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Economic and healthcare determinants of under-five mortality in low-income countries

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Abstract

Background Under-five mortality (U5MR) remains a critical development challenge, particularly in low-income countries (LICs), where children face the highest risk of preventable deaths. This study explores the influence of three key variables, per capita Gross Domestic Product (PGDP), DTP1 immunisation coverage, and Government Healthcare Expenditure (GHE), on U5MR across 19 LICs from 2000 to 2020, providing a clearer understanding of their individual and combined effects.

Methods A balanced panel dataset was analysed using both fixed-effects and random-effects panel regression models. Additionally, country-level insights were derived through multiple linear regression (MLR) to capture variations across different LIC contexts.

Results The analysis revealed a strong inverse relationship between PGDP and U5MR, highlighting the role of economic growth in improving child survival. DTP1 immunisation coverage showed mixed effects, positively linked to reduced mortality in most LICs, but unexpectedly associated with higher U5MR in specific contexts like Malawi and the Central African Republic, suggesting challenges in access or implementation. Similarly, GHE showed varied impacts, with some countries benefiting significantly, while others demonstrated weaker or adverse effects, likely due to inefficiencies in spending.

Conclusions The findings highlight that reducing U5MR in LICs requires more than isolated actions. It calls for combined strategies that connect economic improvements with fair healthcare investments and better immunisation delivery. Policymakers must design context-specific solutions to ensure lasting and meaningful progress in child health outcomes.

Keywords Immunisation, Government healthcare expenditure, Low-income countries, Under-five mortality rate, Panel data analysis

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Introduction

The Under-Five Mortality Rate (U5MR) is a growing concern worldwide and is one of the most essential indicators used to evaluate a nation's social well-being, health status, and quality of life [1, 2]. Over the past few years, a substantial reduction in U5MR has been observed globally, driven by better allocation of resources, economic development, and focused global health initiatives such as the Millennium Development Goals (MDGs) [3–5]. The implementation of health policies and increased government healthcare expenditure, along with improvements in maternal care and education [6], governance, and environmental factors, has helped reduce U5MR significantly [7, 8].

However, despite these improvements, hardly any studies have examined the combined impact of Gross Domestic Product per capita (PGDP), DTP1 vaccination coverage, and Government Healthcare Expenditure (GHE) in a unified framework, particularly in the context of low-income countries (LICs). While some research has been conducted in broader regional contexts such as Sub-Saharan Africa, there remains a clear gap in studies that assess the individual and combined effects of these variables across specific LICs. Moreover, there is a notable scarcity of studies that investigate these relationships using country-level data over a 21-year period. This study aims to fill that gap by evaluating how PGDP, DTP1, and GHE jointly influence U5MR in 19 LICs from 2000 to 2020, providing both cross-national insights and granular country-wise understanding of child mortality determinants in low-resource settings.

Understanding the combined influence of these indicators is essential for policymakers, researchers, and development practitioners who aim to reduce child mortality through more targeted and effective strategies. While existing studies often examine economic output, healthcare expenditure, or immunisation coverage in isolation, this study uniquely integrates all three variables to reflect the complex, real-world interactions that shape child health outcomes in low-income settings. By employing both panel regression and multiple linear regression models, the study not only uncovers macro-level regional patterns but also allows for country-specific interpretations. These findings have strong practical implications for guiding policy reforms, budgeting priorities, and public health interventions across 19 LICs. Specifically, the insights can inform how governments allocate healthcare resources more efficiently, strengthen vaccination outreach efforts, and design economic policies that support child survival and improved health equity in low-income contexts.

The objective of this study is to examine how economic output (PGDP), government GHE, and DTP1 vaccination coverage collectively influence U5MR in LICs. It is hypothesised that higher levels of GHE and increased DTP1 vaccination coverage will significantly reduce U5MR, as these represent direct investments in healthcare infrastructure and access. Meanwhile, the impact of economic output is expected to be more variable, depending on how equitably income is distributed and how effectively economic gains are converted into tangible improvements in public health services.

Figure 1 below illustrates the overall trends in U5MR, PGDP, DTP1, and GHE across LICs from 2000 to 2020, based on data related to Table 1 (further annexed in S1) highlighting the comparative patterns and shifts that inform this study's focus.

