Beyond Spending: Nonlinear Impacts of Health Financing and Out-of-Pocket Costs on Mortality in Africa

Denis Folitse[1], Christopher Odoom[1], Alexander Boateng[2], Luis Alberiko Gil-Alana[3*]

1 Department of Mathematics and Statistics, University of Massachusetts, Amherst, USA

2 Department of Statistics and Actuarial Science, Kwame Nkrumah University of Science and Technology, Ghana

3* Department of Economics, University of Navarra, Pamplona E-31009, Spain and Universidad Francisco de Vitoria, Madrid, Spain

Corresponding author: Prof. Luis A. Gil-Alaña | Email: alana@unav.es

Abstract

Background: Existing evidence suggests that mortality remains disproportionately high across Africa, where gains in life expectancy continue to lag behind global progress. While health financing is central to health-system performance, its relationship with mortality in African settings remains insufficiently characterized, particularly when public spending, household out-of-pocket (OOP) payments, governance conditions, and demographic pressures are considered jointly. Our objective was to use a non-linear regression method to evaluate how health financing structures are associated with mortality and whether the association depends on the mode of financing.

Methods: We use generalized additive mixed models (GAMMs) to allow for potential non-linear relationships between crude mortality rates and public health expenditure, out-of-pocket payments, political stability, and age dependency across 51 African countries from 2002 to 2022 (N = 1,071 country-year observations). A tensor-product interaction assessed whether financial protection modifies the effect of public health spending. Region-specific models were fitted for Central, East, West, Southern, and Northern Africa.

Results: Public health spending was associated with lower mortality across Africa, with the steepest reductions below approximately US$80 per capita and diminishing returns thereafter. Out-of-pocket (OOP) spending modified these returns: OOP burdens below 15% of total health expenditure strengthened the estimated mortality benefit of public investment by about 60%, whereas burdens above 40% substantially eroded it. Regionally, the spending–mortality association was strongest in Central, Eastern, and Western Africa, but weaker in Southern and Northern Africa, where age dependency and governance quality were more prominent predictors. The expenditure–OOP interaction was most pronounced in Eastern Africa (EDF = 9.45, $F = 4.45$, $p < 0.001$). The continent-wide model showed strong explanatory performance (adjusted R^2 = 92.8%; deviance explained = 93.4%; N = 1,009).

Conclusions: Increasing public health spending alone is unlikely to maximize mortality gains in Africa. Its impact depends on financial protection: reducing household out-of-pocket costs through pooled financing should be accompanied by expanded public investment. In Southern and Northern Africa, policy emphasis should also shift toward governance efficiency and demographic pressures. Subregion-specific strategies are therefore essential.

Keywords: health expenditure; mortality; generalized additive mixed models; financial protection; universal health coverage

JEL Classification: C14; C23; I15

Corresponding author: Prof. Luis A. Gil-Alana
University of Navarra
Edificio Amigos
Pamplona E31009
Spain
Email: alana@unav.es

Ethics approval and consent to participate

This study used publicly available, aggregated country-level data from the World Bank World Development Indicators database. No individual-level, identifiable, or human participant data were analyzed; therefore, ethics approval and informed consent were not required.

Consent for publication

n/a

Availability of data and materials

Denis Folitse - Github

Competing interests

There is no competing interests with the publication of the present manuscript.

Funding

Luis A. Gil-Alana gratefully acknowledges financial support from the MINEIC-AEI-FEDER PID2020-113691RB-I00 project from ‘Ministerio de Economía, Industria y Competitividad’ (MINEIC), ‘Agencia Estatal de Investigación’ (AEI) Spain and ‘Fondo Europeo de Desarrollo Regional’ (FEDER), and also from Internal Projects of the Universidad Francisco de Vitoria.

Authors' contributions

Denis Folitse proposed the original idea and contributed with the introduction, review, and methodology, along with the interpretation of results and conclusions.

Christopher Odoom participated in the introduction, literature review, methodology, and conclusions.

Alexander Boateng obtained the data and the empirical results.

Luis Alberiko Gil-Alana contributed to the interpretation of the results and supervision of the manuscript.

Acknowledgements

Luis Alberiko Gil-Alana gratefully acknowledges financial support from the PID2023-149516NB-I00 funded by MCIN/AEI/ 10.13039/501100011033 project from ‘Ministerio de Economía, Industria y Competitividad’ (MINEIC)

1. Introduction

Africa continues to face a substantial overall mortality burden. Crude death rates remain high in many African countries, with several countries recording around 9–11 deaths per 1,000 population in recent World Bank estimates [1]. At the population level, these mortality patterns are reflected in persistently low life expectancy: in 2024, life expectancy in Sub-Saharan Africa was approximately 63 years, well below the 75–80-year range reported for most other world regions [2, 3]. These patterns point to persistent structural inequities in health-system access, financing, governance, and demographic conditions, despite two decades of health-sector investment. Understanding which health-financing instruments most effectively translate expenditure into mortality reductions—and under what institutional and demographic conditions—is therefore a question of considerable scientific and policy urgency.

Crude mortality—the outcome examined in this study—is shaped by multiple, interrelated pathways. Public health expenditure can reduce mortality by expanding service availability and lowering the effective cost of care when it substitutes for household out-of-pocket (OOP) payments [4, 5]. In contrast, high OOP costs can deter timely care-seeking, especially for acute conditions where delays may be fatal [6, 7]. Political stability affects whether public resources are converted into effective services by supporting budget execution, supply-chain continuity, and health-worker deployment [8, 9]. The age dependency ratio also influences crude mortality, both directly through population age structure and indirectly through its effects on service demand and fiscal capacity [10]. These mechanisms are likely interdependent: the mortality returns to public spending may depend on whether households are financially protected at the point of care and whether governance systems can translate budgets into effective coverage.

These empirical pathways are grounded in four complementary theoretical perspectives. Grossman's health demand model conceptualizes health as a form of capital that depreciates over time and can be improved through investment in care; this implies that public health spending may reduce mortality, but with diminishing marginal returns as baseline health-system capacity improves [5]. Rosenzweig and Schultz's health production framework similarly treats health outcomes as the product of medical care and complementary inputs, suggesting that the productivity of public spending depends on whether resources are converted into accessible and effective services [11]. Materialist theories of health inequality emphasize poverty, resource access, and structural barriers as determinants of health, positioning OOP payments as a mechanism through which financial exclusion can translate into preventable mortality [12, 13]. Andersen's behavioral model of healthcare utilization further explains how OOP costs operate as a negative enabling factor by reducing the likelihood that perceived need results in timely care-seeking [14]. Together, these frameworks support the study's integrated focus on public spending, household financial protection, governance capacity, and demographic pressure as joint determinants of crude mortality. They also imply that the mortality effects of health expenditure are unlikely to be uniform across countries but instead depend on financing arrangements and institutional conditions.

Consistent with this expectation, empirical studies show that health spending is generally associated with lower mortality, although the strength of this relationship varies by setting, outcome, and governance context. In an early cross-country analysis, public health spending explained only a modest share of variation in child mortality after socioeconomic and institutional factors were considered [4]. African-focused studies have generally found stronger inverse associations: higher per capita health expenditure has been linked to lower infant and under-five mortality across 47 African countries, with government spending showing larger effects than total health spending [15]. Similarly, public health expenditure has been associated with lower infant and neonatal mortality in 36 sub-Saharan African countries after adjustment for income and urbanization [16]. Broader multicountry evidence further suggests that health spending can reduce mortality but that its returns depend on institutional quality and health-system performance [17, 18].

Related literature highlights financial protection as a key mechanism through which health spending affects mortality. High OOP payments can restrict access to care, delay treatment, and expose households to catastrophic health expenditures [6, 19]. Evidence from sub-Saharan Africa shows that OOP payments above catastrophic thresholds are associated with reduced service utilization, household impoverishment, and poorer health outcomes [6]. Medicines also account for a large share of household health costs in many African settings, reinforcing the role of OOP payments as a barrier to timely care [19]. Studies of pooled financing and insurance reforms suggest that public spending produces larger health gains when households are protected from direct costs at the point of care [20–22]. These findings imply that the mortality return to public expenditure may depend on whether public financing reduces household cost exposure.

Governance and political stability further explain why similar levels of health spending may produce different mortality outcomes across countries. Public health expenditure has been shown to have stronger effects in settings with better governance, stronger public financial management, and more reliable budget execution [23, 24]. Political instability, conflict, and epidemics can weaken these channels by disrupting supply chains, health-worker deployment, facility readiness, and service continuity [25–27]. Demographic structure is also central when crude mortality is the outcome. Unlike age-specific mortality indicators, crude death rates are directly influenced by population age composition. Countries with higher age dependency may face higher baseline mortality risk and greater demand for health services, even when health-system performance is improving [10, 28].

Despite this literature, important gaps remain. First, most studies of health financing and mortality in Africa focus on specific outcomes—such as infant, child, neonatal, or maternal mortality—rather than crude mortality, which captures the broader population-level mortality burden [4, 15, 20]. Second, much of the evidence relies on conventional linear or log-linear panel approaches, including fixed-effects models and dynamic panel estimators, which may obscure nonlinearities, thresholds, or diminishing returns in the spending–mortality relationship [4, 15, 20]. Third, public spending and OOP payments are often included as separate predictors, with limited attention to whether household financial exposure modifies the mortality returns to public investment [15, 16, 20]. Fourth, beyond this financing interaction, less attention has been given to how public spending, household financial exposure, governance quality, and demographic pressure jointly shape crude mortality across African countries [23, 18, 10].

This study addresses these gaps using generalized additive mixed models (GAMMs) applied to a panel of 51 African countries from 2002 to 2022. GAMMs allow predictor–mortality relationships to vary flexibly through penalized smooth functions while accounting for country-level heterogeneity through random effects [29]. A tensor-product interaction was used to evaluate whether the OOP share of health expenditure modifies the mortality returns to public spending, an approach suited to modeling interactions between smooth terms [29,30]. Region-specific models were then fitted to assess how these relationships vary across Africa's five subregions.

The remainder of the paper is organized as follows. Section 2 describes the data, variables, and model specification. Section 3 presents the results. Section 4 discusses the findings in relation to prior evidence and policy implications. Section 5 concludes with recommendations and directions for future research.

2. Methods

2.1 Data, Sample, and Study Countries

We compiled annual, country-level panel data for 51 African countries over 2002-2022, yielding 1,071 country-year observations after listwise deletion of missing values. Three countries—Zimbabwe, South Sudan, and Somalia—were excluded due to extreme data sparsity and severe measurement concerns that would have introduced unreliable influential observations. All variables were retrieved from the World Bank Development Indicators (WDI) database [1]. The study period spans two decades of health system evolution in Africa, including HIV/AIDS treatment scale-up (mid-2000s), the West African Ebola epidemic (2014-16), and the COVID-19 pandemic (2020-22). The 51 study countries, classified by UN subregion, are listed in Appendix Table A1.

2.2 Variable Definitions and Theoretical Justification

Table 1 provides full variable descriptions and sources. Below, we elaborate on the theoretical and empirical justification for each variable, drawing on the theoretical foundation of the factors affecting mortality

Dependent variable — Crude mortality rate (deaths per 1,000 population): The crude death rate is the total number of deaths from all causes per 1,000 population in a given year. It is the most widely available aggregate mortality indicator across African countries and is directly targeted by the Sustainable Development Goals (SDG 3). While age-standardized mortality would be preferable for isolating health system effects, it is unavailable for the full sample; we address this by including the age dependency ratio as a control. The crude death rate has been used as the primary outcome in prior multi-country health financing analyses in Africa [4, 15, 17].

Health expenditure: Public health expenditure was included as the primary financial input to health service delivery, consistent with health demand and health production frameworks [5, 11]. We measured this variable as domestic general government health expenditure per capita, adjusted for purchasing power parity, to improve comparability across countries. A one-year lag was applied to partly reduce reverse causality, since changes in mortality may influence subsequent spending, and to allow for a plausible delay between budgetary commitments and observable mortality changes. Similar lag structures have been used in prior African health expenditure studies [15, 16].

