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Strengthening Rural Water Sustainability through Integrated Management and Stewardship: Evidence from Selected Rural Areas of Tamil Nadu

Kavitha Muthukumaran[1]*, Vani Haridasan[1], Saara S A[2]

[1]Associate Professor, Department of Management Studies, Sri Sivasubramaniya Nadar College of Engineering, Chennai, Tamil Nadu, India

[2]Student, Department of Management Studies, Sri Sivasubramaniya Nadar College of Engineering, Chennai, Tamil Nadu, India

Abstract

The interplay of community participation, operational water management and stewardship behavior with local governance is a growing determinant of the sustainability of rural water. Groundwater recharge, maintenance, institutional accountability and responsible use are weak to ensure long-term water security, without infrastructure creation. In this article these interrelated aspects are analyzed with the primary data collected from 140 respondents across selected rural areas of Tamil Nadu which comprised rural households and farmers. Five constructs, that is, governance mechanisms, stakeholder participation, water management practices, stewardship practices and rural water sustainability were measured using a structured questionnaire. Descriptive statistics, Cronbach's alpha, Pearson correlation and multiple linear regression were used for data analysis. The results reveal all constructs are perceived at a moderate to high level, meaning that they are functional but not mature. The internal consistency (reliability) of the scales ranged between 0.741 and 0.809, reflecting acceptable levels. Positive and significant relationships were observed between each of the four predictors and rural water sustainability using correlation analysis. The model of regression accounted for 58.6% of the variance in the sustainability outcomes. The most important factor was found to be water management practices, followed by stewardship practices, governance mechanisms, and stakeholder participation. Rural water systems must be considered in a whole-of-system context where governance gives institutional discipline, participation gives local ownership, water management gives operational performance and conservation behavior is sustained by stewardship, the study argues. This article provides an empirically supported methodology for enhancing the water sustainability of rural water supply systems by adopting coordinated, accountable and behaviorally informed water management.

Keywords: rural water sustainability; integrated water management; water stewardship; governance mechanisms; stakeholder participation; Tamil Nadu

1. Introduction

Water is one of the most important resources for rural livelihoods, agriculture, public health, sanitation and ecological balance. The access to, and quality of, water in rural areas has an immediate impact on the welfare of households, the farming choices available, livestock management, food security and the resilience of village economies. Rural water systems are more likely to be correlated to local rainfall, groundwater availability, traditional water sources, agricultural water demand and the management practices of the community. So rural water sustainability cannot be just about provision of infrastructure; it also needs to be looked at from the governance, maintenance, participation, conservation behaviour and long-term resource protection perspectives. The water interventions implemented in the past in many rural areas have been very instrumental in expanding access through the construction of wells, borewells, pipelines, tanks, storage structures and connections to households. These are necessary, but not sufficient conditions for sustainability.

A water system may be physically in place but poorly performing if there is no regular maintenance, groundwater recharge, an institutional system of accountability, equitable access and responsible use among the local users of the water system. This leaves behind a water access-water sustainability gap. However, it is not enough to put in place water facilities, it must also be to ensure that these systems are effective, fair and reliable over time.

Groundwater extraction, unpredictable rainfall, agricultural water demand and the uneven institutional capacity, as well as changing land-use, are also placing increasing pressure on rural water systems. These pressures are more significant in rural and rural peri-urban regions of Tamil Nadu where domestic, developmental and agricultural needs are sometimes competing. In these circumstances, water sustainability is not just an environmental concern, but also one of governance and management. It demands cooperation between the various institutions at the local level, involvement of the local people, effective water management and water stewardship by the users.

This article looks at rural water sustainability from an integrated management and stewardship point of view. Governance mechanisms should offer institutional support via accountability, monitoring, coordination, and role clarity. Stakeholder involvement brings formal water systems to the knowledge, needs and experiences of local communities. Plans are realised in water management practices by harvesting rainwater, recharging groundwater, implementing micro-irrigation, conservation and maintenance of infrastructure. Stewardship behaviours reinforce responsible water use, water conservation behaviours, and community stewardship of local water resources.

This study's central argument is that these four dimensions are inter-related and act as a whole to enhance rural water sustainability, as opposed to working independently or in isolation. Primary data on governance mechanisms, stakeholder participation, water management practices and stewardship practices are collected from rural households and farmers in selected rural areas of Tamil Nadu to understand how this influence water sustainability in rural areas. The aim of the article is to describe the existing state of these dimensions, test their reliability, perform correlation and regression analysis to find the magnitude of their contributions to sustainability outcomes. The results will contribute to a more integrated, accountable and behaviourally oriented water management in rural areas.

2. Review of Literature

2.1 From access to functionality and sustainability

The literature on rural water has gradually moved from a narrow concern with access to a wider concern with functionality, continuity, and sustainability. Giné and Pérez-Foguet (2008) argued that rural water programmes should be assessed through long-term service performance rather than through coverage alone. Their sustainability assessment approach is important because it recognises that a water system can be counted as provided but may still fail users if it is not maintained, financed or supported institutionally. Bonsor et al. (2018) similarly called for a standardised approach to assessing rural water functionality, emphasizing that systems must be evaluated by whether they continue to operate, serve users reliably and withstand stress.