Trends in U5MR across different income levels

Globally, U5MR has shown a significant decline over the past two decades, with several LICs and lower-middle-income countries (LMICs) achieving reductions of more than two-thirds since 2000. This progress has largely been attributed to improved healthcare programs, expanded access to vaccinations, and targeted government interventions in subsidizing health services [9]. The adoption of sustainable and strategic health measures has further contributed to reducing child mortality through more effective resource allocation. Nevertheless, children in low- and lower-middle-income countries continue to bear a disproportionate share of the global under-five mortality burden when compared to those in high-income countries [10]. Importantly, progress has been made at the country level, with twelve LICs and LMICs achieving MDG 4 by reducing U5MR by at least two-thirds [11]. Despite income-based disparities, U5MR has exhibited an overall downward trend across all income groups between 2000 and 2020.

Variations in GDP per capita across income categories

Between 2000 and 2020, PGDP trends have exhibited sharp variations across income groups. The 2008 global financial crisis marked a turning point, particularly for high-income countries (HICs), where declines in structural capital and national intellectual capital severely hindered economic growth [12]. During this period, the reliance on complex financial instruments increased exposure to risk, aggravaing the economic downturn [13, 14]. From 2010 to 2015, despite strong employment growth, PGDP in some regions rose only modestly [15]. While developing countries continued to support global growth, their post-crisis contributions were approximately 2% points lower than in pre-crisis years [16]. Notably, PGDP across income categories displayed considerable fluctuation during the 2000–2020 period, with a marked downward trend from 2018 to 2020 indicating renewed economic pressures affecting both high- and low-income nations.

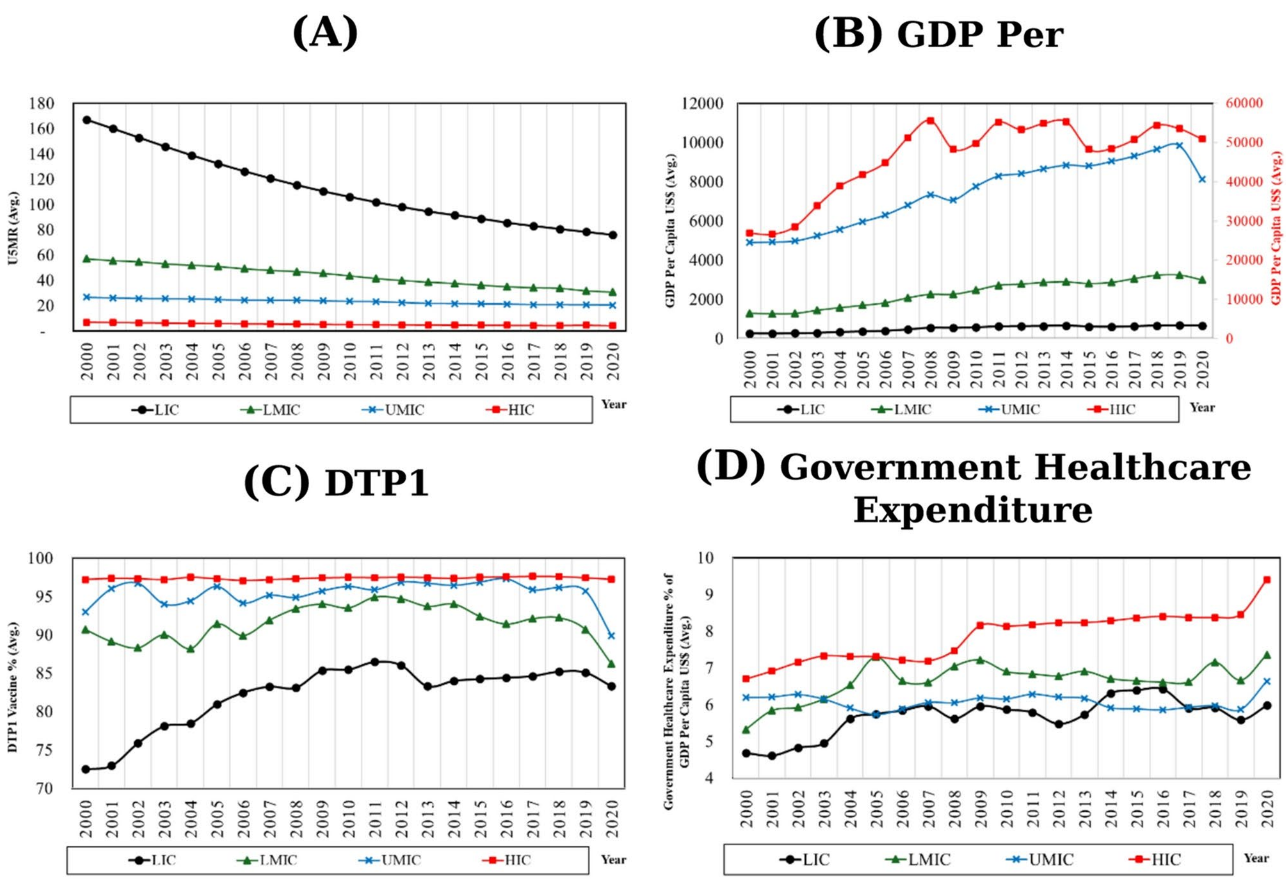

Fig. 1 The overall trend of U5MR, PGDP, DTP1 and GHE for LICs from 2000-2020. Source: Authors' illustrations based on data