Out-of-pocket expenditure (percent of current health expenditure): OOP expenditure is the share of total health spending that households bear directly at the point of service. Out-of-pocket (OOP) costs were included as a key financial barrier to care-seeking, consistent with behavioral and materialist theories of health, which emphasize how financial constraints can prevent households from translating health needs into timely service use [13, 14]. OOP spending was measured as a share of current health expenditure, reflecting the relative extent to which healthcare costs are borne directly by households rather than through pooled financing mechanisms. This variable was included both as a main predictor and as part of the tensor-product interaction with public health expenditure.

Political stability (lagged 1 year, index -2.5 to +2.5): The Political Stability and Absence of Violence/Terrorism index from the World Bank's Worldwide Governance Indicators measures the perceived probability that the government will not be destabilized by unconstitutional means or political violence. Governance quality was included as an enabling condition for converting health budgets into effective service delivery, consistent with evidence that public spending has stronger health effects in settings with better governance and stronger public financial management [23, 24]. The one-year lag reflects the expectation that improvements in governance precede measurable health-system and mortality gains.

Age dependency ratio: The age dependency ratio was included to account for the relationship between population age structure and crude mortality [10]. Because crude death rates are not age-standardized, countries with larger dependent populations may have higher baseline mortality risk independent of health-system performance. This is particularly relevant in parts of West and Central Africa, where high dependency ratios can confound estimates of the relationship between health expenditure and mortality.

COVID-19 pandemic indicator (binary, 1 = 2020-2022): The pandemic caused direct mortality through infection and indirect mortality through health service disruptions [31, 32]. Inclusion prevents pandemic-era mortality spikes from being attributed to financing variables and allows estimation of the ceteris paribus financing effect in non-pandemic years.

Table 1: Variable Description and Sources

Variable	Abbreviation	Description and Measurement	Source
Mortality Rate	Mort	Death rate, crude (per 1,000 people)	WDI [27]
Health Expenditure	HealthExp	Domestic general government health expenditure per capita, PPP-adjusted (current international $), lagged 1 year	WDI [27]
Out-of-Pocket Expenditure	Oop	OOP health expenditure as % of current health expenditure	WDI [27]
Political Stability	Polstab	Political stability and absence of violence/terrorism index (-2.5 = most fragile; +2.5 = most stable), lagged 1 year	WDI [27]
Age Dependency Ratio	Agedep	Dependents aged <15 or >64 per 100 working-age persons (aged 15-64)	WDI [27]
COVID-19 Indicator	Covid19	Binary: 1 = pandemic period (2020-2022); 0 = prior years	Authors

WDI = World Bank Development Indicators.

2.3 Rationale for the GAMM Framework

The choice of GAMM was motivated by three considerations. First, the theoretical framework suggests that the associations between mortality and key predictors may be nonlinear, including diminishing returns to public health spending, threshold effects in OOP burden, and nonlinear effects of demographic composition [5, 10, 13]. Standard linear panel models may fail to detect such patterns unless the functional form is specified in advance [29]. Second, GAMMs replace strictly linear predictor terms with penalized smooth functions, allowing the data to estimate flexible predictor–mortality relationships while penalizing excessive curve complexity [29, 30]. In this study, smooth terms were estimated using thin-plate regression splines, with smoothing parameters selected by restricted maximum likelihood (REML), a commonly recommended approach for stable smoothness estimation in GAMMs [29, 33]. Third, the 21-year country panel contains repeated observations within countries; therefore, country-level random intercepts were included to account for unobserved time-invariant heterogeneity and within-country correlation [34].

2.4 Theoretical Model and Empirical Specification

This study models crude mortality as a function of health financing, household financial exposure, governance capacity, demographic structure, and common time shocks. The theoretical premise is that public health expenditure can reduce mortality by expanding service availability, improving health-system inputs, and lowering the effective cost of care when public provision substitutes for direct household payments. However, the mortality return to public expenditure is not expected to be constant. Health demand and health production frameworks suggest that additional spending may produce larger mortality gains at low levels of baseline health-system capacity but smaller gains once basic infrastructure and service capacity are already established [5, 11]. Out-of-pocket (OOP) payments are expected to weaken this relationship by limiting household access to timely care, while governance quality affects whether public budgets are translated into effective service delivery. Age dependency is included because crude mortality is directly influenced by population age structure, and pandemic-period shocks are captured using a COVID-19 indicator.

Conceptually, the mortality process can be expressed as:

$$Mort_{it} = F(HealthExp_{i,(t-1)}, Oop_{it}, Polstab_{i(t-1)}, Agedep_{it}\ Country_i, Covid19_{it}) + \varepsilon_{it} \quad \textbf{(1)}$$

where (i) indexes countries and (t) indexes years. The function $F(\cdot)$ is not assumed to be linear because the theoretical framework suggests diminishing returns to health expenditure, possible threshold effects in household financial exposure, and nonlinear demographic effects. The interaction between public expenditure and OOP payments is central to the study because it evaluates whether the mortality return to public spending depends on the extent to which households remain exposed to direct healthcare costs.

To estimate this theoretical relationship, we used generalized additive mixed models (GAMMs). The GAMM framework is appropriate because it allows predictor–mortality relationships to vary flexibly through penalized smooth functions while accounting for country-level heterogeneity through random effects [29]. The empirical model was specified as:

$$Mort_{it} = \beta_0 + \beta_1 Covid19_{it} + s_1(Year_t) + s_2(HealthExp_{i,t-1}) + s_3(Oop_{it}) + s_4(Polstab_{i,t-1}) + s_5(Agedep_{it}) + ti(HealthExp_{i,t-1}, Oop_{it}) + s_6(Country_i, bs = "re") + \varepsilon_{it} \quad \textbf{(2)}$$

Here, $Mort_{it}$ denotes the crude mortality rate for a country (i) in year (t). $(HExp_{i,t-1})$ is domestic general government health expenditure per capita, adjusted for purchasing power parity and lagged by one year. $(OOP_{it})$is out-of-pocket expenditure as a share of current health expenditure. $(PolStab_{i,t-1})$ is the one-year lagged political stability measure, and $(AgeDep_{it})$ is the age dependency ratio. $Covid19_{it}$ is a binary indicator for the pandemic period, included as a parametric term to capture the average mortality shift associated with COVID-19. The country-specific random intercept $(Country_i, bs = "re")$ accounts for unobserved time-invariant differences across countries, while $(Year_t)$ captures continent-wide secular mortality changes not explained by the observed covariates. and e_it ~ N(0, sigma^2) is the i.i.d. error term.

The smooth terms (s_1) to (s_6) were estimated using penalized thin-plate regression splines. For a continuous predictor (x), each smooth function can be represented as a basis expansion:

$$s(x) = \sum_{k=1}^{K} \gamma_k b_{k(x)} \quad \textbf{(3)}$$

where $b_{k(x)}$ are spline basis functions and γ_k are coefficients estimated from the data. Thin-plate regression splines provide a low-rank approximation to thin-plate splines and are useful because they avoid the need to manually specify knot locations $(k(x))$ [29,33]. Smoothness is controlled by maximizing a penalized likelihood of the form:

$$\zeta_p(B) = \zeta(B) - \frac{1}{2}\lambda B^T SB \quad \textbf{(4)}$$

In the penalized likelihood, **B** denotes the vector of spline coefficients estimated by the model. The penalty term $B^T SB$ measures the roughness of the fitted smooth function, and the smoothing parameter λ controls how strongly this roughness is penalized. Larger values of λ produce smoother functions, while smaller values allow more flexible curves. Thus, the model allows nonlinear patterns only when supported by the data, reducing the risk of imposing arbitrary functional forms on the spending–mortality relationship.

The tensor-product interaction $ti(HExp_{i,t-1}, OOP_{it})$ was included to estimate the joint association between public health expenditure and OOP burden. Tensor-product smooths are recommended for modeling interactions between smooth terms, particularly when predictors may operate on different scales or require separate smoothing penalties [29,30]. Unlike an additive model, which assumes that the association between each predictor and mortality is independent of the others, the tensor-product smooth allows the spending–mortality relationship to vary across levels of OOP exposure. This directly tests whether household financial protection modifies the mortality returns to public investment.

Smoothing parameters were selected using restricted maximum likelihood (REML), which provides stable smoothness estimation and reduces the risk of overfitting in generalized additive models [29, 30, 33]. Model complexity was summarized using effective degrees of freedom (EDF), where EDF values close to 1 indicate approximately linear relationships and larger values indicate more complex nonlinear patterns. All models were estimated using the mgcv package in R.

3. Results

3.1 Descriptive Statistics and Regional Patterns

Table 2 presents descriptive statistics across the full sample (51 African countries, 2002-2022, N = 1,071). The crude mortality rate exhibits extreme right-skewness (skewness = 5.72, kurtosis = 76.08), with values ranging from 4.59 to 72.48 per 1,000 — reflecting both gradual secular decline and acute crisis-driven spikes in conflict-affected country-years. Health expenditure averages US$122.06 per capita but is highly right-skewed (median = $32.69; SD = $190.34), driven by a small number of outliers (Seychelles, Gabon, Libya, South Africa) far exceeding the continental median. The mean OOP share was 39.83%, approaching the 40% catastrophic health expenditure threshold defined by the World Health Organization [35].

The mean political stability score (-0.53) reflects persistently weak governance across much of the continent. The strong negative correlation between health expenditure and age dependency ratio (r = -0.75) shows the importance of controlling for demographic composition. Regional distributions are shown in Figure 1; mortality rate and expenditure trends across regions from 2002 to 2022 are in Figures 2 and 3. Out-of-pocket political stability and age-dependency ratio trends across African regions are presented in Figure A1-A3, respectively.

Table 2: Descriptive Statistics for Africa (2002-2022)

Measure	Mortality (per 1000)	Health Expenditure (USD)	Oop (%)	Political stability (Index)	Age Dependency Ratio
Mean	9.55	122.06	39.83	-0.53	79.48
SD	3.95	190.34	20.11	0.86	16.68
Median	8.85	32.69	39.06	-0.39	83.58
Min	4.59	0.43	2.99	-2.70	38.39
Max	72.48	1,257.18	86.50	1.20	110.91
Skewness	5.72	2.38	0.06	-0.30	-0.66
Kurtosis	76.08	5.89	-0.98	-0.55	-0.35
Mortality (per 1000)	1.00				
Health Expenditure (USD)	-0.24	1.00			
Oop (%)	0.14	-0.38	1.00		
Political stability (Index)	-0.18	0.32	-0.42	1.00	

Measure	Mortality (per 1000)	Health Expenditure (USD)	Oop (%)	Political stability (Index)	Age Dependency Ratio
Age Dependency Ratio	0.39	-0.75	0.24	-0.43	1.00

Note: SD = standard deviation. OOP = out-of-pocket expenditure as % of current health expenditure. Political Stability Index: -2.5 (most fragile) to +2.5 (most stable). N = 1,071 country-year observations, 51 countries, 2002-2022.

