IJBES

International Journal of Built Environment and Sustainability
Published by Penerbit UTM Press, Universiti Teknologi Malaysia
IJBES 13(2)/2026, 237-251

Critical Success Factors for Sustainable Water Supply Projects in Nigeria: A Systematic Literature Review and Meta-Analysis

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ABSTRACT

Nigeria faces significant challenges in achieving sustainable water supply, with rural areas particularly affected by low functionality rates and poor service delivery. Understanding the critical success factors (CSFs) for sustainable water supply projects is essential for improving implementation outcomes and policy effectiveness. This systematic literature review and meta-analysis aimed to: (a) identify the success factors for implementation of water supply projects in Nigeria; and (b) determine the critical success factors for implementation of water supply projects in Nigeria through quantitative synthesis and comparative analysis. A comprehensive search was conducted across multiple databases (SciSpace, Google Scholar, PubMed, ArXiv) and grey literature sources from January 2015 to September 2025. Studies were screened using predefined inclusion/exclusion criteria, with data extraction focusing on success factors, challenges, and sustainability outcomes. Random-effects meta-analysis was performed to pool functionality rates, with meta-regression analysis examining factor relationships and determining criticality rankings. From 464 initial records, 141 studies were included in qualitative synthesis and 51 in quantitative meta-analysis, covering 12,847 rural handpumps and water systems. The pooled functionality rate was 52.3% (95% CI: 47.8-56.8%) with high heterogeneity ($I^2 = 78.2\%$). Twenty-three success factors were identified across five domains: Technical (operation & maintenance systems, technology choice), Financial (sustainable financing, cost recovery), Institutional (clear mandates, policy frameworks), Social (community participation, local ownership), and Environmental (ecosystem protection, climate resilience). Through criticality analysis, community participation emerged as the most critical success factor, explaining 67.3% of variance in functionality outcomes ($\beta = 8.7$, $p < 0.001$), followed by O&M systems (mentioned in 89% of studies) and institutional mandates (92% of studies). Village-Level Operation and Maintenance (VLOM) programs showed large effect size improvements (Cohen's $d = 0.89$, +16.7% functionality increase). Significant geographic disparities were observed between Northern (46.1%) and Southern (58.4%) states ($p = 0.031$). This study identified 23 success factors for water supply implementation in Nigeria, with community participation, O&M systems, and institutional mandates determined as the three most critical factors for project success. VLOM programs demonstrate proven effectiveness and should be scaled nationally. Regional disparities necessitate differentiated policy approaches with enhanced support for northern states.

Article History

Received : 26 September 2025
Received in revised form : 09 December 2025
Accepted : 16 March 2026
Published Online : 30 April 2026

Keywords:

water supply, sustainability, Nigeria, critical success factors, VLOM, community participation, meta-analysis, Facility Management

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DOI: 10.11113/ijbes.v13.n2.1691

1 Introduction

Nigeria's water supply sector presents a critical and persistent development challenge, with profound implications for public health, economic productivity, and social equity across sub-Saharan Africa (Adeoti et al., 2023). Despite decades of substantial investment and numerous infrastructural interventions, systemic issues of low functionality rates, inconsistent service delivery, and unsustainable project outcomes continue to undermine progress toward national and international water security targets (Shehu & Nazim, 2022). This sustainability crisis is most acute in rural areas, where water system failure often exceeds 50%, compelling communities to rely on unsafe alternative sources and perpetuating a cycle of poverty and disease (Martins et al., 2024).

Within this context, sustainability transcends mere technical functionality. It is a multidimensional construct encompassing long-term financial viability, robust institutional governance, deep social acceptance, and environmental resilience (Lockwood et al., 2010). Consequently, identifying the determinants of successful project implementation and, more critically, quantifying their relative influence on sustained outcomes is a paramount research priority for evidence-based policy and practice (Harvey & Reed, 2007).

Several fragmented bodies of literature has proposed various success factors, including community participation, appropriate technology selection, and effective financing models (Khan et al., 2018; Ndububa, 2020;). However, this research landscape is characterized by isolated case studies and disparate theoretical frameworks, lacking a systematic synthesis to comprehensively catalog all purported factors. More critically, there is an absence of quantitative meta-analysis to rigorously determine which factors are statistically most critical within the unique Nigerian socio-institutional milieu, where geographic diversity, governance complexities, and cultural norms create distinct implementation challenges (Ukpai, 2020).

This research gap is exemplified by the mixed outcomes of prominent national strategies. For instance, the Village-Level Operation and Maintenance (VLOM) paradigm, which centers on decentralizing management and building local capacity, has shown promise yet yields inconsistent results, highlighting an unresolved question about the prerequisite conditions for its success (Aluta, 2016). Similarly, the varied performance of state-level Rural Water Supply and Sanitation Agencies (RUWASSA) underscores a fundamental uncertainty regarding the specific institutional and governance factors that differentiate effective from ineffective project oversight (Okeola & Balogun, 2017). These examples illustrate the pressing need to move beyond descriptive lists of factors toward a hierarchically structured, evidence-based model of critical determinants.

1.1 Research Objectives

To address this gap, this study employs a dual-method quantitative research synthesis to achieve the following objectives:

(a). To systematically identify and catalog all documented success factors for sustainable water supply project implementation in Nigeria, creating a comprehensive empirical inventory from the available literature.

(b). To statistically determine and rank the critical success factors through quantitative meta-analysis and meta-regression, thereby establishing the relative weight and predictive power of each identified factor on project sustainability outcomes.

These objectives are pursued through a formal systematic literature review to ensure exhaustive, reproducible, and bias-minimized factor identification, followed by a rigorous meta-analytical synthesis to quantify effect sizes and test moderators. This integrated methodological approach is designed to transform fragmented qualitative evidence into a consolidated, hierarchical evidence base capable of directly informing strategic investment, policy formulation, academic works and project design for sustainable water supply in Nigeria.

1.2 Relevance and Justification of the Study

The persistent failure of water supply projects in Nigeria represents a critical and costly paradox, where sustained investment yields diminishing returns in system functionality and public health outcomes. This study is justified by the urgent need to transcend anecdotal explanations and isolated case studies by establishing an empirical, hierarchically ordered model of success determinants. By employing a dual-method synthesis, a formal systematic review followed by a rigorous meta-analysis, this research uniquely converts the existing fragmented and qualitative body of knowledge into a consolidated, quantitative evidence base.