Table 1 Data sources and variables

Variables Type	Variables	Measurement	Data Sources
Dependent Variable	U5MR	Number of deaths of children under five years old per 1000 live births	UNICEF https://data.unicef.org/topic/child-survival/under-five-mortality/
Independent Variables	Gross Domestic Product	Per capita GDP in U.S. dollars	World Bank https://data.worldbank.org/indicator/NY.GDP.PCAP.CD
	Immunisation Coverage	Percentage % of DTP1 immunisation vaccine given to children under-age 5	UNICEF https://data.unicef.org/topic/child-health/immunization/
	Government Healthcare Expenditure	Government expenditure on healthcare from percentage % of GDP	World Bank https://data.worldbank.org/indicator/SH.XPD.GHED.GD.ZS

Source: Authors' illustration based on [2] and World-Bank [69]

Examine disparities in DTP1 vaccine across income strata

Disparities in DTP1 vaccine coverage between income groups have persisted throughout the 2000–2020 period, with LICs consistently reporting the lowest levels [17]. The COVID-19 pandemic in 2020 further deepened these disparities due to reduced healthcare workforce availability, shortages of personal protective equipment, and disruptions in immunisation supply chains [18]. These challenges led to significant declines in vaccine uptake and delayed distribution, particularly in vulnerable regions. To mitigate these setbacks, international agencies have recommended catch-up vaccination campaigns, enhanced monitoring of immunisation performance, and the intensification of routine immunisation efforts [19]. Although the long-term trend indicates improvements in DTP1 coverage, periodic dips, particularly between 2018 and 2020, emphasise persistent systemic barriers.

Challenges in GHE among income levels

Healthcare spending remains unevenly distributed across income categories. HICs, such as the United States, consistently spend more per capita on healthcare compared to LICs [20]. In response to the COVID-19 pandemic, global government healthcare expenditure surged by US $9 trillion in 2019, with HICs leading the increase [21]. LICs, however, continued to face difficulties in sustaining external aid and strengthening pandemic preparedness. Notably, government health spending rose considerably between 2007 and 2009 in HICs as part of economic recovery efforts [22]. While GHE continues to rise in LMICs, recent trends show LICs have begun to outpace upper-middle-income countries (UMICs) in terms of growth rates.

According to UNIGME, global U5MR declined from 12.6 million to 5.4 million between 1990 and 2017 [23]. However, Sub-Saharan Africa (SSA), home to 24 of the 48 LICs [24], continues to account for nearly half of all global under-five deaths [25, 26]. Despite some regional improvements, countries within SSA continue to face considerable barriers to child survival, including poverty, poor sanitation, and lack of access to clean water [27, 28]. In these settings, low PGDP restricts household incomes and limits access to nutritious food, intensifying child malnutrition [29]. As the first point of contact with immunisation systems, DTP1 coverage serves as a critical measure of national immunisation performance [30, 31]. Ignoring such programs can lead to devastating health consequences for under-five children, particularly in vulnerable regions.

To contextualise the study, data were collected from 19 low-income countries, 90% of which are in SSA, over a 21-year period (2000–2020). These countries were selected due to their disproportionately high burden of under-five mortality and systemic health financing challenges. The findings of this study are expected to inform policy efforts by highlighting how targeted improvements in economic output, vaccination coverage, and healthcare investment can jointly contribute to lowering U5MR in similar low-resource settings.

This study is guided by multiple theoretical perspectives that support the selection of the study variables. The Preston Curve posits that increases in national income (PGDP) are associated with improvements in population health, particularly in low-income settings. The Social Determinants of Health framework underscores the influence of social and economic environments, such as healthcare spending (GHE), on health outcomes. Sen's Capability Approach emphasizes the role of healthcare access and immunisation (DTP1) in expanding individual freedoms and well-being. Finally, Human Capital Theory views investments in health and education as essential drivers of economic productivity and survival. These frameworks collectively justify the inclusion of PGDP, GHE, and DTP1 as key determinants of U5MR.