Montgomery et al. (2009) linked rural water and sanitation sustainability to technical design, management systems, financing and institutional support. MacAllister et al. (2020) demonstrated that drought conditions expose differences in the performance of rural water supplies, thereby making resilience a key concern. These studies show that rural water sustainability is not a single engineering outcome but a composite result of infrastructure condition, local management, institutional support, resource availability and user behaviour.

2.2 Governance mechanisms and institutional coordination

Water governance refers to the institutions, rules, decision processes and accountability mechanisms through which water resources are planned, allocated and monitored. Ostrom's (1990) theory of common-pool resource governance remains relevant because many rural water sources require collective rules, monitoring and sanctions to prevent overuse and neglect. Pahl-Wostl (2009) emphasised adaptive governance and learning processes, arguing that resource systems require institutions capable of responding to uncertainty and changing conditions.

In practice, governance weaknesses often arise from fragmented responsibilities, unclear roles, weak monitoring and poor coordination among agencies. Hassenforder and Barone (2018) noted that integrated water resource management is difficult to implement when institutional arrangements remain fragmented. In the Indian context, Chaudhuri et al. (2020) observed that rural water supply programmes require not only infrastructure expansion but also service reliability, local institutional capacity and implementation discipline. These arguments justify the inclusion of governance mechanisms as a major predictor of rural water sustainability.

2.3 Stakeholder participation and community ownership

Stakeholder participation is widely considered essential for sustainable rural water systems because communities possess local knowledge about sources, seasonal scarcity, infrastructure problems and usage patterns. Schouten and Moriarty (2003) argued that community management must move from a narrow focus on assets to a broader focus on service responsibility. Hutchings et al. (2017) showed that community management in Indian rural water supply should be understood within specific institutional and social contexts rather than treated as a uniform model.

At the same time, participation is not automatically effective. Harvey and Reed (2007) questioned whether community-managed water supplies remain sustainable when communities lack technical, financial and institutional support. Whaley and Cleaver (2017) further argued that functionality cannot be understood only through the existence of committees; power relations, socio-technical arrangements and wider governance processes also matter. Therefore, participation in this study is treated as a potentially important but quality-dependent factor. It becomes meaningful when women, farmers, residents and local bodies influence planning, monitoring and maintenance rather than merely attending meetings.

2.4 Water management practices and operational performance

Water management practices represent the operational core of rural sustainability. These include rainwater harvesting, groundwater recharge, irrigation efficiency, maintenance of water infrastructure, conservation of local water bodies, leakage control and demand-side management. Katusiime and Schütt (2020) described integrated water resources management as a coordinated approach that links water, land and related resources. Such coordination is especially relevant in rural settings, where agriculture, domestic demand and local ecosystems rely on the same water base.

Azhoni et al. (2017) highlighted the pressure created by climate variability and population growth on water systems in India. Sen and Kansal (2019) connected rural water security to sustainable groundwater management and the need for planned use, recharge and regulation. These studies support the expectation that water management practices will have a strong effect on sustainability because they directly influence availability, efficiency, reliability and resource protection.

2.5 Stewardship and conservation behaviour

Water stewardship refers to responsible use, collective care and long-term protection of water resources. It extends beyond formal governance and physical infrastructure by focusing on the everyday behaviour of users and institutions. Sojamo and Rudebeck (2024) cautioned that stewardship must be linked with accountability and measurable outcomes; otherwise, it risks becoming a broad claim with limited practical impact. Silva (2023) similarly emphasised sustainability-oriented practices in water management, particularly in contexts where resource pressure is high.

Stewardship is significant because rural water outcomes are shaped by repeated choices: how households use water, whether farmers adopt efficient irrigation, whether users report leakage, whether communities protect local ponds and whether institutions respond to early signs of stress. Awareness alone is insufficient. Stewardship becomes effective when awareness is converted into conservation habits, monitoring behaviour, collective responsibility and support for long-term resource protection.

2.6 Policy context and synthesis of literature

India's policy environment increasingly recognises the need to move from infrastructure provision to service sustainability. The Jal Jeevan Mission stresses functional household tap connections, source sustainability, village-level planning and local institutional participation. AMRUT 2.0, while primarily urban in orientation, is relevant to rural-peri-urban transition areas because it emphasises water security, water body rejuvenation and data-driven planning. These policy directions support the need for an integrated approach that connects governance, participation, technical management and stewardship.

The literature therefore supports the conceptual logic of the present study. Governance provides institutional structure, participation provides local legitimacy, water management practices provide operational performance and stewardship provides behavioural continuity. The empirical task is to examine whether these four dimensions significantly influence rural water sustainability and to identify which dimension provides the strongest practical leverage.

Table 1. Thematic Synthesis of Literature and Linkage with the Study Model

Theme	Key literature support	Implication for present study
Functionality and sustainability	Giné & Pérez-Foguet (2008); Montgomery et al. (2009); Bonsor et al. (2018); MacAllister et al. (2020)	Sustainability should be assessed beyond access or infrastructure presence.
Governance and institutions	Ostrom (1990); Pahl-Wostl (2009); Hassenforder & Barone (2018); Chaudhuri et al. (2020)	Institutional accountability, monitoring and coordination are necessary for continuity.
Participation and ownership	Schouten & Moriarty (2003); Harvey & Reed (2007); Hutchings et al. (2017); Whaley & Cleaver (2017)	Participation must be meaningful and supported, not merely formal or symbolic.
Operational water management	Azhoni et al. (2017); Sen & Kansal (2019); Katusiime & Schütt (2020)	Recharge, maintenance, irrigation efficiency and planning influence water availability directly.
Stewardship and behaviour	Silva (2023); Sojamo & Rudebeck (2024)	Conservation behaviour and collective responsibility sustain long-term resource protection.

