institutional Environmental Technological Social framework (FIETS). Sustainability was operationalised using a composite index based on household perceptions of water quality, quantity adequacy, reliability, accessibility, and affordability as key service delivery attributes associated with sustainable rural water services. The study employed quantitative approach using household survey to collect data from 384 households in Chemba District. Partial Least Squares Structural Equation Modelling (PLS-SEM) using SmartPLS 4 with 5,000 bootstrap resamples was used. The measurement model demonstrated satisfactory reliability and validity based on indicator loadings, internal consistency, convergent and discriminant validity. Structural model results indicate that environmental factors is most strongly associated with sustainability with ($\beta = 0.322$, $t = 7.677$, $p < 0.001$), followed by technical with ($\beta = 0.152$, $t = 3.595$, $p < 0.001$), social with ($\beta = 0.142$, $t = 2.785$, $p = 0.005$), institutional with ($\beta = 0.137$, $t = 3.305$, $p = 0.001$), and financial with ($\beta = 0.119$, $t = 2.506$, $p = 0.012$), with all hypothesised relationships statistically significant. These findings indicate that rural water sustainability is best understood as a multidimensional of combined factors, rather than a single-factor." The study contributes to the evidence base on rural water sustainability and support integrated policy design aligned with Sustainable Development Goal number 6 which aims to ensure availability and sustainable management of water and sanitation for all by 2030.

Introduction

Safe and reliable drinking water is foundational to health, human development, and inclusive economic participation. The 2030 Agenda for Sustainable Development positions water at the centre of development transformation, with Sustainable Development Goal 6 calling for universal and equitable access to safe and affordable drinking water, sanitation, and hygiene by 2030 (United Nations, 2015). Global monitoring nevertheless shows persistent shortfalls, with major inequalities between rural and urban populations and continued gaps in safely managed services (WHO &

UNICEF, 2023). These gaps are becoming increasingly difficult to close amid intensifying water stress, climate variability, and ecosystem degradation, which together heighten the fragility of rural service reliability and affordability (Mekonnen & Hoekstra, 2016; UN Water, 2021).

A key lesson from recent evidence is that "access," measured by infrastructure presence, can mask persistent failures in service quality, continuity, and functionality (WHO & UNICEF, 2023). In rural Sub-Saharan Africa, hand-pumps and small piped schemes frequently experience breakdowns and prolonged downtime, with non-functional rates remaining substantial even for recently constructed systems (Fisher et al., 2015; Murray et al., 2024). System age, management effectiveness, availability of spare parts and repair services, financing arrangements for operation and maintenance, and the strength of institutional support systems are key determinants cited in the literature (Foster, 2013; Fisher et al., 2015).

Tanzania has made several efforts to ensure water resources are managed sustainably through various sector reforms and investment programmes, including the Water Sector Development Programme and institutional strengthening aiming to improve service delivery and governance (Ministry of Water, 2022), The Water Supply and Sanitation Act No. 5 of 2019 established the Rural Water Supply and Sanitation Agency (RUWASA) to oversee rural water supply services in Tanzania. Despite the reforms, various reports (Controller and Auditor General, 2021; Ministry of Water, 2025; WaterAid, 2023) show weaknesses. Moreover, water points mapping and analyses have documented notable non-functional water points, including failures within the early years of construction, consistent with broader regional patterns of sustainability risk (Joseph et al., 2019).

Studies (Whaley & Cleaver et al., 2021) show that the dominant community-based management model often underperforms when supply chains for spare parts, professional maintenance services, and consistent institutional support are weak, even where participation is formally present. Likewise, financial mechanisms face structural tensions between affordability and full recovery of operation and maintenance costs, which can constrain the adequacy and predictability of maintenance financing (Truslove et al., 2020; World Bank, 2021). These tensions become sharper in semi-arid settings where environmental conditions increase technical wear, raise operating costs, and reduce household capacity to pay during drought.

FIETS framework adopts a systems perspective by emphasising that rural water service sustainability depends on the interaction of financial viability, institutional capability, environmental resilience, technological appropriateness, and social inclusion (Daniel et al., 2021). The framework is particularly relevant in rural water contexts because weaknesses in one dimension may undermine improvements in others. However, existing studies in Tanzania have largely examined isolated sustainability factors, with limited district-level empirical evidence simultaneously assessing the relative contribution of FIETS dimensions to rural water service sustainability.

This study, therefore, examines the determinants of sustainable rural water supply in a semi-arid setting of Tanzania using Chemba District as a case. The study is informed by Partial Least Squares Structural Equation Modelling to explore financial, environmental, social, technical, and institutional factors. It contributes to the rural water sustainability literature in three ways. First, it advances theory by testing FIETS as a multidimensional explanatory framework for rural water sustainability at the district scale. Second, it strengthens empirical understanding of how sustainability domains interact in climate-stressed rural environments, consistent with emerging evidence that functionality and continuity are shaped by interdependent drivers (Foster, 2013; Fisher et al., 2015; Murray et al., 2024). Third, it provides policy-relevant evidence that can inform the design of integrated interventions to achieve Sustainable Development Goal 6 (United Nations, 2015; WHO & UNICEF, 2023).

