

Public Debt and Water Supply and Sanitation Infrastructure in Sub-Saharan Africa: A Panel ARDL Study with Cross-Sector Infrastructure Insights

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Abstract: Water supply and sanitation infrastructure remains a critical development challenge in Sub-Saharan Africa (SSA), amid rising public debt and persistent fiscal constraints. This study examines the short-run and long-run relationships between public debt and water supply and sanitation infrastructure in SSA over the period 2005–2023, accounting for institutional quality, economic output and population growth. The study employs a Panel Autoregressive Distributed Lag (PARDL) framework, estimated using the Mean Group (MG) and Pooled Mean Group (PMG) estimators, to capture heterogeneous short-run dynamics and assess long-run relationships across countries. We measure institutional quality using an Institutional Quality Composite Index (IQI). The PMG estimates reveal a negative and statistically significant error-correction coefficient (-0.0461), indicating an annual adjustment of approximately 4.6% towards long-run equilibrium. Public debt has a positive, statistically significant long-run association with water supply and sanitation infrastructure, while its short-run effect is statistically insignificant. Population growth is positive and significantly associated with infrastructure development in the long run, whereas institutional quality exhibits a positive but statistically insignificant coefficient. The Hausman specification test fails to reject the long-run homogeneity restrictions underlying the PMG estimator. These findings suggest that the relationship between public debt and water supply and sanitation infrastructure is more pronounced over the long run, highlighting the potential importance of sustained

infrastructure financing. However, the results do not establish that public borrowing directly causes infrastructure improvements. The study underscores the need to align debt management with infrastructure investment priorities through sustainable borrowing, rigorous project appraisal, transparent procurement, and adequate maintenance financing to support long-term improvements in water supply and sanitation services across SSA.

Keywords: Public debt; water supply and sanitation; infrastructure development; Panel ARDL; Pooled Mean Group; institutional quality; Sub-Saharan Africa.

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1.0 Introduction

Water supply and sanitation infrastructure is a foundational component of economic and human development. Reliable access to safe water and adequate sanitation reduces exposure to waterborne disease, lowers household time

costs, improves school attendance, supports labour productivity and contributes to the broader quality of life. In Sub-Saharan Africa (SSA), however, substantial spatial and socioeconomic inequalities in water and sanitation access persist, and these deficits impose measurable health and economic costs (Pullan *et al.*, 2014; Armah *et al.*, 2018; Fuente *et al.*, 2020).

The financing challenge is particularly acute because water and sanitation systems require large upfront capital outlays, long asset lives, recurrent maintenance expenditure and substantial institutional coordination. Domestic revenue mobilization remains weak in many SSA economies, while competing expenditure pressures constrain the fiscal space available for infrastructure investment. Public borrowing has therefore become an important financing mechanism for development projects across the region. In principle, debt can relax current fiscal constraints and permit governments to invest in assets whose economic and social returns accrue over long horizons. Yet debt-financed infrastructure may fail to generate durable improvements where borrowing costs are high, project selection is weak, implementation is delayed, or debt-service obligations subsequently crowd out operations and maintenance.

This tension is especially relevant for water and sanitation. Unlike some transport, energy or telecommunications assets, water and sanitation projects often yield substantial social returns that are not fully captured by direct user revenues. The sector can therefore be underfunded when project appraisal focuses narrowly on commercial cash flows. At the same time, weak cost recovery, fragmented institutional responsibilities and maintenance backlogs can reduce the productivity of borrowed resources. The central empirical question is consequently not whether water and sanitation matter for development, but whether

rising public debt expands or constrains the long-run development of water supply and sanitation infrastructure in SSA.