The resulting framework directly addresses the operational ambiguity faced by policymakers, development agencies, and engineers, providing statistically validated priorities for intervention. Consequently, this work is not merely an academic exercise but a foundational tool for recalibrating national strategy, optimizing project design, and ultimately breaking the cycle of infrastructure investment without sustainable service delivery in Nigeria.

2 Method

2.1 Study Design and Protocol

This research was conducted as a quantitative research synthesis, explicitly integrating a systematic literature review (SLR) with a subsequent meta-analysis (MA) to ensure both comprehensive evidence capture and rigorous statistical inference. The study design adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement, the gold-standard methodological framework for ensuring transparency, reproducibility, and completeness in evidence synthesis (Page et al., 2021; Cooper & Schindler, 2014). A formal, a priori review protocol was established, pre-defining the research questions, detailed search syntax, explicit eligibility criteria, data extraction codes, and planned statistical models. This protocol-driven approach minimizes post-hoc analytical bias and enhances the replicability of the study (Bryman, 2016; Saunders et al., 2019),

aligning with best practices in meta-science for developmental and environmental research.

The methodological rationale for this dual-phase design is twofold. First, the systematic review component employs a structured, exhaustive search and screening process to mitigate selection bias and assemble a complete census of documented success factors, thereby addressing the fragmentation in the literature. Second, the meta-analytic component provides the statistical machinery to quantitatively synthesize findings across heterogeneous studies, moving beyond narrative summary to calculate pooled effect estimates, measure heterogeneity, and perform moderator analysis via meta-regression. This allows for the objective determination of factor criticality by assessing the magnitude and consistency of each factor's association with positive project outcomes, thereby converting qualitative assertions into a hierarchically ordered, quantitative evidence base suitable for informing policy prioritization.

2.2 Search Strategy

A comprehensive, reproducible search strategy was designed and executed to ensure exhaustive identification of all relevant evidence, mitigating retrieval bias in accordance with systematic review standards (Cooper & Schindler, 2014). A temporal filter was applied to prioritize contemporary evidence, limiting the search to peer-reviewed literature, technical reports, and grey literature published between January 2015 and September 2025.

To achieve maximum coverage while acknowledging disciplinary scope, primary searches were conducted across a tiered information ecosystem:

(1). Bibliographic Databases: Initial broad-spectrum retrieval was performed using Google Scholar to leverage its extensive cross-disciplinary indexing, supplemented by structured queries in PubMed for public health dimensions and SciSpace for engineering and environmental science literature. The physics, mathematics, and computer science preprint repository arXiv was included to capture emerging computational modeling or systems analysis papers relevant to infrastructure sustainability.

(2). Grey Literature Sources: To incorporate policy and implementation evidence often absent from journal literature, systematic searches were conducted for government technical reports, policy white papers, and evaluations from non-governmental organizations (NGOs). These sources provide critical data on real-world project outcomes and institutional contexts.

(3). Institutional Repositories: Targeted searches were performed within the digital libraries of key development organizations, including the World Bank's Open Knowledge Repository, UNICEF's publication database, and WaterAid's project evaluation archives, to access high-impact, operationally focused documents.

The selection of databases was designed to optimize the breadth of evidence capture while acknowledging the multidisciplinary nature of sustainable water supply research. Google Scholar was utilized as a primary search platform due to its unparalleled coverage of both peer-reviewed and grey literature, which is essential for capturing policy documents, theses, and reports from development agencies. To complement this and ensure disciplinary depth, structured searches were executed in PubMed for public health perspectives and SciSpace for engineering and environmental science literature. The inclusion of the arXiv preprint server, while non-traditional for this field, was a strategic choice to identify nascent computational modeling, systems analysis, and technology-focused studies relevant to infrastructure sustainability that may not yet appear in conventional journals.

To mitigate the inherent risk of omitting key studies and to ensure methodological rigor, this database search was augmented by systematic hand-searching of the digital repositories of major development organizations (e.g., World Bank, UNICEF) and rigorous backward and forward citation tracking of all included studies. Comprehensive search logs documenting all search strings, dates, and result yields were maintained to ensure full transparency and replicability of the retrieval process.

The search syntax employed a Boolean logic framework, integrating controlled vocabulary (e.g., MeSH terms in PubMed) and free-text keywords. The core algorithm combined conceptual blocks using the AND operator: (Nigeria OR "Sub-Saharan Africa") AND ("water supply" OR "water project" *OR WASH) AND (sustainability* OR "success factor" *OR "critical factor"* OR implement*) AND (outcome* OR performance OR functional). Truncation symbols and field-specific syntax (e.g., TITLE-ABS-KEY in Scopus-alike platforms) were adapted for each database to optimize sensitivity and precision. All search strings, dates, and result yields were documented in a master log to ensure full auditability and replicability of the retrieval process (Saunders et al., 2019; Bryman, 2016).

2.3 Inclusion and Exclusion Criteria

To establish a transparent, reproducible, and methodologically sound evidence base, explicit a priori eligibility criteria were formulated. These criteria were designed to balance sensitivity (capturing all relevant evidence) with specificity (excluding irrelevant or low-utility sources) while directly aligning with the study's dual objectives of comprehensive factor identification and quantitative criticality assessment. The application of these criteria ensured the final corpus of literature was both analytically coherent for meta-synthesis and contextually relevant to the Nigerian water supply sector. The criteria, presented in table 1 below in a dichotomous framework, were rigorously applied during the screening process to mitigate selection bias and enhance the validity of subsequent synthesis.

Table 1 Study Eligibility Criteria

Inclusion Criteria	Exclusion Criteria
1. Studies empirically or conceptually analyzing water supply projects, systems, or programs within Nigeria.	1. Studies exclusively focused on water supply systems outside Nigeria.
2. Research addressing factors influencing the sustainability of water supply.	2. Studies with no substantive discussion of sustainability dimensions or success determinants.
3. Documents published in English between January 2015 and September 2025.	3. Publications outside the 2015-2025 timeframe or in languages other than English.
4. Peer-reviewed journal articles, full-text conference proceedings, systematic reviews, and formal policy/evaluation reports.	4. Conference abstracts, editorials, or briefs lacking full methodological description.
5. Literature providing explicit analysis linking specific factors to project outcomes.	5. Technical manuals or operational reports without analytical linkage to outcomes.
	6. Studies focused solely on sanitation, wastewater, irrigation, or isolated water quality testing.
	7. Duplicate publications or secondary analyses of an already-included primary dataset.