3. Research Gap and Objectives

The reviewed literature shows that rural water sustainability has been studied from different perspectives, including access, functionality, governance, community management, integrated water resource management and stewardship. However, many studies examine these dimensions separately. Governance is often studied as an institutional issue, participation as a community issue, water management as a technical issue and stewardship as a behavioural issue. Fewer studies bring these dimensions together in a single empirical framework to examine how they jointly influence rural water sustainability. This creates a need for an integrated model that connects institutional, participatory, operational and behavioural factors.

The primary objective of this study is to empirically evaluate the effectiveness of integrated rural water sustainability and stewardship practices in selected rural areas of Tamil Nadu. More specifically, the study seeks to assess the current status of rural water governance, stakeholder participation, water management practices and stewardship behaviour among rural households and farmers. It also examines the relationship between these factors and rural water sustainability and identifies the relative strength of each predictor. Based on the findings, the study aims to develop managerial and policy-oriented recommendations for strengthening long-term rural water sustainability through an integrated management and stewardship framework.

4. Conceptual Framework and Hypotheses

The conceptual framework treats rural water sustainability as the dependent variable and positions governance mechanisms, stakeholder participation, water management practices and stewardship practices as independent variables. The framework is based on the assumption that sustainable rural water outcomes require institutional capacity, community ownership, operational efficiency and conservation-oriented behaviour. Each variable contributes through a different pathway: governance improves accountability and coordination; participation improves local legitimacy and responsiveness; management practices improve technical and operational performance; and stewardship encourages responsible use and long-term protection.

The framework is intentionally integrated rather than single-dimensional. Rural water sustainability cannot be explained only by infrastructure, only by institutions or only by community participation. It emerges when formal governance, local participation, practical water management and conservation behaviour reinforce one another. Fig. 1 presents the conceptual framework used in the study.

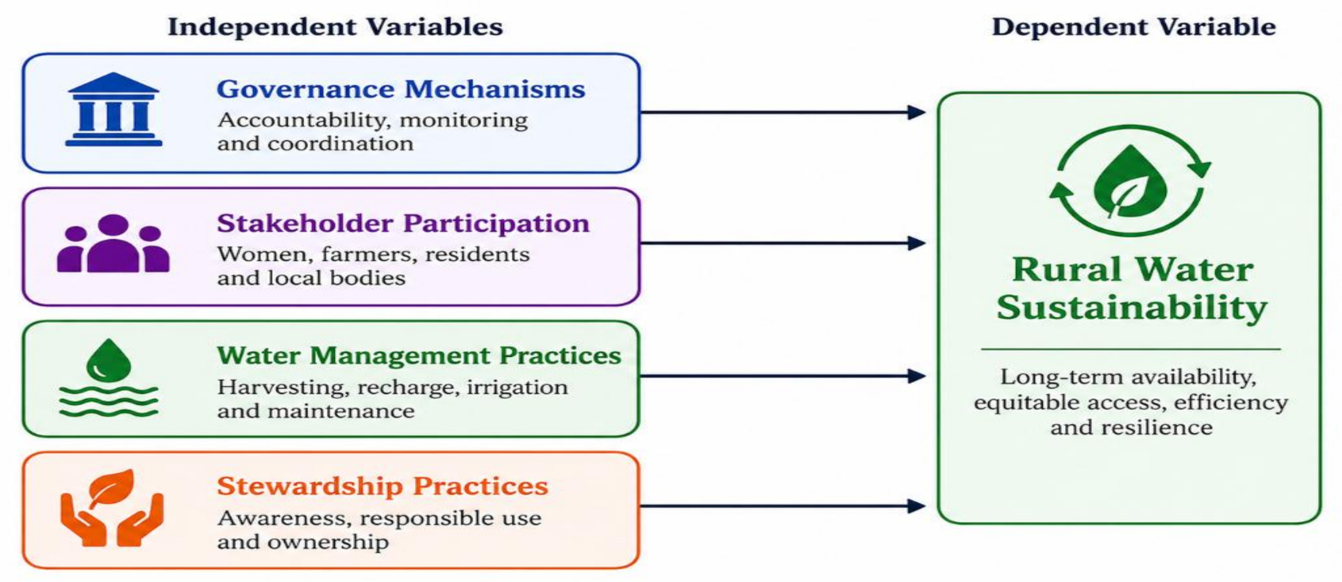

Figure 1. Conceptual Framework for Rural Water Sustainability

Table 2. Hypotheses with Conceptual Justification

Hypothesis	Statement	Conceptual justification	Expected direction
H1	Stakeholder participation has a significant positive impact on rural water sustainability.	Participation improves local ownership, feedback, monitoring and acceptance of water-related decisions.	Positive
H2	Water management practices have a significant positive impact on rural water sustainability.	Operational practices such as recharge, rainwater harvesting, irrigation efficiency and maintenance directly affect availability and reliability.	Positive
H3	Governance mechanisms have a significant positive impact on rural water sustainability.	Accountability, monitoring, role clarity and coordination provide the institutional conditions required for sustainable service delivery.	Positive
H4	Stewardship practices have a significant positive impact on rural water sustainability.	Responsible use, conservation behaviour and collective care reduce wastage and support long-term protection of water resources.	Positive

