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Exploring Health Development Aid and Anthropogenic Stress as Drivers of Under-Five Malaria Mortality in Nigeria with Domestic Public Health Spending as a Moderator: A Bootstrap ARDL Analysis

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ABSTRACT

Background: Malaria remains a going health concern, particularly in Nigeria, where under-5 mortality related to the disease continues to undermine human capital development. Despite sustained inflows of development assistance for health, progress in reducing malaria-related child mortality has not been proportional. This study is important because it evaluates whether development assistance, domestic government health expenditure, and anthropogenic environmental stress jointly shape under-5 malaria mortality outcomes in Nigeria.

Aims: This study investigates the short-run and long-run effects of development assistance for health and anthropogenic environmental stress on under-5 malaria mortality in Nigeria. It further determines the moderating role of domestic government health expenditure, while controlling for income and urbanization.

Methods: The study uses quarterly time-series secondary data for Nigeria from 2000 to 2022, obtained from reputable sources. The Bootstrap Autoregressive Distributed Lag approach is employed to test for the existence of a long-run cointegrating relationship and to distinguish short-run and long-run dynamics among under-5 malaria deaths development assistance for health, anthropogenic stress and domestic government health expenditure. In addition, the study employs the Toda-Yamamoto causality procedure is to correctly isolate the direction of causality among the variables.

Results: The cointegration among the variables is confirmed using the Bootstrap ARDL results. Development assistance for health is found to be associated with higher under-5 malaria mortality in the long-run estimates both in the short- and long-run, and its interaction with domestic government health expenditure further strengthens this effect. Domestic government health spending independently decreases malaria deaths. However, Anthropogenic stress also increases malaria mortality risk over time, same as urbanization. The Toda-Yamamoto causality results indicate unidirectional causality running from under-5 malaria mortality to development assistance for health, suggesting that increased aid inflows is a response to increased under-5 malaria deaths rather than the cause.

Conclusion: The findings show that while domestic government health expenditure contributes to reducing under-5 malaria mortality in Nigeria, development assistance for health is associated with higher mortality and appears to reinforce adverse outcomes when interacting with domestic spending. Improved coordination between foreign health aid and domestic health spending, alongside more targeted and efficiency-oriented interventions, is necessary to reduce under-5 malaria mortality in Nigeria.

Keywords: *Malaria deaths; Development assistance for health; Government health expenditure; Urbanization.*

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1. Introduction

Low- and middle-income countries continue to confront preventable child deaths, yet the challenge is particularly acute in Nigeria. Malaria remains one of the leading causes of mortality among children under five, the age group with the weakest immunity and the highest vulnerability to severe infection. Nigeria alone accounts for about 25 percent of global malaria cases and a substantial share of malaria-related deaths (Institute for Health Metrics and Evaluation, 2018). More critically, a large proportion of these deaths occur among children under five, contributing to over 100,000 preventable child deaths annually from malaria and other infectious diseases (United Nations Children's Fund, 2021). The central concern of this study is therefore not general malaria prevalence, but the persistence of under-5 malaria mortality in Nigeria despite sustained intervention efforts.

This focus is justified because reductions in malaria incidence do not automatically translate into proportional declines in mortality among children. Mortality reflects failures in timely diagnosis, access to effective treatment, household living conditions, and health system responsiveness. Despite being the highest global recipient of development assistance for health since 2015, receiving 2.193 billion dollars in 2015, 1.25 billion dollars in 2016, and 787 million dollars in 2017 (Institute for Health Metrics and Evaluation, 2018), Nigeria continues to record the largest share of malaria-related deaths globally, accounting for between 19 and 24 percent of global malaria deaths in 2017 and 2018 (Institute for Health Metrics and Evaluation, 2018). Life expectancy remains low at 54.8 years in 2020 according to the United Nations World Population Prospects, reflecting persistent survival challenges. The coexistence of high aid inflows and sustained under-5 malaria mortality signals a policy and efficiency puzzle that extends beyond aggregate malaria burden.

Moreover, environmental conditions may intensify mortality risks among children. Anthropogenic stress, measured as ecological deficit where ecological footprint exceeds biocapacity, can alter ecosystems in ways that favor mosquito breeding and disease transmission. The World Health Organization (2018) reports that approximately seven million deaths annually are linked to environmental pollution, stressing the scale of the interactions between environment and health. In a malaria-endemic country such as Nigeria, environmental degradation may amplify exposure risks for children under five whose physiological resilience is limited.

The problem addressed in this study is therefore specific and tightly framed: why does under-5 malaria mortality remain high in Nigeria despite substantial development assistance for health and domestic public health expenditure? By focusing explicitly on mortality among children under five rather than on aggregate malaria burden, the study isolates the most vulnerable population group and the most critical health outcome.

This study improves the literature on this broad subject in three distinctive paths. (i) Unlike extant studies, it offers an examination of the relationship between development assistance for health and under-5 malaria mortality. The relationship between development finance and under-5 malaria mortality as a health outcome measure has not been empirically tested by extant studies on Nigeria. Two reasons account for this significance. Firstly, Nigeria is one of the highest recipients of development assistance for health of which malaria intervention is prioritized. Secondly, malaria is still a critical going health concern and Nigeria is curiously, a country with the highest malaria burden. (ii) Global Environmental Changes (GECs) arising from anthropogenic effects have been identified to be reinforcing conditions that favour malaria transmission.

In spite of this awareness, our study is the first to model the influence of anthropogenic stress holistically in the malaria mortality function in Nigeria. Of particular additional significance to literature is the use in this study of the difference between ecological footprint and biocapacity as a proxy for anthropogenic stress. In this sense, a positive value for anthropogenic stress indicates ecological deficit, suggesting that resource consumption exceeds local ecological capacity. A negative value on the other hand, relates to ecological surplus, indicating that resource consumption is within the limits of its biocapacity. This approach offers a distinct merit by providing a more comprehensive insight to environmental sustainability. The measure considers both the demand and supply sides of the environmental equation. This is also significant because it actively resonates with Goal 3 of the United Nation's Sustainable Development Goals which highlights the promotion of a holistic approach to health, recognizing the importance of a clean and sustainable environment. (iii) On the methodological front, no previous study has employed the bootstrap ARDL recently developed by McNown et al (2018) to examine the equilibrium long-run relationship between development assistance for health and any measure of health outcomes in Nigeria.

Bootstrap ARDL is particularly advantageous when dealing with small sample sizes. It helps overcome the limitations associated with conventional estimation methods, ensuring more reliable estimates.

