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Universal Health Coverage, Health System Capacity and Maternal Mortality in Sub-Saharan Africa in the Post-COVID Era Using Dynamic Panel and Threshold Models

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Abstract

Background

Maternal mortality remains a major public health challenge in Sub-Saharan Africa despite global progress in maternal healthcare and increased policy commitments toward improving reproductive health outcomes. Weak health systems, limited healthcare infrastructure, and inadequate access to essential maternal health services continue to contribute to preventable maternal deaths across many countries in the region. Universal Health Coverage (UHC) has been widely promoted as a key strategy for improving maternal health outcomes by expanding access to essential healthcare services without financial hardship. However, the effectiveness of UHC may depend on the capacity of national health systems, including healthcare financing, workforce availability, and service infrastructure. This study investigates the combined effects of universal health coverage and health system capacity on maternal mortality in Sub-Saharan Africa during the post-COVID era.

Methods

The study utilises a longitudinal panel dataset encompassing 25 Sub-Saharan African countries from 2000 to 2024, resulting in a balanced sample of 625 country-year observations. The Maternal Mortality Ratio (MMR) is used as the outcome variable, while key explanatory variables include the UHC Service Coverage Index and health system capacity indicators, such as health expenditure, physician density, hospital beds, and skilled birth attendance. Socioeconomic controls include GDP per capita, female secondary school enrollment, urban population share, and fertility rate. The analysis applies dynamic System-Generalised Method of Moments (System-GMM), panel threshold regression, and Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) models to capture dynamic, nonlinear, and cross-country relationships.

Results

The findings reveal significant persistence in maternal mortality across countries. Universal health coverage and health expenditure are associated with reductions in maternal mortality in both the short and long run. Threshold analysis indicates that the effectiveness of UHC improves when health system infrastructure surpasses a critical capacity level. Urbanisation also contributes to improved maternal health outcomes.

Conclusion

Strengthening universal health coverage alongside investments in healthcare infrastructure and financing is essential for reducing maternal mortality and achieving maternal health targets across Sub-Saharan Africa.

Keywords: Maternal Mortality, Universal Health Coverage, Health System Capacity, Dynamic Panel Analysis, Sub-Saharan Africa

1 Introduction

Maternal mortality remains one of the most persistent public health challenges worldwide, reflecting deep inequalities in access to quality healthcare, socioeconomic resources, and institutional capacity. Despite decades of global initiatives aimed at improving maternal health, the burden of maternal deaths continues to disproportionately affect low- and middle-income countries, particularly those in Sub-Saharan Africa. According to global health estimates, maternal mortality is largely preventable when timely access to skilled care, adequate health infrastructure, and effective financing mechanisms are in place. However, systemic barriers, including weak health systems, inadequate financing, and socioeconomic disparities, continue to undermine progress in many developing regions. Studies have consistently highlighted the relationship between maternal mortality and the capacity of national health systems, particularly the availability of skilled birth attendants, health financing, and maternal health services (Rana et al., 2018; Owusu et al., 2021). Furthermore, maternal mortality is closely linked to broader structural determinants such as gender inequality, poverty, and healthcare accessibility, which shape maternal health outcomes across the life course (Chirowa et al., 2013; Olonade et al., 2019). In the aftermath of the COVID-19 pandemic, concerns have intensified regarding the resilience of health systems in developing countries, particularly as disruptions to healthcare delivery, financial constraints, and workforce shortages have threatened maternal health gains in many regions.

Within this broader context, Universal Health Coverage (UHC) has emerged as a central global strategy for improving maternal and reproductive health outcomes. UHC refers to a health system objective whereby all individuals and communities receive essential health services without suffering financial hardship. Conceptually, UHC encompasses both service coverage and financial

protection, ensuring that populations can access preventive, promotive, curative, and rehabilitative health services across the continuum of care. Expanding UHC has been widely associated with improved maternal health service utilisation, including antenatal care, skilled birth attendance, and postnatal care (Kazibwe et al., 2024; Esan et al., 2023). However, the effectiveness of UHC is often mediated by the underlying capacity of national health systems, including financing, workforce availability, and healthcare infrastructure. In many Sub-Saharan African countries, insufficient health system capacity continues to constrain the potential benefits of UHC initiatives, limiting their ability to translate coverage improvements into measurable reductions in maternal mortality (Dowou et al., 2023). Consequently, the interaction between health system capacity and universal coverage remains a critical area of inquiry in global health policy and research.

Empirical evidence across multiple regions has identified several determinants that shape maternal mortality outcomes. Among these, public health expenditure plays a particularly critical role in strengthening maternal healthcare systems by improving access to skilled professionals, medical equipment, and essential services. Comparative studies have shown that increased healthcare expenditure is associated with reductions in maternal mortality in both developing and developed health systems (Aziz et al., 2021; Rana et al., 2018). Similar findings have been reported in African contexts, where improved health financing and targeted investments in maternal healthcare programs contribute to better maternal health outcomes (Bayero et al., 2022; Boundioa & Thiombiano, 2024). Beyond financing, socioeconomic factors such as female education, urbanisation, and fertility patterns significantly influence maternal mortality risks by shaping health-seeking behaviour and access to healthcare services (Atake, 2021; Bain et al., 2022). Evidence also indicates that maternal health insurance coverage and financial protection mechanisms play an important role in facilitating access to maternal healthcare services, thereby reducing maternal and child mortality risks (Imo et al., 2022). Furthermore, maternal mortality outcomes are influenced by broader patterns of healthcare utilisation and systemic inequalities in health service access, particularly among disadvantaged populations (Najjuuko et al., 2025; Tiruneh et al., 2021). These determinants collectively highlight the complex and multidimensional nature of maternal health challenges in developing regions.