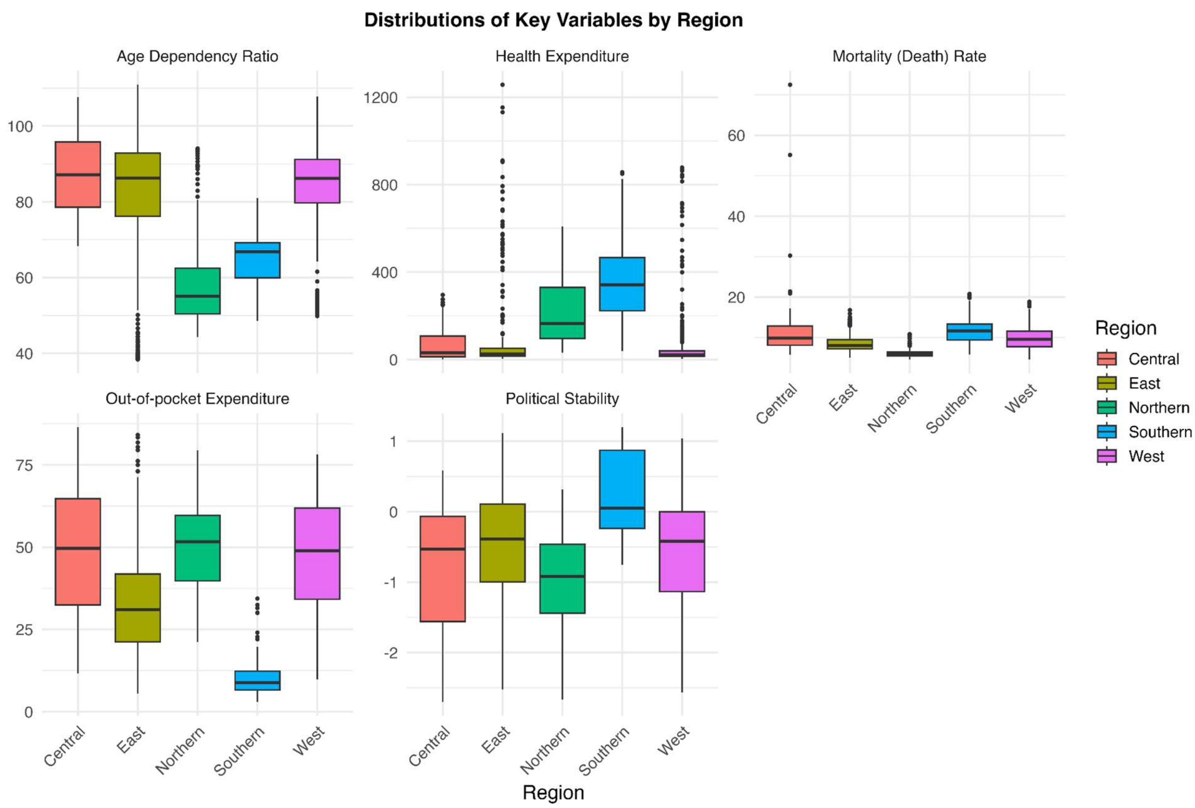


Figure 1: Distribution of Key Variables by Region

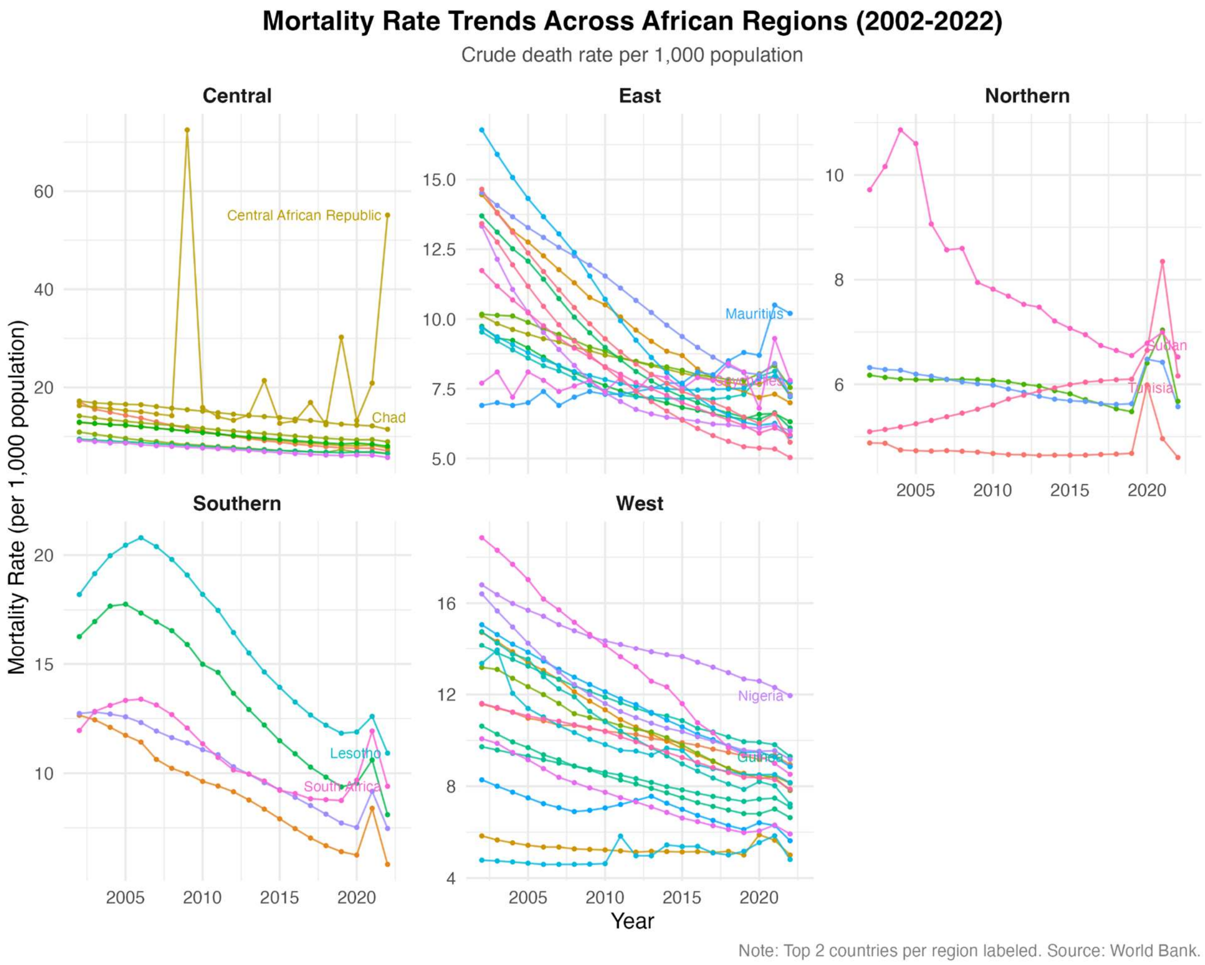


Figure 2: Mortality Rate Trends Across African Regions (2002-2022)

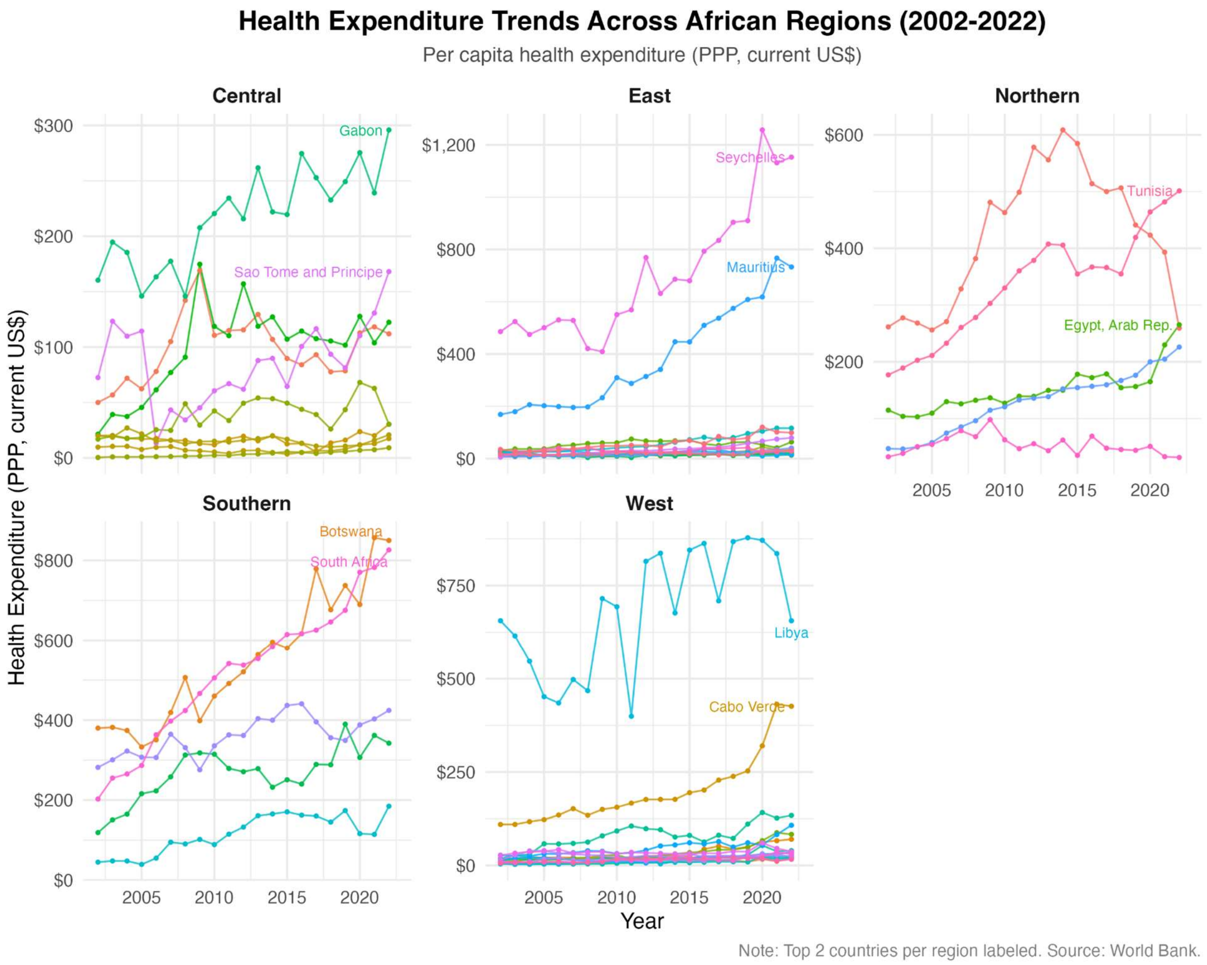


Figure 3: Health Expenditure Trends Across African Regions (2002-2022)

3.2 Continent-Wide GAMM Results

Table 3 presents the continent-wide results. The model achieves an adjusted R^2 of 92.8% and deviance explained of 93.4% (N = 1,009). The COVID-19 period is associated with a statistically significant increase of 0.46 deaths per 1,000 (SE = 0.14, p = 0.001), consistent with pandemic-related service disruptions causing excess indirect mortality beyond direct COVID-19 deaths [31, 32].

Health expenditure (lagged 1 year) shows a highly significant nonlinear association with mortality (EDF = 7.73, F = 11.30, p < 0.001; Figure 4, upper left). Mortality declines steeply as spending rises from near-zero to approximately US$80 per capita (Figure 4, upper left) — reflecting the high marginal productivity of initial primary health care investments (immunization, skilled birth attendants, oral rehydration therapy) consistent with the Grossman model's prediction of decreasing marginal product of health investment [5]. The large EDF value (7.73) confirms the nonlinear character of this relationship, which could not have been detected by linear panel estimators. Beyond approximately US$80 per capita, marginal benefits diminish sharply. Apparent upward inflections at the highest expenditure values are confined to data-sparse country-years (Seychelles, Gabon, Libya) and reflect model extrapolation rather than robust negative returns — consistent with Filmer and Pritchett's (1999) finding that efficiency and governance become binding constraints at higher spending levels [4].