2. Methods

Study Design and Research Procedures

This study adopts a quantitative time-series research design to examine the dynamic relationship between development assistance for health, anthropogenic environmental stress, domestic government health expenditure, income, urbanization, and under-5 malaria mortality in Nigeria. The analysis is based exclusively on secondary macroeconomic data and does not involve human participants, key informants, or primary survey instruments. The original secondary macroeconomic data is reported in the respective sources annually. However, they are interpolated into quarterly frequency to increase the number of observations and enhance the efficiency of time-series estimation. The final sample covers the period 2000Q1 to 2022Q4.

The empirical procedure follows a structured sequence. Preliminary tests are conducted to determine the time-series properties of the variables. The Bootstrap Autoregressive Distributed Lag approach is employed to test for the existence of a long-run relationship and to estimate the short-run and long-run dynamics. The Toda-Yamamoto causality procedure is subsequently applied to determine the direction of causality among the variables.

Data type, Measurements and Sources

This study uses quarterly frequency data to investigate the impact of development assistance for health and environmental quality on health outcomes in Nigeria using under-5 malaria mortality in Nigeria. Quarterly interpolation was performed to enhance the number of observations since the data on under-5 malaria mortality is only available from year 2000. Abberger et al (2023) suggests that this could improve degrees of freedom, since relying simply on annual data would generate a small sample that weakens ARDL cointegration and dynamic estimations. It also better approximates intra-annual fluctuations in health spending and seasonal malaria transmission patterns even if mortality totals are given annually by entities such as the World Health Organization. The interpolation approach preserves annual averages, maintaining agreement with official data while boosting the credibility of short-run and long-run estimations (Lepot et al, 2017). Data on the variables selected for the model are collected from public databases namely: malaria mortality (MAM), Development Assistance for Health (DAH), urbanization (URB), government health expenditure (GHE) and gross domestic product per capita (GDP). Data on DAH (External Assistance to Health per capita), GDP (Per Capita GDP in constant 2010 US$), GHE (Domestic General Government Health Expenditure per capita) and URB (urban population growth in %) were sourced from World Development Indicators. Anthropogenic Stress (EFP) was derived from data obtainable from the global footprint network while data on MAM measured as malaria deaths of children (from 0 to 59months) was obtained from WHO global burden of disease databank.

Definition of Anthropogenic stress

The study derived anthropogenic stress as a balance obtained by subtracting biocapacity from ecological footprint, both measured in global hectares per person. This is a vital variable developed to gauge the ecological impact of human activities on the environment. Symbolically, this variable is realized as:

$$EFP = ECO - BIO$$

Where;

EFP = Anthropogenic stress ; ECO = Ecological footprint ; BIO = Biocapacity

The interpretation of this variable is unambiguous. A negative EFP value indicates ecological surplus, signifying that human activities are within the planet's capacity to regenerate resources. Conversely, a positive EFP value signifies an ecological deficit, suggesting that human consumption surpasses the earth's ability to replenish resources sustainably. Sustainable ecological practices target to drive EFP towards zero or into the negative regime. Achieving a balanced or surplus EFP is indicative of a harmonious coexistence with the environment.

In its expanded form, anthropogenic stress can be further decomposed by representing ECO and BIO in terms of their component variables:

$$ECO = \sum_{i=1}^{n} C_i \times R_i$$

$$BIO = \sum_{j=1}^{m} P_j \times Y_j$$

Where:

C_i = Consumption of resource *i* (e.g., food, energy, water)

R_i = Resource use intensity for C_i (hectares per unit of resource)

P_j = Productivity of biocapacity source *j* (e.g., cropland, forest area)

Y_j = Yield factor for source *j* (hectares per unit productivity)

Thus,

$$EFP = \left(\sum_{i=1}^{n} C_i \times R_i \right) - \left(\sum_{j=1}^{m} P_j \times Y_j \right)$$

In this sense, anthropogenic stress increases (ecological deficit intensifies), following this definition. Hence, malarial deaths (MAM) can be modelled as a positive function of anthropogenic stress:

$$MAM = f(EFP) \text{ where } \frac{\partial MAM}{\partial EFP} > 0$$

This positive relationship on apriority suggests that health risks due to habitat disruptions and vector proliferation may be exacerbated by rising ecological strain. This aligns with the broader goal of minimizing humanity's ecological impact and promoting long-term environmental health which is consistent with SDG 15.

Development of the Analytical model

Following the Grossman health production function, Anyanwu and Erhijakpor (2013) specified a health outcome equation linking under-five and infant mortality rates with health expenditure per capita, ethno-linguistic fractionalization, female literacy, urban population, number of physicians and GDP per capita. This study adapts their model in line with the objectives as earlier stated. Here, the proxy for health outcome is malaria deaths. In specifying the structural model to be estimated, we begin from a baseline statement that realizes malaria deaths as a stochastic function of the regressors in the form:

$$MAM_t = \alpha_0 + \alpha_1 DAH_t + \alpha_2 EFP_t + \alpha_3 GHE_t + \alpha_4 GDP_t + \alpha_5 URB_t + \xi_t \quad (1)$$

Where DAH is Development Assistance for Health per capita, EFP stands for Anthropogenic Stress, the proxy for environmental quality, GHE represents Government Health Expenditure per capita and GDP is for Gross Domestic Product per capita while URB is the acronym for Urbanization. ξ is the Stochastic error term. Further, the study hypothesized that domestic government fiscal health provision could complement development assistance for health to deliver improved health outcomes. We test this hypothesis by including the interaction of development assistance for health with government health expenditure to the baseline model. The augmented equation becomes:

$$\ln MAM_t = \alpha_0 + \alpha_1 \ln DAH_t + \alpha_2 \ln GHE_t + \alpha_3 \ln GDP_t + \alpha_4 \ln EFP_t + \alpha_5 \ln URB_t + \alpha_6 \ln \Omega_t + \varepsilon_t \quad (2)$$

The log transformation in (2) reduces skewness and heteroskedasticity common in macro–health time series, thereby improving estimator efficiency and stabilizing variance (Feng et al, 2014). It also allows the coefficients to be interpreted as elasticities, providing meaningful percentage responses of under-5 malaria mortality to changes in health financing, environmental stress, and income. Potential endogeneity between development assistance for health and under-5 malaria mortality may occur from reverse causality, as higher mortality burdens can attract greater external health assistance. To alleviate this risk, the study relies on the dynamic specification of the ARDL framework, which features lag structures to reduce simultaneity bias, with Toda–Yamamoto causality testing to clarify the direction of influence. In econometrics literature, one of the greatest criticisms of modelling with interaction terms is the argument that it introduces the problem of multicollinearity. However, Allison (2012) argued that multicollinearity can be safely ignored if the high variance inflation factors are caused by the inclusion of powers or products of other variables already listed as regressors.