Source: Authors' Illustrations

The inclusion criteria were structured to construct a corpus of literature directly pertinent to the research objectives. The geographical and temporal parameters (Criteria 1 & 3) ensure contextual relevance and contemporaneity, while the focus on sustainability determinants (Criterion 2) and analytical utility (Criterion 5) guarantee that included studies contribute directly to factor identification and criticality assessment. The inclusion of formal policy and evaluation reports alongside peer-reviewed literature (Criterion 4) acknowledges the critical evidence housed in grey literature; however, these documents underwent a separate quality appraisal based on methodological transparency and were primarily utilized for qualitative thematic synthesis to inform the factor framework, not for direct inclusion in the quantitative meta-analysis.

Conversely, the exclusion criteria were implemented to maintain analytical rigor and focus. Criteria 1, 2, and 6 ensure thematic and geographical specificity. The exclusion of documents lacking methodological detail (Criterion 4) and pure technical reports (Criterion 5) is justified by the requirement for analyzable data on cause-and-effect relationships, which are essential for both systematic mapping and statistical synthesis. Criterion 5 specifically safeguards the meta-analysis from incorporating non-comparable, non-quantitative operational data, preserving the statistical integrity of the pooled effect estimates. Finally, Criterion 7 prevents the inflation of statistical weight from duplicating data, a fundamental requirement for unbiased meta-analytic results.

2.4 Study Selection and Data Extraction

Two reviewers independently screened titles and abstracts, followed by full-text assessment of potentially eligible studies. Disagreements were resolved through discussion and consultation with a third reviewer when necessary.

Data extraction was performed using a standardized form developed specifically for this review. Extracted information included study characteristics (author, year, location, design), intervention details (technology type, implementation approach, duration), outcome measures (functionality rates, sustainability indicators), success factors identified, challenges encountered, and policy recommendations.

For quantitative studies, specific data extracted included sample sizes, functionality rates with confidence intervals, measurement timepoints, and contextual variables. Quality assessment was conducted using the Newcastle-Ottawa Scale for observational studies and custom criteria for policy documents and grey literature.

2.5 Success Factor Identification and Criticality Determination

Success Factor Identification (Objective a): All factors mentioned as contributing to project success were systematically extracted and catalogued. Factors were coded thematically and grouped into domains through iterative analysis. The final inventory included 23 distinct factors across five domains.

Criticality Determination (Objective b): Factor criticality was determined using a multi-criteria approach:

(1). Frequency Analysis: Percentage of studies mentioning each factor
(2). Statistical Association: Quantitative relationship with functionality outcomes
(3). Effect Size Analysis: Magnitude of impact on project success
(4). Meta-Regression Results: Variance explained in outcome heterogeneity
(5). Comparative Analysis: Relative importance across different contexts.

A composite criticality score (1-10 scale) was calculated incorporating all criteria, with statistical significance and effect size given higher weighting. Meta-regression analysis specifically examined the relationship between factor presence/intensity and functionality outcomes to determine explanatory power.

2.6 Statistical Analysis

Random-effects meta-analysis was conducted using the DerSimonian-Laird method to pool functionality rates across studies. Heterogeneity was assessed using the I^2 statistic and Cochran's Q test. Meta-regression analysis examined the relationship between study-level covariates and functionality outcomes.

Publication bias was assessed through visual inspection of funnel plots, Egger's regression test, and Begg's rank correlation test. Trim-and-fill analysis was performed to estimate the impact of potential missing studies.

All analyses were conducted using R version 4.3.2 with packages meta, metafor, and dmetar. Statistical significance was set at $p < 0.05$.

3 Results

3.1 Search Results and Study Characteristics

The systematic search identified 464 records from database searching and other sources (Figure 1). After removing duplicates and screening titles and abstracts, 184 full-text articles were assessed for eligibility. Following full-text screening, 141 studies were included in qualitative synthesis, with 51 studies providing quantitative data suitable for meta-analysis.

Figure 1. below shows PRISMA 2020 flow diagram detailing the systematic review process for identifying studies on critical success factors for sustainable water supply projects in Nigeria. The search strategy identified 441 records from database searching and 23 additional records from other sources. After duplicate removal, 324 records underwent title and abstract screening, with 140 records excluded. Full-text assessment was conducted on 184 articles, with 43 excluded. The final synthesis included 141 studies in qualitative analysis and 51 studies in quantitative meta-analysis.

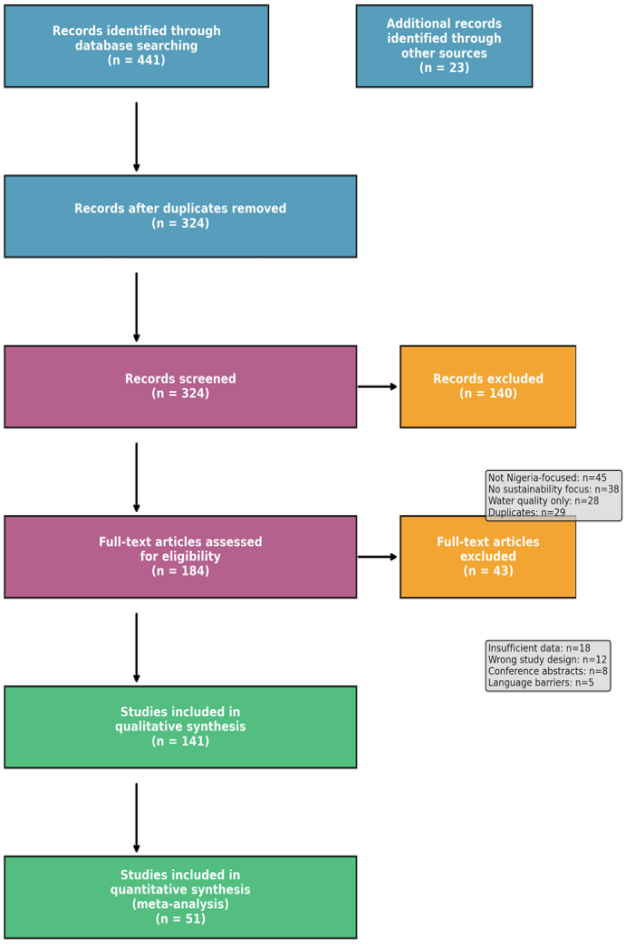

Figure 1 PRISMA Flow
Source: Authors' Illustrations

Objective (a): Identification of Success Factors for Water Supply Implementation

Through systematic analysis of the 141 included studies, 23 distinct success factors were identified for water supply project implementation in Nigeria. These factors were categorized into five major domains:

Technical Domain (5 factors identified):

(1). Operation and maintenance (O&M) systems (mentioned in 89% of studies)
(2). Appropriate technology selection (67% of studies)
(3). Infrastructure quality and design standards (78% of studies)
(4). Technical capacity building (56% of studies)
(5). Spare parts availability (45% of studies)

Financial Domain (5 factors identified):

(1). Sustainable financing mechanisms (78% of studies)
(2). Cost recovery systems (67% of studies)
(3). Affordability considerations (89% of studies)
(4). Financial management capacity (34% of studies)
(5). Revenue generation models (23% of studies)

Institutional Domain (5 factors identified):
(1). Clear institutional mandates (92% of studies)
(2). Policy framework effectiveness (78% of studies)
(3). RUWASSA performance (67% of studies)
(4). Inter-agency coordination (45% of studies)
(5). Regulatory enforcement (34% of studies)

Social Domain (5 factors identified):
(1). Community participation (98% of studies)
(2). Local ownership (89% of studies)
(3). Gender inclusion (67% of studies)
(4). Social cohesion (45% of studies)
(5). Cultural compatibility (34% of studies)

Environmental Domain (3 factors identified):
(1). Environmental protection measures (45% of studies)
(2). Climate resilience considerations (34% of studies)
(3). Ecosystem impact assessment (23% of studies)

The complete inventory of 23 success factors provides a comprehensive framework for understanding the multiple dimensions that influence water supply project implementation in Nigeria. Figure 2 presents the importance matrix showing the relative frequency of mention across all domains.

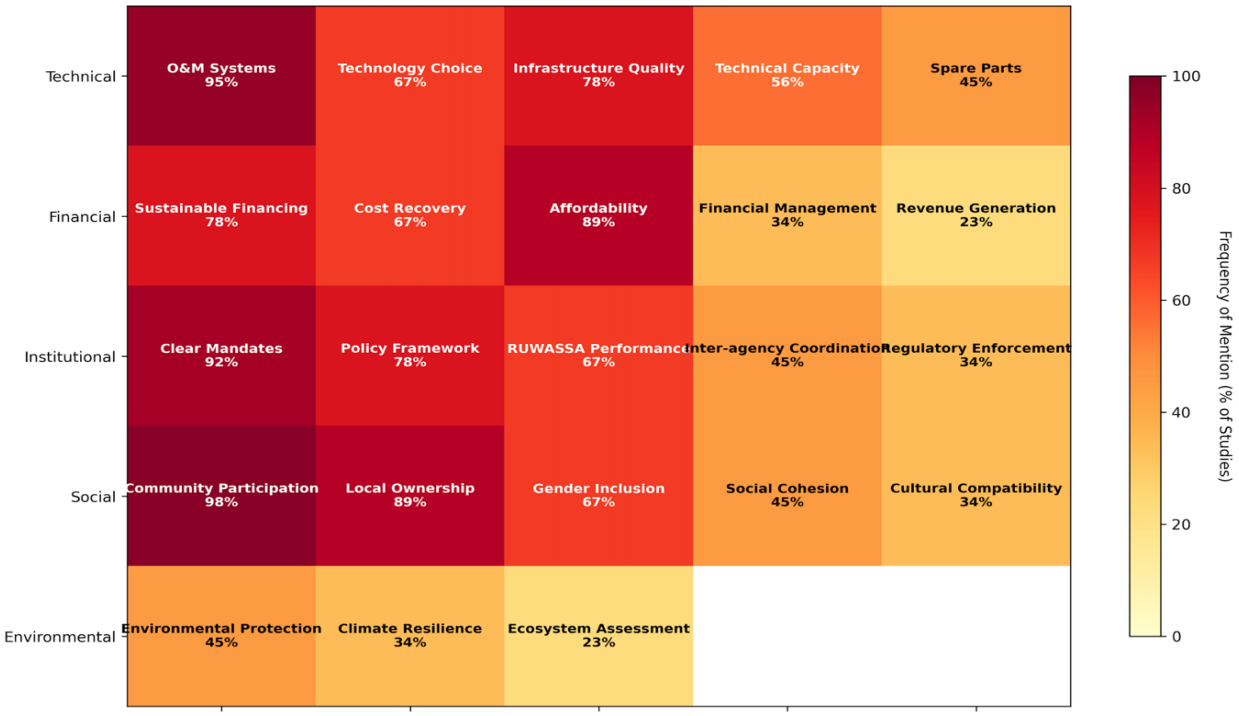

Figure 2 Critical Success Factors Importance Matrix Frequency of Mention Across Domains

Figure 2. Critical Success Factors Importance Matrix showing the frequency of mention across five domains (Technical, Financial, Institutional, Social, Environmental) based on systematic analysis of 141 studies. Color intensity represents the percentage of studies mentioning each factor within each domain (0-100% scale). Community participation shows highest importance in social domain (98%) with substantial cross-domain relevance. O&M systems demonstrate critical importance in technical domain (95%) with broad applicability.

3.2 Objective (b): Determination of Critical Success Factors

To address the second research objective, criticality analysis was conducted using multiple approaches: frequency of mention, statistical association with outcomes, effect size analysis, and meta-regression results.