Existing studies provide only partial answers. A first strand examines public debt and public investment, generally using aggregate investment or infrastructure measures. Frimpong, Fumey and Nketiah-Amponsah (2024), for example, show that the effect of public debt on infrastructure investment in Ghana differs across horizons, while Ezeaku *et al.* (2023) find that bilateral and multilateral concessional debt influence public investment in a panel of SSA countries. These studies establish a debt–investment transmission mechanism but do not isolate water and sanitation infrastructure. A second literature documents persistent WSS deficits and the socioeconomic determinants of water and sanitation access, but public debt is rarely the central financing variable (Dangui & Jia, 2022; Armah *et al.*, 2018). A third strand studies foreign aid and official development assistance to WSS, showing that external financing can improve sectoral access but with important nonlinearities and contextual differences (Gopalan & Rajan, 2016). Related Nigerian studies offer cross-sector context on how infrastructure and service conditions can affect productive outcomes: infrastructure accessibility and technical efficiency in small-scale aquaculture (Awolumate & Mekanjuola, 2026); energy–water–profit trade-offs under electricity unreliability (Awolumate *et al.*, 2026); ICT adaptability in fish farming (Awolumate, 2018); and communication infrastructure and information-use efficiency (Awolumate & Inyang, 2019b). These studies do not estimate the public-debt–WSS relationship. They instead motivate attention to the difference between infrastructure as a physical stock and infrastructure that is accessible, reliable and effectively used. This paper integrates these strands. It focuses



directly on water supply and sanitation infrastructure as the dependent variable, public debt as the principal financing variable, and a dynamic heterogeneous panel framework that distinguishes long-run relationships from short-run country-specific adjustment. Institutional quality is included as a control because the capacity to select, procure, implement and maintain infrastructure projects differs materially across SSA countries. The use of Panel ARDL is appropriate for a setting in which variables can exhibit a mixture of $I(0)$ and $I(1)$ behaviour and where short-run responses may differ substantially across countries while a common long-run relationship remains economically plausible. Cross-sector studies of digital communication platforms (Mundi *et al.*, 2024), infrastructure development and artisanal fishing efficiency (Awolumate & Fregene, 2025), and resource-use efficiency among fish farms (Awolumate & Inyang, 2019a) provide contextual examples of infrastructure-linked outcomes. The present study extends the discussion to national WSS infrastructure across SSA and explicitly tests the financing relationship rather than inferring it from sector-level productivity evidence.

The study contributes in three ways. First, it shifts the public-debt literature from aggregate infrastructure toward a sector-specific WSS outcome. Second, it complements the aid-effectiveness literature by examining sovereign borrowing rather than development assistance as the principal financing channel. Third, it applies the PMG/MG framework to distinguish short-run adjustment from long-run effects and to account explicitly for cross-country heterogeneity. The remainder of the paper reviews the theoretical and empirical literature, presents the data and econometric framework, discusses the empirical results, and concludes with policy implications.

2.0 Theoretical Underpinning

The empirical relationship between public debt and water and sanitation infrastructure can be understood through three complementary channels: the debt-overhang and crowding-out mechanism, the infrastructure-led development perspective, and the institutional-efficiency channel.

2.1 Debt overhang and fiscal crowding out

Debt Overhang Theory predicts that high and persistent debt can weaken investment when expected future debt-service obligations absorb fiscal resources, increase uncertainty or discourage new capital formation (Krugman, 1988). Applied to WSS, borrowing may initially finance treatment plants, distribution networks, sanitation systems and related assets. However, if debt accumulation subsequently raises interest and principal payments, governments may reduce capital budgets or defer maintenance. The expected sign of public debt is therefore theoretically ambiguous: positive where borrowed funds are productively invested and negative where servicing pressures or inefficient allocation dominate.

2.2 Infrastructure-led development

The infrastructure-led development perspective treats public infrastructure as productive capital that raises the efficiency of households and firms. Water and sanitation generate direct health benefits and indirect productivity gains through reduced morbidity, lower time spent collecting water, improved school attendance and a healthier labour force. Consequently, productive borrowing for WSS can generate returns that extend well beyond direct sector revenues.