Beyond simply ignoring the case of multicollinearity, Ergün and Göksu (2013) submitted that multicollinearity in interactions is not something to be concerned about because the correlations can be greatly moderated by centering the variables before creating the powers or the products. This study therefore centered government health expenditure and development assistance for health by subtracting the means of these variables from the individual observed values over the sample period. The interaction term between DAH and domestic government health expenditure captures whether domestic spending amplifies or dampens the marginal effect of external assistance on under-5 malaria mortality. Economically, a positive interaction coefficient shows that increased domestic spending decreases the mortality-reducing effectiveness of DAH, whereas a negative value indicates complementarity, where domestic expenditure enhances assistance effectiveness.

It has been suggested in the literatures that development assistance for health contributes significantly to malaria intervention programmes in Nigeria. The inclusion of this variable in the model is consistent with the Grossman Health Production Function (1972) as well as the Social Ecological Model that both emphasize the import of non-biomedical determinants like investment in health in the health outcome equation. The relevance of anthropogenic stress in the model is underscored by empirical arguments linking the quality of the environment and health outcomes (see Nwude et al., 2020). Further, the nexus between health outcomes and urbanization has long been contemplated in the literatures and empirically tested in a number of studies. For instance, Bendavid (2014) controlled for urbanization in a study linking foreign aid and under-5 mortality in low- and middle-income countries. This therefore justifies the inclusion of urbanization in the model. Government health expenditure is also suggested to be included by literature while income per capita accounts for the role of income in the model as suggested by the Grossman Production Function. Apart from anthropogenic stress that is expected to be positively related to malaria deaths, all the other regressors (DAH, GHE, GDP and URB) are negatively signed on apriority.

Statistical Techniques

Unit Root Test

According to Asteriou and Hall (2007), most macroeconomic time series are trended and nonstationary, hence estimations using such data may be inaccurate. Stationarity tests are consequently, stressed in time series econometrics to avoid misleading analysis. Unit root tests like the Augmented Dickey-Fuller (ADF), Phillips–Perron (PP) (1989), and Kwiatkowski, Phillips, Schmidt, & Shin (KPSS) are found in the econometrics literature, although most do not account for structural breakdowns. When data are trend stationary with structural breaks, which is prevalent in most macroeconomic series, these tests favor a false unit root null. This study uses the Lee and Strazicich (2003) test to reinforce our analysis against these flaws.

Bootstrap ARDL for Cointegration and Estimation of Coefficients

Cointegration testing helps identify long-run equilibrium relationships in time series analysis of most macroeconomic data. McNown, Sam, and Goh (2018)'s bootstrap autoregressive distributed lag (ARDL) test is used to assess model variables for cointegration. Here the ARDL procdure by Pesaran, Shin, and Smith (2001) is resampled via bootstrap. The ARDL specification of our model in our study is:

$$\Delta \ln MAM = \alpha_0 + \alpha_1 \ln MAM_{t-1} + \alpha_2 \ln DAH_{t-1} + \alpha_3 \ln GHE_{t-1} \alpha_4 \ln GDP_{t-1} + \alpha_5 \ln EFP_{t-1} + \alpha_6 \ln URB + \alpha_7 \ln \Omega + \sum_{i=0}^{p} \varphi_1 \Delta \ln MAM_{t-1} + \sum_{i=0}^{p} \varphi_2 \Delta \ln DAH_{t-1} + \sum_{i=0}^{p} \varphi_3 \Delta \ln GHE_{t-1} + \sum_{i=0}^{p} \varphi_4 \Delta \ln GDP_{t-1} + \sum_{i=0}^{p} \varphi_5 \Delta \ln EFP_{t-1} + \sum_{i=0}^{p} \varphi_6 \Delta \ln URP_{t-1} + \sum_{i=0}^{p} \varphi_7 \Delta \ln \Omega_{t-1} + \lambda ECM_{t-1} + \varepsilon_t \quad (4)$$

The null hypotheses relating to the three tests for cointegration proposed by McNown, Sam and Goh (2018) as aforementioned are as follows:

1. $F_{(overall)}$: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = 0$
2. $T_{(dep)}$: $\alpha_1 = 0$
3. $F_{(indep)}$: $\alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = 0$

For conclusion to be reached that cointegration exists, the null hypotheses for all the three tests must be rejected.

Toda -Yamamoto Dolado and Lukehtpol Model for Non-causality

Investigating the nature and direction of causality is necessary given the inherent policy implication that can be gleaned from such analysis. This study adopted the Toda-Yamamoto (1995), Dolado and Lukehtpol (1996) technique for non-causality because of its high predictive power among variables. The Toda-Yamamoto, Dolado and Lukehtpol causality test (TYDL hereafter) is a modified fashion of the Wald test (MWALD) and has been proven to have enviable advantages over the traditional Granger causality test. Firstly, contemporary studies, for instance Ziramba (2008); Chiawa, Torruam and Abur (2012) and Rauf, Qayum and Zaman (2012) have found the TYDL to be superior to the Ordinary Granger Causality as it does not require the pre-testing of variables for cointegration. This implies that researchers do not have to test for cointegration of the variables. Therefore, the TY-DL helps in circumventing the problem of asymptotic critical values when causality tests are done in the presence of non-stationarity or no cointegration. It is therefore known to have greater resilience. Beyond its resilience, it is suitable for the standard VAR whereby the variables can be estimated in their levels rather than the first difference as in the case with the conventional Granger Causality and therefore researchers do not need to transform VAR into Vector Error Correction Mechanism (VECM). The technique is structured in a Vector Autoregressive framework VAR with (K+ d_{max}) where, K is the optimal order of integration in the VAR and d_{max} is the maximum order of integration relating to all the series in a model.

Ethical clearance

No human or animal participants were involved in this study. Ethical Approval to collect data was, however, given by the Research and Ethics Committee at University of South Africa (Ref #: 10888).

3. Results

Descriptive Statistics

The empirical analysis proceeds with a summary of the statistical properties of the data as presented in Table 1. The descriptive analysis of a series is a necessary pre-estimation procedure because it helps in determining the nature of data transformation methods to be employed in efforts to achieve the goal of obtaining robust estimates. The statistics subsumed here are measures of central tendency and dispersion, minimum and maximum analysis for determination of extreme values or outliers, skewness for determination of tilt, kurtosis to determine the shape of the distribution of the series and Jarque-Bera statistics for inference about the normality of the dataset. Based on the range and standard deviations of the distributions, urbanization, malaria mortality and anthropogenic stress are the least volatile of the series. In Table 5, urbanization shows a standard deviation of 0.062, followed by malaria mortality with 0.089, suggesting that these two have changed at a predictable pace over the review period. Anthropogenic stress and GDP reported 0.107 and 0.192, respectively. With a higher standard deviation of 1.12, government healthcare expenditure demonstrated relatively high variance from the mean. An inspection of the series as revealed by kurtosis shows that malaria mortality (MAM), development assistance for health (DAH), domestic government health expenditure (GHE) and gross domestic product (GDP) were platykurtic which infers that these distributions had kurtosis values less than 3.