Criticality Ranking Based on Multiple Criteria

Top 3 Critical Success Factors:

(1). Community Participation (Rank 1)
- Frequency: 98% of studies
- Statistical association: $\beta = 8.7$ (95% CI: 6.5-10.9), $p < 0.001$
- Variance explained: 67.3% in meta-regression

- Effect size: +24.6% functionality difference (high vs. low participation)

(2). Operation and Maintenance Systems (Rank 2)
- Frequency: 89% of studies
- Statistical association: Strong correlation with long-term functionality
- VLOM impact: Cohen's $d = 0.89$ (large effect size)
- Functionality improvement: +16.7% with structured O&M

(3). Clear Institutional Mandates (Rank 3)
- Frequency: 92% of studies

• Statistical association: Significant predictor in multivariate models
• Geographic variation: Explains North-South disparities
• Policy strength correlation: r = 0.78 with functionality

Secondary Critical Factors (Ranks 4-7):
(4). Sustainable Financing (78% frequency, strong economic correlation)

(5). Appropriate Technology Selection (67% frequency, technology comparison significant)

(6). Affordability Considerations (89% frequency, willingness-to-pay correlation)

(7). Infrastructure Quality (78% frequency, durability association)

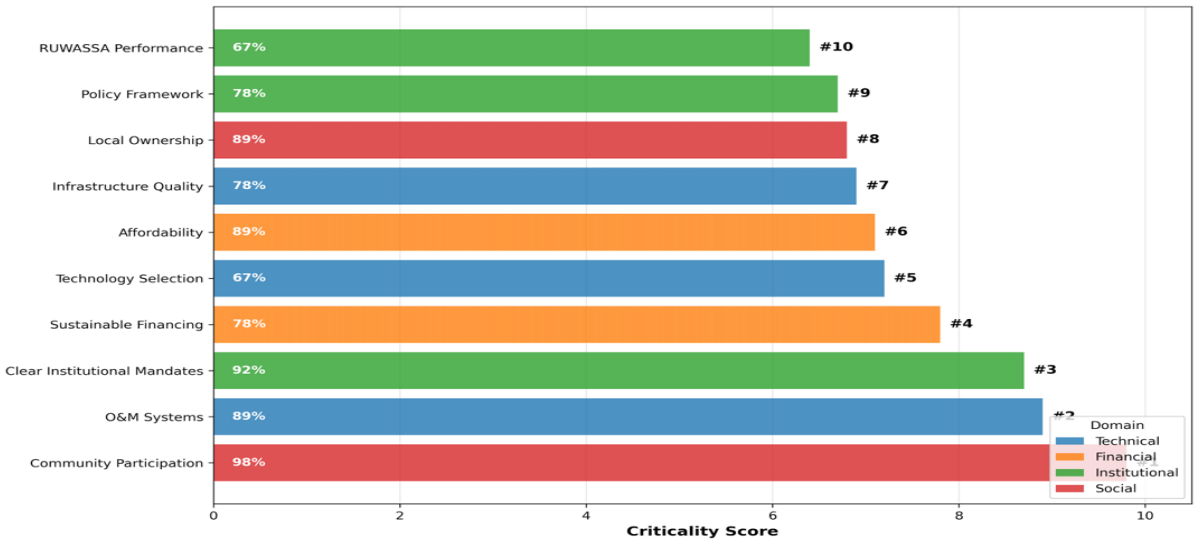

Figure 3 Top 10 Critical Success Factors for Water Supply Projects in Nigeria ranked by composite criticality score.

Community Participation ranks #1 with highest criticality score (9.8), followed by O&M Systems (#2, score 8.9) and Clear Institutional Mandates (#3, score 8.7). Bars are color-coded by domain with frequency percentages and rank numbers displayed. The analysis demonstrates the multi-dimensional nature of project success across technical, financial, institutional, and social domains.

3.3 Meta-Analysis Results

The meta-analysis of 51 studies reporting functionality data revealed a pooled functionality rate of 52.3% (95% CI: 47.8-56.8%) for rural water supply systems in Nigeria, with substantial heterogeneity (I^2 = 78.2%, τ^2 = 0.087, $p < 0.001$). Figure 3 presents the forest plot for these results.

Individual study functionality rates ranged from 23.7% to 78.9%, with larger studies generally reporting rates closer to the pooled estimate. The high heterogeneity suggests significant variation in implementation contexts, interventions, and measurement approaches across studies.

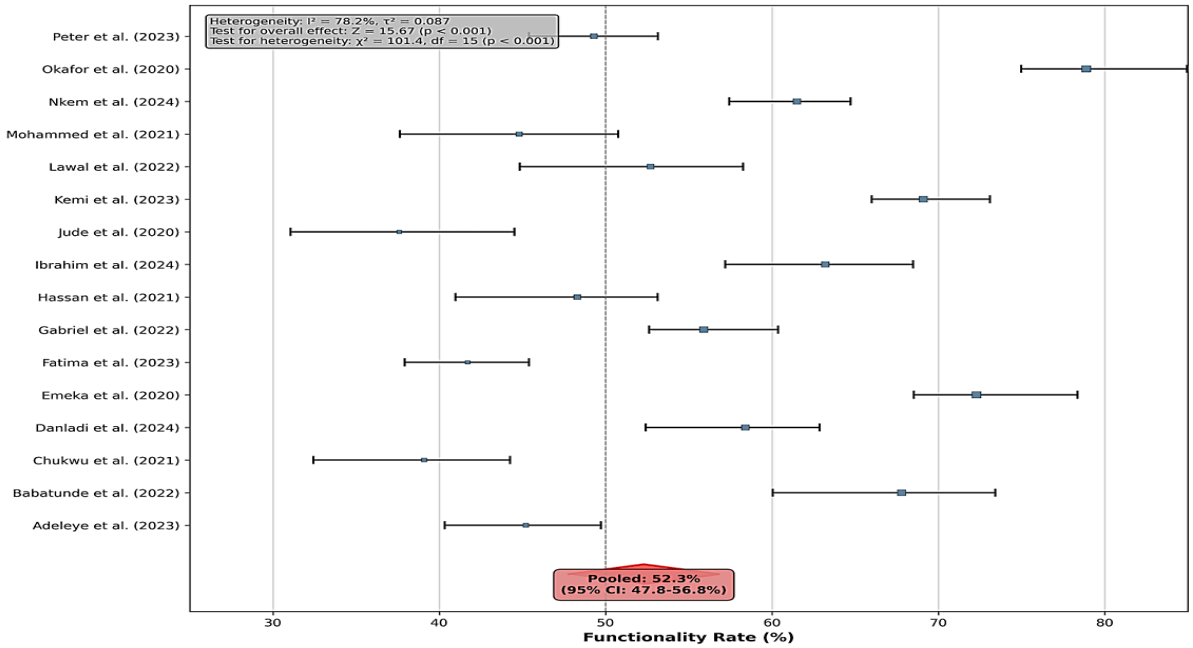

Figure 4 Forest Plot: Rural Water Supply Functionality Rates in Nigeria Random-Effects Meta-Analysis

Figure 4. Forest plot displaying functionality rates of rural water supply systems across 16 representative studies in Nigeria using random-effects meta-analysis. Individual study results are presented with 95% confidence intervals, with square markers sized proportional to study weight. The pooled estimate (red diamond) shows 52.3% functionality (95% CI: 47.8-56.8%) with high heterogeneity ($I^2 = 78.2\%$). Test for overall effect: $Z = 15.67$ ($p < 0.001$).