Table 3: Continent-Wide GAMM Results — All Africa (N = 1,009)

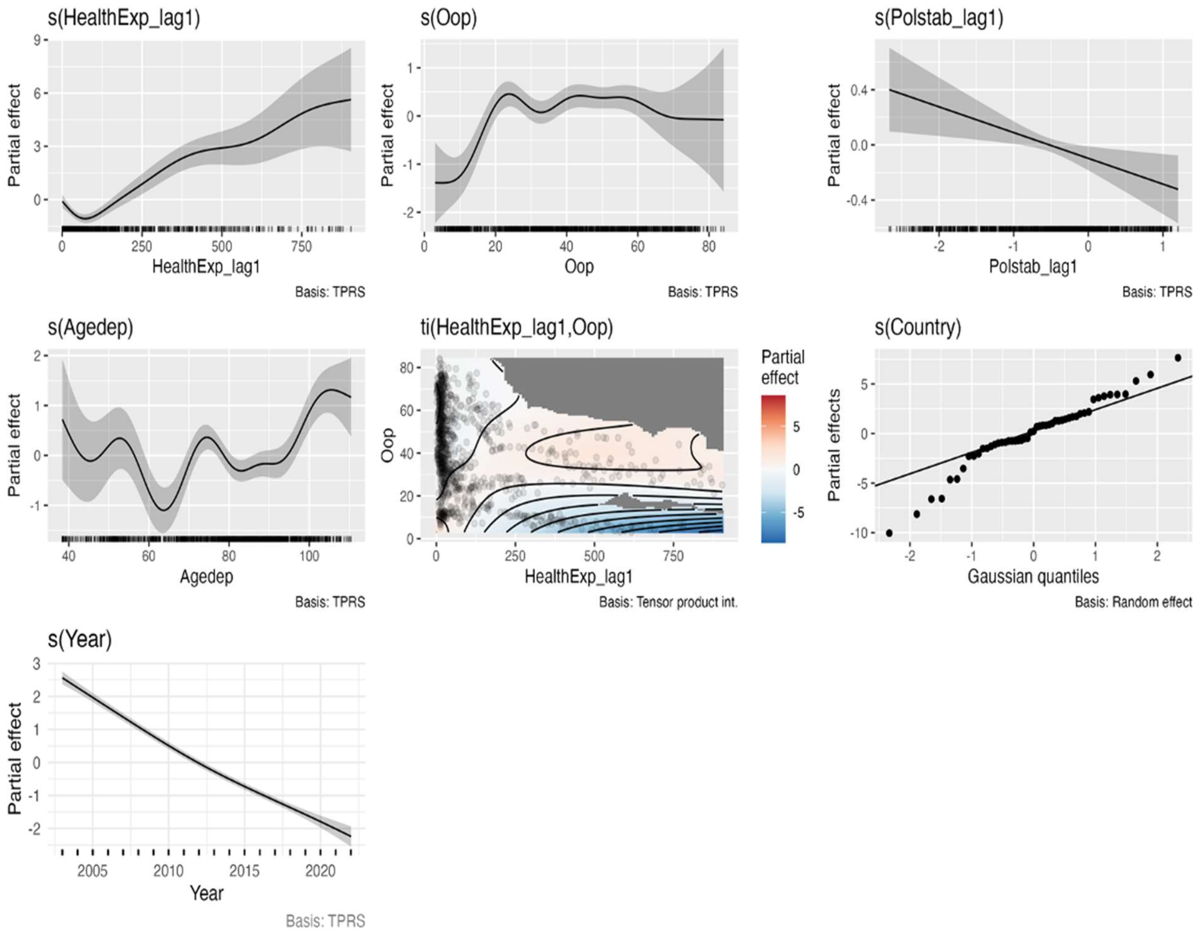
Panel A: Parametric Terms

	Est.	Std. Error	t-value	p-value	Signif.
Intercept	9.41	0.49	19.36	<0.001	***
Covid-19	0.46	0.14	3.20	0.001	**

Panel B: Smooth Terms

Term	edf	F	p-value	Signif.
Health Expenditure (lag 1)	7.73	11.30	<0.001	***
Out-of-Pocket Expenditure	8.00	7.78	<0.001	***
Political Stability (lag 1)	1.00	6.85	0.009	**
Age Dependency Ratio	8.61	13.04	<0.001	***
ti(Health Expenditure (lag 1) ,Out-of-Pocket Expenditure)	8.69	15.49	<0.001	***
Country Random Effect	49.53	87.77	<0.001	***
Year Trend	2.87	279.30	<0.001	***

EDF = Effective Degrees of Freedom (EDF = 1: linear relationship; EDF > 1: nonlinear). Adj. R2 = 92.8%; Deviance Explained = 93.4%. Significance: ***p < 0.001, **p < 0.01, *p < 0.05.



Note: Shaded areas represent 95% confidence intervals. Source: Filtered African data (mortality <20, health expenditure <1000).

Figure 4: Partial Effects of Key Predictors from the Africa-Wide GAM Analysis

The OOP share showed a complex nonlinear association with mortality (EDF = 8.00, F = 7.78, p < 0.001; Figure 4, upper middle). The partial effect increased steeply above OOP values of approximately 40%, aligning with the catastrophic health expenditure threshold and with evidence that pooled financing yields greater mortality reductions per dollar than systems financed heavily through direct user payments [18, 20]. The large EDF indicates that a linear or log-linear OOP specification would not adequately capture the observed relationship.

Political stability showed an approximately linear association with mortality (EDF = 1.00, F = 6.85, p = 0.009), with higher stability associated with lower mortality. This pattern is consistent with evidence that governance quality and public financial management influence whether health spending translates into improved health outcomes [8, 9]. The age dependency ratio showed the strongest nonlinear association in the model (EDF = 8.61, F = 13.04, $p < 0.001$), reinforcing the importance of demographic composition when comparing crude mortality across countries [10].

The tensor-product interaction between health expenditure and OOP burden was the central empirical finding of the analysis (EDF = 8.69, F = 15.49, $p < 0.001$; Figure 4, middle center). The interaction surface indicated that OOP burdens below approximately 15% of health spending strengthened the mortality-reducing returns to public investment by about 60%, whereas OOP burdens above 40% eroded a comparable share of those benefits. This extends prior evidence on the importance of pooled financing by quantifying how household financial exposure modifies the spending–mortality relationship in the African context [20]. Country random effects were large (EDF = 49.53, F = 87.77, $p < 0.001$), suggesting substantial unobserved cross-country heterogeneity in crude mortality beyond the measured covariates, consistent with evidence that institutional and socioeconomic conditions account for much of the variation in mortality across countries [4].

3.3 Regional Heterogeneity: Subregion-Specific GAMM Results

Table 4 presents regional smooth term results; Table 5 presents model fit statistics. All five models achieve high explanatory power (Adj. R2 = 93.1-98.4%), but substantial heterogeneity emerges in which predictors drive mortality variation across subregions.

The smooth effect of lagged health expenditure varied across subregions. Evidence of an expenditure–mortality association was strongest in East Africa (EDF = 8.39, F = 12.67, $p < 0.001$), followed by West Africa (EDF = 7.94, F = 5.39, $p < 0.001$) and Central Africa (EDF = 4.66, F = 2.62, $p = 0.014$). The corresponding evidence was weaker in Southern Africa ($p = 0.062$) and limited in Northern Africa ($p = 0.748$).

This gradient is structurally explained by the expenditure distribution: Central, East, and West African countries cluster predominantly below $100 per capita, within the steep portion of the continent-wide spending-mortality curve, while Southern and Northern African countries include higher-spending cases (South Africa, Botswana, Tunisia, Algeria) operating in the diminishing-returns zone. In Northern Africa, relatively more universal primary care access means that additional public spending provides limited incremental mortality reductions at the margin [36].

The age dependency ratio showed the most consistent evidence of association across the five regional models, with $p < 0.001$ in every subregion and EDF values ranging from approximately 3 to 9. This pattern indicates that demographic composition is a major cross-regional driver of crude mortality variation and should be accounted for in African health-financing analyses [10]. Political stability showed stronger evidence of association in East Africa ($p < 0.001$), West Africa ($p < 0.001$), and Southern Africa ($p = 0.002$), with weaker evidence in Central Africa ($p = 0.144$) and Northern Africa ($p \approx 0.09$). This regional pattern is consistent with evidence that conflict and instability can disrupt service delivery and increase mortality risks [26, 27].

The tensor-product interaction between public health expenditure and OOP burden showed the strongest evidence in East Africa (EDF = 9.45, F = 4.45, $p < 0.001$), weaker evidence in Northern Africa ($p \approx 0.063$), and limited evidence in the remaining subregions. The East African pattern suggests that household financial protection may modify the mortality returns to public spending in this subregion, consistent with evidence from Rwanda's community-based health insurance expansion [21]. In the interaction plots, apparent negative returns at high expenditure and low OOP levels were confined to sparse data regions involving only one to six country-year observations, including Gabon, Seychelles, Cabo Verde, Libya, and Algeria. These patterns should therefore be interpreted as model extrapolation rather than policy-reliable thresholds (Figures B1–B5).

Table 4: Regional GAMM Smooth Term Results

Panel A: Parametric Terms

Region	Variable	Est.	SE	t-val	p-value	Sig.
Central Africa	Intercept	10.29	0.61	16.89	<0.001	***
	Covid-19	0.27	0.20	1.32	0.188	
East Africa	Intercept	8.28	0.76	10.94	<0.001	***
	Covid-19	0.30	0.19	1.56	0.119	
West Africa	Intercept	9.49	0.64	14.73	<0.001	***
	Covid-19	0.39	0.18	2.09	0.037	*
Southern Africa	Intercept	11.63	0.63	18.38	<0.001	***
	Covid-19	0.64	0.34	1.86	0.067	†
Northern Africa	Intercept	5.71	0.38	15.13	<0.001	***

Region	Variable	Est.	SE	t-val	p-value	Sig.
	Covid-19	0.95	0.19	4.98	<0.001	***

Panel B: Smooth Terms

Region	Term	edf	F	p-value	Sig.
	Health Expenditure (lag 1)	4.66	2.62	0.014	*
	Out-of-Pocket Expenditure	3.28	1.37	0.246	
	Political Stability (lag 1)	3.29	1.73	0.144	
Central Africa	Age dependency Ratio	3.39	9.45	<0.001	***
	ti(Health Expenditure (lag 1),Out-of-Pocket Expenditure)	5.32	1.57	0.136	
	Country Random Effect	7.61	31.54	<0.001	***
	Year Trend	1.88	211.40	<0.001	***
	Health Expenditure (lag 1)	8.39	12.67	<0.001	***
	Out-of-Pocket Expenditure	4.08	1.46	0.216	
	Political Stability (lag 1)	1.70	7.24	<0.001	***
East Africa	Age dependency Ratio	7.06	21.44	<0.001	***
	ti(Health Expenditure (lag 1),Out-of-Pocket Expenditure)	9.45	4.45	<0.001	***
	Country Random Effect	13.56	27.76	<0.001	***
	Year Trend	3.05	145.99	<0.001	***
	Health Expenditure (lag 1)	7.94	5.39	<0.001	***
	Out-of-Pocket Expenditure	2.82	1.23	0.369	
	Political Stability (lag 1)	4.68	4.63	<0.001	***
West Africa	Age dependency Ratio	6.16	8.26	<0.001	***
	ti(Health Expenditure (lag 1),Out-of-Pocket Expenditure)	1.00	1.39	0.239	
	Country Random Effect	15.73	113.87	<0.001	***
	Year Trend	2.87	98.00	<0.001	***
	Health Expenditure (lag 1)	5.03	2.20	0.062	†
	Out-of-Pocket Expenditure	2.33	2.04	0.103	
	Political Stability (lag 1)	3.42	4.59	0.002	***
Southern Africa	Age dependency Ratio	7.86	9.48	<0.001	***
	ti(Health Expenditure (lag 1),Out-of-Pocket Expenditure)	4.10	2.01	0.119	
	Country Random Effect	3.26	14.02	<0.001	***
	Year Trend	4.97	17.61	<0.001	***
Northern Africa	Health Expenditure (lag 1)	1.00	0.10	0.748	

Region	Term	edf	F	p-value	Sig.
	Out-of-Pocket Expenditure	1.00	0.84	0.362	
	Political Stability (lag 1)	3.22	2.10	0.090	†
	Age dependency Ratio	6.48	20.13	<0.001	***
	ti(Health Expenditure (lag 1),Out-of-Pocket Expenditure)	3.40	2.38	0.063	†
	Country Random Effect	2.87	17.60	<0.001	***
	Year Trend	3.51	1.39	0.274	

EDF = Effective Degrees of Freedom. Significance: ***p < 0.001, **p < 0.01, *p < 0.05, † p<0.10

Table 5: Regional Model Fit Statistics

Model	Adj R^2	Deviance Explained	AIC	N
Central Africa	0.968	97.4%	308.3	175
East Africa	0.931	94.2%	509.4	297
West Africa	0.959	96.4%	637.3	340
Southern Africa	0.984	98.9%	141.1	97
Northern Africa	0.948	96.0%	60.8	100

Note: Higher R^2 and deviance explained indicate better model fit; lower AIC indicates better model

4. Discussion

This study shows that the health spending–mortality relationship in Africa is not uniform across the expenditure range. Public health spending was associated with the steepest mortality reductions below approximately US$80 per capita, with diminishing returns beyond this level. This pattern helps reconcile earlier studies that reported inverse spending-mortality associations but largely relied on linear or log-linear specifications [15, 16]. The GAMM estimates suggest that the mortality return per dollar is substantially larger at low spending levels than at higher levels, consistent with theoretical expectations of diminishing marginal returns to health investment [5].