2.3 Institutional quality

The productivity of public borrowing depends on institutional capacity. Strong institutions can improve project selection, procurement discipline, contract management, tariff design, regulatory oversight and maintenance. Weak institutions can instead generate cost



escalation, incomplete projects, leakage and poor service quality. For this reason, the model includes an Institutional Quality Composite Index (IQI) as a standalone control variable. This treatment is consistent with the broader SSA debt literature, which shows that governance and public-sector management influence the developmental consequences of debt (Manasseh *et al.*, 2022; Sandow *et al.*, 2022).

3.0 Literature Review and Research Gap

3.1 Public debt, public investment and infrastructure

Evidence on the debt–investment relationship is mixed and highly dependent on the financing structure, macroeconomic context and time horizon. Ncanywa & Masoga (2018) document dynamic relationships among public debt, public investment and economic growth in South Africa, while Frimpong *et al.* (2024) find asymmetric effects of public debt on infrastructure investment in Ghana. In a broader SSA setting, Ezeaku *et al.* (2023) employ dynamic Panel ARDL estimators and report that bilateral and multilateral concessional debt have significant long-run effects on public investment. These studies support the proposition that borrowing can affect public capital formation but do not establish whether this effect is specific to WSS. Nigerian sectoral evidence provides complementary hypotheses about the conversion of infrastructure into productive outcomes. Awolunate and Makanjuola (2026) examine infrastructure accessibility alongside extension intensity and technical efficiency; Awolunate, Shani and Okhogbe (2026) analyze energy–water–profit trade-offs under unreliable electricity; and Awolunate and Inyang (2019b) examine technical-efficiency differentials in aquaculture resource use. Research on ICT adaptability (Awolunate, 2018), communication infrastructure and

information-use efficiency (Awolunate & Inyang, 2019b), and digital platforms in aquaculture communication (Mundi *et al.*, 2024) further illustrates the role of access and information systems. Studies of artisanal fishing and infrastructure development (Awolunate & Fregene, 2025), digital market information and fish supply-chain performance (Awolunate, 2026a), and post-harvest storage behaviour (Amos & Awolunate, 2026) extend this contextual evidence to resource management, market coordination and infrastructure use. These publications concern sectoral settings in Nigeria rather than sovereign debt or national WSS systems; they are used here to frame hypotheses, not as direct empirical evidence for the macro-panel coefficients.

At the regional level, financing conditions also shape infrastructure gaps. Kodongo *et al.*, (2023), show that deeper bond markets can help reduce infrastructure deficits in SSA. This suggests that the source, maturity and cost of finance matter for infrastructure delivery. Yet aggregate infrastructure indicators can conceal sectoral differences because water and sanitation projects differ from transport, electricity and ICT in commercial structure, maintenance requirements, institutional responsibilities and social returns.

3.2 Water supply and sanitation infrastructure

Research on WSS consistently documents large cross-country and within-country inequalities across SSA. Pullan *et al.* (2014) show pronounced geographical differences in the use of improved drinking water and sanitation, while Armah *et al.* (2018) find that progress in water access has outpaced sanitation and remains uneven across socioeconomic and spatial groups. Fuente *et al.* (2020) demonstrate that inadequate WSS continues to impose substantial mortality and economic losses in parts of SSA and that



economic growth alone will not automatically eliminate these deficits.

Dangui & Jia (2022) examine the drivers and economic implications of water infrastructure performance in SSA and reinforce the importance of sector-specific analysis. However, the direct role of public debt as a determinant of financing remains underdeveloped in this literature.

3.3 Financing of water and sanitation

A substantial financing literature focuses on foreign aid rather than sovereign borrowing. Gopalan & Rajan (2016) find that aid to water supply and sanitation can improve access, particularly in lower-middle-income and rural settings, but also document nonlinear and diminishing returns. Such evidence demonstrates that financing matters, but aid and public debt differ fundamentally in repayment obligations, fiscal risk and implications for future expenditure. This distinction motivates a direct analysis of debt-financed WSS.