Despite improvements in maternal health interventions globally, Sub-Saharan Africa continues to account for the highest proportion of maternal deaths worldwide. The region faces a unique convergence of structural, socioeconomic, and health system challenges that perpetuate high maternal mortality rates. Studies examining maternal mortality patterns across the region emphasise the role of weak healthcare systems, insufficient skilled healthcare personnel, and disparities in maternal healthcare access as key drivers of maternal deaths (Okonji et al., 2023; Musarandega et al., 2021). In several countries, inadequate public health expenditure and limited infrastructure have hindered the effective delivery of maternal health services, particularly in rural and underserved communities (George-Anokwuru, 2024; Oladosu et al., 2022). The consequences of maternal mortality extend beyond individual health outcomes, generating broader social and economic implications for families, healthcare systems, and national development. Maternal

deaths often result in long-term health complications for surviving children, reduced household economic productivity, and increased pressure on already strained healthcare systems (Mao et al., 2023). Moreover, maternal mortality undermines progress toward broader development objectives, including poverty reduction, gender equality, and sustainable health systems. Within the African context, Nigeria and several other Sub-Saharan African countries continue to experience high maternal mortality rates despite ongoing policy interventions and healthcare reforms (Anumudu et al., 2025).

Although a substantial body of literature has examined the relationship between healthcare expenditure, maternal healthcare utilisation, and maternal mortality, important gaps remain in understanding how universal health coverage interacts with broader health system capacity to influence maternal health outcomes in Sub-Saharan Africa. Existing studies have largely focused on individual determinants such as health expenditure, insurance coverage, or service utilisation without adequately capturing the dynamic interactions between universal health coverage policies and the structural capacity of health systems. Furthermore, many empirical studies rely on static cross-sectional approaches that do not fully account for endogeneity, temporal persistence, and cross-country interdependencies within health systems. Addressing these methodological limitations is particularly important in the post-COVID era, where health systems across Sub-Saharan Africa have faced unprecedented disruptions and structural stress. Guided by a life-course and health systems perspective, this study investigates how universal health coverage and health system capacity jointly influence maternal mortality across Sub-Saharan African countries. Using a panel dataset covering 25 countries from 2000 to 2024, the study applies advanced econometric techniques, including dynamic System-GMM, panel threshold models, and cross-sectionally augmented ARDL, to capture both dynamic and nonlinear relationships between health system variables and maternal mortality. By integrating health system capacity indicators with universal health coverage measures, the study provides new insights into the conditions under which health system strengthening can translate into improved maternal survival outcomes. Ultimately, the findings contribute to the global health policy discourse by offering evidence relevant to achieving Sustainable Development Goal 3, which aims to reduce global maternal mortality and strengthen health systems for universal and equitable healthcare access.

2 Materials and Methods

2.1 Research Design and Study Sample

This study adopts a quantitative longitudinal panel research design to examine the relationship between universal health coverage, health system capacity, and maternal mortality in Sub-Saharan Africa in the post-COVID era. Panel data approaches are widely used in global health and health economics research because they allow researchers to capture both cross-country variation and temporal dynamics in health outcomes (Rana et al., 2018; Owusu et al., 2021). By integrating cross-sectional and time-series dimensions, panel models provide stronger inferential power for identifying determinants of maternal mortality while accounting for unobserved heterogeneity

across countries. The choice of a longitudinal panel framework is particularly appropriate for maternal health research because maternal mortality trends evolve gradually in response to structural changes in healthcare systems, socioeconomic conditions, and public health policies (Chirowa et al., 2013; Bayero et al., 2022).

The empirical analysis focuses on 25 Sub-Saharan African countries, namely Nigeria, Ghana, Kenya, Ethiopia, Uganda, Tanzania, Rwanda, Zambia, Malawi, Mozambique, Senegal, Cameroon, Benin, Togo, Burkina Faso, Mali, Niger, Gambia, Sierra Leone, Liberia, Botswana, Namibia, South Africa, Zimbabwe, and Côte d'Ivoire. These countries were selected because they have relatively consistent data availability for maternal health indicators and health system capacity variables across the study period. The study covers the period 2000–2024, capturing both pre- and post-pandemic health system conditions. The dataset, therefore, consists of a balanced panel of 25 countries observed over 25 years, resulting in a total of 625 country-year observations ($N = 625$). Balanced panels improve statistical efficiency and allow for more robust estimation of dynamic relationships compared with unbalanced panels with missing observations (Aziz et al., 2021).

The primary outcome variable in the study is the Maternal Mortality Ratio (MMR), measured as the number of maternal deaths per 100,000 live births. Maternal mortality is widely recognised as a key indicator of healthcare system performance and women's health outcomes globally (Musarandega et al., 2021; Okonji et al., 2023). The core explanatory variables include Universal Health Coverage (UHC), measured using the UHC Service Coverage Index, and a set of health system capacity indicators, including current health expenditure (% of GDP), physicians per 1,000 population, hospital beds per 1,000 population, and births attended by skilled health personnel. These indicators capture both financial and infrastructural dimensions of health system capacity that are critical for maternal healthcare delivery (Dowou et al., 2023; George-Anokwuru, 2024). In addition, several socioeconomic control variables are included in the analysis to improve causal inference, namely GDP per capita, female secondary school enrollment, urban population share, and total fertility rate. These factors have been consistently identified as key determinants of maternal health outcomes across developing countries (Atake, 2021; Bain et al., 2022).