Literature Review

The sustainability of rural water supply has long been recognised as a multidimensional development challenge. Early engineering-centred approaches emphasised construction quality and technical design as the primary determinants of long-term service performance (Lockwood & Smits, 2011). However, subsequent evidence revealed that infrastructure alone cannot guarantee sustained service delivery, particularly in low-income and climate-vulnerable rural settings (Fisher et al., 2015; Cleaver et al., 2021). This perspective is consistent with theories of sustainable development, which emphasise that durable service outcomes emerge from the alignment of governance capacity, economic incentives, ecological integrity, and social legitimacy (Sachs, 2015; Raworth, 2017).

The FIETS framework offers one of the most comprehensive operationalisations of this systems logic (Daniel et al., 2021). The FIETS framework emphasises that rural water service sustainability depends on the combined contributions of the financial, institutional, environmental, technological, and social dimensions, and that weaknesses in one domain may undermine overall system performance. Despite its conceptual appeal, the empirical literature on FIETS remains limited, especially in semi-arid rural settings where climate stress and institutional constraints are most pronounced (Daniel et al., 2021; Win et al., 2024). This study therefore adopts FIETS as the guiding theoretical framework to examine the determinants of sustainable rural water supply in Chemba District.

Environmental Factors and Water Supply Sustainability

Environmental conditions fundamentally shape the performance and durability of rural water systems. Climate variability, groundwater depletion, catchment degradation, and pollution intensify operational stress on infrastructure and increase service unreliability (Mekonnen & Hoekstra, 2016; Rockström et al., 2014; Vörösmarty et al., 2018). Semi-arid environments, in particular, are highly exposed to drought cycles, rainfall variability, and rising evapotranspiration, which collectively undermine the reliability of water sources and household water security (IPCC, 2022; Grey).

Empirical studies consistently demonstrate that climate shocks significantly increase the probability of system breakdowns, reduce functionality durations, and raise maintenance costs (Klug et al., 2018; Murray et al., 2024). Degraded catchments and pollution further compromise water quality and the sustainability of water sources, exacerbating health risks and increasing maintenance requirements (UNEP, 2021; WHO, 2017). Environmental governance capacity therefore plays a central role in sustaining rural water services (Pahl-Wostl, 2015; IPCC, 2022).

Within the FIETS framework, environmental resilience is viewed as a structural foundation of sustainability, particularly in climate-stressed rural regions (Daniel et al., 2021; Win et al., 2024). On this basis, the study proposes:

H_1: Environmental factors are positively associated with the sustainability of rural water supply.

Technical Factors and Water Supply Sustainability

Technical performance remains a core determinant of service reliability. Infrastructure functionality, technology appropriateness, preventive maintenance regimes, and availability of skilled technicians strongly influence long-term system performance (Fisher et al., 2015; Klug et al., 2018). Large-scale analyses of rural water point data in Africa demonstrate that technical factors such as construction quality, system age, and repair response times significantly predict functionality and downtime (Fisher et al., 2015; Murray et al., 2024). Moreover, technical failures often trigger cascading institutional and financial pressures, reinforcing the systemic nature of sustainability (Cleaver et al., 2021).

FIETS recognises technological reliability as a central operational pillar that interacts continuously with governance and financial mechanisms (Daniel et al., 2021). Accordingly:

H_2: Technical factors have a positive and significant effect on the sustainability of rural water supply.

Social Factors and Water Supply Sustainability

Community participation, equitable access, gender inclusion, and local responsibility mechanisms enhance compliance, reduce conflict, and strengthen maintenance behaviour (Etongo et al., 2018). Conversely, exclusionary governance, weak participation, and inequitable access undermine trust and accelerate system degradation (Cleaver et al., 2021).

Studies across Africa and Asia demonstrate that communities with high levels of participation and shared ownership exhibit greater willingness to pay, stronger monitoring behaviour, and improved service continuity (Etongo et al., 2018). Social capital further strengthens informal enforcement mechanisms that support collective action in resource management (Ostrom, 2009). Within FIETS, social inclusion functions as a stabilising mechanism that sustains institutional legitimacy and technical upkeep (Daniel et al., 2021). Therefore:

H_3: Social factors have a significant effect on the sustainability of rural water supply.

Institutional Factors and Water Supply Sustainability

Effective governance systems reduce transaction costs, align incentives, and support compliance with operational standards (Cleaver et al., 2021). In rural water services, weak institutions frequently manifest as poor oversight, unclear roles, and fragmented coordination, which undermine sustainability (Lockwood & Smits, 2011; Smits et al., 2015). Empirical evidence confirms that institutional capacity, transparency, and inter-agency coordination significantly influence service reliability and system longevity (Whaley & Cleaver, 2017; Jama, 2019). Institutional failures often amplify technical breakdowns and financial stress, creating reinforcing cycles of system collapse (Cleaver et al., 2021).

FIETS explicitly embeds institutional strength as a core sustainability pillar (Daniel et al., 2021). Hence:

H_4: Institutional factors have a significant effect on the sustainability of rural water supply.