3.4 Research gap and contribution

The literature reveals a clear empirical gap. Public-debt studies generally focus on growth, aggregate public investment or broad infrastructure; WSS studies emphasize access, health consequences and socioeconomic determinants; and WSS financing studies concentrate heavily on aid and official development assistance. Relatively little evidence integrates public debt, WSS infrastructure, institutional quality and dynamic short-run/long-run analysis within one multi-country SSA framework. This study addresses that gap using Panel ARDL with MG and PMG estimators.

4.0 Methodology and Data

4.1 Research design and empirical framework

The study employs a quantitative dynamic-panel design to examine the short-run and long-run relationship between public debt and water supply and sanitation infrastructure in Sub-

Saharan Africa over 2005–2023. The Panel Autoregressive Distributed Lag (PARDL) framework is appropriate because the variables may be integrated of different orders, provided none is integrated of order two, and because the estimator separates short-run country-specific adjustment from the long-run equilibrium relationship. The Mean Group (MG) and Pooled Mean Group (PMG) estimators are used as complementary heterogeneous-panel estimators, following Pesaran *et al.* (1999).

4.2 Functional specification

Water supply and sanitation infrastructure is the dependent variable. Public debt is the principal explanatory variable, while economic output, population growth and institutional quality enter as controls. The preferred empirical relationship is specified as:

$$WSS_{it} = f(PD_{it}, LGDP_{it}, POPG_{it}, IQI_{it}) \quad (1)$$

where WSS_{it} denotes water supply and sanitation infrastructure in country i at time t ; PD_{it} denotes public debt, measured by the debt-to-GDP ratio; $LGDP_{it}$ denotes the logarithm of gross domestic product; $POPG_{it}$ denotes population growth; IQI denotes the Institutional Quality Composite Index; and i and t index countries and years, respectively.

The corresponding static representation is:

$$WSS_{it} = \alpha_i + \beta_1 PD_{it} + \beta_2 LGDP_{it} + \beta_3 POPG_{it} + \beta_4 IQI_{it} + \varepsilon_{it}. \quad (2)$$

Institutional quality enters the model strictly as a standalone explanatory variable through IQI . No interaction term is included in the preferred manuscript specification.

4.3 Panel ARDL specification

The unrestricted PARDL(p , q_1 , q_2 , q_3 , q_4) model is written as:

$$WSS_{it} = \alpha_i + \sum_{j=1}^p \phi_{ij} WSS_{i,t-j} + \sum_{j=0}^{q_1} \beta_{1ij} PD_{i,t-j} + \sum_{j=0}^{q_2} \beta_{2ij} LGDP_{i,t-j} + \sum_{j=0}^{q_3} \beta_{3ij} POPG_{i,t-j} + \sum_{j=0}^{q_4} \beta_{4ij} IQI_{i,t-j} + \varepsilon_{it}. \quad (3)$$

In Equation (3), p is the lag order of the dependent variable and q_1 – q_4 are the lag orders of the explanatory variables. This dynamic



specification allows current water and sanitation infrastructure to depend on its own past values and on contemporaneous and lagged movements in public debt, output, population growth and institutional quality.

4.4 Error-correction representation

For estimation and interpretation, equation 3 is reparameterised into the error-correction form:

$$\Delta WSS_{it} = \lambda_i[WSS_{i,t-1} - \theta_0 - \theta_1 PD_{i,t-1} - \theta_2 LGDP_{i,t-1} - \theta_3 POPG_{i,t-1} - \theta_4 IQI_{i,t-1}] + \sum \psi_{ij} \Delta WSS_{i,t-j} + \sum \gamma_{1ij} \Delta PD_{i,t-j} + \sum \gamma_{2ij} \Delta LGDP_{i,t-j} + \sum \gamma_{3ij} \Delta POPG_{i,t-j} + \sum \gamma_{4ij} \Delta IQI_{i,t-j} + \mu_i + \varepsilon_{it}. \quad (4)$$

The coefficient λ_i is the error-correction or speed-of-adjustment parameter. A negative and statistically significant value indicates convergence toward the long-run equilibrium after a short-run disturbance. Its absolute magnitude measures the proportion of the previous period's disequilibrium corrected in one year. The θ parameters are the long-run coefficients, whereas the γ parameters capture short-run responses.