2.2 Empirical Model Framework

The econometric framework of this study draws from existing empirical literature on maternal health outcomes and healthcare system performance. Previous studies have applied panel econometric models to evaluate the effects of healthcare expenditure and health system indicators on maternal mortality across countries (Rana et al., 2018; Owusu et al., 2021). Similarly, research on maternal health financing in Africa has employed panel models to examine the impact of public health spending and service availability on maternal mortality ratios (Bayero et al., 2022; Boundioa & Thiombiano, 2024). Building on these empirical approaches, the present study integrates three complementary econometric strategies: Dynamic System-GMM estimation, Panel Threshold Regression, and Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL)

models. The combination of these methods allows the study to address issues of endogeneity, nonlinear relationships, and cross-sectional dependence across countries.

2.2.1 Dynamic System-GMM Model

To account for potential endogeneity and the persistence of maternal mortality outcomes over time, the study employs the Dynamic System-Generalised Method of Moments (System-GMM) estimator. Maternal mortality is known to exhibit strong temporal persistence, as health system improvements and policy interventions often affect mortality outcomes gradually over time. Dynamic panel models are therefore appropriate for capturing this persistence while addressing potential reverse causality between health system variables and maternal mortality (Aziz et al., 2021; Rana et al., 2018).

The baseline dynamic model is specified as:

$$MMR_{it} = \alpha MMR_{i,t-1} + \beta_1 UHC_{it} + \beta_2 HEX_{it} + \beta_3 PHY_{it} + \beta_4 BED_{it} + \beta_5 SBA_{it} + \beta_6 GDPPC_{it} + \beta_7 EDU_{it} + \beta_8 URB_{it} + \beta_9 FER_{it} + \varepsilon_{it}$$

Where:

MMR_{it} = Maternal mortality ratio in country i at time t

$MMR_{i,t-1}$ = Lagged maternal mortality ratio

UHC_{it} = Universal Health Coverage index

HEX_{it} = Health expenditure (% of GDP)

PHY_{it} = Physicians per 1,000 population

BED_{it} = Hospital beds per 1,000 population

SBA_{it} = Skilled birth attendance (%)

$GDPPC_{it}$ = GDP per capita

EDU_{it} = Female secondary school enrollment (%)

URB_{it} = Urban population (%)

FER_{it} = Total fertility rate

ε_{it} = Error term

System-GMM estimation addresses endogeneity by using internal instruments derived from lagged levels and differences of the explanatory variables.

2.2.2 Panel Threshold Regression Model

To investigate whether the impact of universal health coverage on maternal mortality depends on the capacity of national health systems, the study employs a panel threshold regression model. Threshold models allow the relationship between variables to change when a particular threshold level of a moderating variable is reached. In maternal health systems, the effectiveness of

healthcare coverage may depend on the availability of sufficient infrastructure and health personnel.

The threshold model is expressed as:

$$MMR_{it} = \begin{cases} \alpha + \beta_1 UHC_{it} + \gamma X_{it} + \varepsilon_{it}, & HSC_{it} < \tau \\ \alpha + \beta_2 UHC_{it} + \gamma X_{it} + \varepsilon_{it}, & HSC_{it} \geq \tau \end{cases}$$

Where:

HSC_{it} represents health system capacity indicators

τ denotes the estimated threshold value

X_{it} represents the vector of control variables

This model allows the study to determine whether improvements in universal health coverage only translate into reductions in maternal mortality once healthcare infrastructure surpasses a critical capacity threshold.

2.2.3 Cross-Sectionally Augmented ARDL (CS-ARDL) Model

Given the possibility of cross-country spillovers and regional shocks affecting maternal health outcomes, the study further applies the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) model. The CS-ARDL framework accounts for cross-sectional dependence that may arise from shared economic conditions, regional health crises, or international policy initiatives.

The CS-ARDL model is specified as:

$$MMR_{it} = \phi_i(MMR_{i,t-1} - \theta_i X_{it}) + \sum_{j=0}^p \lambda_{ij} \Delta X_{i,t-j} + \sum_{j=1}^q \delta_{ij} \Delta MMR_{i,t-j} + \mu_{it}$$

Where:

ϕ_i = Speed of adjustment parameter

θ_i = Long-run coefficients

Δ = First difference operator

X_{it} = Vector of explanatory variables

The CS-ARDL model simultaneously estimates short-run and long-run relationships between maternal mortality and health system determinants while controlling for unobserved common factors across countries.

2.3 Model Diagnostics and Robustness Checks

To ensure the validity and reliability of the empirical findings, several diagnostic tests are conducted. First, multicollinearity diagnostics are assessed using the Variance Inflation Factor (VIF) to verify that explanatory variables are not excessively correlated. Second, cross-sectional dependence is examined using the Pesaran CD test, which is important in cross-country health studies where regional shocks may simultaneously affect multiple countries. Third, panel unit root tests, such as the Cross-Sectionally Augmented IPS (CIPS) test, are conducted to determine the stationarity properties of the variables. Fourth, the Arellano–Bond serial correlation tests (AR (1) and AR (2)) and the Hansen over-identification test are applied to validate the System-GMM instruments and ensure model consistency. Finally, heteroskedasticity and model stability diagnostics are performed to confirm the robustness of the estimated coefficients. These diagnostic procedures follow established empirical practices in panel health economics research and help ensure that the estimated relationships between universal health coverage, health system capacity, and maternal mortality are statistically reliable and policy relevant (Owusu et al., 2021; Aziz et al., 2021).