The results in Table 1 show that MAM, DAH, GHE and GDP had 2.092, 2.546, 2.346 and 2.291 respectively suggesting that negative outliers are highly frequent. On the other hand, Urbanization (URB) had 6.134 and the value for interaction term (Ω) was 5.576 which means these distributions were leptokurtic. The implication is that positive outliers are highly frequent, yielding positive excess kurtosis. Anthropogenic stress with 3.260, was however, bell-shaped and mesokurtic connoting the absence of outliers. This is because the kurtosis value for this distribution is not significantly different from 3.

Table 1. Descriptive Statistics of the Series

Variable	Mean	Median	Std. Dev.	Skew.	Kurt.	J-B
MAM	10.917	8.527	0.089	0.166	2.092	2.955
DAH	0.133	0.168	0.667	-0.344	2.546	2.154
EFP	17.626	4.120	0.107	-1.193	3.260	18.240***
GHE	4.496	17.65	1.120	0.759	2.346	8.648***
GDP	6.238	6.295	0.192	-0.699	2.291	7.796**
URB	1.157	1.184	0.062	-1.543	6.134	61.240***
Ω	0.2142	0.047	0.3580	1.7458	5.5760	59.621***

Note: The sample period is from 2000Q1 to 2018Q4. **(***) denote 5%(1%) level of significance.

Correlation Matrix

The study investigated the nature of correlation among the series as presented in Table 2. Throughout the matrix of association, the variables have mixed nature of correlation. Example, malaria mortality (defined in this study to mean malaria deaths in children from age 0-59 months) (MAM) is positively correlated with Domestic government health expenditure (DHE) and urbanization. However, negative correlation was indicated between development assistance for health (DAH), GDP per capita, anthropogenic stress and the interaction term (Ω). Interestingly, all the pairwise correlations produced relatively low coefficients implying that multicollinearity does not exist among the variables.

Table 2. Correlation Matrix of the Series

SERIES	MAM	DAH	GHE	GDP	EFP	URB	Ω
MAM	1						
DAH	-0.429137	1					
GHE	0.377210	-0.766852	1				
GDP	-0.376858	0.496997	-0.731217	1			
EFP	-0.251311	0.699313	-0.563413	0.625493	1		
URB	0.665915	-0.457698	0.558750	-0.231723	-0.104200	1	
Ω	-0.208062	-0.445086	0.258342	-0.463601	-0.630424	0.091373	1

Unit Root Test Analysis

This study began the investigation of stationarity with a graphical exploration of the time series properties of all the modelled variables. In econometric analysis, this helps to reveal the visual effect of how variables change over time. Figure 1 shows the time series plots of the variables in order to correctly isolate potential drift, seasonality, trend, and structural breaks. As illustrated, malaria mortality, development assistance for health, domestic government health expenditure and anthropogenic stress are associated with noticeable fluctuations, which can be traceable to structural breaks. In the case of malaria mortality, the fluctuating increase took a turn, declining till 2016 after which it spiked moderately. While HIV mortality remained stable for most of the time from 2000 to 2018, there is evidence of a positive spike towards the last flank of the review period. The moment of this shock also witnessed significant fall in development assistance for health that appears not to be merely coincidental.

However, gross domestic product per capita and urbanization trended upward over the time. Turning to GDP per capita, the period after 2015 is indicated by the plots to have witnessed a stagnation of average incomes. One possible reason for this could be the glut in global oil prices. Nigeria depends heavily on oil revenue. The time plot for urbanization shows the progressive and persistent growth of urban population. This trend could be easily justified by the fact that Nigeria's population has increased rapidly in recent periods, and as a result, more people are migrating to the urban centres in search of better opportunities and improved living conditions. In Nigeria, insecurity which has escalated since 2015, and chains of negative oil price shocks are some of the factors negatively impacting income and positively driving urban population.