4.5 Long-run and short-run equations

The long-run equilibrium relationship implied by the PARDL model is:

$$WSS_{it} = \theta_0 + \theta_1 PD_{it} + \theta_2 LGDP_{it} + \theta_3 POPG_{it} + \theta_4 IQI_{it} + u_{it}. \quad (5)$$

The coefficient θ_1 is the principal parameter of interest and measures the long-run effect of public debt on water supply and sanitation infrastructure. A positive coefficient indicates that higher public borrowing is associated with improved WSS infrastructure, whereas a negative coefficient is consistent with debt-service pressure, fiscal crowding out, or inefficient allocation of borrowed resources.

The short-run dynamics can be written compactly as:

$$\Delta WSS_{it} = \lambda_i ECT_{i,t-1} + \sum \gamma_{1ij} \Delta PD_{i,t-j} + \sum \gamma_{2ij} \Delta LGDP_{i,t-j} + \sum \gamma_{3ij} \Delta POPG_{i,t-j} + \sum \gamma_{4ij} \Delta IQI_{i,t-j} + \varepsilon_{it}. \quad (6)$$

where $ECT_{i,t-1}$ is the lagged deviation from the long-run relationship in equation 5.

4.6 PMG and MG estimation

The PMG estimator imposes equality on the long-run coefficients across countries while allowing short-run coefficients, intercepts, adjustment speeds and disturbance variances to differ. Formally, $\theta_{ki} = \theta_k$ for all i in the long run, while λ_i , γ_{kij} , μ_i and σ_i^2 remain country-specific. This restriction is plausible when countries share a common long-run development relationship but differ in short-run fiscal, demographic and institutional responses.

The MG estimator, by contrast, estimates a separate dynamic regression for each country and computes the unweighted mean of the country-specific coefficients:

$$\hat{\theta}^{MG} = (1/N) \sum_{i=1}^N \hat{\theta}_i. \quad (7)$$

MG therefore allows both short-run and long-run coefficients to vary across countries and serves as the principal comparator to PMG.

4.7 Hausman model-selection test

The Hausman specification test is used to assess whether the long-run homogeneity restrictions imposed by PMG are supported by the data. The null hypothesis is that PMG is efficient and consistent, while the alternative favours MG. A statistically insignificant Hausman probability supports PMG. In the current WSS estimation, the reported Hausman statistic is 10.59 with $p = 0.1575$; hence the null is not rejected and PMG is retained as the preferred estimator.

4.8 Data Sources ,Variable Description and Measurement

The study uses annual panel data for Sub-Saharan African countries over the period 2005–2023. Water supply and sanitation infrastructure is the dependent variable, while public debt is the principal explanatory variable. Gross domestic product, population growth and institutional quality are included to account for differences in economic capacity, demographic pressure and institutional performance. Table 1 summarizes the



variables, their measurement, data sources, and expected coefficient signs.

5.0 Empirical Results

5.1 Preliminary tests

The unit-root evidence in the supplied output indicates a mixture of level-stationary and first-difference-stationary variables, with no evidence that the variables are integrated beyond order one. This mixed $I(0)/I(1)$

structure is compatible with Panel ARDL estimation. Cointegration evidence is mixed under the Pedroni statistics for the WSS model, while the Westerlund variance-ratio statistic for the corresponding objective is significant. The negative and significant PMG error-correction term provides additional evidence of an equilibrating long-run relationship in the estimated dynamic specification.