5. Methodology

The study adopted a descriptive and analytical research design. The descriptive component was used to understand the demographic profile of respondents and their perceptions of rural water governance, stakeholder participation, water management practices, stewardship practices and sustainability outcomes. The analytical component was used to examine the relationships among the study variables and to determine the relative influence of each predictor on rural water sustainability.

A quantitative survey approach was considered appropriate because the study aimed to measure clearly defined constructs and test statistically significant relationships among them. The respondents consisted of rural households and farmers from selected rural areas of Tamil Nadu. These respondents were selected because they are direct users of rural water resources and are closely affected by issues related to water availability, irrigation, groundwater use, local storage systems, infrastructure maintenance and conservation practices.

A total of 140 respondents participated in the study. Stratified random sampling was used to improve representation across important demographic and livelihood categories such as gender, age, occupation and years of residence. This was important because perceptions of rural water sustainability may vary between agricultural households and non-farm households, between recent and long-term residents, and between different age and gender groups. Including these groups helped capture a broader understanding of local water conditions and management practices.

Primary data were collected through a structured questionnaire. The questionnaire used a five-point Likert scale ranging from strong disagreement to strong agreement. It measured five major constructs: governance mechanisms, stakeholder participation, water management practices, stewardship practices and rural water sustainability. Governance-related items focused on accountability, monitoring, responsiveness, coordination and role clarity. Participation-related items measured community involvement, farmer participation, women's participation, local decision-making and collective action. Water management items focused on rainwater harvesting, groundwater recharge, irrigation efficiency, infrastructure maintenance and conservation practices. Stewardship items measured awareness, responsible use, conservation behaviour and community responsibility. Sustainability items captured perceived water availability, reliability, equity, continuity and long-term water security.

The collected data were analysed in stages. Percentage analysis was first used to describe the demographic profile of the respondents. Descriptive statistics were then used to assess the current level of agreement for each construct. Cronbach's alpha was applied to test the internal consistency and reliability of the measurement scales. Pearson correlation analysis was used to examine the direction and strength of association between the independent variables and rural water sustainability. Finally, multiple linear regression was applied to identify the relative predictive strength of governance mechanisms, stakeholder participation, water management practices and stewardship practices.

The methodology is suitable for the study because rural water sustainability is shaped by both observable management practices and user perceptions of governance, participation and stewardship. However, the findings should be interpreted with reasonable caution because the study is cross-sectional and based on survey responses. The results indicate association and predictive influence, but they do not establish strict causality. Participation was voluntary, and the responses were treated confidentially for academic purposes.

6. Results and Analysis

6.1 Respondent profile

The respondent profile shows that the sample includes a stable and locally experienced rural population. This is important because water sustainability is strongly connected to local knowledge, long-term observation of seasonal patterns and lived experience with water availability and infrastructure functioning.

Table 3. Respondent Profile and Relevance to the Study

Variable	Dominant/important category	Frequency (%)	Analytical relevance
Gender	Male respondents	77 (55.0%)	Male respondents formed the majority, but female representation was also substantial.
	Female respondents	56 (40.0%)	Female responses are important because household water use and water collection concerns are often closely linked to women.
Age	25-34 years	48 (34.3%)	Largest age group, indicating strong working-age participation.
	45 years and above	35 (25.0%)	Older respondents contribute long-term local water experience.
Occupation	Agriculture	55 (39.3%)	Largest livelihood group; confirms direct dependence on water resources.
	Non-farm categories combined	85 (60.7%)	Shows livelihood diversity beyond agriculture.

Years of residence	More than 20 years	50 (35.7%)	Largest residence group; indicates strong local knowledge of water conditions.
	11-20 years	35 (25.0%)	Adds further evidence of experienced respondents.

The profile shows that the sample includes both agricultural and non-agricultural respondents, with a strong presence of long-term residents. This strengthens the study because respondents with longer residence are more likely to possess practical knowledge of local water availability, seasonal variation and infrastructure performance. The presence of agricultural respondents is also important because farming households are directly affected by irrigation availability, groundwater conditions and water management practices.

6.2 Construct measurement focus

Before interpreting the statistical results, it is useful to clarify how each construct contributes to rural water sustainability. This link between the construct and its practical meaning helps connect the empirical analysis with the conceptual framework.

Table 4. Construct Measurement Focus and Practical Relevance

Construct	Measurement focus	Practical relevance
Governance mechanisms	Accountability, institutional responsiveness, monitoring, coordination, and clarity of roles	Creates the institutional foundation for planning, maintenance, transparency and dispute resolution.
Stakeholder participation	Community meetings, farmer involvement, women's participation, local decision-making, and collective action	Improves ownership, local legitimacy and responsiveness of water-related decisions.
Water management practices	Rainwater harvesting, irrigation efficiency, groundwater recharge, infrastructure maintenance and conservation practices	Improves operational performance and directly affects water availability and reliability.
Stewardship practices	Responsible usage, awareness, conservation behaviour, community responsibility and long-term protection	Builds sustained behavioural commitment and reduced wasteful water use.
Rural water sustainability	Availability, reliability, equity, continuity, and long-term resource security	Represents the desired outcome of integrated management and stewardship.