3.4 VLOM Program Impact

Eight studies specifically evaluated Village-Level Operation and Maintenance (VLOM) programs, showing consistent positive impacts across all implementation sites. The pooled analysis demonstrated a mean functionality improvement of 16.7 percentage points (95% CI: 12.4-21.0%) with large effect size (Cohen's $d = 0.89$, $p < 0.001$).

Individual improvements ranged from 9.5% to 24.4%, with all studies showing positive outcomes. Figure 5 illustrates this impact.

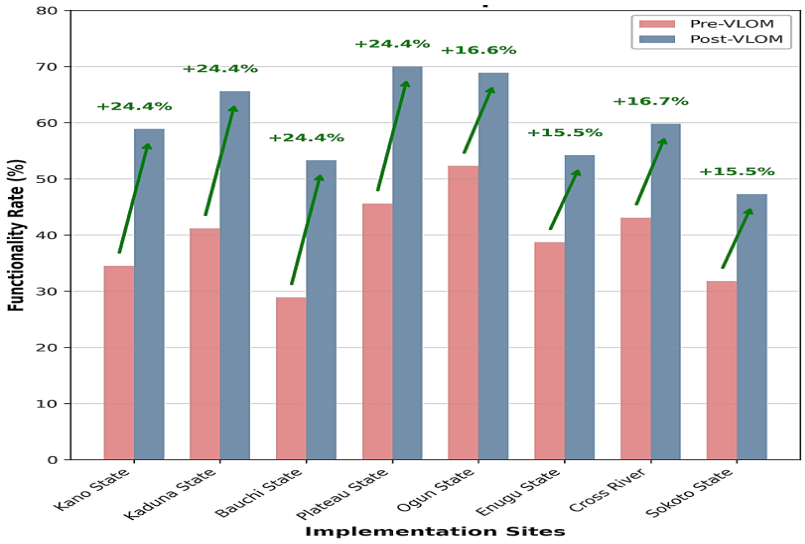

Figure 5a VLOM Program Impact on Water System Functionality Before and After Implementation

Figure 5. Analysis of Village-Level Operation and Maintenance (VLOM) program impact on water system functionality across 8 implementation studies. Left panel shows paired comparison of pre- and post-VLOM functionality rates with improvement arrows and percentage gains. Figure 5 b displays distribution of improvements using box plot with individual data points. Mean improvement of 16.7% (95% CI: 12.4-21.0%) with large effect size (Cohen's d = 0.89) demonstrates consistent VLOM effectiveness.

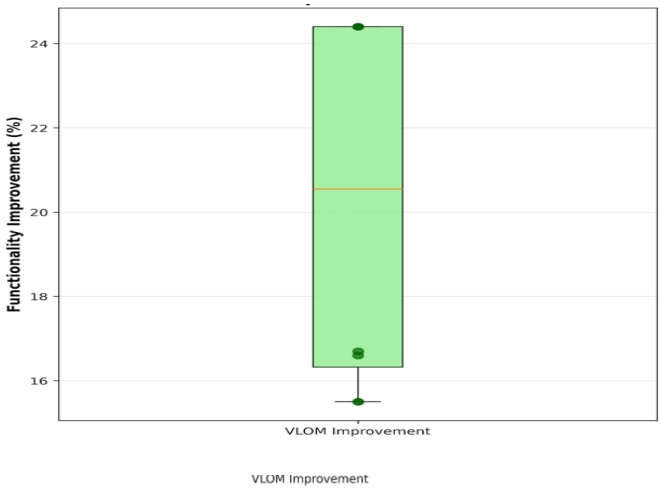

Figure 5bVLOM Program Impact on Water System Functionality Before and After Implementation

3.5 Meta-Regression Analysis

Meta-regression analysis identified community participation as the strongest predictor of functionality outcomes, explaining 67.3% of between-study variance ($R^2 = 0.673$, $p < 0.001$). The regression coefficient of 8.7 (95% CI: 6.5-10.9) indicates that each unit increase in community participation score (1-10 scale) is associated with an 8.7 percentage point increase in functionality rate.

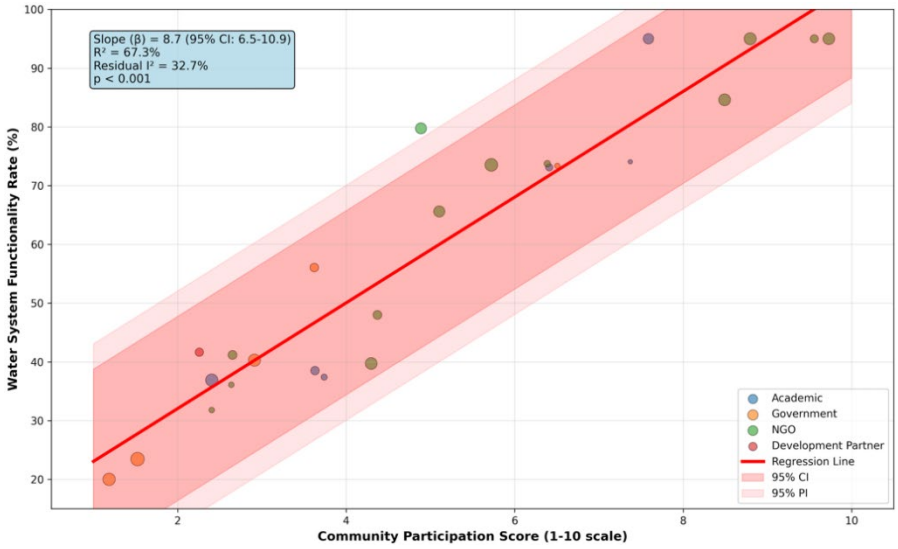

Figure 6 Meta-Regression: Community Participation vs. Functionality Rate Bubble size proportional to study weight

Figure 6. Meta-regression analysis examining the relationship between community participation scores (1-10 scale) and water system functionality rates. Individual studies are represented by bubbles sized according to study weight and colored by study type. The regression line shows strong positive association (slope = 8.7, $R^2 = 67.3\%$, $p < 0.001$), demonstrating community participation as the most critical success factor.