Financial Factors and Water Supply Sustainability

Financial sustainability ensures that adequate resources are available for operation, maintenance, rehabilitation, and expansion of services (Truslove et al., 2020; World Bank, 2021). Cost recovery mechanisms, affordability, financial management capacity, and access to external funding jointly determine the viability of rural water services (Truslove et al., 2020). While cost recovery remains difficult in low-income rural contexts, empirical studies show that sound financial management significantly improves system longevity (Whittington et al., 2020). In the FIETS model, financial capacity operates as the enabling foundation for all other domains (Daniel et al., 2021). Accordingly:

H_5: Financial factors have a significant effect on the sustainability of rural water supply.

Conceptual Framework

This study is anchored in the FIETS framework, which conceptualises rural water supply sustainability as the outcome of interacting multidimensional constructs. The framework posits that long-term service performance emerges from the alignment of financial capacity, institutional effectiveness, environmental resilience, technological reliability, and social inclusion. These all together contributes additively to overall sustainability. Weakness in any single dimension can affect overall sustainability performance and outcomes.

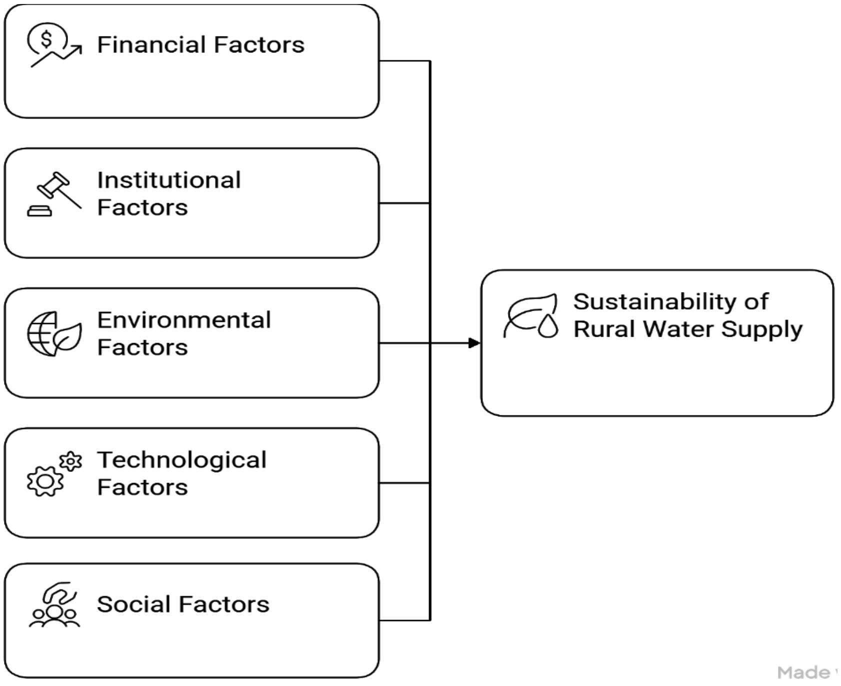

Figure 1: Conceptual Model

Source: *Adapted from the FIETS sustainability framework developed by SNV Netherlands Development Organisation (2012) and applied by Daniel et al. (2021).*

Method

Study design

This study employed a quantitative cross-sectional design grounded in a positivist research philosophy. The approach assessed household perceptions of rural water service sustainability at a single point in time during 2025 using key service delivery attributes, including water quality, quantity, reliability, accessibility, and affordability. These indicators were used as proxies for sustainability because they reflect the extent to which water services consistently meet users' needs under prevailing FIETS conditions. The design was also appropriate for examining predictive associations among constructs within the FIETS conceptual framework in development and sustainability (Hair et al., 2022; Creswell & Plano Clark, 2018).

Study area

The empirical investigation was conducted in Chemba District, located in the Dodoma Region of central Tanzania. Chemba lies within a semi-arid ecological zone characterised by low, highly variable rainfall, frequent droughts, heavy reliance on groundwater, and dispersed rural settlements. These conditions generate significant vulnerability in rural water service provision and render the district a highly suitable setting for examining sustainability. Also, district records indicated non-functionality of several water schemes and widespread reliance on unimproved water sources during dry seasons, reinforcing the relevance of Chemba as a case for sustainability analysis.

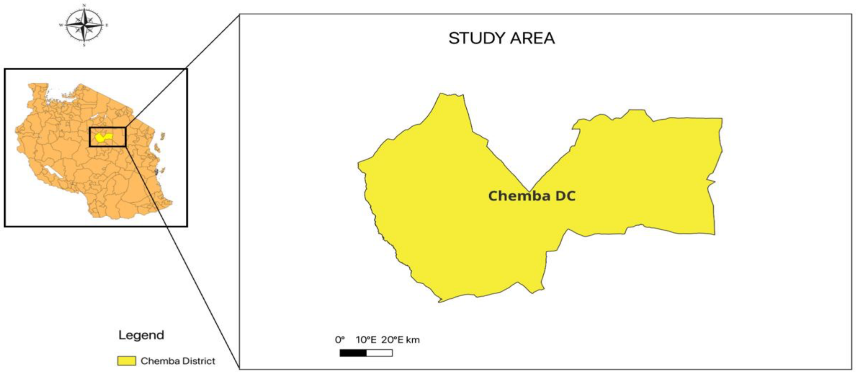

Figure 1: Study area

Sample Size and Sampling Procedure

The target population comprised rural households residing in water service areas across Chemba District. A multistage random sampling procedure was employed. In the first stage, representative wards were selected using stratified sampling to ensure geographic and hydrological diversity. In the second stage, villages were randomly selected from each ward. In the third stage, households were selected using systematic random sampling from village household registers. The final sample consisted of 384 households, determined using Cochran's (1977) formula at a 95% confidence level and 5% margin of error. Although clustering effects associated with multistage sampling may reduce the effective sample size, the achieved sample exceeded recommended minimum thresholds for PLS-SEM and remained adequate for model estimation and bootstrapping procedures (Hair et al., 2022).