The remainder of this article are classified as follows: Section two explores the theoretical framework to evaluate the economic impact, and the impact of DTP1 and GHE on U5MR through theories. Section three describes the literature review, while section four elaborates on the data. Section five evaluates the methodology and section six examines the findings and discussions. Practical implications of the study are examined in detail in section seven, followed by a section dedicated for limitations and future research directions. Finally, the paper ends with a concise conclusion.

Theoretical framework

This study is grounded in four theoretical frameworks that collectively explain the potential impact of PGDP, DTP1, and GHE on U5MR in LICs.

First, the Preston curve illustrates the relationship between national income, which is measured by PGDP and U5MR, where an increase in PGDP leads to enhanced healthcare facilities, further improving health outcomes and cutting down the rate of under-five deaths [32]. Second, social determinants of health framework imply the impact of economic, environmental and social factors on health outcomes [33]. Third, Sen's capability approach, which determines the capability of an individual to achieve value in their life, improves the individuals' ability and capability through economic and social factors such as education, healthcare and social security [34]. Fourth, human capital theory refers to investments focused on health and education in terms of improving health outcomes where it is heavily influential on mortality rates by developing the medical field and quality of health [35]. These frameworks collectively offer a multidimensional lens to understand how economic capacity, healthcare systems, and immunisation access influence child mortality across LICs.

Literature review

PGDP as a determinant of U5MR

Child mortality remains disproportionately high in the world's poorest countries, particularly LICs, where systemic issues such as poor nutrition and inadequate healthcare infrastructure persist [36–38]. U5MR is widely regarded as a reliable proxy for assessing child health and overall societal well-being, capturing deficiencies in both healthcare systems and socioeconomic development [1]. Research confirms a significant negative relationship between PGDP and U5MR, with studies reporting that a 1% increase in PGDP can reduce U5MR by up to 0.093% [39]. This finding is further supported by evidence highlighting a strong inverse association between PGDP and child mortality [40, 41].

Despite this trend, the relationship is not always straightforward. It has been observed that U5MR tends to rise sharply during economic downturns, illustrating how fragile health gains can be in LICs with limited fiscal resilience [32, 42]. Studies in Uganda [43, 44] and Sierra Leone [45] demonstrate how extremely low PGDP restricts public investments in maternal and child health. On the other hand, higher PGDP can facilitate broader access to maternal education, prenatal services, and postnatal care [46, 47]. Income improvements have been found to increase care-seeking behaviours and enhance child survival rates [48]. Moreover, female labour force participation, often associated with stronger economic conditions, has been shown to contribute to better child health outcomes [49].

However, during recessionary periods, LICs often face constrained healthcare delivery due to reduced revenues and weakened infrastructure. In such contexts, even modest declines in PGDP can have adverse effects on child survival, reinforcing the need for economic stability and inclusive growth policies.

Immunisation as a determinant of U5MR

Immunisation plays a critical role in preventing child deaths and improving public health outcomes. Between 2000 and 2020, vaccination programmes prevented approximately 37 million deaths in low- and middle-income countries [50]. Improved coverage of key vaccines such as DTP1 is strongly associated with reductions in U5MR [51]. Studies conducted in Ghana and Tanzania show that increased DTP1 uptake resulted in significant declines in child mortality [52, 53].

Nonetheless, challenges persist in achieving full vaccine coverage in LICs. In many rural areas, logistical barriers limit access to vaccines [54], while delays or improper administration of DTP1 can diminish its protective effects or even exacerbate health risks [55]. Interestingly, in some contexts, U5MR was paradoxically found to be higher among vaccinated children, suggesting that other contextual factors such as malnutrition or inadequate healthcare might undermine the benefits of immunisation [54]. These mixed findings highlight the importance of improving vaccine delivery systems and addressing contextual health inequities to maximise immunisation effectiveness.

GHE as a determinant of U5MR

GHE is a critical determinant of child health in LICs. Higher GHE is generally associated with improved access to skilled birth attendance, maternal care, immunisation services, and child nutrition programmes [56, 57]. Studies affirm that greater investment in health systems contributes to lowering U5MR [58–62].

However, the impact of GHE is heavily dependent on how resources are allocated. It has been argued that governance quality and institutional capacity determine whether increased spending translates into better health outcomes [7, 57]. Some studies even report contradictory findings. While GHE can lower U5MR, it has been found to have minimal effect on overall life expectancy [63]. Similarly, in some settings, increased GHE has correlated with higher U5MR, potentially due to inefficiencies, corruption, or misallocated resources [64–66].

Education and employment indirectly influence child health outcomes by enhancing health literacy and care-seeking behaviour. Female education, in particular, has been shown to improve maternal health decisions and uptake of antenatal care [67, 68].