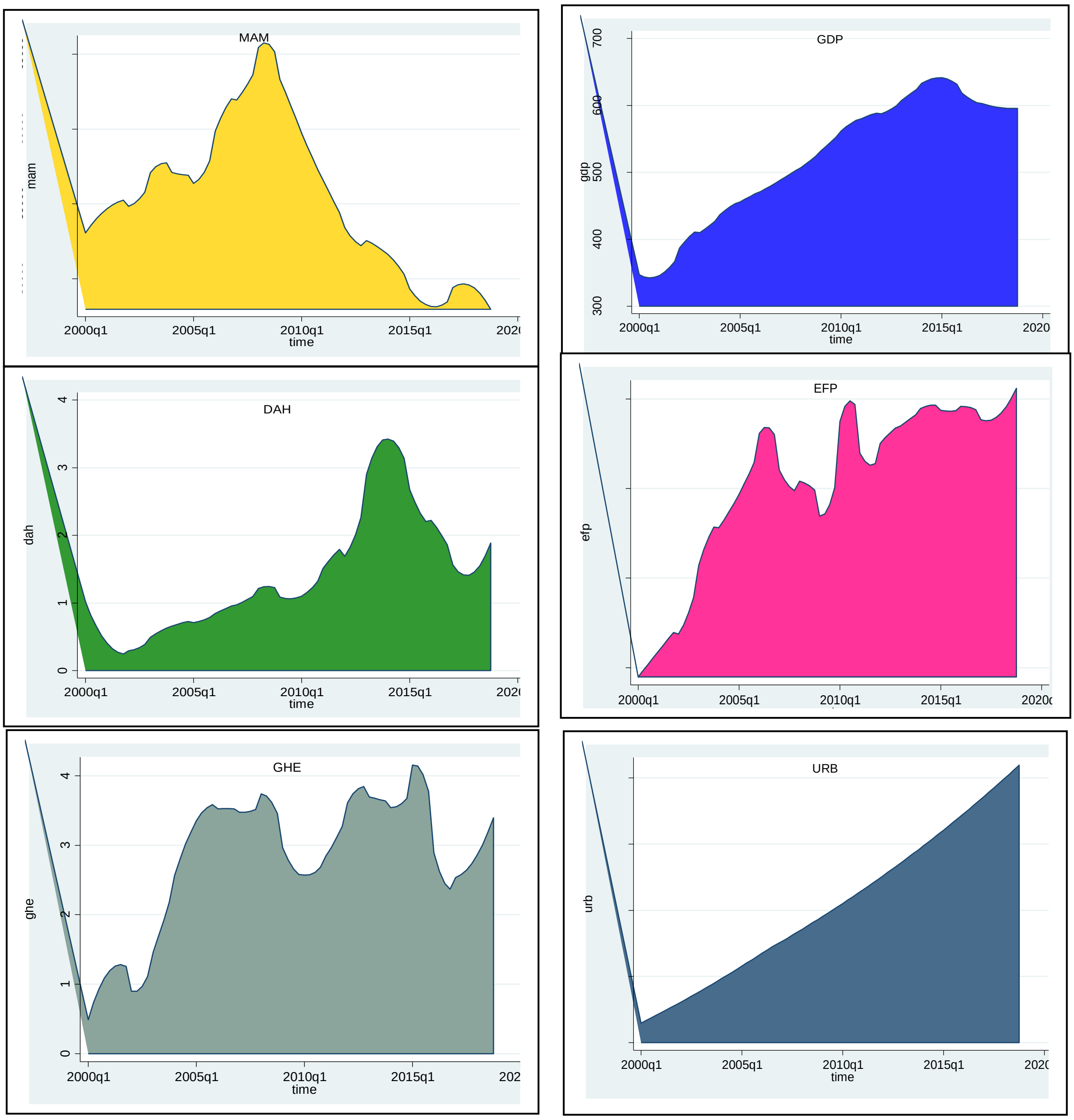

Figure 1: Time Plots of the Series in the Models

MAM = Malaria Mortality ; GDP = Gross Domestic Product ; DAH = Development Assistance for Health
GHE = Government Health Expenditure ; EFP = Anthropogenic Stress ; URB = Urbanization

Stochastic convergence or Stationarity analysis has become necessary for most methods of econometric investigations as a step towards appropriate model selection as well as a measure to guard against spurious results and misleading inferences. Many techniques exist in the literature for testing the stationarity status of modelled series. However, standard non-stationarity tests do not perform optimally in instances where structural breaks exist in the series. In order to avoid this pitfall, the time series data in this study were tested for stationarity using the Lee and Strazicich unit root test which provides for one structural break. Findings of the study obtained from the stationarity test as presented in Table 3 reveal that two variables including urbanization and the interaction between development assistance for health were levels stationary. However, when the test was applied on the differenced levels of the series, malaria mortality, HIV mortality, development assistance for health, domestic government health expenditure, gross domestic product per capita and anthropogenic stress were found to be stationary. This test was conducted at the 5% level of significance.

Table 3. Results of Lee and Strazicich Unit Root Test with Structural Breaks

Variables	*L-S Test @ level*		*L-S Test @ first difference*	
	Test Statistic	***Break Dates***	***Test Statistic***	***Break Dates***
lnMAM	-2.3303(2)	2003Q1; 2005Q1	-5.2141(2)**	2006Q1; 2016Q2
lnDAH	-2.8977(2)	2006Q1; 2001Q2	-8.7303(2)**	2001Q2; 2002Q3
lnGHE	-2.5013(2)	2013Q4; 2013Q4	-5.2335(2)**	2013Q4; 2011Q3
lnGDP	-1.7295(2)	2001Q2; 2001Q1	-4.5316(2)**	2005Q1; 2003Q1
LnEFP	-1.6182(2)	2005Q1; 2001Q2	-5.4087(2)**	2001Q4; 2003Q1
LnURB	-1.6182(2)	2001Q2; 2001Q4	-5.4087(2)**	2005Q1; 2003Q1
Ω	-3.2922(2)	2006Q1; 2001Q2	-6.8462(2)*	2001Q2; 2002Q2
Sig. Level	**Crit. Values**			
1%	-5.34		-5.34	
5%	-4.93		-4.93	
10%	-4.58		-4.58	

Note: Values in parenthesis are the lag length of variables, ** denote rejection of null hypothesis 5% level.

Bootstrap ARDL Cointegration Test Result for the Malaria Mortality

Having determined the stationarity properties, the study adopted the Bootstrap Autoregressive Distributed Lag (BARDL) model to investigate long-run linear relationship among the variables of the empirical models, including the interaction between development assistance for health and domestic government health expenditure. The Boostrap ARDL model was considered very robust for improving inference about cointegration. The estimated result of the test is presented in Table 4. As could be observed, the *F*-statistic for all the variables of the model ($F_{overall}$) was 10.34 and this is greater than the lower bound and the upper bound of the Narayan (2005) critical values at the 5% level of significance.

Table 4. MSG (2018) Cointegration Test Result: Estimated Model: lnMAM=f(lnDAH, lnGHE, lnGDP, lnEFP, lnURB, Ω)

Test	*K*	Statistic	Test Critical Values					
			Narayan (2005) critical values					
			10%		5%		1%	
$F_{OVERALL}$	6	10.34***	⇩ 2.02	⇧ 3.05	⇩ 2.34	⇧ 3.46	⇩ 3.02	⇧ 4.35
			Bootstrap Critical Values					
			5%		2.5%		1%	
			5.720		6.590		7.690	
			PSS (2005) critical values					
			10%		5%		1%	
t_{DEPV}	6	-9.88***	⇩ 2.39	⇧ 3.58	⇩ 2.86	⇧ 4.57	⇩ 3.93	⇧ 5.41
			Bootstrap Critical Values					
			5%		2.5%		1%	
			-3.730		-4.030		-4.400	
			SMG (2019) critical values					
			10%		5%		1%	
F_{INDEP}	6	7.79**	⇩ 1.81	⇧ 3.22	⇩ 2.15	⇧ 3.74	⇩ 2.91	⇧ 4.86
			Bootstrap Critical Values					
			5%		2.5%		1%	
			7.570		8.490		10.310	

Note: *** and ** represent significance at the 1% and 5% confidence intervals, respectively ⇩ and ⇧ represent lower and upper bounds, respectively. Upper and lower bound values for $F_{OVERALL}$ and t_{DEPV} are obtained from Pesaran et al. (2001). However, bound values for F_{IDV} are obtained from Sam et al. (2019). We chose case 3 with K=6 and n=∞. Moreover, these bound values are obtained at 1% level of significance.

This test statistic is also greater than the bootstrap critical value at the 5% level of significance, generated using 2000 replications. The *t*-test on the lagged dependent variable (t_{DEP}) based on the Peseran, Shin and Smith (2001) the critical value was found to be 9.88. Here, the bootstrap critical value at the 5% significance level is -3.730, and less than the test statistic. This indicates that it is also statistically significant because it is greater than the *I*(0) and *I*(1) values of 2.86 and 4.57 critical values at the 5% level of significance. In order to augment the conventional bound testing approach for cointegration, a test was applied on the lagged independent variables (F_{INDEP}) and the test statistic obtained from this bootstrap approach generated using 2000 repetitions is 7.79. This is greater than the *I*(0) and *I*(1) critical values of 2.15 and 3.74 respectively, using the Sam, McNown and Goh (2019) tables. It is also greater than the 5% bootstrap critical value of 7.570. The outcome of these three tests suggests the presence of cointegration among the variables. This means that there exists a long-run relationship between malaria mortality and the independent variables extended to also capture the interaction between development assistance for health and domestic government health expenditure in Nigeria. The BARDL result presented in Table 4, the test statistic corresponding to $F_{OVERALL}$, t_{DEP} and F_{INDEP} are all greater than the I(0) and I(1) bounds. This confirms the existence of a long-run association among the variables of the study.