Environmental factors were measured using indicators that captured climate variability, adaptive capacity, ecosystem and catchment management, pollution control, and waste management. Technical factors were operationalised through technology appropriateness, infrastructure functionality, and maintenance and repair effectiveness. Social factors captured community participation, equitable access, and collective ownership and responsibility. Institutional factors measured governance participation, inter-institutional coordination, and accountability and transparency mechanisms. Financial factors were measured using cost recovery practices, financial management effectiveness, and access to funding mechanisms. Sustainability was measured through water quality, quantity, reliability, accessibility, and affordability.

The questionnaire was pretested in a pilot study to ensure clarity, reliability, and contextual relevance. Necessary modifications were made prior to the main data collection exercise.

Data Analysis

The analytical framework was grounded in the FIETS conceptual model and implemented using Partial Least Squares Structural Equation Modelling. PLS-SEM was selected because it is well-suited to analysing complex predictive and associative models involving latent constructs, particularly in exploratory and theory-building research (Hair et al., 2022; Henseler et al., 2015).

The structural model specified five exogenous latent constructs, which were operationalised reflectively because the indicators were specified as manifestations of respondents' perceptions, and one endogenous latent construct. All hypothesised relationships were modelled as direct effects. The model was estimated using SmartPLS 4. Bootstrapping with 5,000 subsamples was employed to generate standard errors, t-statistics, and p-values for hypothesis testing.

The reflective measurement model was evaluated in accordance with PLS-SEM guidelines. Indicator reliability was assessed using standardised factor loadings. Internal consistency reliability was examined through Cronbach's alpha and composite reliability. Convergent validity was evaluated using Average Variance Extracted. Discriminant validity was assessed using both the Fornell–Larcker criterion and the Heterotrait–Monotrait ratio. Multicollinearity was examined using Variance Inflation Factors. Overall model fit was assessed using the standardised root mean square residual and the normed fit index.

The structural model was evaluated by examining path coefficients, t-values, and p-values. Explanatory power was assessed using the coefficient of determination (R^2). Effect sizes were evaluated using Cohen's f^2. Predictive relevance was assessed using Stone–Geisser's Q^2 via blindfolding procedures. Model fit was further evaluated using SRMR and NFI. All inferential tests were conducted at a 95% confidence level.

Ethical Consideration

Ethical clearance was obtained from the Mzumbe University Research Ethics Committee. Permission was also obtained from the Dodoma Regional Office and the Chemba District Council. Participation was voluntary, and informed consent was obtained from all respondents prior to data collection. Confidentiality and anonymity of participants were maintained throughout the study.

Results

Demographic Profile of Respondents

Results presented in Table 1 show that female respondents constituted 58.2 per cent (n = 223) of the sample, while 41.8 per cent (n = 160) were male. This gender composition reflects the strong role of women in household water management in rural Tanzania. The age structure indicates a predominantly working-age population, with the largest proportion of respondents falling within the 30–39 years age group (34.2 per cent), followed by 40–49 years (26.9 per cent), 18–29 years (19.1 per cent), and 50 years and above (19.8 per cent).

Table 1: Demographic Profile of Respondents (n = 384)

Variable	Category	Frequency	Percentage
Gender	Female	223	58.2
	Male	160	41.8
Age (years)	18–29	73	19.1
	30–39	131	34.2
	40–49	103	26.9
	50+	76	19.8
Household size	1–3	108	28.2
	4–6	186	48.6
	7+	88	23.2
Education level	No formal education	64	16.7
	Primary education	257	67.1
	Secondary education	47	12.3
	Higher education	15	3.9
Employment status	Farmer	210	54.8
	Self-employed	116	30.3
	Employed	24	6.3
	Unemployed	33	8.6

Household size was largely concentrated between 4–6 members (48.6 per cent), followed by 1–3 members (28.2 per cent) and 7 or more members (23.2 per cent). Education levels reveal limited formal schooling: 67.1 per cent of respondents had primary education, 16.7 per cent had secondary education, 16.7 per cent had no formal education, and only 3.9 per cent had higher education. In terms of employment, the rural economy is dominated by agriculture, with 54.8 per cent of respondents identifying as farmers, followed by 30.3 per cent self-employed, 8.6 per cent unemployed, and 6.3 per cent formally employed.

Measurement Model Evaluation

Prior to assessing the structural relationships, the reflective measurement model was evaluated for reliability and validity following established PLS-SEM procedures, including indicator reliability, internal consistency reliability, convergent validity, discriminant validity, collinearity diagnostics, and global model fit (Hair et al., 2022). Indicator loadings of 0.70 or higher were considered desirable. However, indicators with loadings between 0.40 and 0.70 were retained when their removal did not substantially improve composite reliability or average variance extracted (AVE) and when they remained theoretically important for representing the construct domain, consistent with PLS-SEM recommendations.