Although substantial literature exists on the individual roles of PGDP, DTP1, and GHE in reducing U5MR, very few studies examine the combined effects of these determinants within a single analytical framework, especially in the LIC context. Even where studies have been conducted within SSA, most have failed to undertake disaggregated, country-level analysis over extended time periods. This study aims to address this research gap by exploring the individual and joint impacts of PGDP, DTP1, and GHE on U5MR across 19 LICs over a 21-year span. By integrating these variables in a unified model and applying both panel and multiple regression techniques, this research provides new insights that are context-specific and policy-relevant.

Data

Table 1 provides a detailed description of the variables used in this study and the data sources from which reliable data was collected.

To conduct an impactful examination, this study uses a panel data set comprising 19 LICs from 2000 to 2020, taken into account where the data has no gaps, resulting in a strongly balanced dataset giving much more accurate results. The data file used to conduct the study is presented in the S1 Appendix.

Methodology

Panel regression is a set of two-dimensional cross-section data consisting of time and space [70]. The following Eq. 1, is used to examine the impact of PGDP, DTP1 and GHE on U5MR for the low-income context, where in generating results that concluded both Fixed Effects (FE) and Random Effects (RE) models, which is a much better determinant when it comes to assessing data in a larger group. Further, this can be simply identified as the data set is formed by intercepting certain value characteristics of *i* objects at *t* different times nodes.

$$U5MR_{it} = \beta_0 + \beta_1 PGDP_{it} + \beta_2 DTP1_{it} + \beta_3 GHE_{it} + \varepsilon_{it} \tag{1}$$

In the equation, t denotes the time span that is under consideration. The subscript i shows the country or region as well as the standard error which ϵ_{it} included. The intercept and the coefficients of variables is denoted as β_0, β_k and α_0, α_k.

$$U5MR_t = \alpha_0 + \alpha_1 PGDP_t + \alpha_2 DTP1_t + \alpha_3 GHE_t + \varepsilon_t \tag{2}$$

The MLR model was used to generate results, which are much more effective in assessing the impact individually over a period of time since the characteristics of both space and time dimensions of the widespread impact can be separately explored [71]. Equation 2, was included to assess the country-specific impact of PGDP, DTP1 and GHE on U5MR.

As mentioned above, this exploration uses panel regression to examine the dataset and the focal point of this analysis is to articulate if PGDP, DTP1 and GHE impact U5MR. There are several benefits of panel data analysis. First, the identification and discrimination between competing hypotheses where it evaluates different possible scenarios and justifies which one is the most accurate based on evidence [72]. Second, the elimination or reduction of estimation bias where it ensures the clarity in which the estimation is accurate and does not lean towards specific estimation [73]. Third, reducing the problems of data multicollinearity where the issue is addressed regarding the independent variable being highly correlated which can make the coefficients unreliable [74]. Further, this issue can be addressed by removing variable s that are similar or simply combining them as one.

Before the models were tested, the stationarity and stability of the dataset were examined using Panel Vector Autoregression and the Levin Lin Chu unit root test [75, 76]. The results from the Levin Lin Chu test indicated that all variables were either stationary at level or became stationary after first differencing, confirming their appropriateness for use in panel regression analysis. This ensured the validity of the long-run relationships among the variables and the reliability of subsequent model estimations.

Moreover, the next step is testing out the specification tests to determine which models of FE, RF or Pool ordinary least squares can be used, which is a series of tests such as Breusch Pagan Test, Hausman Test and the F test [77]. The Breusch-Pagan LM test is used to determine whether a random effects (RE) model is preferred over a simple pooled OLS model by checking if significant variance exists across entities. The F-test evaluates whether a fixed effects (FE) model is more suitable than pooled OLS by testing if all intercepts are the same across entities. The Hausman test then compares the FE and RE models to determine which one is more appropriate; it checks whether the unique errors (unobserved effects) are correlated with the explanatory variables. If they are, the FE model is preferred, as it provides consistent estimates. These tests collectively ensured that the choice of the FE model in this study was statistically justified and theoretically appropriate.

Based on the results of the specification tests, particularly the Hausman test, the FE model was selected as the primary model for interpretation. The Hausman test revealed significant differences between the FE and RE estimators, suggesting that the unobserved country-specific effects were correlated with the independent variables, thus favouring the FE model. This aligns with the theoretical reasoning, as the countries in our sample possess unique structural and institutional characteristics that do not vary over time but may influence U5MR. Therefore, using the FE model allows us to control for such time-invariant heterogeneity and obtain more consistent estimates. However, results from the RE and pooled OLS models were also reported to ensure robustness and transparency in comparison. After the model is chosen, the model is tested out to gain the results to further evaluate and expand this study.