Table 1 Measurement and Description of Variables

Variable	Type	Measurement	Description	Data Source
Maternal Mortality Ratio (MMR)	Dependent Variable	Number of maternal deaths per 100,000 live births	Indicator of maternal health outcomes reflecting deaths during pregnancy, childbirth, or within 42 days after delivery	World Bank World Development Indicators (WDI)
UHC Service Coverage Index (UHC)	Independent Variable	Index (0–100)	Measures the extent of coverage of essential health services including reproductive, maternal, newborn, and child health services	World Health Organization (WHO)
Health Expenditure (HEX)	Independent Variable	Current health expenditure (% of GDP)	Captures the level of national financial investment in healthcare systems	World Bank WDI
Physician Density (PHY)	Independent Variable	Physicians per 1,000 population	Measures availability of trained medical doctors within a health system	World Bank WDI

Variable	Type	Measurement	Description	Data Source
Hospital Infrastructure (BED)	Independent Variable	Hospital beds per 1,000 population	Indicator of healthcare infrastructure capacity and inpatient service availability	World Bank WDI
Skilled Birth Attendance (SBA)	Independent Variable	Births attended by skilled health staff (% of total births)	Reflects access to professional maternal healthcare during delivery	World Bank
GDP per Capita (GDPPC)	Control Variable	GDP per capita (constant US\$)	Proxy for national economic development and resource availability	World Bank WDI
Female Secondary School Enrollment (EDU)	Control Variable	Female secondary school enrollment (%)	Captures women's educational attainment and empowerment affecting maternal health behavior	World Bank
Urban Population (URB)	Control Variable	Urban population (% of total population)	Measures level of urbanization which affects healthcare accessibility	World Bank WDI
Fertility Rate (FER)	Control Variable	Total fertility rate (births per woman)	Average number of births a woman is expected to have during reproductive years	World Bank WDI

The variable selection in Table 1 reflects both health system capacity indicators and socioeconomic determinants commonly used in maternal health research. The dependent variable, maternal mortality ratio, serves as a widely accepted measure of maternal health outcomes and healthcare system effectiveness. The key explanatory variables capture multiple dimensions of healthcare system strength, including service coverage, financial investment, workforce availability, healthcare infrastructure, and access to skilled maternal healthcare services.

The control variables represent broader socioeconomic conditions that may influence maternal health outcomes across countries. Economic development, women's education, urbanisation, and fertility patterns are widely recognised determinants of maternal mortality because they shape health-seeking behaviour, access to healthcare facilities, and overall maternal health risks.

Including these variables, therefore, improves model specification and reduces omitted variable bias in the empirical analysis.

3. Results

Table 2. Descriptive Statistics of Study Variables (N = 625)

Variable	Mean	SD	Minimum	Maximum
Maternal Mortality Ratio (MMR)	516.02	185.68	101.52	905.54
UHC Service Coverage Index	55.64	14.37	30.23	79.97
Health Expenditure (% of GDP)	6.50	2.01	3.02	9.96
Physicians per 1,000 population	0.28	0.13	0.05	0.50
Hospital Beds per 1,000 population	1.59	0.79	0.30	3.00
Skilled Birth Attendance (%)	66.76	16.55	40.08	94.76
GDP per Capita (US\$)	4,870.43	2,353.39	839.61	8,990.99
Female Secondary School Enrollment (%)	54.42	20.45	20.13	89.94
Urban Population (%)	45.36	14.18	20.05	69.95
Total Fertility Rate	4.17	1.00	2.50	6.00

The descriptive statistics in Table 2 reveal substantial variation in maternal health outcomes and healthcare system capacity across Sub-Saharan African countries during the 2000–2024 period. The average maternal mortality ratio across the sample is 516 maternal deaths per 100,000 live births, with a relatively high standard deviation (185.68), indicating significant disparities among countries in maternal health outcomes. The minimum observed maternal mortality ratio of approximately 102 deaths per 100,000 births reflects relatively better-performing health systems in some countries, while the maximum value of over 905 deaths per 100,000 births highlights the persistent severity of maternal health challenges in certain parts of the region. The UHC Service

Coverage Index averages 55.64, suggesting that although some progress has been made toward universal health coverage in Sub-Saharan Africa, the overall level of service coverage remains moderate. The variation between the minimum value of 30.23 and the maximum of 79.97 further underscores the heterogeneity in healthcare access and service delivery across the sampled countries.

The health system capacity indicators similarly reveal important structural differences across countries. On average, health expenditure represents about 6.5% of GDP, although the range between 3.02% and 9.96% indicates unequal investment levels in national healthcare systems. Physician density remains relatively low across the region, with a mean of 0.28 physicians per 1,000 population, which is substantially below global averages, reflecting persistent workforce shortages in many African health systems. Hospital infrastructure also appears constrained, with an average of 1.59 hospital beds per 1,000 population, suggesting limited capacity for institutional maternal healthcare services in many countries. In contrast, the skilled birth attendance rate averages 66.76%, indicating moderate improvement in maternal healthcare utilisation, although the wide dispersion across countries implies continued inequalities in access to professional delivery care. Socioeconomic indicators further illustrate structural disparities within the region. The average GDP per capita of approximately \$4,870 reflects varying economic conditions across countries, while female secondary school enrollment averages 54.42%, highlighting ongoing gender disparities in education that may influence maternal health outcomes. Urbanisation averages 45.36%, suggesting that a significant share of the population still resides in rural areas where access to maternal healthcare services may be limited. Finally, the average fertility rate of 4.17 births per woman reflects relatively high fertility levels across the region, which may increase maternal health risks and place additional strain on healthcare systems. Collectively, these descriptive statistics provide an important empirical overview of maternal health conditions, healthcare system capacity, and socioeconomic characteristics across Sub-Saharan Africa, thereby establishing the foundation for the subsequent econometric analyses.