Indicator Reliability

Results presented in Table 2 show that most indicator loadings exceeded the recommended threshold of 0.60, with values ranging from 0.561 to 0.857, indicating acceptable item–construct relationships. Although several indicators were below the preferred threshold of 0.70, they were retained because their removal did not substantially improve composite reliability or average variance extracted (AVE), and they remained theoretically important for representing the construct domain (Hair et al., 2022

Table 2: Factor loading indicators

	Environmental Factors	Financial Factors	Institutional Factors	Social Factors	Sustainability of Water supply	Technical Factors
FF1		0.728				
FF2		0.798				
FF3		0.679				
FF4		0.612				
FF5		0.852				
FF6		0.689				
FF7		0.717				
FF8		0.821				
FF9		0.585				
EF1	0.705					
EF10	0.662					
EF2	0.769					
EF3	0.840					
EF4	0.686					
EF5	0.797					
EF6	0.636					
EF7	0.720					
EF8	0.829					
EF9	0.754					
IF1			0.818			
IF2			0.702			
IF3			0.827			
IF4			0.724			

IF5	0.711			
IF6	0.690			
IF7	0.639			
IF8	0.595			
IF9	0.804			
SF1		0.610		
SF2		0.790		
SF3		0.682		
SF4		0.722		
SF5		0.779		
SF6		0.786		
SF7		0.657		
SF8		0.833		
SF9		0.828		
SW1			0.741	
SW2			0.747	
SW3			0.857	
SW4			0.681	
SW5			0.606	
TF1				0.779
TF2				0.748
TF3				0.678
TF4				0.825
TF5				0.561
TF6				0.786
TF7				0.610
TF8				0.722
TF9				0.645

Internal Consistency, Reliability and Convergent Validity

Results presented in Table 3 show that Cronbach's alpha values ranged from 0.779 to 0.908 and composite reliability values from 0.850 to 0.924, exceeding the recommended threshold of 0.70 and indicating acceptable internal consistency. AVE values ranged from 0.505 to 0.557, suggesting acceptable but relatively modest convergent validity, as all constructs exceeded the minimum threshold of 0.50. Although several indicators had loadings below the preferred threshold of 0.70, they were retained because their removal did not substantially improve composite reliability or AVE, and they remained theoretically important for representing the construct domain (Hair et al., 2022).

Table 3: Constructs' reliability and validity for each construct

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Environmental Factors	0.908	0.912	0.924	0.552
Financial Factors	0.884	0.894	0.908	0.526
Institutional Factors	0.887	0.897	0.909	0.529
Social Factors	0.899	0.905	0.918	0.557
Sustainability of Water supply	0.779	0.804	0.850	0.535
Technical Factors	0.876	0.893	0.901	0.505

Given the use of cross-sectional, self-reported Likert-scale data from a single source, common method bias was assessed using Harman's single-factor test and full collinearity diagnostics. The first factor explained 41.28%, which is below 50% of the total variance, while all inner VIF values remained below the recommended threshold of 3.3 (Kock, 2015), suggesting that common method bias was unlikely to substantially affect the results.

Discriminant Validity

The Fornell–Larcker results presented in Table 4a show that the square root of the AVE for each construct exceeded its correlations with all other constructs, satisfying the criterion for discriminant validity. The HTMT matrix results in Table 4b further confirm discriminant validity, with all HTMT values falling well below the conservative threshold of 0.85. Together, these findings demonstrate that the latent constructs are empirically distinct and capture unique dimensions of rural water supply sustainability.

Table 4a: Fornell–Larcker criterion

	Environmental Factors	Financial Factors	Institutional Factors	Social Factors	Sustainability of Water supply	Technical Factors
Environmental Factors	0.743					
Financial Factors	0.336	0.725				
Institutional Factors	0.186	0.345	0.727			
Social Factors	0.285	0.319	0.405	0.747		
Sustainability of Water supply	0.469	0.362	0.318	0.363	0.731	
Technical Factors	0.268	0.272	0.148	0.231	0.324	0.711

Table 4b: Discriminant Validity – HTMT ratio

	Environmental Factors	Financial Factors	Institutional Factors	Social Factors	Sustainability of Water supply	Technical Factors
Environmental Factors						
Financial Factors	0.376					
Institutional Factors	0.210	0.388				
Social Factors	0.315	0.355	0.454			
Sustainability of Water supply	0.542	0.430	0.382	0.418		
Technical Factors	0.303	0.303	0.164	0.253	0.380	

Collinearity Diagnostics and Global Model Fit

Results presented in Table 5, show that all VIF values indicators assessed using Variance Inflation Factor (VIF) values show to be below 3.0, with a range between 1.275 and 2.701 respectively, indicating no collinearity concerns.