The analysis was conducted using robust standard errors, which help mitigate issues related to heteroscedasticity. Additionally, the relatively large and balanced panel sample contributed to reducing potential concerns related to non-normality and multicollinearity. Although larger samples help minimize collinearity issues by improving the stability of the variance and reducing interdependence among predictors [78, 79]. Variance Inflation Factor (VIF) scores were also calculated to confirm that multicollinearity remained within acceptable thresholds. These steps collectively support the robustness and reliability of the model estimations in the current study.

Results and discussions

The FE model was selected for the main analysis, as justified by specification tests detailed in the methodology. Summary statistics were generated for the LICs as a whole and on a country-wise basis to enable a clearer understanding of the behavioural patterns of each variable. The descriptive statistics, which are presented in S2 Appendix, include the number of observations, the mean value, standard deviation, and the minimum and maximum values of DTP1, PGDP, GHE, and U5MR respectively. Within the low-income context, the average U5MR is 112.0665, the mean PGDP is 506.7719, while DTP1 and GHE average at 82.1579 and 1.2370 respectively. Country-wise, the highest mean values are recorded for GHE in Burundi (2.1543), DTP1 in Rwanda (97.0952), and PGDP in Chad (682.5238). Figure 2 presents the behavioural trends of U5MR, PGDP, DTP1 and GHE over the period from 2000 to 2020.

To evaluate the relationship between each determinant and U5MR, Fig. 3 presents the regression plots for all 19 LICs. These visual representations supplement the empirical findings and assist in observing the impact pathways.

Table 2 highlights the percentage change in the trend of U5MR among 19 LICs categorised into two time periods