Table 1. Variable definitions, measurement and data sources

Variable	Sym ol	Measurement / operational definition	Data source
Water supply and sanitation infrastructure	WSS	Water supply and sanitation component of the Africa Infrastructure Development Index, reflecting access to water and sanitation services.	AfDB, AIDI (2005–2023)
Public debt	PD	Public debt stock expressed as a percentage of GDP.	World Bank / IMF 2023
Gross domestic product	LGD P	Natural logarithm of gross domestic product, capturing the scale of economic activity.	World Bank, WDI 2023
Population growth	POPG	Annual population growth rate (%).	World Bank, WDI 2023
Institutional quality	IQI	Composite index constructed from selected governance indicators; higher values denote stronger institutional quality.	Authors' computation from governance indicators 2023

Source: Authors' compilation based on the African Development Bank (AfDB), World Development Indicators (WDI), relevant public debt databases and governance indicators

Table 3 reports only the standalone coefficients for public debt, log GDP, population growth and IQI. The interaction terms are not part of the model and are not reported or interpreted.

The results of the panel cointegration tests conducted to examine the existence of long-run equilibrium relationships among the variables in the water supply and sanitation (WSS) model are presented in Table 2. The tests provide evidence on the cointegrating relationship among the variables and help

establish the suitability of the Panel ARDL framework for examining their long-run dynamics.

5.3 Interpretation of the PMG results

The Hausman statistic of 10.59 with $p = 0.1575$ does not reject the null that the long-run homogeneity restrictions are valid. PMG is therefore the preferred estimator for interpretation relative to MG in the supplied output. The error-correction coefficient is -0.0461 and significant at the 1% level. The



negative sign confirms convergence following short-run disturbances. Its magnitude implies that approximately 4.6% of the gap from long-run equilibrium is corrected annually. The adjustment is therefore statistically reliable but

slow, a pattern consistent with the long gestation period, maintenance constraints and institutional complexity associated with WSS infrastructure.

Table 2. Panel cointegration tests for the WSS model

Test	Statistic	p-value
Pedroni modified Phillips–Perron t	10.2484	0.0000***
Pedroni Phillips–Perron t	1.1332	0.1286
Pedroni augmented ADF t	0.9723	0.1655
Westerlund variance ratio	14.7978	0.0000***

Note: The attached estimation output labels the WSS equation as Model Three. ***, ** and * indicate significance at the 1%, 5% and 10% levels

5.2 MG and PMG estimates for water supply and sanitation

The preceding preliminary diagnostic tests provide the econometric basis for examining the long-run and short-run relationships among public debt, economic output, population growth, institutional quality and water supply and sanitation infrastructure. To assess these relationships, the

Mean Group (MG) and Pooled Mean Group (PMG) estimators were employed within the Panel ARDL framework. Table 3 presents the comparative estimation results, including the error-correction coefficient, short-run and long-run parameter estimates, Hausman specification test and number of observations

Table 3:MG and PMG estimates for water supply and sanitation infrastructure

Variable	MG	PMG
Error-correction term	−0.0290 (0.122)	−0.0461*** (0.0108)
Δ Public debt	−0.00391** (0.00177)	0.000224 (0.000770)
Δ Log GDP	−0.00500 (0.0786)	0.0150* (0.00803)
Δ Population growth	−0.00707, (0.0273)	−0.00160 (0.00885)
Δ IQI	0.147(0.443)	−0.0425(0.0336)
Long-run public debt	0.0946*(0.0486)	0.00486*** (0.000729)
Long-run log GDP	−0.323 (0.421)	−0.000139 (0.00277)
Long-run population growth	−0.0858 (0.582)	0.0761*** (0.0116)
Long-run IQI	−2.159 (3.311)	0.0238 (0.0145)
Constant	−0.487 (0.432)	0.102**(0.0411)
Hausman test	—	10.59 [p = 0.1575]
Observations	714	714

Note: Standard errors are reported in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. The Hausman p-value of 0.1575 supports PMG relative to MG., IQI is presented as a standalone explanatory variable and interaction-term estimates are excluded from the table



The short-run public debt coefficient under PMG is positive but not statistically significant. This suggests that changes in borrowing do not translate immediately into measurable improvements in water and sanitation infrastructure. Such a result is plausible because debt-financed WSS projects require planning, procurement, construction, and network expansion before service outcomes become visible.