The steep initial gradient likely reflects the high productivity of foundational health-system investments where baseline coverage is low. Additional public resources at low expenditure levels may finance high-impact services such as immunization, skilled birth attendance, essential medicines, and community-based management of common infectious conditions. At higher expenditure levels, the weaker marginal returns suggest that financing volume alone may become less decisive than allocative efficiency, implementation quality, and institutional capacity. This interpretation is consistent with evidence that public spending explains only part of mortality variation once socioeconomic and governance conditions are considered and that government health spending has stronger effects in countries with better governance [4, 18]. The presence of large country-level random effects in our models further indicates that similar expenditure levels can correspond to different mortality outcomes across countries, likely reflecting unobserved differences in institutional capacity, health-system organization, disease burden, and data quality.

The tensor-product interaction between public health expenditure and OOP burden is among the most policy-relevant findings of this study. The results indicate that the mortality returns to public spending depend on household financial exposure: lower OOP burdens strengthen the estimated mortality benefit of public investment, whereas higher OOP burdens weaken it. This finding is consistent with evidence that pooled financing produces stronger health gains than systems reliant on direct user payments [20]. It also aligns with behavioral and materialist theories of health, which suggest that high OOP costs reduce timely care-seeking and convert financial exclusion into preventable mortality [13, 14].

The interaction was most pronounced in East Africa, where the tensor-product term showed strong evidence of a joint expenditure–OOP association. This regional pattern is consistent with evidence from Rwanda's community-based health insurance expansion, where reduced household cost exposure was associated with improvements in child and maternal health outcomes beyond what spending increases alone would predict [21]. In other subregions, weaker evidence of the interaction should be interpreted with caution. It may reflect sparse observations in high-spending, low-OOP regions of the data rather than the absence of financial protection effects. Accordingly, the interaction surfaces are best interpreted within the observed data range, and apparent threshold patterns in sparsely populated regions should not be treated as policy-reliable estimates.

Governance and demographic structure help explain why spending returns differ across subregions. Political stability showed stronger evidence of association in East, West, and Southern Africa, supporting the view that governance conditions influence whether health budgets are converted into effective services through budget execution, supply-chain continuity, and health-worker deployment [24, 25]. In Northern Africa, weaker spending-mortality associations may reflect higher baseline health-system capacity and broader primary care coverage, where additional spending produces smaller marginal gains. In Southern Africa, the relationship between spending and crude mortality may be complicated by the long-term mortality burden of HIV/AIDS and other structural health-system pressures.

Age dependency showed the most consistent evidence of association across all five regional models. This finding reinforces the importance of accounting for demographic composition when crude mortality is the outcome, since crude death rates are directly affected by population age structure [10]. Countries with high dependency ratios may experience higher baseline mortality and greater service demand independent of health financing levels. Therefore, health financing strategies aimed at reducing crude mortality may need to be complemented by longer-term demographic and social investments, including reproductive health services, family planning, girls' education, and broader policies that reduce dependency pressures over time.

5. Conclusions and Policy Recommendations

This study used generalized additive mixed models to examine how public health expenditure, out-of-pocket (OOP) payments, governance quality, and demographic structure relate to crude mortality across 51 African countries from 2002 to 2022. Four main conclusions emerge.

First, public health spending was associated with lower crude mortality, but the relationship was nonlinear. The mortality returns were steepest at lower spending levels and diminished beyond approximately US$80 per capita. This suggests that additional public investment may produce the largest mortality gains in lower-spending settings, particularly in Central, East, and West Africa. In these subregions, increasing public health expenditure remains a priority, especially where current spending remains below basic service-coverage benchmarks.

Second, the effect of public spending depended on the level of household financial exposure. Lower OOP burdens strengthened the estimated mortality benefits of public investment, whereas higher OOP burdens weakened them. This finding indicates that increasing public health spending alone may be insufficient if households continue to face substantial direct costs at the point of care. Policies that expand pooled financing, reduce user fees for essential services, and protect households from medicine-related OOP costs should accompany increases in public expenditure.

Third, demographic composition was consistently associated with crude mortality across all regional models. Because crude mortality is directly affected by population age structure, health financing policies should account for age dependency rather than treating mortality differences as a reflection of health-system performance alone. In high-dependency settings, especially in West and Central Africa, financing strategies should be linked to investments in reproductive health, child health, and services targeted to age groups with higher mortality risk.

Fourth, the regional models showed that the mortality returns to spending varied across Africa. In Southern and Northern Africa, additional spending showed weaker marginal returns than in Central, East, and West Africa. These patterns suggest that policy priorities should differ by subregion. Where spending levels are low, expanding public investment and reducing OOP exposure may yield larger gains. Where spending returns are weaker, the priority should shift toward improving governance, budget execution, service efficiency, and targeting resources to populations with the greatest mortality risk.

This study's findings support a subregion-specific approach to health financing in Africa. Public spending remains important, but its mortality impact depends on whether households are financially protected, whether governance systems can translate budgets into services, and whether demographic pressures are explicitly addressed.

5.5 Limitations and Future Research Directions

Several limitations constrain the strength of causal claims. The study is observational and ecological; the GAMM framework flexibly captures nonlinearities and controls for key confounders through country random effects and lagged predictors but cannot establish causality. Some high-spending/low-OOP combinations are represented by very few country-year observations, and apparent mortality reversals in these sparse cells reflect model extrapolation rather than reliable policy inference. Measurement error in national health expenditure and OOP estimates — particularly in countries with weak national health accounts — may attenuate effect estimates. Unmeasured health system inputs, including workforce density, facility availability, and service quality, likely account for some portion of the country's random effect variation.

Three directions for future research follow. First, causal inference approaches exploiting major financing reform events — national health insurance law implementations or exogenous aid flow shocks — would strengthen the causal interpretation of the OOP moderation effect. Second, facility-level or individual-level studies linking financing inputs to care utilization and mortality outcomes would illuminate the household-level mechanisms behind the aggregate nonlinear effects. Third, improving data coverage in small island states and conflict-affected countries would reduce extrapolation at the high-expenditure tail. Lastly, although COVID-19 was included as a pandemic-period control, future work should incorporate other major outbreak indicators, such as the 2014–2016 West African Ebola epidemic, to better account for localized mortality shocks and health-system disruptions not captured by the current model.

5.6 Takeaway Message

The overarching message of this study is that Africa's progress against preventable mortality is determined not by how much countries spend on health, but by the combination of (a) spending above a minimum effective threshold of approximately US$80 per capita and (b) keeping OOP cost exposure below 15% of health expenditure so that households can afford to access the services that public spending provides. The single most actionable implication is that reducing OOP costs—through health insurance expansion, user fee elimination for essential services, and supply chain financing of essential medicines—must accompany, not follow, increases in public health budgets. Subregion-specific implementation of this principle, calibrated to the heterogeneous financing landscapes documented in this study, offers the most credible path to accelerating mortality reduction across Africa in the coming decade.

References

1. World Bank. Crude death rate (per 1,000 people). World Development Indicators. World Bank; 2024.

2. Our World in Data. Life expectancy in Africa is lower than on other continents. Published October 10, 2025.

3. World Bank. Life expectancy at birth, total (years) — Sub-Saharan Africa. World Development Indicators. World Bank; 2024.

4. Filmer D, Pritchett L. The impact of public spending on health: does money matter? Soc Sci Med. 1999;49(10):1309-23.

5. Grossman M. On the concept of health capital and the demand for health. J Polit Econ. 1972;80(2):223-55.

6. Njagi PG, Arsenijevic J, Groot W. Understanding variations in catastrophic health expenditure, its underlying determinants and impoverishment in sub-Saharan African countries: a scoping review. Syst Rev. 2018;7:136.

7. Asmamaw G, Tewuhibo D, Asffaw N. Out-of-pocket payment, affordability and availability of essential medicines in Africa: a systematic review. J Anal Pharm Res. 2021;10(2):58-63.

8. Rajkumar AS, Swaroop V. Public spending and outcomes: does governance matter? J Dev Econ. 2008;86(1):96-111.

9 Piatti-Fünfkirchen M, Smets L. Public financial management, health financing and under-five mortality: a comparative empirical analysis. IDB Working Paper No. 976. Washington DC: Inter-American Development Bank; 2019.

10. Bloom DE, Canning D, Sevilla J. The Demographic Dividend: A New Perspective on the Economic Consequences of Population Change. Santa Monica: RAND Corporation; 2003.

11. Rosenzweig MR, Schultz TP. Estimating a household production function: heterogeneity, the demand for health inputs, and their effects on birth weight. J Polit Econ. 1983;91(5):723-46.

12. Solar O, Irwin A. A conceptual framework for action on the social determinants of health. Geneva: World Health Organization; 2010.

13. Lynch J, Smith GD, Kaplan GA, House JS. Income inequality and mortality: importance to health of individual income, psychosocial environment, or material conditions. BMJ. 2000;320(7243):1200-4.

14. Andersen RM. A Behavioral Model of Families' Use of Health Services. Chicago: Center for Health Administration Studies, University of Chicago; 1968.

15. Anyanwu JC, Erhijakpor AEO. Health expenditures and health outcomes in Africa. Afr Dev Rev. 2009;21(2):400-33.

16. Kiross GT, Chojenta C, Barker D, Loxton D. The effects of health expenditure on infant mortality in sub-Saharan Africa: evidence from panel data analysis. Health Econ Rev. 2020;10(1):5.

17. Owusu PA, Sarkodie SA, Pedersen PA. Relationship between mortality and health care expenditure: evidence from least developed, low- and middle-income countries. PLoS ONE. 2021;16(2):e0247413.

18. Farag M, Nandakumar AK, Wallack S, Hodgkin D, Gaumer G, Erbil C. Health expenditures, health outcomes and the role of good governance. Int J Health Care Finance Econ. 2013;13(1):33-52.

19. Asmamaw G, Tewuhibo D, Asffaw N. Out-of-pocket payment, affordability and availability of essential medicines in Africa: a systematic review. J Anal Pharm Res. 2021;10(2):58-63.

20. Moreno-Serra R, Smith PC. Does progress towards universal health coverage improve population health? Lancet. 2012;380(9845):917-23.

21. Sekabaraga C, Diop F, Soucat A. Can innovative health financing policies increase access to MDG-related services? Evidence from Rwanda. Health Policy Plan. 2011;26 Suppl 2:ii52-62.

22. Wagstaff A, Neelsen S. A comprehensive assessment of universal health coverage in 111 countries: a retrospective observational study. Lancet Glob Health. 2020;8(1):e39-49.

23. Rajkumar AS, Swaroop V. Public spending and outcomes: does governance matter? J Dev Econ. 2008;86(1):96-111.

24. Piatti-Fünfkirchen M, Smets L. Public financial management, health financing and under-five mortality: a comparative empirical analysis. IDB Working Paper No. 976. Washington DC: Inter-American Development Bank; 2019.

25. Olafsdottir AE, Reidpath DD, Pokhrel S, Allotey P. Health systems performance in sub-Saharan Africa: governance, outcome and equity. BMC Public Health. 2011;11:237.