6.3 Descriptive statistics

Descriptive statistics were used to assess the current level of perception for each construct. A higher mean indicates stronger perceived performance, while the standard deviation shows the level of agreement among respondents.

Table 5. Descriptive Statistics of Study Variables

Variable	N	Mean	Median	Std. deviation	Minimum	Maximum	Rank
Governance mechanisms	140	3.46	3.50	0.459	2.25	4.75	5
Stakeholder participation	140	3.63	3.75	0.467	2.75	5.00	2
Water management practices	140	3.68	3.75	0.458	2.50	4.75	1
Stewardship practices	140	3.51	3.50	0.450	2.50	4.50	4
Rural water sustainability	140	3.59	3.63	0.332	2.75	4.50	3

Water management practices recorded the highest mean (M = 3.68), indicating that operational practices such as conservation, infrastructure maintenance, rainwater harvesting and efficient water use are perceived as relatively stronger than the other dimensions. Stakeholder participation recorded the second highest mean (M = 3.63), suggesting that local involvement exists to a reasonable extent.

Rural water sustainability recorded a mean of 3.59. This indicates moderate satisfaction rather than strong sustainability. The system is therefore not failing, but it has not reached a mature or optimal level. Stewardship practices recorded a mean of 3.51, suggesting that awareness and conservation behaviour require reinforcement. Governance mechanisms recorded the lowest mean (M = 3.46), indicating weaker performance in accountability, monitoring, coordination and responsiveness.

Table 6. Interpretation of Mean Scores

Mean range	Level	Meaning for this study
1.00-1.80	Very low	The practice is weak or largely absent.
1.81-2.60	Low	The practice exists minimally and requires urgent improvement.
2.61-3.40	Moderate	The practice is present but not sufficiently strong.
3.41-4.20	Moderate to high	The practice is functioning but still has clear scope for improvement.
4.21-5.00	High	The practice is strong and widely accepted.

All variables fall in the moderate-to-high range. This should be interpreted carefully. It does not mean that the system is fully effective; it means that the basic structures and practices are present but still need strengthening. The standard deviation values, ranging from 0.332 to 0.467, show fairly consistent respondent perceptions.

6.4 Reliability analysis

Reliability analysis was conducted using Cronbach's alpha to test the internal consistency of the measurement scales. A value above 0.70 is generally accepted in social science research. All constructs crossed this threshold, confirming that the questionnaire items were sufficiently consistent for further analysis.

Table 7. Reliability Analysis Using Cronbach's Alpha

Construct	Cronbach's alpha	Reliability level	Interpretation
Governance mechanisms	0.808	Good	Items consistently measured institutional and governance dimensions.
Stakeholder participation	0.794	Acceptable to good	Items reliably captured participation and community involvement.
Water management practices	0.809	Good	Items consistently measured operational and technical practices.
Stewardship practices	0.794	Acceptable to good	Items reliably captured conservation behaviour and responsible use.
Rural water sustainability	0.741	Acceptable	Items adequately measured sustainability outcomes.

Governance and water management practices showed the highest reliability, indicating that respondents interpreted these items consistently. Rural water sustainability recorded the lowest alpha value, but it remained above the acceptable threshold. This is reasonable because sustainability is a broader outcome construct that includes availability, reliability, equity and long-term security.

6.5 Correlation analysis

Pearson correlation analysis examined the direction and strength of association between each independent variable and rural water sustainability. All four predictors showed positive and statistically significant relationships with sustainability.

Table 8. Pearson Correlation Matrix

Variable	Governance	Participation	Management	Stewardship	Sustainability
Governance	1.000	0.030	0.014	0.128	0.431**
Participation	0.030	1.000	0.036	-0.026	0.363**
Management	0.014	0.036	1.000	-0.215	0.372**
Stewardship	0.128	-0.026	-0.215	1.000	0.346**
Sustainability	0.431**	0.363**	0.372**	0.346**	1.000

Note: ** indicates significance at the 0.01 level.

Table 9. Variable-Wise Correlation Interpretation

Predictor	Correlation with sustainability	Strength	Interpretation
Governance mechanisms	r = 0.431	Moderate positive	Strongest bivariate relationship: institutional effectiveness is closely linked with sustainability outcomes.
Water management practices	r = 0.372	Moderate positive	Operational practices support sustainability through maintenance, recharge and efficient use.
Stakeholder participation	r = 0.363	Moderate positive	Participation contributes to sustainability but requires empowerment to create stronger impact.
Stewardship practices	r = 0.346	Moderate positive	Responsible behaviour and conservation awareness support sustainability, especially when institutionally reinforced.

The correlation findings support the integrated nature of the framework. No correlation is excessively high, which indicates that rural water sustainability is not explained by a single factor. Governance shows the strongest bivariate association even though it has the lowest descriptive mean. This makes governance a strategic improvement area: respondents perceive it as weaker, yet it is highly connected with sustainability outcomes.