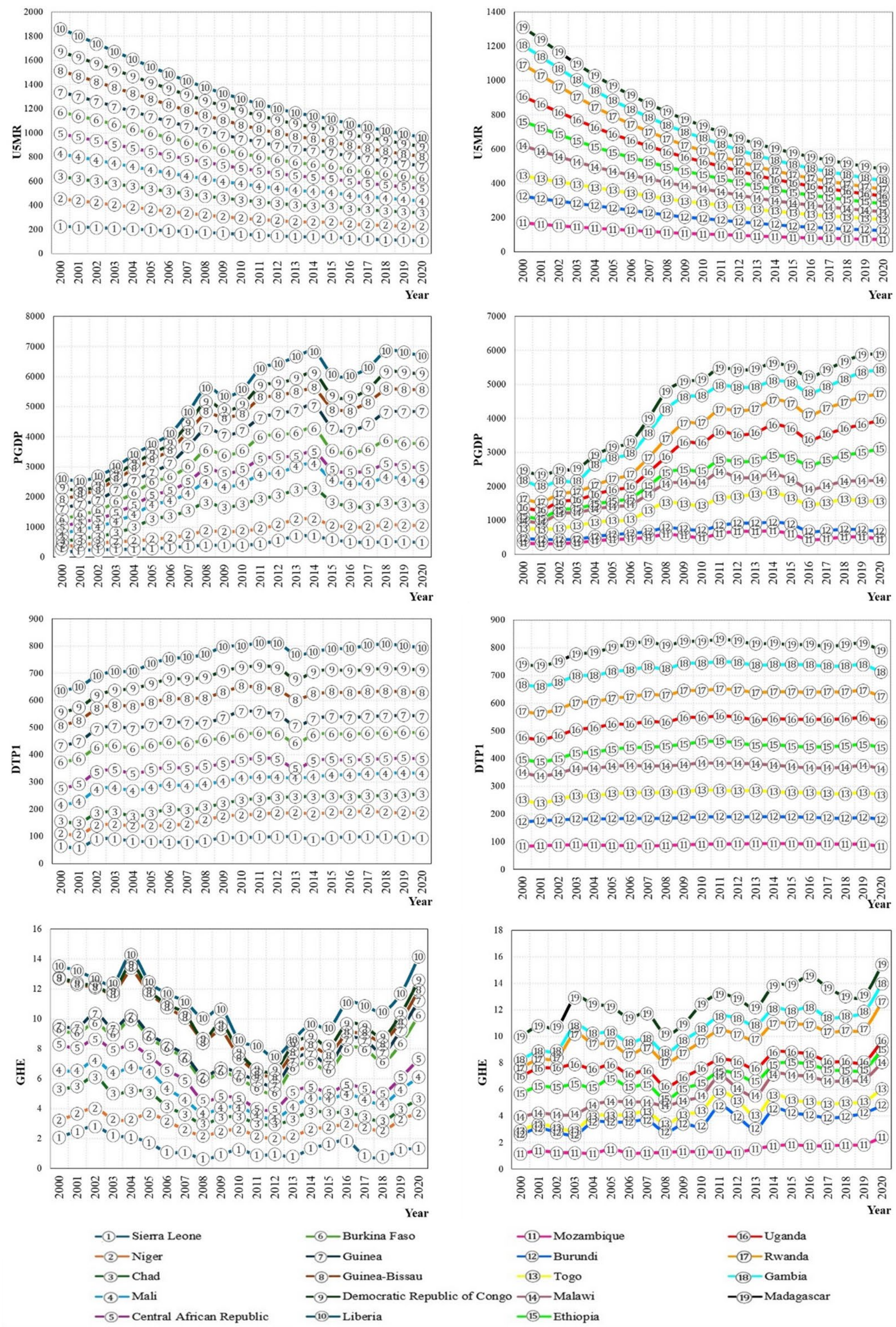

Fig. 2 Behavioural patterns of U5MR, PGDP, DTP1 and GHE from 2000–2020. Source: Authors' illustration based on data from [2] and World-Bank [69]