26. Druetz T, Browne L, Bicaba F, Mitchell MI, Bicaba A. Effects of terrorist attacks on access to maternal healthcare services: a national longitudinal study in Burkina Faso. BMJ Glob Health. 2020;5(9):e002879.

27. Elston JWT, Cartwright C, Ndumbi P, Wright J. The health impact of the 2014-15 Ebola outbreak. Public Health. 2017;143:60-70.

28. United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects 2022. New York: UN DESA; 2022.

29. Wood SN. Generalized Additive Models: An Introduction with R. 2nd ed. Boca Raton: Chapman & Hall/CRC; 2017.

30. Wood SN, Scheipl F, Faraway JJ. Straightforward intermediate rank tensor product smoothing in mixed models. Stat Comput. 2013;23(3):341-360.

31. Roberton T, Carter ED, Chou VB, Stegmuller AR, Jackson BD, Tam Y, et al. Early estimates of the indirect effects of the COVID-19 pandemic on maternal and child mortality in low-income and middle-income countries: a modelling study. Lancet Glob Health. 2020;8(7):e901-8.

32. World Health Organization. Pulse Survey on Continuity of Essential Health Services During the COVID-19 Pandemic: Interim Report 27 August 2020. Geneva: WHO; 2020.

33. Wood SN. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. J R Stat Soc Series B. 2011;73(1):3-36.

34. Pinheiro JC, Bates DM. Mixed-Effects Models in S and S-PLUS. New York: Springer; 2000.

35. World Health Organization. World Health Report 2010: Health Systems Financing — The Path to Universal Coverage. Geneva: WHO; 2010.

36. World Health Organization. World Health Statistics 2023: Monitoring Health for the SDGs. Geneva: WHO; 2023.

Appendix: Study Countries by UN Subregion

Appendix A

Table A1: Countries Included in the Study (N = 51 African Countries), by UN Subregion

Subregion	Countries (N in parentheses)
Central Africa (9)	Angola, Cameroon, Central African Republic, Chad, Congo Republic, Democratic Republic of Congo, Equatorial Guinea, Gabon, Sao Tome and Principe
East Africa (15)	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Seychelles, Tanzania, Uganda, Zambia
West Africa (17)	Benin, Burkina Faso, Cabo Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Libya, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo
Southern Africa (5)	Botswana, Eswatini, Lesotho, Namibia, South Africa
Northern Africa (5)	Algeria, Egypt, Morocco, Sudan, Tunisia
Excluded (3)	Somalia, South Sudan, Zimbabwe — excluded due to extreme data sparsity and severe measurement concerns

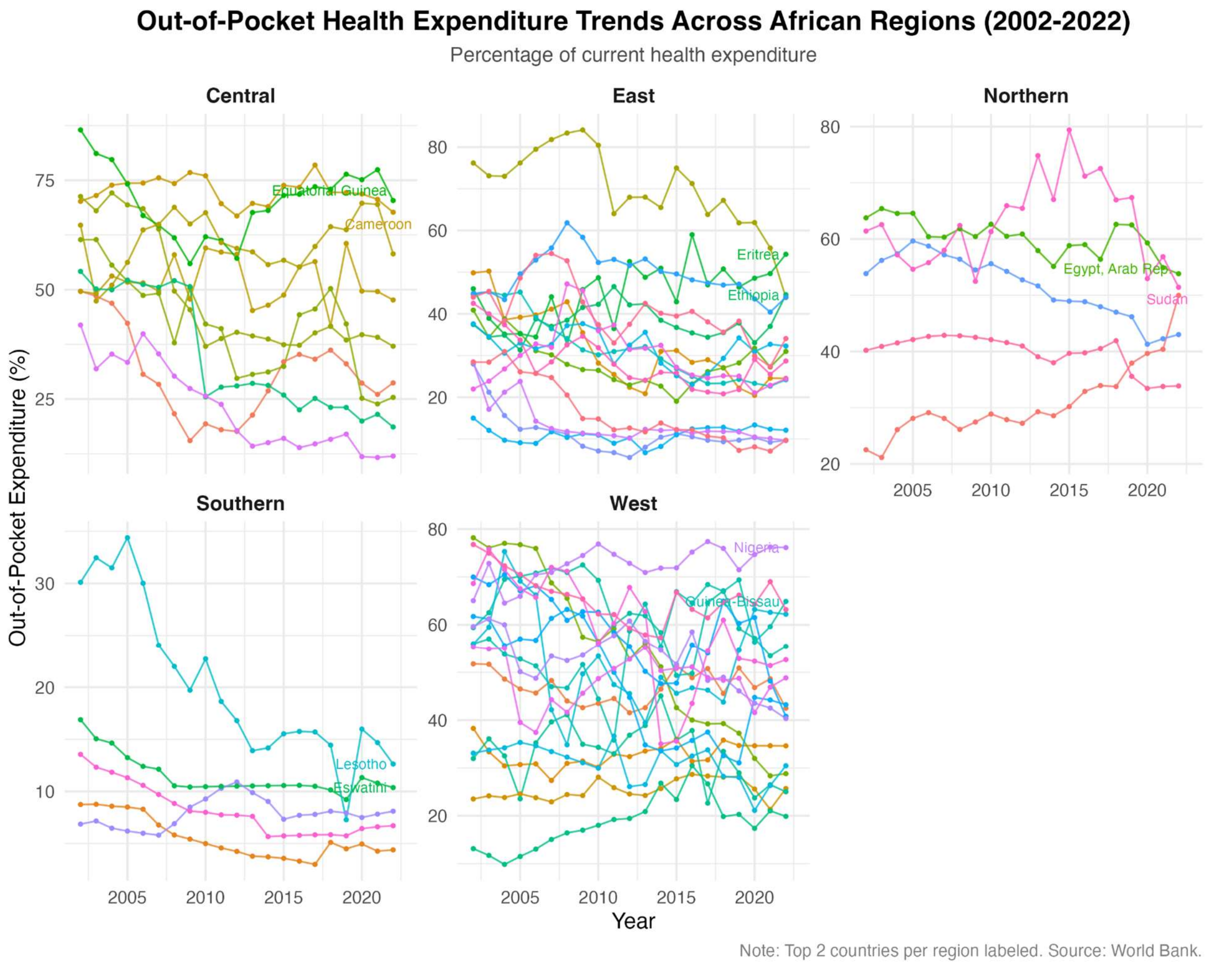


Figure A1: Out-of-Pocket Health Expenditure Trends Across African Regions (2002-2022)

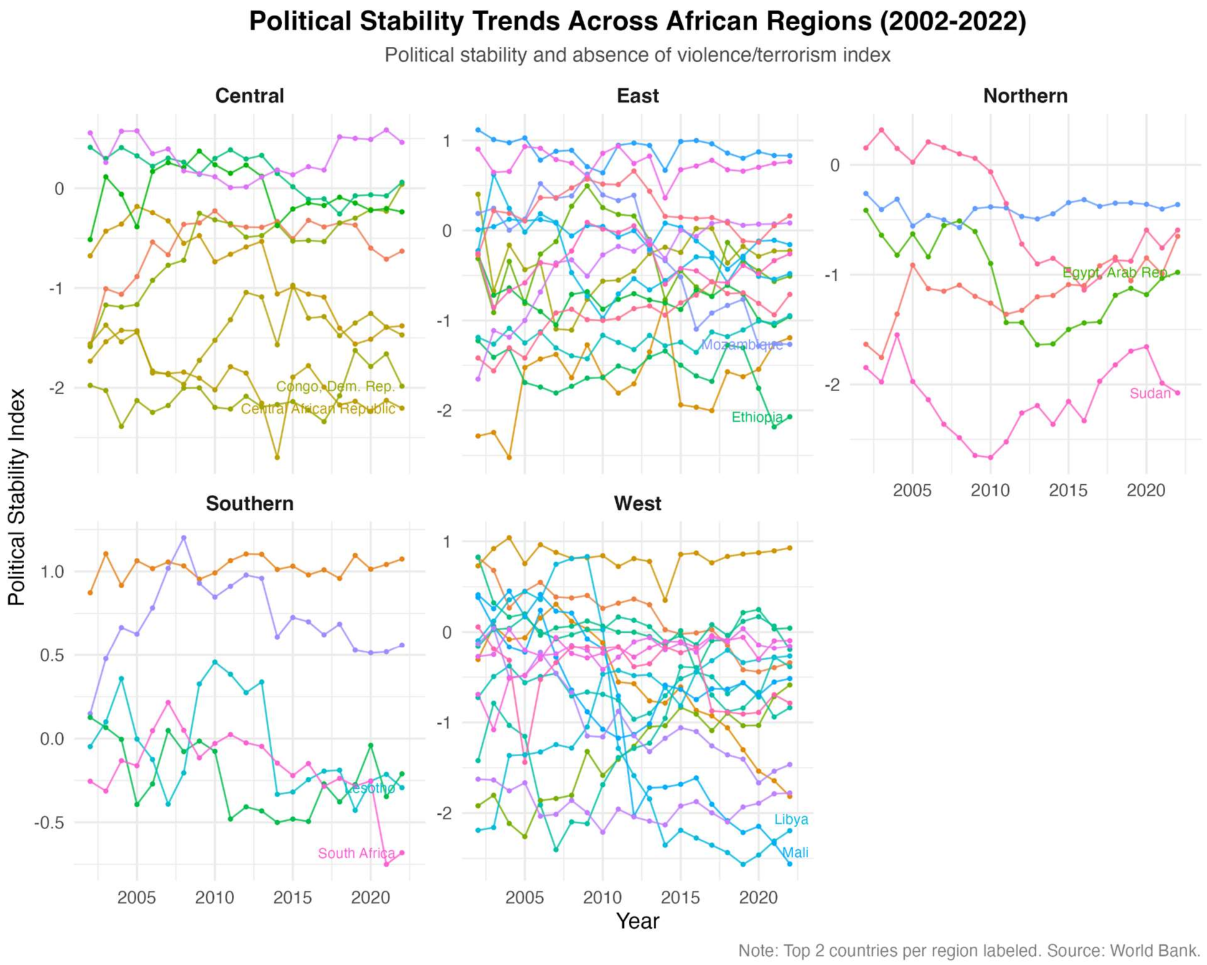


Figure A2: Political Stability Index Trends Across African Regions (2002-2022)