6.6 Regression analysis

Multiple linear regression was applied to identify the relative influence of governance mechanisms, stakeholder participation, water management practices and stewardship practices on rural water sustainability. Regression is stronger than correlation for this purpose because it examines each predictor while the other predictors are considered in the same model.

Table 10. Regression Model Summary

Model indicator	Value	Interpretation
R	0.766	Indicates a strong combined relationship between the predictors and rural water sustainability.
R square	0.586	The model explains 58.6% of the variation in rural water sustainability.
Unexplained variation	41.4%	Other factors such as rainfall, income, infrastructure age, land use, policy implementation and water quality may also influence sustainability.
Model significance	$p < 0.001$	The overall model is statistically significant.

Table 11. Regression Coefficients and Empirical Meaning

Predictor	Beta estimate	t-value	Significance	Rank	Empirical meaning
Water management practices	0.319	7.76	$p < 0.001$	1	Strongest predictor: practical management is the most direct lever for improving sustainability.
Stewardship practices	0.297	7.05	$p < 0.001$	2	Second strongest predictor: conservation behavior and responsible use have a measurable effect.
Governance mechanisms	0.262	6.49	$p < 0.001$	3	Institutional effectiveness significantly supports sustainability, but current performance needs strengthening.
Stakeholder participation	0.246	6.26	$p < 0.001$	4	Participation is significant, but its lower coefficient suggests that current participation may be more consultative than empowered.
Intercept	-0.426	-1.46	$p = 0.148$	-	The intercept is not statistically significant and is not substantively interpreted.

The regression results show that all four predictors have a positive and statistically significant impact on rural water sustainability. The result validates the conceptual framework and shows that the independent variables are not merely theoretically relevant; they also have empirical support in the sample.

Water management practices have the highest beta value (β = 0.319). This means the operational layer of the framework is the most powerful direct predictor. In practical terms, rainwater harvesting, groundwater recharge, micro-irrigation, conservation practices and infrastructure maintenance should be treated as the first-order intervention areas. These practices affect water availability and reliability more immediately than broad institutional reforms.

Stewardship practices form the second strongest predictor (β = 0.297). This indicates that sustainability is also shaped by user behaviour. Responsible water use, conservation awareness, community monitoring and shared ownership are not secondary concerns; they are measurable contributors to sustainability. Governance mechanisms rank third (β = 0.262), confirming that institutional support is essential. Stakeholder participation ranks fourth (β = 0.246), but it remains statistically significant. This suggests that participation is useful, but its current form may need to shift from consultation to shared decision-making and monitoring responsibility.

Table 12. Reading the Regression Results with the Integrated Framework

Framework layer	Regression evidence	Interpretation for the model
Institutional foundation: governance mechanisms	β = 0.262, $p < 0.001$; lowest mean score	Governance is statistically important but comparatively weaker in current practice. It should be strengthened through accountability and coordination.
Participatory enabler: stakeholder participation	β = 0.246, $p < 0.001$	Participation contributes to sustainability, but its impact can improve if communities are given real planning and monitoring roles.
Operational core: water management practices	β = 0.319, $p < 0.001$; highest beta	Operational water management is the main driver and should receive priority investment and monitoring.
Behavioural enabler: stewardship practices	β = 0.297, $p < 0.001$	Stewardship converts awareness into responsible use and long-term conservation behaviour.
Outcome: rural water sustainability	R2 = 0.586	The four layers together explain a substantial share of sustainability outcomes.

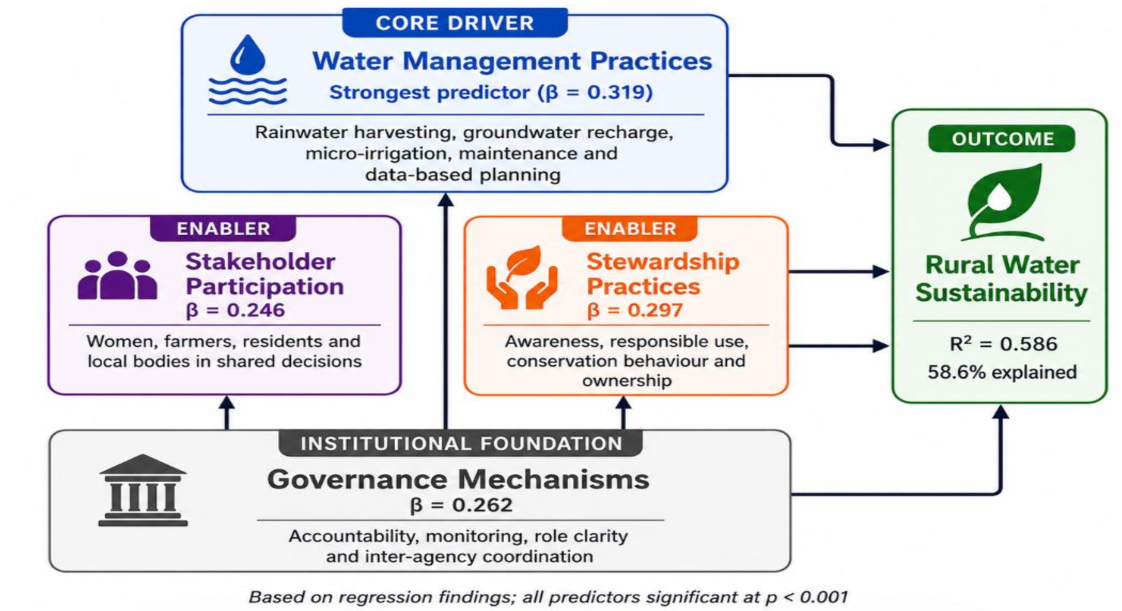

Figure 2. Empirical Integrated Framework for Rural Water Sustainability Based on Regression Findings