Table 5: Collinearity statistics - VIF

	VIF
EC1	1.780
EC2	2.137
EC3	1.583
EC4	1.372
EC5	2.650
EC6	1.585
EC7	1.651
EC8	2.382
EC9	1.352
EF1	1.659
EF10	1.560
EF2	2.021
EF3	2.701
EF4	1.616
EF5	2.345
EF6	1.523
EF7	1.730
EF8	2.596
EF9	1.962
IF1	2.283
IF2	1.626
IF3	2.355
IF4	1.703
IF5	1.687
IF6	1.601
IF7	1.481
IF8	1.367
IF9	2.292
SF1	1.386
SF2	2.186
SF3	1.642
SF4	1.763
SF5	2.058
SF6	2.108
SF7	1.494
SF8	2.530
SF9	2.489
SW1	1.460
SW2	1.564
SW3	2.016
SW4	1.441
SW5	1.275
TF1	1.864
TF2	1.794
TF3	1.556
TF4	2.350
TF5	1.360
TF6	2.109
TF7	1.372
TF8	1.696
TF9	1.551

The results of the Global model fit using the Standardised Root Mean Square Residual (SRMR) and the Normed Fit Index (NFI) in Table 6 show that the model achieved an SRMR value of 0.048 and an NFI value of 0.840, implying that both meet recommended thresholds for acceptable model fit in PLS-SEM.

Table 6: Model Fit

	Saturated model	Estimated model
SRMR	0.048	0.048
d_ULS	3.052	3.052
d_G	0.772	0.772
Chi-square	1587.541	1587.541
NFI	0.840	0.840

Figure 2 presents the complete measurement model, including standardised loadings and relationships among the study constructs estimated in SmartPLS.

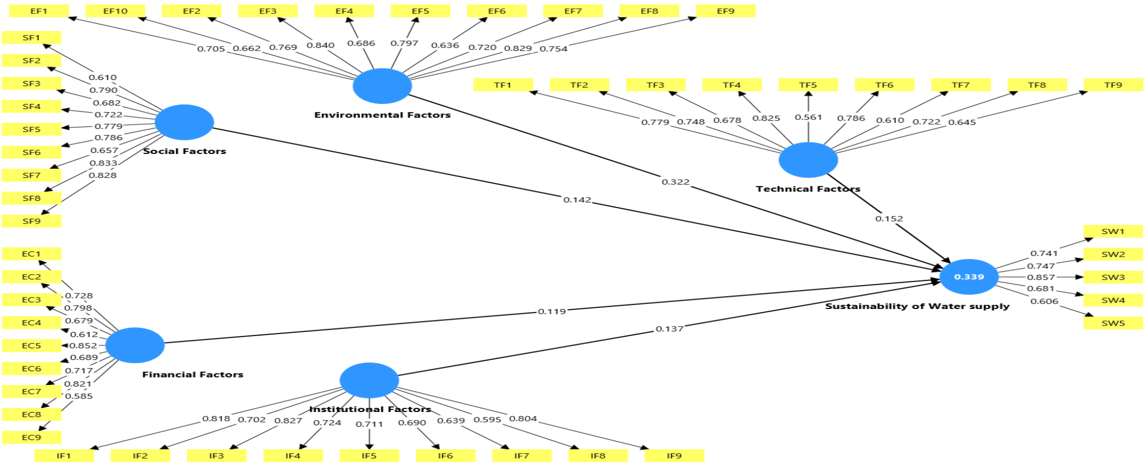

Figure 2: Measurement model estimated in SmartPLS

Structural Model Results and Hypothesis Testing

Following confirmation of the reliability and validity of the measurement model, the structural model was performed to test the hypothesised relationships among the FIETS constructs and the sustainability of rural water supply. The assessment followed established PLS-SEM procedures and involved examination of path coefficients, statistical significance, explanatory power, effect sizes, predictive relevance, and collinearity diagnostics (Hair et al., 2022).

Path Coefficients and Hypothesis Testing

The estimated structural relationships are presented in Figure 3, while the corresponding numerical results are reported in Table 7, which shows that all hypothesised paths exhibit positive and statistically significant effects on the sustainability of rural water supply. Although diagnostic tests suggested no substantial common method bias, the use of self-reported cross-sectional data may still introduce some degree of shared method variance.

Table 7: Path Coefficients, Effect Sizes, and Hypothesis Testing Results

Hypothesis	Structural Path	β (Path Coefficient)	t-value	p-value	Effect Size (f^2)	Decision
H_1	Environmental → Sustainability	0.322	7.677	< 0.001	0.130	Supported
H_2	Technical → Sustainability	0.152	3.595	< 0.001	0.031	Supported
H_3	Social → Sustainability	0.142	2.785	0.005	0.023	Supported
H_4	Institutional → Sustainability	0.137	3.305	0.001	0.022	Supported
H_5	Financial → Sustainability	0.119	2.506	0.012	0.016	Supported

Environmental factors show the strongest association on sustainability with ($\beta = 0.322$, $t = 7.677$, $p < 0.001$), providing strong support for H_1. This result indicates that climate resilience, catchment management, pollution control, and environmental adaptation capacity constitute the most influential sustainability drivers in the Chemba District.

Technical factors demonstrate a positive and significant effect on sustainability with ($\beta = 0.152$, $t = 3.595$, $p < 0.001$), thus supporting H_2. This finding highlights the importance of technology appropriateness, infrastructure functionality, and maintenance effectiveness in sustaining reliable water supply services.