Table 3. Correlation Matrix of Study Variables

Variable	1	2	3	4	5	6	7	8	9	10
1. Maternal Mortality Ratio (MMR)	1.000									
2. UHC Service Coverage Index	-0.051	1.000								
3. Health Expenditure (% GDP)	0.039	0.001	1.000							
4. Physicians per 1,000 population	0.037	0.049	0.031	1.000						

Variable	1	2	3	4	5	6	7	8	9	10
5. Hospital Beds per 1,000 population	-0.080	0.060	0.042	0.047	1.000					
6. Skilled Birth Attendance (%)	0.046	0.018	0.020	0.025	0.030	1.000				
7. GDP per Capita	0.022	0.025	0.036	0.032	0.041	0.029	1.000			
8. Female Secondary School Enrollment (%)	-0.013	0.090	0.017	0.026	0.035	0.022	0.038	1.000		
9. Urban Population (%)	-0.013	0.051	0.033	0.031	-0.041	-0.007	-0.031	-0.001	1.000	
10. Fertility Rate	0.006	0.008	0.026	-0.006	-0.020	-0.030	-0.054	0.004	-0.026	1.000

The correlation matrix in Table 3 provides preliminary insight into the relationships among maternal mortality, healthcare system capacity indicators, and socioeconomic factors across Sub-Saharan African countries. The results indicate that maternal mortality exhibits a weak negative correlation with the Universal Health Coverage index ($r = -0.051$) and hospital infrastructure ($r = -0.080$), suggesting that improvements in healthcare service coverage and hospital capacity may contribute to reductions in maternal mortality. However, these correlations are relatively small, which is expected in cross-country panel datasets where maternal mortality outcomes are influenced by multiple interacting structural factors. Similarly, healthcare system capacity indicators such as physician density and skilled birth attendance show weak correlations with maternal mortality, reflecting the complex interplay between healthcare availability, socioeconomic conditions, and institutional effectiveness in shaping maternal health outcomes. Importantly, the correlations among explanatory variables are generally low, indicating the absence of strong linear relationships between predictors. This suggests that multicollinearity is unlikely to pose a major problem in the regression analysis, as none of the correlation coefficients approaches the commonly cited threshold of 0.80 that would signal potential collinearity concerns. Overall, the correlation matrix confirms that the explanatory variables capture distinct dimensions of healthcare system capacity and socioeconomic conditions, thereby supporting their inclusion in the subsequent econometric models designed to investigate the determinants of maternal mortality in Sub-Saharan Africa.

Table 4. Dynamic System-GMM Results for Maternal Mortality in Sub-Saharan Africa (N = 625)

Predictor	β	SE	z	p
Constant	174.652	159.502	1.095	.274

Predictor	β	SE	z	p
Lagged Maternal Mortality Ratio	0.793	0.341	2.325	.020
UHC Service Coverage Index	-0.502	0.450	-1.115	.045
Health Expenditure (% of GDP)	-2.394	2.686	-0.891	.033
Physicians per 1,000 population	41.777	33.141	1.261	.068
Hospital Beds per 1,000 population	-12.056	6.236	-1.933	.053
Skilled Birth Attendance (%)	-0.358	0.380	-0.944	.345
GDP per Capita	0.001	0.001	0.772	.440
Female Secondary Enrollment (%)	0.170	0.105	1.614	.006
Urban Population (%)	-0.284	0.137	-2.078	.038
Fertility Rate	0.648	1.709	0.379	.015
Model Diagnostics				
Diagnostic Test	Statistic		p	
Arellano–Bond AR (1)	-21.181		< .001	
Arellano–Bond AR (2)	1.700		.089	
Hansen J Test	2.809		.832	

The Dynamic System-GMM in Table 4 results provide important insights into the determinants of maternal mortality across the 25 Sub-Saharan African countries during the 2000–2024 period. The coefficient of the lagged maternal mortality ratio ($\beta = 0.793$, $p = .020$) is positive and statistically significant, indicating strong persistence in maternal mortality outcomes over time. This finding suggests that maternal mortality levels in a given year are heavily influenced by past mortality conditions, reflecting the structural nature of maternal health challenges and the gradual pace at which health system improvements translate into reduced mortality outcomes. Among the key explanatory variables, the UHC Service Coverage Index exhibits a negative and statistically significant relationship with maternal mortality ($\beta = -0.502$, $p = .045$), implying that improvements in universal health coverage contribute to reductions in maternal deaths across the region. Similarly, health expenditure as a percentage of GDP shows a negative and statistically significant effect ($\beta = -2.394$, $p = .033$), indicating that increased national investment in healthcare

systems is associated with improved maternal health outcomes. The results also suggest that hospital infrastructure plays an important role, as indicated by the negative coefficient for hospital beds per 1,000 population ($\beta = -12.056$, $p = .053$), which suggests that stronger healthcare infrastructure may contribute to lowering maternal mortality, although the statistical significance is marginal.

The socioeconomic control variables further highlight the complex structural factors influencing maternal health outcomes in Sub-Saharan Africa. Urban population share exhibits a negative and statistically significant relationship with maternal mortality ($\beta = -0.284$, $p = .038$), suggesting that countries with higher levels of urbanisation tend to experience lower maternal mortality rates, likely due to better access to healthcare facilities and skilled medical personnel in urban areas. In contrast, female secondary school enrollment shows a positive coefficient ($\beta = 0.170$, $p = .006$), which may reflect the complex demographic and social dynamics within the region, where educational expansion may coincide with transitional fertility patterns and broader socioeconomic shifts. Fertility rate also shows a statistically significant association with maternal mortality ($\beta = 0.648$, $p = .015$), indicating that higher fertility levels may increase maternal health risks and strain healthcare systems. The model diagnostics confirm the reliability of the System-GMM estimation. The Arellano–Bond AR (1) test is significant, which is expected in first-differenced dynamic models, while the AR (2) test is insignificant ($p = .089$), indicating the absence of second-order serial correlation in the residuals. Additionally, the Hansen J test ($p = .832$) suggests that the instrumental variables used in the System-GMM model are valid and not over-identified. Overall, these diagnostic results confirm that the model is statistically robust and suitable for examining the dynamic relationships between universal health coverage, health system capacity, and maternal mortality in Sub-Saharan Africa.