Figure 2 should be read as an empirical extension of the basic conceptual model. The conceptual model proposed four direct predictors of rural water sustainability, and the regression results confirm that all four predictors are significant. The integrated figure therefore retains the same direct paths to the outcome while adding empirical strength: water management practices show the strongest effect, followed by stewardship practices, governance mechanisms and stakeholder participation. The figure does not include a reverse feedback arrow because the regression model tests predictor-to-outcome effects and should not visually imply reverse causality.

6.7 Hypothesis testing

Table 13. Summary of Hypothesis Testing

Hypothesis	Statement	Statistical result	Decision	Meaning
H1	Stakeholder participation has a significant positive impact on rural water sustainability.	$\beta = 0.246$, $p < 0.001$	Accepted	Community involvement contributes significantly to sustainability.
H2	Water management practices have a significant positive impact on rural water sustainability.	$\beta = 0.319$, $p < 0.001$	Accepted	Operational and technical practices are the strongest driver.
H3	Governance mechanisms have a significant positive impact on rural water sustainability.	$\beta = 0.262$, $p < 0.001$	Accepted	Institutional effectiveness significantly supports sustainability.
H4	Stewardship practices have a significant positive impact on rural water sustainability.	$\beta = 0.297$, $p < 0.001$	Accepted	Responsible behaviour and conservation awareness are major contributors.

All four hypotheses were accepted. This confirms that the integrated model is empirically supported. The findings also justify the use of an integrated framework rather than a single-factor explanation. Rural water sustainability improves when governance, participation, management and stewardship operate together.

6.8 Priority analysis for action

To strengthen the practical value of the findings, the mean scores and regression coefficients were considered together. The mean score indicates current perceived performance, while the beta coefficient indicates predictive importance. A variable with high predictive importance and weak current performance should be treated as a priority for intervention.

Table 14. Priority Action Matrix Based on Mean and Regression Strength.

Variable	Mean score	Beta value	Current position	Recommended priority
Water management practices	3.68	0.319	Highest performance and strongest predictor	Maintain and scale; this is the main performance lever.
Stewardship practices	3.51	0.297	Moderate performance and second strongest predictor	Strengthen through continuous awareness and conservation programmes.
Governance mechanisms	3.46	0.262	Lowest performance but statistically significant	Urgent improvement through accountability, monitoring and coordination.
Stakeholder participation	3.63	0.246	Good perceived participation but lowest predictor	Convert participation from attendance to real decision-making power.

The priority matrix shows that the main policy message is not simply to improve the lowest-scoring variable or the highest-scoring variable. Water management practices must be scaled because they have the strongest impact. Governance requires urgent strengthening because it has the lowest mean score and remains statistically significant. Stewardship should be treated as a long-term behavioural strategy, while participation should be deepened from consultation to shared decision-making.

7. Discussion

The findings show that rural water sustainability in the study area is functional but not fully mature. The moderate-to-high mean scores indicate that institutions, participation channels, water management practices and stewardship behaviour are present to some extent. However, none of the mean scores reaches a very high level. This indicates that the system has a foundation but requires stronger coordination, monitoring and implementation discipline.

The most important empirical finding is the role of water management practices. The regression coefficient for water management practices is the highest among the predictors, showing that operational practices have the greatest direct influence on sustainability. This finding is consistent with the literature that treats functionality, recharge, maintenance and efficient resource use as central to sustainability. In the integrated framework, water management practices are therefore positioned as the core driver rather than as one activity among many. Practical improvements in rainwater harvesting, micro-irrigation, groundwater recharge and infrastructure maintenance can produce visible improvements in availability and reliability.

The second major finding is the strength of stewardship practices. Stewardship is sometimes treated as a soft or awareness-based dimension, but the regression result shows that it has a strong measurable contribution. This means that conservation behaviour, responsible use and community ownership should be considered part of the sustainability system. Awareness programmes should not remain one-time campaigns. They should be linked with local monitoring, school education, farmers' training, self-help groups and village-level conservation practices.

Governance presents an important tension in the results. It has the lowest mean score but the strongest bivariate correlation with sustainability. This means respondents perceive governance as comparatively weaker, but governance remains closely connected to sustainability outcomes. The practical implication is that governance is both a weakness and a strategic lever. Without clear accountability, monitoring and inter-agency coordination, technical practices may be implemented inconsistently and community participation may remain symbolic.

Stakeholder participation was significant but had the lowest beta coefficient. This does not mean participation is unimportant. Rather, it suggests that the current form of participation may not yet be strong enough to influence sustainability at the level of management or stewardship. Participation must move beyond attendance in meetings. Women, farmers, long-term residents, local water users and local bodies should be involved in planning, scheme monitoring, maintenance decisions and feedback mechanisms.