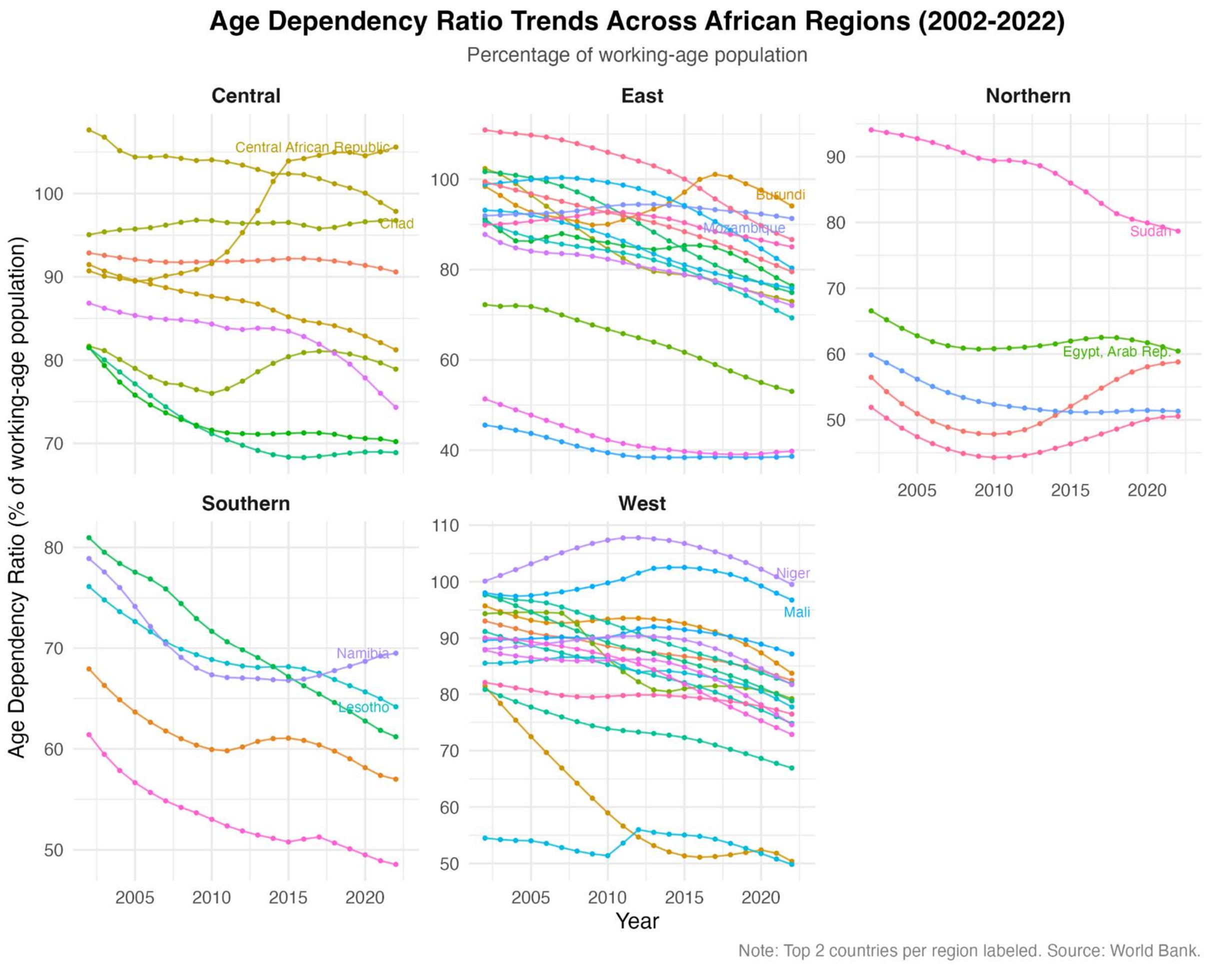


Figure A3: Age Dependency Ratio Trends Across African Regions (2002-2022)

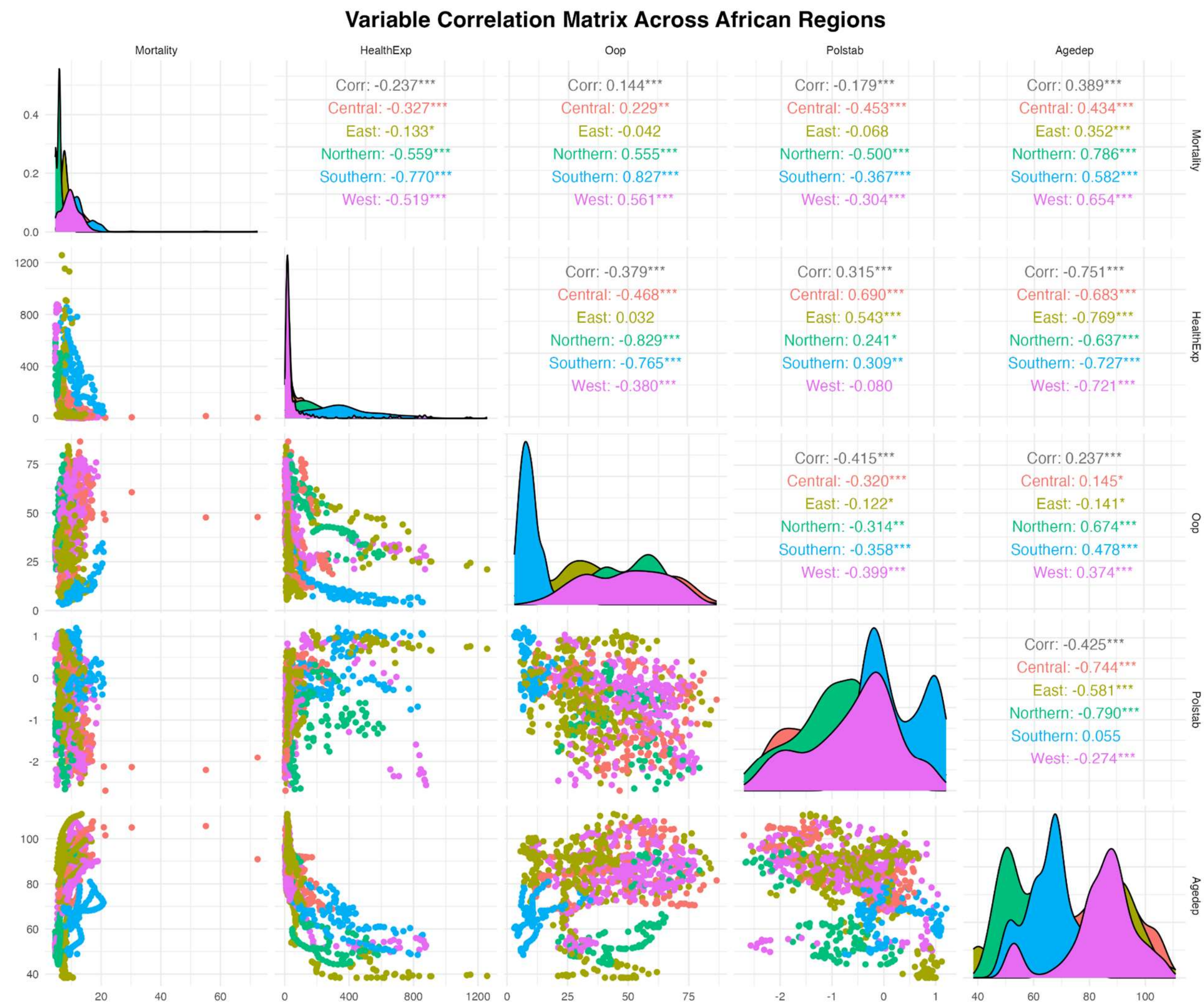


Figure A4: Correlation Matrix Across African Regions (2002-2022)

Appendix B

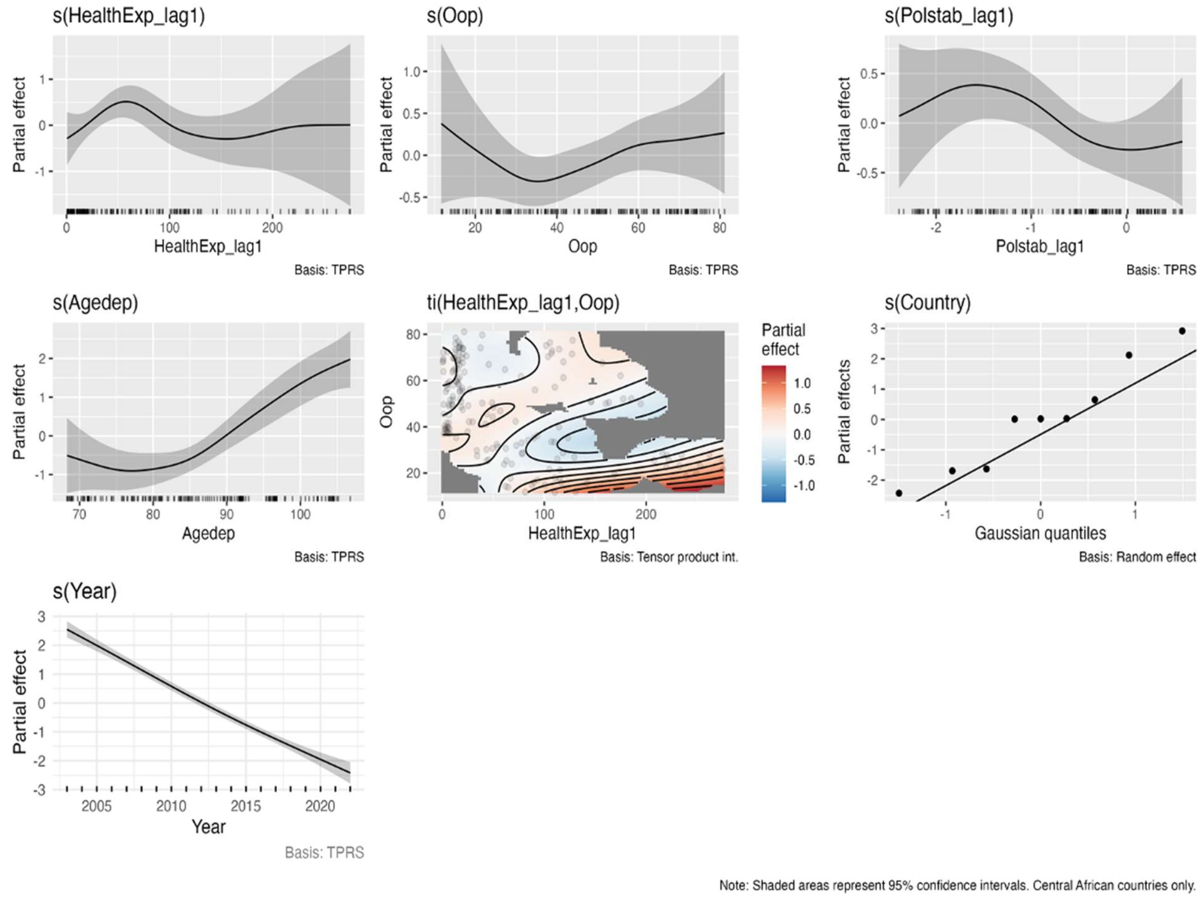


Figure B1: Partial Effects of Key Predictors from the Central Africa GAM Analysis