4. Discussion

The study used Bootstrap ARDL to analyze the impact of development assistance for health and its interaction with domestic government health expenditure. The short-run regression results show that DAH had a statistically significant coefficient of 0.103325. In the short run, Table 5 shows that 1% more health development support increases malaria mortality by 0.10 percent. Malaria mortality is quantified as malaria deaths among children aged 0-59 months, which approximates under-5 malaria mortality by capturing the age range most biologically vulnerable to malaria. Although the estimated elasticity of 0.103 implies that a 1 percent increase in development assistance for health raises mortality by only 0.10 percent, this magnitude is economically meaningful in Nigeria where even a 0.10 percent change translated into dozens to hundreds of additional child deaths annually, given the large baseline mortality burden. The positive association between development assistance for health and under-5 malaria mortality reflects more than simple crowding-out. In Nigeria, substantial DAH inflows may be undermined by inefficiencies in allocation, weak absorptive capacity, and governance challenges, such that funds are delayed, misaligned, or spent on programs that do not target the highest-risk populations (Bachani & Swiss, 2019). Fragmentation of aid across multiple donors, overlapping programs, and vertical interventions may further dilute impact, leaving critical gaps in service delivery, commodity supply, and surveillance (Doucouliagos, Hennessy, & Mallick, 2021). Contextual factors, including uneven distribution across states, poor monitoring, and local implementation bottlenecks, can convert ostensibly generous funding into suboptimal health outcomes, explaining why higher DAH does not automatically reduce under-5 malaria deaths (Pickbourn & Ndikumana, 2018). This demonstrates that the effectiveness of health aid depends critically on institutional quality, policy coherence, and execution efficiency.

Turning to environmental degradation, anthropogenic stress has a coefficient of 0.116583, suggesting that a 1 percent rise in environmental pressure correlates to a 0.116583 percent increase in under-5 malaria mortality, with the result statistically significant at 0.0006. In the Nigerian context, severe anthropogenic stress shows extensive deforestation, land-use change, urban growth, and unsustainable resource exploitation, all of which affect local ecosystems in ways that encourage mosquito breeding and malaria transmission. For example, deforested areas might increase sunny water pools suited for Anopheles mosquito larvae, while agricultural expansion and irrigation projects create new breeding habitats. This environmental approach agrees with the findings of Majeed and Ozturk (2020) and Mordecai et al. (2020), who highlight how declining environmental conditions increase malaria and other vector-borne diseases. Similarly, Fletcher et al. (2022) and Alimi et al. (2020) confirm that ecosystem change elevates malaria risk. By tying anthropogenic stress directly to ecological changes that boost mosquito habitats, the study indicates that environmental degradation is not only connected with malaria mortality but also operates through well-defined transmission pathways in Nigeria.

The study also indicates that GHE reduced malaria mortality in Nigeria. It found that a 1% increase in government health expenditure reduced malaria mortality by 0.0062%. This finding is consistent with the apriori expectation that increased domestic health expenditure will decrease malaria mortality. Although the impact is small, it implied that higher levels of government health expenditure are associated with a slightly lower malaria mortality rate. This outcome is theoretically consistent and is supported by Akinlo and Sulola (2018) for Sub-Saharan Africa, Mohapatra (2019) for India, and Odeme and Olisakwe (2019) for Nigeria. This constant pattern shows the importance of local healthcare infrastructure and resource investment in fighting malaria. It indicates that governments may enhance health outcomes by supporting healthcare services, especially in malaria-endemic areas.

Table 5. Short-Run and Long-Run Coefficients from Bootstrap ARDL

Dependent variable = MAM

Variables	Panel (A) short-run Coefficient	SE	t-Statistic	P-value
Intercept	-0.528816	0.053598	-9.866403	0.0000
*Δln*DAH	0.103325	0.009096	11.35901	0.0000
lnDAH	0.152341	0.116432	1.308409	0.1962
*Δln*EFP	0.116583	0.031222	3.733958	0.0006
lnEFP	2.166911	0.726079	2.984399	0.0042
*Δln*GHE	-0.006209	0.002024	-3.068168	0.0039
lnGHE	-0.065448	0.033636	-1.945786	0.0568
ΔlnGDP	-0.439469	0.111436	-3.943709	0.0003
lnGDP	-2.196998	0.989421	-2.220489	0.0305
ΔlnURB	0.597659	0.126444	4.726659	0.0000
LnURB	1.572984	0.493230	3.189146	0.0024
Δln Ω	0.086674	0.037048	2.339502	0.0207
Ln Ω	0.413629	0.696553	0.622535	0.5938
ΔD_2016 Q2	-0.011734	0.003461	-3.390010	0.0016
D_2016 Q2	1.321617	0.753269	1.754508	0.0872
ΔD_2006 Q1	0.019508	0.004169	4.679622	0.0000
D_2006 Q1	-0.494376	0.392098	-1.260848	0.2149
CointEq(-1)	-0.032832	0.003325	-9.875793	0.0000

Notes: *, **, *** show level of significance at 10%, 5%, and 1% respectively.

However, the negative and statistically significant coefficient of -0.439469 for gross domestic product per capita shows that a 1% increase in average incomes of Nigerians is associated with reduced malaria mortality. This means that economic development is linked to better health outcomes in the short run. The study further found that malaria mortality is an increasing function of urbanization in the short run analysis. It is revealed that a 1% increase in urbanization coincides with a 0.59% increase in malaria deaths of children aged 0-59 months in Nigeria. This implies that higher levels of urbanization are associated with higher malaria mortality rates, possibly due to factors like increased population density or inadequate healthcare infrastructure in urban areas, urban poverty and emergence of urban slums.

Turning to the interaction term, the study found a short-run coefficient of 0.086674 and is statistically significant at the 5% level of significance. The moderating effect of domestic government health expenditure is examined through the marginal effect expression ∂MAM/∂DAH = 0.103325 + 0.086674(GHE). The positive interaction coefficient (0.086674) indicates that the effect of development assistance for health on under-5 malaria mortality increases as domestic health expenditure rises. For instance, at low GHE (1 unit), the marginal effect of DAH is 0.1900; at moderate GHE (3 units), it rises to 0.3633; and at high GHE (5 units), it further increases to 0.5367. This pattern demonstrates positive moderation, implying that higher domestic spending increases rather than mitigates the mortality-increasing association of DAH, suggesting weak complementarity or coordination inefficiencies between external aid and domestic health financing in reducing under-5 malaria mortality.