The R square value of 0.586 is strong for a community-level social science study. It shows that the four variables explain a substantial share of sustainability outcomes. At the same time, the unexplained 41.4% is analytically important. Future models may include rainfall variability, groundwater depth, water quality, household income, landholding size, infrastructure age, irrigation type, tariff systems, institutional capacity and climate exposure.

The discussion supports an integrated approach. Governance without participation can become top-down and less responsive. Participation without technical management can become symbolic. Management without stewardship may produce short-term gains but fail to change long-term use behaviour. Stewardship without governance may remain voluntary and inconsistent. Rural water sustainability therefore requires these dimensions to operate as a connected system.

8. Proposed Integrated Framework for Rural Water Sustainability

Based on the empirical results, the study proposes an integrated framework consisting of four enabling dimensions and one sustainability outcome: governance mechanisms, stakeholder participation, water management practices, stewardship practices and rural water sustainability. The institutional foundation is represented by governance mechanisms, including accountability, monitoring, role clarity, inter-agency coordination and transparent reporting. Participatory enablers involve rural households, farmers, women, local leaders and community organisations in planning and monitoring. The operational core consists of water management practices such as rainwater harvesting, groundwater recharge, efficient irrigation, maintenance and data-based planning. The stewardship layer includes awareness, conservation habits, responsible use and shared ownership. The outcome is rural water sustainability, reflected in availability, reliability, equity and resilience.

The framework should be used as a planning and implementation guide. Governance should define responsibility and monitoring. Participation should bring user knowledge into decisions. Water management should translate planning into field-level practices. Stewardship should sustain behaviour beyond the project period. Sustainability outcomes should then be reviewed periodically so that future actions are corrected based on evidence.

Table 15. Integrated Rural Water Sustainability Framework

Framework layer	Key components	Expected contribution
Institutional foundation	Governance, accountability, monitoring, role clarity and inter-agency coordination	Improves planning quality, responsiveness, transparency and implementation discipline.
Participatory enablers	Women's participation, farmer involvement, Gram Sabha water discussions and community monitoring	Improves ownership, local legitimacy and early identification of water problems.
Operational core	Rainwater harvesting, micro-irrigation, groundwater recharge, infrastructure maintenance and data-based planning	Improves availability, reliability, efficiency and resource protection.
Stewardship layer	Awareness, conservation behaviour, school education, local leadership and responsible use	Creates long-term behavioural change and reduces unsustainable consumption.
Outcome monitoring	Periodic review, local reporting, dashboards and corrective action plans	Ensures that the system improves continuously instead of remaining scheme-driven.

9. Managerial and Policy Recommendations

First, rural water plans should prioritise water management practices because they are the strongest predictor of sustainability. Rainwater harvesting, groundwater recharge, micro-irrigation, infrastructure maintenance and water-use efficiency should be scaled and monitored.

Second, governance accountability should be strengthened because governance recorded the lowest mean score. Local responsibility matrices, monitoring schedules, public reporting and grievance mechanisms should be introduced or strengthened.

Third, participation should move from consultation to shared decision-making. Women, farmers and long-term residents should be represented in water committees and should have a role in planning, monitoring and maintenance decisions.

Fourth, stewardship should be institutionalised through continuous awareness campaigns, school-level water education, self-help group engagement, farmer training and local conservation champions.

Fifth, local water planning should be aligned with Jal Jeevan Mission and AMRUT 2.0 principles, particularly service sustainability, water quality monitoring, source protection and data-driven governance.

Finally, GIS-based mapping and simple dashboard systems should be used to track water bodies, borewells, recharge points, infrastructure condition, maintenance requirements and seasonal stress points.

10. Conclusion

The study concludes that sustainable rural water systems require integrated management and stewardship rather than fragmented interventions. Governance mechanisms, stakeholder participation, water management practices and stewardship practices all have significant positive effects on rural water sustainability. The model explains 58.6% of the variation in sustainability, confirming that the selected variables provide a strong explanatory framework.

Water management practices emerged as the strongest predictor, showing that operational interventions have the highest direct influence on sustainability outcomes. Stewardship practices ranked second, confirming that responsible behaviour and conservation awareness are major determinants of long-term water security. Governance mechanisms and stakeholder participation also had significant effects, highlighting the need for institutional accountability and meaningful community engagement.

The central contribution of the study is that it reframes rural water sustainability as an integrated and outcome-oriented system. A rural water system becomes sustainable not merely when water is supplied, but when water resources are governed responsibly, managed efficiently, used equitably and protected collectively over time.

11. Limitations and Scope for Further Research

The study is limited to selected rural areas of Tamil Nadu and uses cross-sectional survey data. Therefore, the results should not be generalised without caution to all rural regions. The study is based on respondent perceptions, which are useful for understanding governance and stewardship but may be strengthened further with hydrological, environmental and infrastructure-level data.

Future research can include longitudinal data, water quality testing, groundwater-level records, seasonal rainfall data, GIS mapping and larger samples across multiple districts or states. Future models may also include income, landholding size, irrigation type, water tariff systems, institutional capacity and climate risk exposure.

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