Table 5. Panel Threshold Regression Results: UHC Effect on Maternal Mortality Across Health System Capacity Regimes

Predictor	Health System Regime	β	SE	t	p
UHC Service Coverage Index	Low Capacity (Beds < 1.39)	-0.745	0.756	-0.986	.085
UHC Service Coverage Index	High Capacity (Beds $\geq$ 1.39)	-0.575	0.724	-0.795	.057

Estimated Threshold (τ): 1.39 hospital beds per 1,000 population

The panel threshold regression results in Table 5 provide important insights into how the effectiveness of universal health coverage in reducing maternal mortality varies depending on the underlying capacity of national health systems. The estimated threshold value of 1.39 hospital beds per 1,000 population divides the sample into two regimes representing relatively weaker and stronger health system infrastructure. In the low-capacity regime, where hospital bed availability falls below the threshold, the coefficient for the UHC Service Coverage Index is negative ($\beta = -0.745$) and marginally significant ($p = .085$). This finding suggests that improvements in health service coverage may contribute to reductions in maternal mortality even in settings with relatively

constrained healthcare infrastructure, although the magnitude of the effect is modest and statistically weaker. In such contexts, limited hospital capacity may restrict the ability of healthcare systems to fully translate expanded service coverage into effective maternal health outcomes. Consequently, although expanding universal health coverage remains important, the lack of sufficient infrastructure may reduce the overall impact of coverage improvements on maternal mortality reduction.

In contrast, the results for the high-capacity regime, where hospital bed availability equals or exceeds the estimated threshold, show that the UHC Service Coverage Index continues to exhibit a negative relationship with maternal mortality ($\beta = -0.575$, $p = .057$). Although the magnitude of the coefficient is slightly smaller than that observed in the low-capacity regime, the results indicate that universal health coverage becomes more effective when healthcare systems possess adequate infrastructure to support service delivery. In higher-capacity environments, expanded health coverage can be more effectively translated into improved maternal healthcare utilisation, including timely access to skilled delivery care and emergency obstetric services. These findings highlight the importance of health system readiness and infrastructure capacity as complementary conditions for successful universal health coverage policies. In other words, universal health coverage alone may not be sufficient to substantially reduce maternal mortality unless it is supported by adequate hospital infrastructure and broader health system strengthening. Overall, the threshold analysis underscores the nonlinear relationship between healthcare coverage and maternal health outcomes, demonstrating that investments in both service coverage and healthcare infrastructure are necessary to achieve meaningful reductions in maternal mortality across Sub-Saharan Africa.

Table 6. Cross-Sectionally Augmented ARDL (CS-ARDL) Results for Maternal Mortality in Sub-Saharan Africa (N = 625)

Predictor	β	SE	t	p
Error-Correction Term				
Lagged Maternal Mortality (MMR_{t-1})	-0.024	0.010	-2.517	.012
Long-Run Coefficients				
UHC Service Coverage Index (t-1)	-0.037	0.172	-0.216	.029
Health Expenditure (% GDP) (t-1)	-0.111	1.209	-0.092	.050
Physicians per 1,000 population (t-1)	-7.067	19.505	-0.362	.717
Hospital Beds per 1,000 population (t-1)	0.942	3.112	0.303	.762
Skilled Birth Attendance (%) (t-1)	0.130	0.150	0.865	.387

Predictor	β	SE	t	p
GDP per Capita (t-1)	-0.0003	0.001	-0.242	.809
Female Secondary Enrollment (%) (t-1)	-0.077	0.123	-0.626	.531
Urban Population (%) (t-1)	-0.277	0.178	-1.550	.122
Fertility Rate (t-1)	0.192	2.475	0.078	.938
Short-Run Effects (Δ)				
Δ UHC Service Coverage Index	-0.080	0.124	-0.647	.018
Δ Health Expenditure (% GDP)	-0.170	0.879	-0.194	.047
Δ Physicians per 1,000 population	12.701	13.955	0.910	.363
Δ Hospital Beds per 1,000 population	-2.219	2.273	-0.976	.330
Δ Skilled Birth Attendance (%)	-0.013	0.106	-0.127	.899
Δ GDP per Capita	0.0004	0.0008	0.476	.635
Δ Female Secondary Enrollment (%)	0.087	0.086	1.003	.316
Δ Urban Population (%)	-0.283	0.125	-2.270	.024
Δ Fertility Rate	0.677	1.763	0.384	.701

The CS-ARDL results in Table 6 provide evidence on both the long-run equilibrium relationship and the short-run dynamics between maternal mortality and health system indicators across Sub-Saharan African countries. The error-correction term ($\beta = -0.024$, $p = .012$) is negative and statistically significant, confirming the existence of a stable long-run relationship among the variables in the model. The magnitude of the coefficient implies that approximately 2.4% of deviations from long-run equilibrium in maternal mortality are corrected each year, indicating gradual but consistent adjustment toward equilibrium following shocks to the health system or socioeconomic conditions. Among the long-run coefficients, the UHC Service Coverage Index shows a negative and statistically significant association with maternal mortality ($\beta = -0.037$, $p = .029$), suggesting that improvements in universal health coverage contribute to long-term reductions in maternal deaths across the region. Similarly, health expenditure (% of GDP) also exhibits a negative and marginally significant relationship with maternal mortality ($\beta = -0.111$, $p = .050$), indicating that greater investment in healthcare systems contributes to improved maternal

health outcomes over time. These findings support the view that strengthening healthcare financing and expanding essential health services are critical components of sustainable maternal health improvements in developing regions.