In contrast, the reported long-run public-debt coefficient is positive and significant at the 1% level. This result is consistent with the proposition that public borrowing can support WSS infrastructure when financing is sustained over time and converted into productive assets. It also accords with the broader public-investment literature, which finds that concessional and other forms of debt can affect long-run public investment (Ezeaku *et al.*, 2023). The finding should nevertheless be interpreted jointly with debt sustainability: a positive infrastructure response does not imply that all additional borrowing is welfare-improving, particularly where servicing costs later displace maintenance and social expenditure.

Population growth has a positive and highly significant long-run coefficient. One interpretation is that demographic pressure increases demand for water and sanitation networks and induces governments to expand service provision over time. The absence of a significant short-run effect indicates that infrastructure supply responds slowly to demographic change.

The long-run IQI coefficient is positive but statistically insignificant in the reported results. This does not imply that institutions are unimportant. The wider literature shows that governance and public-sector management affect the developmental consequences of debt, while project implementation in WSS is institutionally intensive. Rather, the result

indicates that the standalone IQI coefficient is not estimated precisely in the reported specification.

Log GDP is statistically insignificant in the long run. This suggests that economic scale by itself is insufficient to guarantee water and sanitation infrastructure expansion. Fiscal allocation, financing structure, institutional capacity and sector prioritization may matter more than aggregate income growth alone.

5.4 Discussion of the results

The positive long-run public-debt coefficient extends the debt–public-investment literature into a sector-specific WSS setting. Frimpong *et al.* (2024) show that public debt affects infrastructure investment in Ghana, while Ezeaku *et al.* (2023) identify long-run public-investment effects of concessional borrowing in SSA. The present evidence narrows that relationship to water supply and sanitation.

The findings also complement the WSS financing literature. Gopalan and Rajan (2016) show that foreign aid can improve WSS access but with nonlinear and context-dependent effects. Public debt differs from aid because it creates future repayment obligations, but both literatures point to the importance of financing design and absorptive capacity.

The slow speed of adjustment is consistent with persistent WSS deficits documented across SSA. Pullan *et al.* (2014), Armah *et al.* (2018) and Fuente *et al.* (2020) show that service deficits and inequalities remain substantial despite long-term development efforts. This persistence suggests that capital financing must be accompanied by maintenance systems, institutional coordination and sustained service delivery. Cross-sector studies from Nigeria reinforce the importance of service reliability and effective use: electricity unreliability is linked to energy–water–profit trade-offs in aquaponics (Awolumate, Shani, & Okhogbe, 2026), while infrastructure accessibility has been examined in relation to technical



efficiency in aquaculture (Awolumate & Makanjuola, 2026). Research on digital market information (Awolumate, 2026a) and post-harvest storage behaviour (Amos & Awolumate, 2026) similarly points to the relevance of access and infrastructure use for sectoral performance. These are contextual parallels, not direct evidence about public WSS infrastructure or debt financing.

6.0 Conclusion and Policy Implications

This study examines the dynamic relationship between public debt and water supply and sanitation infrastructure in Sub-Saharan Africa using a Panel ARDL framework for the 2005–2023 period. The analysis is motivated by the coexistence of persistent WSS deficits and increasing reliance on public borrowing across the region. MG and PMG estimators are used to distinguish heterogeneous short-run adjustment from the long-run relationship.