Social factors are also found to significantly predict sustainability with ($\beta = 0.142$, $t = 2.785$, $p = 0.005$), confirming H_3. The result stresses the role of community participation, equitable access, and collective ownership in promoting long-term service performance.

Institutional factors exhibit a positive and statistically significant relationship with sustainability ($\beta = 0.137$, $t = 3.305$, $p = 0.001$), supporting H_4. This indicates that governance participation, inter-institutional coordination, and accountability mechanisms substantially contribute to sustainable service delivery.

Finally, financial factors show a positive and significant but modest effect on sustainability ($\beta = 0.119$, $t = 2.506$, $p = 0.012$), thereby supporting H_5. The result supports that cost recovery, financial management, and access to funding remain essential components of sustainability. This suggests that financial conditions have policy relevance; they can produce substantial gains if accompanied by stronger institutional accountability, timely technical maintenance, environmental resilience, and community participation.

Environmental factors show the strongest association with sustainability

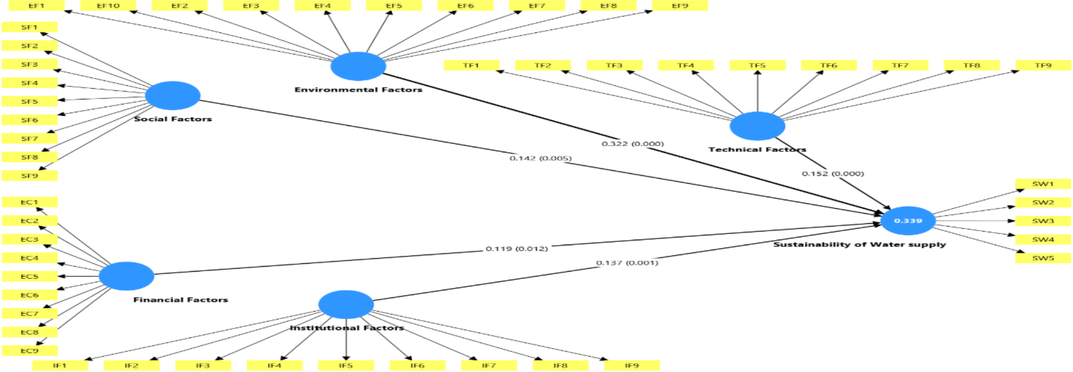

Figure 3: The estimated structural relationships

Explanatory Power and Effect Sizes

The structural model demonstrates meaningful explanatory power for the sustainability of rural water supply. The five FIETS dimensions jointly explain 33.9% of the variance in sustainability outcomes ($R^2 = 0.339$). The coefficient of determination (R^2) indicates that the five FIETS dimensions jointly explain a considerable proportion of the variance in sustainability outcomes. The model's effect size estimates, presented in Table 7 above, reveal that environmental factors exert a moderate practical effect ($f^2 = 0.130$), while technical ($f^2 = 0.031$), social ($f^2 = 0.023$), institutional ($f^2 = 0.022$), and financial ($f^2 = 0.016$) factors exhibit small but meaningful effects.

These effect sizes reinforce the conclusion that environmental conditions are the dominant sustainability constraint in semi-arid rural settings, while the remaining FIETS dimensions play complementary yet essential roles.

Predictive Relevance and Collinearity Assessment

Predictive relevance was assessed using the Stone–Geisser Q^2 statistic obtained through blindfolding procedures. The model achieved a Q^2 value of 0.313, indicating moderate out-of-sample predictive capability for the sustainability of rural water supply.

Table 10: PLS Predict LV summary

	Q^2predict	RMSE	MAE
Sustainability of Water supply	0.313	0.832	0.659

Discussion

This study set out to empirically examine factors for sustainable rural water supply in a semi-arid district of Tanzania using the FIETS framework. The structural model results provide context-specific empirical evidence consistent with the FIETS framework, indicating that sustainability in rural water services is a multidimensional outcome influenced by several interrelated environmental, technical, social, institutional, and financial domains. All hypothesised relationships were positive and statistically significant, providing empirical support for the multidimensional logic of the FIETS framework by demonstrating that sustainability outcomes are associated with the combined influence of all five constructs.

Environmental factors showed the strongest association with perceived sustainability of rural water service. The strong and statistically significant path coefficient for environmental factors indicates that climate variability, groundwater stress, ecosystem degradation, and environmental adaptation capacity constitute the most powerful constraints on long-term service performance in Chemba District. This result aligns closely with a growing body of evidence demonstrating that hydrological variability and environmental degradation increasingly undermine the reliability of water systems in semi-arid regions (Grey & Sadoff, 2007; Mekonnen & Hoekstra, 2016; Vörösmarty et al., 2018; IPCC, 2022). Previous studies in sub-Saharan Africa have documented how drought cycles, declining groundwater tables, and catchment degradation accelerate infrastructure failure and raise maintenance costs, thereby undermining sustainability even where institutional and financial systems are in place (Foster, 2013; Klug et al., 2018; Murray et al., 2024). The present findings reinforce the argument that climate adaptation and environmental governance must occupy a central place in rural water policy, particularly in semi-arid landscapes.