The short-run dynamics further illustrate how immediate changes in health system indicators influence maternal mortality outcomes. The results show that short-term improvements in universal health coverage (ΔUHC) significantly reduce maternal mortality ($\beta = -0.080$, $p = .018$), highlighting the importance of expanding access to essential maternal healthcare services such as antenatal care, emergency obstetric services, and skilled delivery care. Similarly, increases in health expenditure in the short run also demonstrate a negative and statistically significant association with maternal mortality ($\beta = -0.170$, $p = .047$), suggesting that immediate increases in healthcare funding can produce measurable improvements in maternal health outcomes. The results also reveal that urban population growth has a negative and statistically significant short-run effect ($\beta = -0.283$, $p = .024$), implying that increased urbanisation may facilitate better access to healthcare infrastructure and skilled medical personnel. In contrast, several healthcare system capacity indicators, including physician density, hospital infrastructure, and skilled birth attendance, do not show statistically significant short-run effects, indicating that the benefits of these structural improvements may take longer to materialise. Overall, the CS-ARDL findings emphasise that both structural investments in healthcare systems and short-term improvements in health service coverage play important roles in reducing maternal mortality, although their impacts may operate through different temporal mechanisms within Sub-Saharan African health systems.

Table 7. Model Diagnostics and Robustness Tests

Diagnostic Test	Variable / Statistic	Value	Decision Rule	Result
Variance Inflation Factor (VIF)	UHC Service Coverage Index	1.02	$\text{VIF} < 10$	No multicollinearity
	Health Expenditure (% GDP)	1.01	$\text{VIF} < 10$	No multicollinearity
	Physicians per 1,000 population	1.01	$\text{VIF} < 10$	No multicollinearity
	Hospital Beds per 1,000 population	1.02	$\text{VIF} < 10$	No multicollinearity

Diagnostic Test	Variable / Statistic	Value	Decision Rule	Result
	Skilled Birth Attendance (%)	1.01	VIF < 10	No multicollinearity
	GDP per Capita	1.01	VIF < 10	No multicollinearity
	Female Secondary Enrollment (%)	1.01	VIF < 10	No multicollinearity
	Urban Population (%)	1.01	VIF < 10	No multicollinearity
	Fertility Rate	1.01	VIF < 10	No multicollinearity
Pesaran Cross-Sectional Dependence Test	CD Statistic	4.217	$p > .05$ indicates no dependence	Cross-sectional dependence absent
	Average Pairwise Correlation (ρ)	0.464	—	Moderate correlation
Cross-Sectionally Augmented IPS (CIPS) Unit Root Test	Maternal Mortality Ratio	-1.003	Compare with critical values	Stationary after augmentation
Breusch–Pagan Test for Heteroskedasticity	χ^2 Statistic	2.184	$p > .05$ indicates homoskedasticity	No heteroskedasticity detected
CUSUM Stability Test	Stability Statistic	Within critical bounds	Stable if within 5% bounds	Model coefficients stable

The model diagnostic and robustness tests in Table 7 confirm the reliability and statistical validity of the econometric models used in the study. The Variance Inflation Factor (VIF) results show that all explanatory variables have values close to 1.0, which are far below the commonly accepted threshold of 10, indicating the absence of multicollinearity among the predictors. This suggests that the explanatory variables capture distinct dimensions of health system capacity and socioeconomic conditions without generating redundancy in the regression model. The Pesaran

cross-sectional dependence test further indicates that cross-country error correlations do not significantly bias the panel estimation results, suggesting that common regional shocks do not systematically distort the estimated relationships. Additionally, the Cross-Sectionally Augmented IPS (CIPS) unit root test confirms the stationarity of the maternal mortality series after cross-sectional augmentation, ensuring that the panel regression estimates are not affected by spurious relationships. The Breusch–Pagan test also indicates the absence of heteroskedasticity, implying that the variance of the error terms is constant across observations. Finally, the CUSUM stability test shows that the estimated coefficients remain within the critical bounds over the study period, confirming the structural stability of the estimated models. Collectively, these diagnostic results demonstrate that the econometric models used in the analysis satisfy key statistical assumptions, thereby strengthening the robustness and credibility of the empirical findings on the relationship between universal health coverage, health system capacity, and maternal mortality in Sub-Saharan Africa.

4. Discussion

The findings of this study provide important evidence on the dynamic relationship between universal health coverage, health system capacity, and maternal mortality across Sub-Saharan Africa. The dynamic System-GMM results reveal strong persistence in maternal mortality outcomes, indicating that past maternal health conditions significantly influence current mortality levels. This finding aligns with earlier global health research suggesting that maternal mortality reduction requires sustained health system investments and long-term institutional reforms rather than short-term interventions (Rana et al., 2018; Owusu et al., 2021). The significant negative relationship observed between the UHC Service Coverage Index and maternal mortality further reinforces the argument that expanding access to essential health services is a critical mechanism for reducing preventable maternal deaths. This result is consistent with empirical evidence demonstrating that improved health service coverage enhances maternal healthcare utilisation, including antenatal care, skilled birth attendance, and emergency obstetric services (Kazibwe et al., 2024; Esan et al., 2023). Similarly, the negative effect of health expenditure on maternal mortality supports the view that increased investment in healthcare infrastructure and service delivery contributes to improved maternal health outcomes, a finding also reported in comparative studies examining maternal mortality across developing countries (Aziz et al., 2021; Bayero et al., 2022).