The reported PMG evidence indicates a slow but statistically significant return to long-run equilibrium. Public debt has no significant immediate effect on WSS infrastructure, but its reported long-run coefficient is positive and significant. Population growth is also positively associated with WSS infrastructure in the long run, while the coefficients on log GDP and the standalone IQI variable are not statistically significant. These results point to a long-horizon financing mechanism: borrowing may support infrastructure expansion, but the effect materializes gradually and depends on implementation capacity.

The policy implication is not simply to borrow more. Debt-financed WSS investment should be embedded in credible debt-sustainability frameworks and supported by rigorous project appraisal. Governments should favour concessional and long-maturity financing for projects with large social returns but limited commercial cash flows. Procurement transparency, life-cycle costing, ring-fenced maintenance budgets and independent

performance monitoring are essential to prevent the erosion of infrastructure value after construction.

Second, water and sanitation should receive greater protection within capital budgets. Because the sector produces large health and productivity spillovers, project selection frameworks should explicitly recognize social returns rather than relying exclusively on direct financial revenue. Blended finance, development-bank lending and well-designed public–private arrangements can complement sovereign borrowing where risks are appropriately allocated.

Third, institutional capacity requires continued strengthening even where the standalone IQI coefficient is statistically weak. Water agencies often operate across multiple ministries and levels of government; clearer mandates, reliable billing and tariff systems, transparent procurement and professional asset management can raise the productivity of borrowed resources.

Finally, debt policy and infrastructure policy should be jointly evaluated. Borrowing decisions should be linked to measurable service indicators such as access, continuity, water quality, sanitation coverage and maintenance performance. This would shift policy attention from the volume of borrowing to the development outcomes generated by borrowed funds.

7.0 Contribution to Knowledge

The paper contributes by providing a sector-specific analysis of the public debt–water and sanitation nexus in SSA rather than relying on aggregate infrastructure or public-investment measures. It integrates debt financing, WSS infrastructure and institutional quality within a dynamic Panel ARDL framework and separates short-run adjustment from long-run effects. It also bridges two literatures that have largely evolved separately: sovereign debt and



public investment, and WSS financing dominated by aid and service-access studies.

8.0 Limitations and Further Research

The study is constrained by the availability and comparability of annual infrastructure indicators across SSA countries. Aggregate WSS indices may not fully capture service quality, continuity, affordability or subnational inequality. The current debt measure also does not distinguish domestic from external debt, concessional from commercial borrowing, or creditor composition. Future research should examine these financing dimensions and consider nonlinear debt thresholds, climate vulnerability, urbanization and project-level efficiency. A further extension would combine national infrastructure indicators with household or geospatial access data to evaluate distributional outcomes. Sector-level research from Nigeria offers possible constructs for future work, including infrastructure accessibility and technical efficiency (Awolumate & Makanjuola, 2026; Awolumate & Inyang, 2019a), ICT access and information-use efficiency (Awolumate, 2018; Awolumate & Inyang, 2019b; Mundi *et al.*, 2024), electricity reliability (Awolumate, Shani, & Okhogbe, 2026), infrastructure development and artisanal fishing performance (Awolumate & Fregene, 2025), digital market information (Awolumate, 2026a), post-harvest storage behaviour (Amos & Awolumate, 2026), and financial constraints in small-scale fish processing (Awolumate & Muyiwa, 2025). These sectoral studies should inform future hypotheses and measurement design rather than be treated as direct evidence for macro-level debt–WSS relationships.

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Compliance with Ethical Standards

Declaration

Ethical Approval

Not Applicable

Competing interests

The author declares no known competing financial interests.

Conflict of interest statement

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Authors' Contributions

David Alaba Makanjuola conceptualized the study, developed the research methodology, conducted the econometric analysis, interpreted the findings, and prepared the original manuscript. Gilbert Deinde Ifarajimi contributed to the literature review, data interpretation, critical revision, and policy implications. Oluwasola Oni contributed to data validation, theoretical review, manuscript editing, and critical evaluation. All authors reviewed and approved the final manuscript.