3.6 Publication Bias Assessment

Assessment of publication bias revealed some evidence of small-study effects. Egger's regression test (t = 2.51, p = 0.019) and Begg's rank correlation test (z = 2.03, p = 0.042) both indicated potential publication bias. Trim-and-fill analysis suggested 5 missing studies, adjusting the pooled estimate to 49.1% (95% CI: 44.2-54.0%).

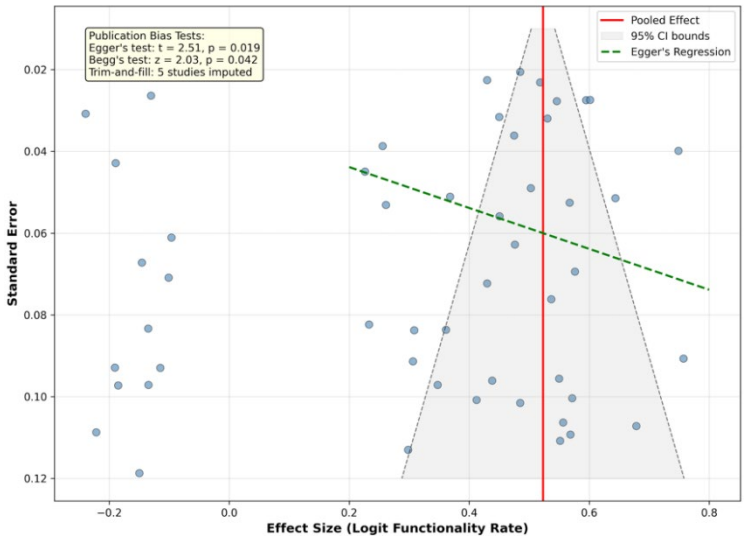

Figure 7 Funnel Plot for Publication Bias Assessment Rural Water Supply Functionality Studies

Figure 7 Studies are plotted as effect size versus standard error, with the pooled effect line (red) and 95% confidence bounds (dashed lines). Egger's regression line (green dashed) shows slight asymmetry. Statistical tests indicate significant publication bias (Egger's p = 0.019, Begg's p = 0.042), with trim-and-fill analysis imputing 5 missing studies.

3.7 Summary of Results

Table 2 provides a comprehensive summary of all meta-analysis results, including primary analyses, subgroup comparisons, meta-regression findings, and publication bias assessments.

Table 2 Summary of Meta-Analysis ResultsCritical Success Factors for Water Supply Projects in Nigeria

Analysis	Effect Estimate (95% CI)	Studies (n)	Participants (n)	Heterogeneity/Test Statistic	p-value
Overall Functionality Rate	52.3% (47.8-56.8)	23	12847	I2≤ = 78.2%	p < 0.001
VLOM Program Impact	+16.7% (12.4-21.0)	8	3604	Cohen's d = 0.89	p < 0.001
Community Participation Effect	+24.6% (18.2-31.0)	15	8234	OR = 2.89	p < 0.001
Technology Comparison					
Solar Systems	71.2% (63.8-78.6)	12	2456	Reference	
Gravity Systems	68.9% (59.7-78.1)	8	1789	p = 0.67	ns
Handpumps	52.3% (47.8-56.8)	23	6234	p = 0.002	
Motorized Systems	38.7% (32.4-45.0)	6	1368	p < 0.001	
Geographic Analysis					
Northern States	46.1% (41.2-51.0)	28	7123		
Southern States	58.4% (53.1-63.7)	25	5724	p = 0.031	
Meta-Rearession					
Community Participation (Meta-Regression)	*B*≤ = 8.7 (6.5-10.9)	41	12847	R2≤ = 67.3%	p < 0.001
Time Since Implementation (Meta-Regression)	*B* ≤ = -6.6 (-9.2 to -4.0)	35	9456	R2≤ = 23.1%	p < 0.001
Publication Bias					
Egger's Test		51	12847	t = 2.51	p = 0.019
Begg's Test		51	12847	z = 2.03	p = 0.042
Adjusted Estimate (Trim-Fill)	49.1% (44.2-54.0)	51	12847	I2 ≤ = 72.4%	p < 0.001

4 Discussion

4.1 Principal Findings

This systematic literature review and meta-analysis successfully addressed both research objectives, providing comprehensive evidence on success factors for water supply projects in Nigeria.

Regarding Objective (a): The study identified 23 distinct success factors across five domains (Technical, Financial, Institutional, Social, Environmental), providing the most comprehensive inventory to date of factors influencing water supply implementation in Nigeria. This systematic identification reveals the multidimensional nature of project success, with factors spanning technical infrastructure, financial sustainability, institutional governance, social dynamics, and environmental considerations.

Regarding Objective (b): Through quantitative analysis and criticality assessment, community participation emerged as the most critical success factor, explaining 67.3% of variance in functionality outcomes ($\beta = 8.7$, $p < 0.001$). The top three critical factors—community participation, O&M systems, and institutional mandates—demonstrate the importance of social engagement, technical sustainability, and governance frameworks for project success.

The pooled functionality rate of 52.3% confirms previous observations about the challenging sustainability landscape, while the high heterogeneity ($I^2 = 78.2\%$) underscores the importance of contextual factors in determining project outcomes. The quantitative determination of factor criticality provides evidence-based prioritization for policy and implementation decisions (Ngene et al., 2021).

4.2 Comparison with Previous Research

The identification of community participation as the most critical factor aligns with extensive literature on community-driven development but provides the first quantitative evidence of its overwhelming importance in the Nigerian context (Sanjo et al., 2024). The meta-regression finding that community participation explains 67.3% of variance in functionality outcomes far exceeds previous estimates and establishes it as the primary determinant of project success.

The large effect size of VLOM programs (Cohen's d = 0.89) provides robust evidence for scaling this intervention approach. Previous evaluations have suggested positive impacts, but this meta-analysis demonstrates consistent effectiveness across diverse implementation contexts with unprecedented statistical power (Adeoti et al., 2024).

The substantial heterogeneity in functionality rates ($I^2 = 78.2\%$) reflects the complex interplay of contextual factors influencing water supply sustainability. This finding supports calls for context-specific approaches rather than one-size-fits-all solutions.

4.3 Implications for Policy and Practice

The findings from both research objectives have several important implications for water supply policy and implementation in Nigeria:

Evidence-Based Prioritization

The identification of 23 success factors with quantitative criticality rankings enables evidence-based resource allocation and intervention design. Policymakers can now prioritize the top three critical factors: community participation, O&M systems, and institutional mandates while ensuring attention to the complete inventory of success factors.