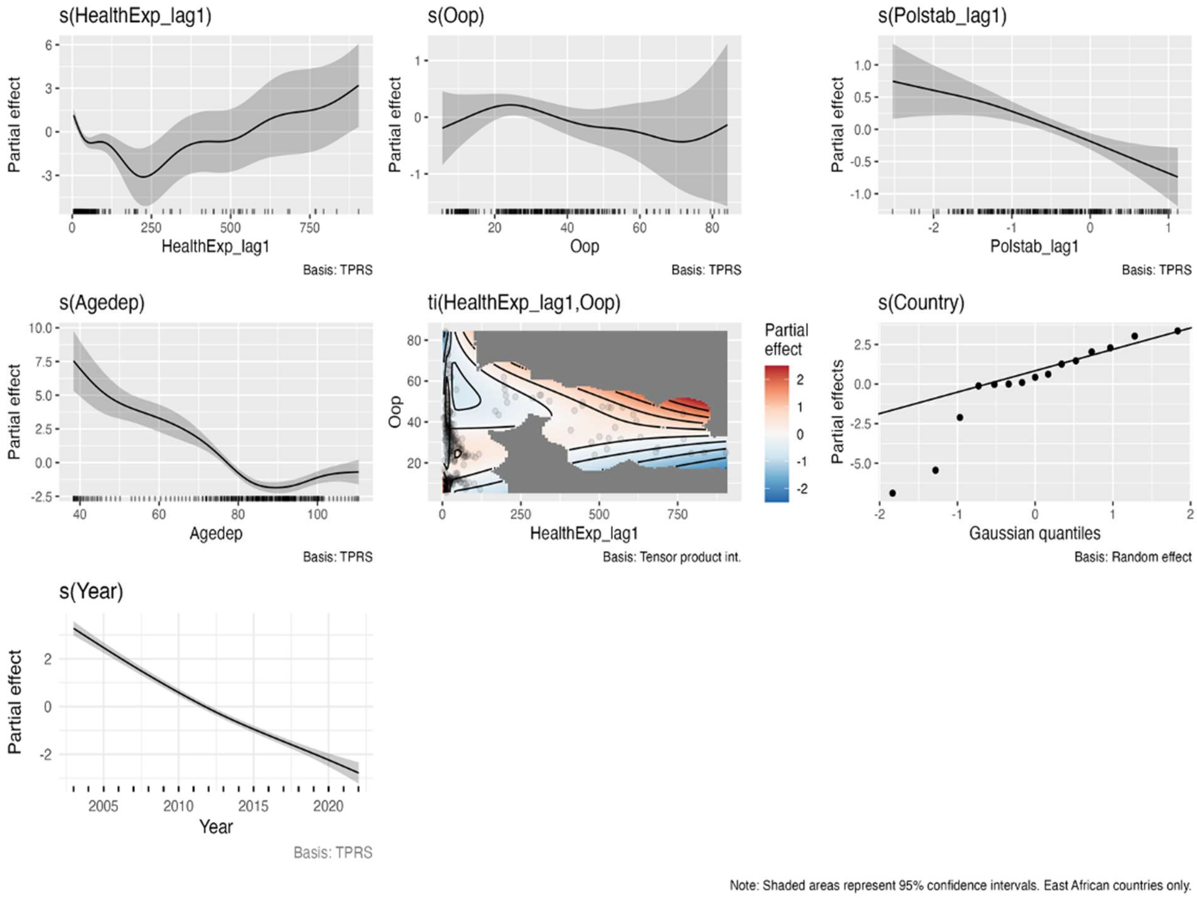


Figure B2: Partial Effects of Key Predictors from the East Africa GAM Analysis

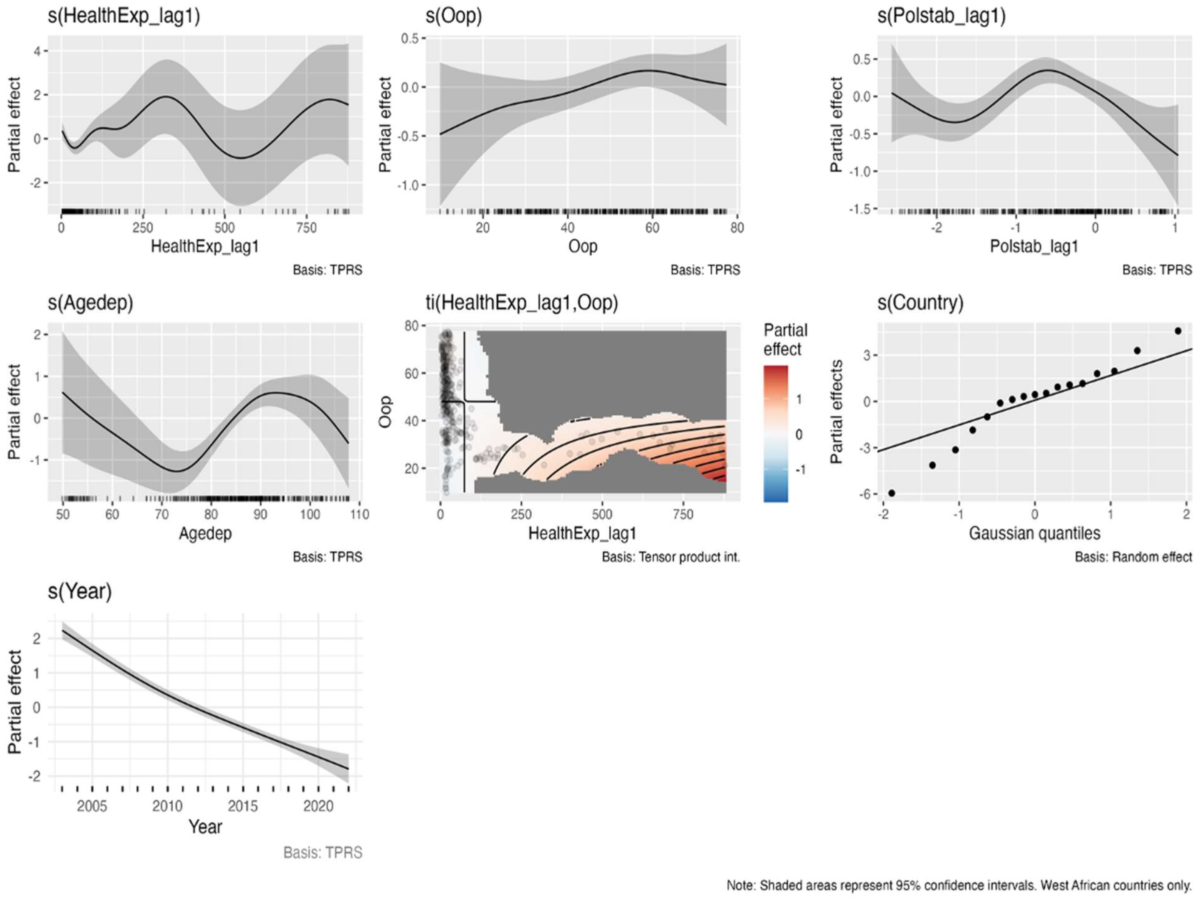


Figure B3: Partial Effects of Key Predictors from the West Africa GAM Analysis

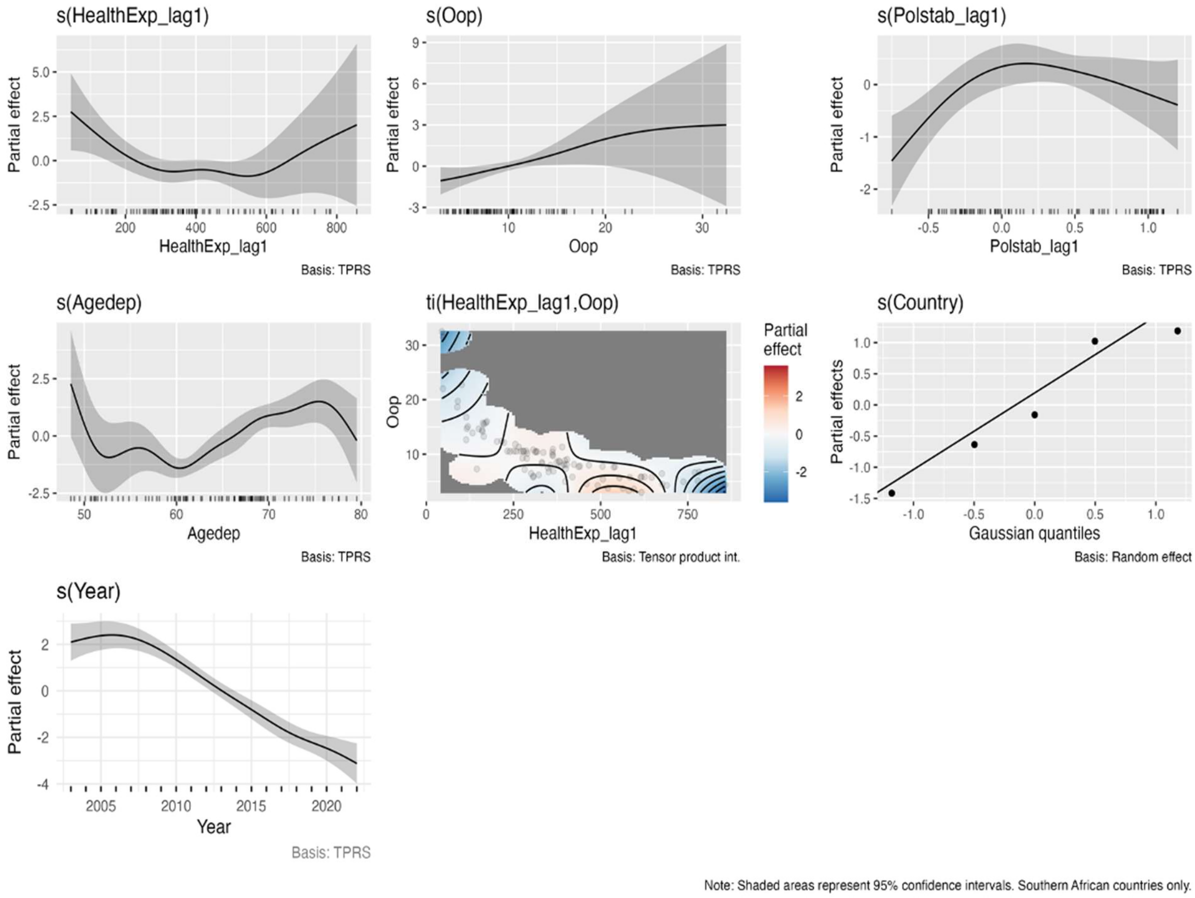


Figure B4: Partial Effects of Key Predictors from the Southern Africa GAM Analysis

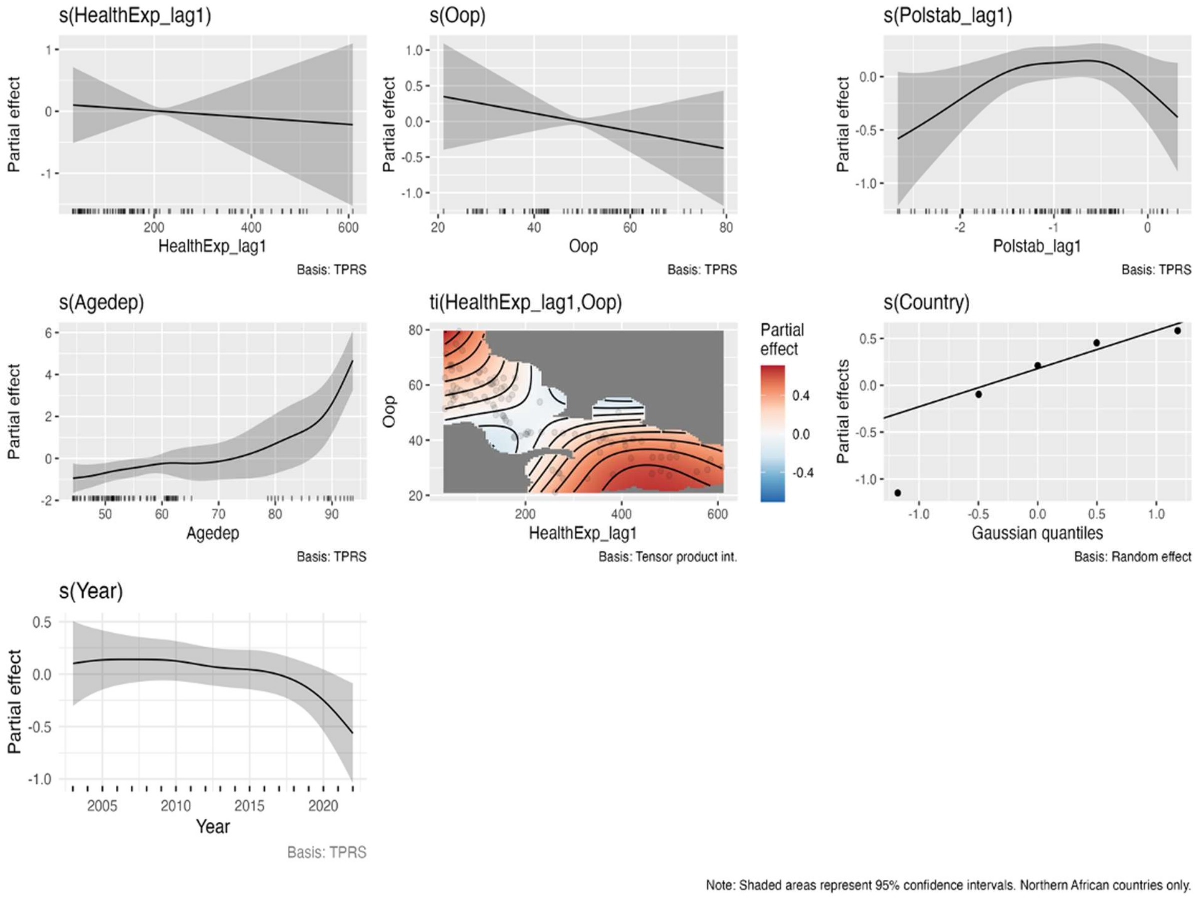


Figure B5. Partial Effects of Key Predictors from the Northern Africa GAM Analysis