The significant effect of technical factors confirms that infrastructure quality, technology appropriateness, and maintenance effectiveness remain indispensable for service continuity. This finding is consistent with extensive empirical work demonstrating that construction quality, preventive maintenance, availability of spare parts, and skilled technical support are among the strongest predictors of rural water system functionality (Harvey & Reed, 2006; Fisher et al., 2015; Smits et al., 2015; Klug et al., 2018). In Chemba District, the model's technical constraints suggest that even well-intentioned financing and governance reforms cannot compensate for weak maintenance regimes and inappropriate technology choices. This reinforces the long-standing critique of infrastructure-led development models that prioritise construction over life-cycle management (Lockwood & Smits, 2011; Foster, 2013).

The significant contribution of social factors highlights the importance of community participation, collective ownership, and equitable access in sustaining water services. This result echoes social capital theory and collective action research, which emphasise that communities with strong participation and shared norms are more likely to protect infrastructure, enforce usage rules, and mobilise resources for maintenance (Ostrom, 2009; Putnam, 2000; Mansuri & Rao, 2013). Empirical evidence from rural Africa and Asia consistently shows that participatory governance improves tariff compliance, reduces conflict, and strengthens accountability mechanisms (Marks & Davis, 2012; Etongo et al., 2018). The present findings demonstrate that social inclusion remains a core stabilising mechanism within the FIETS system.

The significant effect of institutional factors further confirms that governance quality fundamentally shapes sustainability outcomes. Institutional capacity, transparency, coordination, and accountability mechanisms determine how effectively technical, financial, and social resources are translated into reliable services (North, 1990; Ostrom, 2005; Pahl-Wostl, 2015). Weak institutional environments, characterised by fragmented authority and unclear roles, have been widely documented as key drivers of service failure in rural water systems (Whaley & Cleaver, 2017; Jama, 2019; Cleaver, 2021). The results from Chemba District demonstrate that institutional coherence is not merely supportive but constitutive of sustainability.

Financial capacity remains an indispensable foundation for sustainability. Cost recovery mechanisms, sound financial management, and access to reliable funding determine service providers' ability to finance routine operations, preventive maintenance, and system rehabilitation (Foster, 2013; Truslove et al., 2020; World Bank, 2021). The relatively small coefficient likely reflects the structural affordability constraints faced by rural households in semi-arid regions, where income volatility limits the effectiveness of full-cost recovery models. This finding supports the growing consensus that financial sustainability must be embedded within broader institutional and social support systems rather than treated as an isolated solution (Lockwood & Smits, 2011; Cleaver, 2021).

Conclusions

This study offers strong empirical evidence on the factors for sustainable rural water supply in semi-arid Tanzania by showing that sustainability of rural water services is associated with the combination of factors. All hypothesised relationships were statistically significant, providing empirical support for the FIETS framework's applicability in a semi-arid district context as a comprehensive explanatory model for rural water sustainability. Environmental factors emerged as the most strongly associated dimension of sustainability, highlighting the growing importance of climate resilience, ecosystem protection, and adaptation capacity in semi-arid regions. Technical reliability followed closely, reinforcing the central role of appropriate technology selection, infrastructure quality, and effective maintenance systems. Social and institutional dimensions also demonstrated substantial influence, confirming that community participation, governance coordination, accountability, and institutional coherence are essential pillars of long-term service performance. Financial factors exhibited the smallest standardised effect; their statistical significance highlights that sound financial management and predictable funding remain foundational requirements for sustainability.

This study contributes to the literature on rural water service sustainability in semi-arid settings by applying the FIETS framework at the district level. It provides context-specific evidence on how financial, institutional, environmental, technical, and social conditions are associated with household experiences of water quality, reliability, accessibility, affordability, and adequacy of quantity. Practically, the study highlights the usefulness of FIETS as a district-level diagnostic and planning tool for strengthening integrated rural water governance. Such coordinated planning can enhance the effectiveness of rural water interventions and contribute to progress toward Sustainable Development Goal 6. The study also contributes methodologically by operationalising FIETS dimensions through a latent-variable approach, thereby offering a structured basis for assessing sustainability-related conditions in rural water services.

The findings suggest that policymakers should prioritise interventions that strengthen the key factors of rural water service sustainability identified in this study. District and local government authorities should allocate adequate financial resources for operation and maintenance, strengthen institutional capacity through regular monitoring and technical support, promote active community participation in water governance, and encourage environmentally sustainable water resource management. Development partners and water sector stakeholders should align their interventions with the FIETS sustainability dimensions to improve the long-term functionality and resilience of rural water supply systems. These actions can contribute to achieving sustainable and reliable rural water services in the district and Tanzania at large.

This study has three limitations: First, the cross-sectional design limits causal inference and captures sustainability conditions only at one point in time. Second, the focus on a single district limits generalizability to other rural or semi-arid contexts. Third, the model estimated only direct relationships and did not test interactions, mediation, feedback loops, or system-level dynamics among FIETS dimensions. Financial and Institutional constructs were modelled reflectively to align with PLS-SEM procedures; however, they may be conceptually formative, and confirmatory tetrad analysis was not conducted. Despite these limitations, the study provides useful empirical evidence on the sustainability of rural water services in semi-arid Tanzania and demonstrates the practical value of the FIETS framework as a diagnostic tool for identifying constraints that can support more integrated local planning and sustainable rural water service delivery.

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