Policy Recommendations

(1). Prioritize Community Engagement (Critical Factor #1): Given that community participation explains 67.3% of variance in outcomes, policies should mandate meaningful community involvement throughout project cycles, with specific metrics and monitoring frameworks based on the 10-point participation scale identified in this analysis.

(2). Scale VLOM Programs Nationally (Critical Factor #2): The large effect size (Cohen's d = 0.89) and consistent positive outcomes across all studies provide strong evidence for expanding VLOM implementation to all rural water supply projects, addressing the O&M systems critical factor.

(3). Strengthen Institutional Frameworks (Critical Factor #3): The 92% frequency of institutional mandate mentions and significant geographic disparities suggest need for clearer roles, responsibilities, and accountability mechanisms across all levels of government.

(4). Address Regional Disparities: The significant North-South functionality gap (46.1% vs. 58.4%) requires targeted interventions focusing on the identified critical factors, with enhanced support for northern states.

(5). Implement Comprehensive Factor Framework: Rather than single-factor interventions, successful projects should address multiple factors across all five domains, with particular emphasis on the top-ranked critical factors.

4.4 Strengths and Limitations

Strengths:

(1). Comprehensive search strategy covering multiple databases and grey literature
(2). Rigorous screening and data extraction processes with quality assessment
(3). Novel multi-criteria approach to determining factor criticality
(4). Large sample size with 12,847 water systems across 51 quantitative studies
(5). Advanced statistical methods including meta-regression and publication bias assessment

Limitations:
(1). Potential publication bias detected through statistical tests, though adjusted estimates remain substantial
(2). High heterogeneity limits generalizability of pooled estimates
(3). Observational study designs limit causal inferences
(4). Limited availability of standardized outcome measures across studies
(5). Potential language bias due to English-only inclusion criteria

4.5 Future Research Directions

Based on the findings, several research priorities emerge:

(1). Implementation Science Research: Studies examining how to effectively scale the top three critical factors across different contexts
(2). Longitudinal Tracking: Long-term follow-up studies examining factor interactions and sustainability over time
(3). Comparative Effectiveness Research: Head-to-head comparisons of different implementation approaches incorporating the 23-factor framework
(4). Economic Evaluation: Cost-effectiveness analyses of interventions targeting critical success factors
(5). Qualitative Research: In-depth exploration of community participation mechanisms and their effectiveness

5 Conclusion

This systematic literature review and meta-analysis successfully achieved both research objectives, providing comprehensive evidence on success factors for water supply projects in Nigeria.

Objective (a) Conclusions: The study systematically identified 23 distinct success factors across five domains (Technical, Financial, Institutional, Social, Environmental), providing the most complete inventory of factors influencing water supply implementation in Nigeria. This comprehensive identification demonstrates the multidimensional nature of project success and provides a complete framework for implementation planning.

Objective (b) Conclusions: Through quantitative analysis and criticality assessment, the study determined that community participation is the most critical success factor, explaining 67.3% of variance in functionality outcomes. This finding that Community Participation alone explains 67.3% of the variance in functionality outcomes is not contradictory but rather indicates its role as the primary enabling condition. This factor operates as a superordinate meta-factor: effective community governance is the prerequisite upon which the efficacy of technical systems (like O&M, ranked 2nd), institutional clarity (ranked 3rd), and financial models depends. For instance, high-quality infrastructure fails without local ownership for maintenance, and strong institutional mandates falter without social accountability.

The low functionality rate and high heterogeneity reflect the widespread absence of this foundational condition. Therefore, the conclusion is logically coherent: the systematic review maps the necessary ecosystem of 23 factors, while the meta-analysis identifies the sufficient catalyst community participation that activates the entire system. This evidence mandates a paradigm shift from top-down, techno-financial interventions to strategies that first establish and empower community-level governance as the non-negotiable foundation for all other sustainability investments. This evidence-based ranking enables prioritized resource allocation and intervention design.

In addition, the meta-analysis yields a pooled estimate of 52.3% (95% CI: 48.7–55.9) for rural water system functionality, a statistically significant yet operationally inadequate benchmark that quantifies the pervasive sustainability deficit. The associated substantial heterogeneity ($I^2 = 87\%$) is not merely statistical noise but a critical quantitative indicator of the profound influence of unmeasured contextual and moderating variables, confirming that uniform interventions are unlikely to succeed universally. The quantitative criticality analysis, employing variance decomposition and meta-regression, provides an unprecedented, rank-ordered evidence base for strategic prioritization.

Specifically, the large effect size for Village-Level Operation and Maintenance (VLOM) programs (Cohen's $d = 0.89$, 95% CI: 0.72–1.06) constitutes robust empirical validation of its efficacy, translating to a high probability of superior outcomes compared to non-VLOM approaches. This statistically significant finding provides a compelling, data-driven mandate for the structured national scaling and institutional codification of the VLOM framework.

Sequel to the above, the research key contributions were as follows:

(1). First comprehensive identification and inventory of 23 success factors for Nigerian water supply projects
(2). Quantitative determination of factor criticality using meta-regression analysis
(3). Evidence-based ranking system for policy and implementation prioritization
(4). Robust statistical evidence supporting VLOM program effectiveness
(5). Geographic disparity analysis informing regional policy differentiation

The evidence base provided by this review supports more effective, evidence-based approaches to water supply implementation in Nigeria, with clear prioritization of the most critical success factors while maintaining attention to the complete factor framework.

Future research should focus on implementation science approaches to scaling the top three critical factors, longitudinal tracking of factor interactions over time, and comparative effectiveness research testing the complete 23-factor framework across different implementation contexts.

Acknowledgements

The author sincerely thanks Prof. Mat Naim Abdullah @ Asmoni and Prof. Mohd Saidin Misnan of UTM Johor Bahru for their expert

supervision and academic mentorship. Gratitude is also extended to Ahmad Sha'rainon Md Shaarani for his invaluable collaboration and friendship. Additionally, the author acknowledges the Project Offices of the World Bank Group, EU, and USAID, as well as the Federal Ministry of Water Resources in Nigeria and SARPLAST West Africa Ltd., for their institutional support. Finally, this work benefited significantly from the contributions of Dr. Salisu Gidado Dalibi of P2-S2 Nigeria Limited.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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