The error correction term for the malaria mortality function is negative, less than one and also statistically significant. The coefficient for the ECT (-1) of -0.033 implies that any shock to the malaria mortality function from all the modeled sources of variation are corrected by about 3,3% within a quarter. The study also modelled for two break dates: 2016 q1 and 2006q2. This was aimed at correcting the instability of the model inferred from a significant CUSUM and CUSUM squares test. These break dates turned out significant as shown in table 5. In 2015, Nigeria experienced a significant health policy change with the launch of the National Health Act. The Act aimed to provide a legal framework for the regulation, development, and management of the Nigerian health system. It also outlined provisions for funding mechanisms, health insurance, and the establishment of the Basic Healthcare Provision Fund (BHCPF) to provide essential health services to vulnerable populations. This policy change could potentially be linked to the significant break date of 2016 Q1, as it marked a notable shift in health financing and service delivery in Nigeria. In 2006, Nigeria implemented a significant health policy known as the National Health Insurance Scheme (NHIS). While the NHIS was officially launched in 2005, its implementation and expansion continued in the subsequent years. The NHIS aimed to provide affordable healthcare services to all Nigerians through various healthcare financing mechanisms, including the establishment of health insurance schemes. The introduction of the NHIS in 2005-2006 could be relevant to the significant break date of 2006 Q2 in the study. This policy change likely had an impact on the healthcare landscape, government health expenditure, and possibly the relationship between development assistance for health and health outcomes like malaria mortality.

In the long-run model, a 1% increase in the share of Development Assistance for Health (DAH) in total health expenditure correlates with a 0.152% increase in malaria mortality among children, indicating that these resources may not be effectively targeted or utilized. Therefore, this study specifically demonstrates that development aid for health does not lower under-5 malaria mortality in Nigeria; instead, it is associated with a statistically significant increase in deaths among children aged 0–59 months. A 1% increase in anthropogenic stress is associated with a 2.167% increase in malaria mortality, suggesting that unsustainable environmental practices and resource consumption exacerbate malaria risks. Domestic Government Health Expenditure shows that a 1% increase per capita leads to a 2.197% decrease in malaria mortality, highlighting the positive impact of government investment in healthcare on child survival.

Like in the short-run, the long-run analysis also suggests that malaria mortality grows with urbanization, with a 1 percent increase in urban population equating to a 0.59 percent increase in deaths among children aged 0–59 months. Although theory suggests urban areas should bear health advantages through improved access to healthcare and infrastructure, in Nigeria fast urbanization often outpaces service provision, creating dense settlements, informal slums, and overstretched health facilities. These factors intensify malaria risk by facilitating vector reproduction in poorly drained water bodies, limiting prompt access to diagnosis and treatment, and concentrating vulnerable individuals in areas with inadequate sanitation. Thus, the urban advantage is negated by structural, environmental, and socio-economic vulnerabilities that enhance under-5 malaria mortality despite proximity to health care. Savi et al (2024) also found that urbanization does not drive decrease in malaria deaths in Ghana. The positive interaction effect of Government health expenditure is shown to persist but is not statistically significant. The results imply that development assistance for health amplifies under-5 malaria mortality when domestic government health expenditure is large, underlining a major policy sequencing concern. Such sequencing could eliminate inefficiencies, promote coordination, and enable development aid to complement, rather than unnecessarily exacerbate, child malaria mortality in Nigeria.

Diagnostic Checks on the Malaria Model

The results of the diagnostic tests performed on the coefficients and residuals of the malaria regression model are presented in Table 6. The study found that the null hypothesis of no regression specification error based on the Ramsey test was accepted implying that the model has the correct functional form. Also, the study could not reject the null hypothesis that the residuals were not serially correlated, showing the absence of autocorrelation in the model. Further, the study tested for the presence of constant variance in the residuals using the Arch LM test suggested by Engel (1982). As indicated in Table 6, the presence of homoscedasticity was confirmed based on the probability values.

Table 6. Diagnostic Test Results for the Malaria Mortality Model

	Statistic	P-value	Decision
χ^2_{RESET}	3.049590	0.6371	Null Accepted
χ^2_{SERIAL}	13.61293	0.3240	Null Accepted
χ^2_{NORMAL}	69.82312	0.0000	Null Rejected
χ^2_{ARCH}	34.38343	0.7230	Null Accepted
CUSUM test	-	-	Stable
$CUSUM^2$ test	-	-	Stable

However, the null hypothesis of normality in the residuals was rejected as the Jarque-Bera statistic is statistically significant. Notably, the Bootstrap ARDL model is generally less sensitive to the assumption of normality compared to traditional methods (Sam, McNown & Goh, 2019). The bootstrap technique is a resampling method that does not assume any specific distribution for the data. It involves repeatedly sampling from the observed data with replacement to generate many resampled datasets and then calculating the estimates of interest for each resampled dataset. Because the bootstrap does not assume a specific distribution for the data, it can provide valid inference even when the normality assumption is violated. This makes it particularly useful in cases where the residuals or errors might not be normally distributed as in the present case. The stability of the estimates of this model was tested using the Cumulative Sum and the Cumulative Sum of Squares presented in Figure 2. All the plots were indicated to be within the 5% critical bounds as required for the rejection of the null hypothesis of non-stability of the coefficients. This shows that the estimates are stable and could be used to form a basis for informed policy direction.