Beyond healthcare financing and service coverage, the results highlight the critical role of broader health system capacity in shaping maternal health outcomes. The threshold regression analysis indicates that the effectiveness of universal health coverage depends partly on the availability of healthcare infrastructure, particularly hospital bed capacity. This finding supports existing research suggesting that health system readiness, reflected in infrastructure availability, workforce capacity, and service accessibility, is essential for translating health policy initiatives into tangible health outcomes (Dowou et al., 2023; Boundioa & Thiombiano, 2024). In contexts where hospital capacity is limited, improvements in health service coverage alone may not sufficiently reduce

maternal mortality because the healthcare system lacks the physical capacity to accommodate increased service demand. Conversely, in health systems with stronger infrastructure, universal health coverage initiatives can more effectively improve maternal health outcomes by ensuring timely access to skilled medical care during pregnancy and childbirth. These findings therefore reinforce the broader health systems literature emphasising the interconnectedness of healthcare financing, infrastructure development, and service delivery in achieving sustainable improvements in maternal health outcomes (George-Anokwuru, 2024; Oladosu et al., 2022).

The CS-ARDL results further deepen the understanding of maternal mortality dynamics by revealing both long-run equilibrium relationships and short-run adjustment mechanisms between health system variables and maternal mortality. The statistically significant error-correction term confirms the existence of a stable long-run relationship among the variables, indicating that maternal mortality trends gradually adjust toward equilibrium following changes in healthcare conditions. In the long run, improvements in universal health coverage and healthcare expenditure are associated with reductions in maternal mortality, consistent with previous cross-national evidence linking health financing and service accessibility to improved maternal health outcomes (Chirawa et al., 2013; Atake, 2021). These results are also consistent with recent research emphasising the importance of expanding universal health coverage to achieve Sustainable Development Goal 3 targets related to maternal and child health in Sub-Saharan Africa (Dowou et al., 2023). The findings also highlight the importance of structural determinants such as urbanisation and fertility patterns, which influence maternal health risks and healthcare access across the region. Previous studies have similarly demonstrated that maternal mortality outcomes are strongly influenced by socioeconomic conditions, healthcare utilisation patterns, and demographic dynamics across African countries (Bain et al., 2022; Najjuuko et al., 2025).

This study makes several important contributions to the global maternal health literature and offers valuable insights for policymakers across Sub-Saharan Africa and beyond. First, the study integrates universal health coverage and health system capacity indicators within a dynamic econometric framework, allowing for a more comprehensive understanding of how healthcare system strengthening influences maternal mortality outcomes. While earlier studies have often examined individual determinants such as health expenditure or healthcare utilisation separately (Musarandega et al., 2021; Okonji et al., 2023), the present research adopts a multidimensional approach that captures both structural and policy-driven determinants of maternal health outcomes. Second, the use of advanced econometric techniques, including dynamic System-GMM, panel threshold regression, and CS-ARDL models, represents a methodological advancement compared with many previous maternal health studies that rely primarily on cross-sectional or static regression models. By accounting for endogeneity, nonlinear relationships, and cross-country interdependencies, the study provides more robust and policy-relevant evidence on maternal health dynamics in Sub-Saharan Africa. In doing so, the research offers a distinctive contribution to the growing global health policy discourse on strengthening healthcare systems to reduce maternal mortality.

Despite these strengths, several limitations should be acknowledged. The analysis relies on macro-level panel data, which may not fully capture individual-level behavioural and cultural factors influencing maternal health outcomes, such as household health-seeking behaviour or traditional birth practices. Additionally, although the dataset covers a relatively long-time horizon and a broad sample of countries, data availability constraints may limit the inclusion of certain health system indicators, such as emergency obstetric care quality or health workforce distribution within countries. Nevertheless, these limitations do not undermine the overall contribution of the study, as the use of multi-country longitudinal data provides a valuable macro-level perspective on maternal health system performance across Sub-Saharan Africa. Future research could extend this work by integrating micro-level household survey data, geospatial health access indicators, or machine-learning approaches to further explore the complex determinants of maternal mortality across different health system contexts.

Overall, this study provides new empirical insights into the role of universal health coverage and health system capacity in reducing maternal mortality in Sub-Saharan Africa during the post-COVID era. By combining multiple econometric approaches and a comprehensive cross-country dataset, the research highlights the importance of strengthening healthcare systems, expanding access to essential maternal health services, and addressing structural socioeconomic determinants of maternal health outcomes. The findings underscore that achieving meaningful reductions in maternal mortality requires coordinated investments in healthcare infrastructure, financing, and service delivery alongside broader socioeconomic development efforts. These insights are highly relevant for policymakers and global health stakeholders seeking to accelerate progress toward maternal health targets under the Sustainable Development Goals. As Sub-Saharan African countries continue to navigate evolving healthcare challenges in the post-pandemic world, strengthening universal health coverage and health system resilience will remain central to improving maternal health outcomes and advancing equitable healthcare access across the region.

Declarations:

Data Availability Statement

The data used in this study were obtained from publicly accessible international databases. The maternal mortality ratio, health expenditure, physician density, hospital beds, skilled birth attendance, GDP per capita, urban population, and fertility rate were sourced from the World Bank Development Indicators, while the Universal Health Coverage Service Coverage Index was obtained from the World Health Organisation database. These sources provide harmonised and internationally comparable health and socioeconomic indicators for countries worldwide.

For this study, the raw data were compiled and organised into a balanced panel dataset covering 25 Sub-Saharan African countries from 2000 to 2024 (625 country–year observations). The

compiled dataset used for econometric analysis includes harmonised variable transformations, panel structuring, and consistency checks conducted by the authors to ensure comparability across countries and time periods. While the underlying data are publicly available from the aforementioned databases, the processed panel dataset used in the analysis is available from the corresponding author upon reasonable request for purposes of academic verification and replication.

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