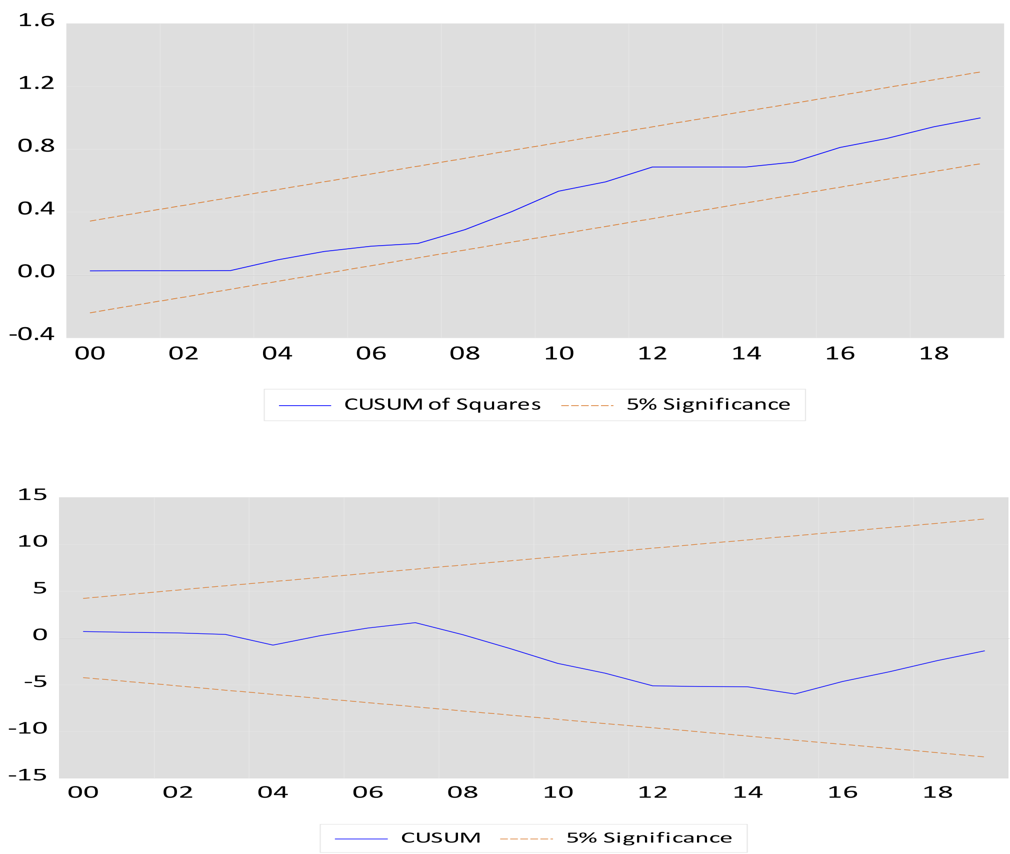

Figure 2. CUSUM and CUSUM of Squares Plots for the Model

This study examined causality to exclude confounding variables, spurious correlations, and reverse causation in the observed regression relationships. The Toda-Yamamoto Granger non-causality test results are summarized in Table 7. Specifically, the coefficient of development assistance for health (DAH) was not significant, but malaria mortality in the DAH model was significant (p-value = 0.0252, coefficient = 3.826). This suggests a unidirectional causal relationship from malaria mortality to DAH, indicating that past malaria mortality rates influence future DAH patterns. This reflects the reactive nature of global health interventions, where increased malaria mortality triggers external assistance to address the crisis. This finding aligns with the Bootstrap ARDL results, showing a positive association between DAH and health outcomes in Nigeria.

Table 7. Toda-Yamamoto Granger Non-causality

Direction of Causality							
Variables	lnMAM	lnDAH	lnGHE	lnGDP	lnEFP	lnURB	lnINT
lnMAM	-	3.493	5.662**	9.184**	2.458**	19.476***	4.332**
lnDAH	3.826**	-	4.646	3.652	7.576	6.060	7.610
lnGHE	1.998	17.017***	-	14.717**	2.137	8.316	17.608***
lnGDP	15.146***	14.836**	14.421**	-	8.280	15.707**	14.965**
lnEFP	13.988**	9.945	7.369	4.537	-	2.645	11.670*
lnURB	41.571***	11.996*	15.429**	1.669	2.267	-	4.270
$\ln\Omega$	4.301	3.318	4.884	6.010	5.025	11.471	-

Notes: The test uses X^2-statistics. *, ** and *** represent the rejection of the null hypothesis at 10%, 5% and 1% respectively.

In the malaria model, domestic government health expenditure was significant at the 5% level (p-value = 0.0321), consistent with theoretical expectations. However, malaria mortality was not significant in the domestic government health expenditure model, indicating unidirectional causality from government health expenditure (GHE) to malaria mortality in Nigeria. Bidirectional causality was found between GDP and malaria mortality, suggesting a reciprocal influence. Higher GDP can improve healthcare infrastructure and access, reducing malaria mortality. Conversely, high malaria mortality can decrease workforce productivity, increase healthcare costs, and hinder economic growth, perpetuating poverty and disease (Wei, Rahim & Wang, 2022).

Similarly, bidirectional causality exists between anthropogenic stress and malaria mortality. Environmental degradation, habitat destruction, and climate change can increase malaria vector proliferation, while malaria's economic burden can lead to practices exacerbating environmental degradation (Yahyoui & Bouchoucha, 2020; Majeed & Ozturk, 2020; Oluwatoyin, Osabohien, Fasina & Afolake, 2018; Sirag, Nor & Lacheheb, 2016). Bidirectional causality was also found between urbanization and malaria mortality. Rapid urbanization can lead to poor living conditions conducive to mosquito breeding, increasing malaria transmission. Despite health challenges, economic opportunities in urban areas continue to attract people, enhancing transmission. Malaria mortality and urbanization were both significant in their respective models (p-values = 0.0034 and 0.0000, respectively). Finally, unidirectional causality was found between the interaction term (development assistance and government health expenditure) and malaria mortality, suggesting that foreign aid supports domestic health efforts, including malaria control (United Nations Programme on HIV and AIDS, 2020; Akinola & Asaolu, 2022).

5. Conclusion

This study reveals that the effectiveness of development assistance for health (DAH) in lowering under-5 malaria mortality in Nigeria is conditional on domestic government health expenditure (GHE). Empirically, increased GHE magnifies the observed mortality-increasing effect of DAH, demonstrating that without sufficient sequencing and coordination, external help may fail to complement domestic investment and, ironically, worsen results. Quantitatively, the strongest long-run driver of under-5 malaria death is the interaction between DAH and GHE, followed by anthropogenic stress and urbanization, underlining the essential role of finance, environmental, and demographic factors.

Despite these insights, the study is hampered by data quality and measurement limitations. DAH and malaria mortality are sourced from secondary sources, and interpolated quarterly statistics may not completely capture short-term variations or local variability in aid allocation and disease burden. Similarly, anthropogenic stress is proxied using ecological footprint metrics, which, while helpful, may not capture all environmental factors of malaria transmission at subnational scales. For practical direction, Nigeria should prioritize scaling up and enhancing domestic health expenditure before large external help is provided, ensuring absorptive capacity, service delivery, and monitoring mechanisms are solid. Development aid should be structured as matching or conditional grants, targeting high-burden regions, increasing local ownership, and creating alignment with national malaria control priorities. Coordinated planning, real-time monitoring, and collaborative accountability procedures between donors and government agencies are critical to improve the synergy between DAH and domestic spending, eliminate inefficiencies, and maximize reductions in under-5 malaria mortality.

Conflict of Interest

The author has no conflict of interest to declare.

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