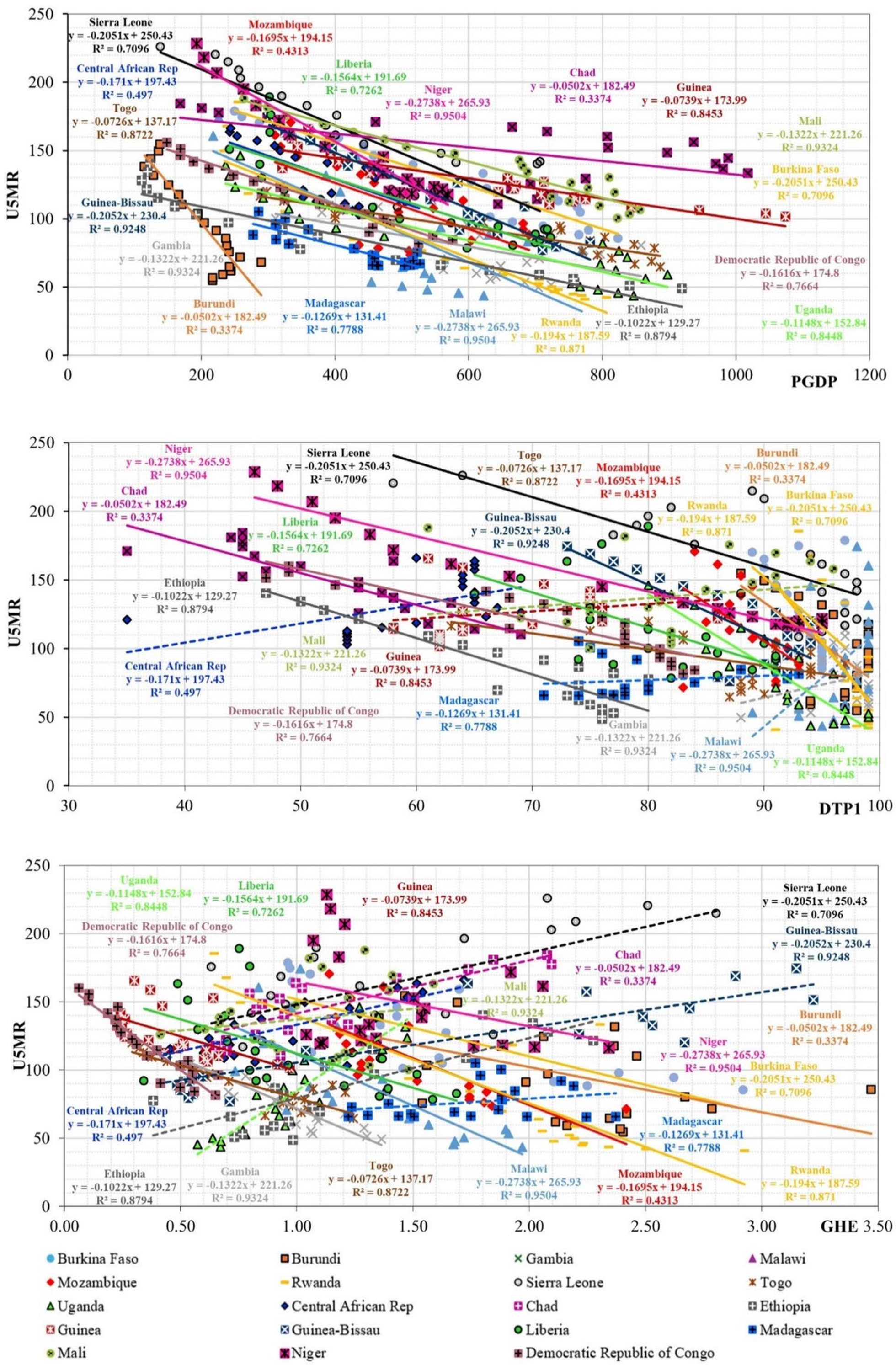

Fig. 3 Regression graphs assessing the impact of PGDP, DTP1 and GHE on U5MR. Source: Authors' illustration based on data from [2] and World-Bank [69]

Table 2 Percentage changes of average U5MR from 2000–2006 and 2014–2020 for 19 LICs

Country	Average of U5MR from 2000-2006	Average of U5MR from 2014-2020	Percentage Change
Burkina Faso	163.79	94.7	-42%
Burundi	137.15	62.31	-55%
Central African Republic	156.61	110.77	-29%
Chad	174.23	121.91	-30%
Democratic Republic of Congo	146.36	90.46	-38%
Ethiopia	121.66	56.59	-53%
Gambia	100.43	55.77	-44%
Guinea	148.12	108.19	-27%
Guinea-Bissau	157.18	85.75	-45%
Liberia	152.83	84.66	-45%
Madagascar	92.65	65.98	-29%
Malawi	135.16	51.07	-62%
Mali	169.62	109.39	-36%
Mozambique	146.81	78.99	-46%
Niger	195.04	118.61	-39%
Rwanda	136.18	44.91	-67%
Sierra Leone	208.44	123.75	-41%
Togo	109.86	71.3	-35%
Uganda	123.22	50.71	-59%

Source: Authors' calculations based on data from UNICEF [2]

starting from 2000 to 2006 and 2014–2020. While the data indicate a downward trend overall, the rate of reduction varies significantly by country.

Accordingly, Sierra Leone has the highest rate of under-five deaths in periods of 2000–2006 and 2014–2020. This is mainly due to the exposure of under-five children to deadly diseases such as malaria [80]. Furthermore, Madagascar has the lowest rate of under-five deaths in 2000–2006, whereas in 2014–2020, the lowest U5MR is recorded in Rwanda. Moreover, this reduction is mainly due to growth in GDP and improvements in the economy. Drastically, the U5MR reduced by 67% for Rwanda from an average of 136 per thousand live births to 45 per thousand live births compared to the two-time spans' which are the highest reduction amongst 19 LICs [81, 82]. However, Guinea has a percentage reduction of 27% from an average of 148 per thousand live births to 108 per thousand live births comparing the two periods, which is recorded as the lowest percentage decrease among the 19 LICs [83]. The significant reduction in U5MR is due to better economic conditions resulting in quality health outcomes.

According to the Levin Lin Chu unit root test, implies that the variable taken passes the stationarity test for U5MR, PGDP and DTP1. However, the GHE stationary tests came out as negative which was further corrected by generating the first difference of the variable "ΔGHE", which passed the stationery and stability tests afterwards. Stationarity and the stability of the dataset were, examined, where results came out positive after the amendments which gave us the green flag to proceed with the tests and model run, which is presented in the S3 Appendix where all the eigenvalues lie inside the unit circle in the Panel vector autoregression giving a positive stability condition.

Table 3 summarises the FE and RE model results and the specification tests conducted. The Hausman test revealed significant differences between FE and RE estimators, leading to the selection of the FE model as the most appropriate due to its ability to account for time-invariant heterogeneity across countries. This decision is supported by both empirical evidence and theoretical justification. The use of the Breusch-Pagan LM test, F-test, and Hausman test in the Methodology section are elaborated to help readers better understand how each statistical test informed the model selection process.

The results suggest that a 1% increase in PGDP reduces U5MR by approximately 0.11 units in both FE and RE

Table 3 Model results of RE & FE and the specification test of the low-income context and examining the impact on U5MR

Variables	**RE**	**FE**
PGDP	-0.1090***	-0.1109***
	(0.01)	(0.02)
DTP1	-0.6686***	-0.6322**
	(0.25)	(0.26)
ΔGHE	-2.892	-2.7611
	(2.04)	(2.02)
Constant	221.1826***	219.1501***
	(21.56)	(19.19)
Specification Test		
F Test	**Hausman Test**	**Breusch Pagan LM Test**
H_0: POLS	**H_0: REM**	**H_0: POLS**
H_1: FEM	**H_1: FEM**	**H_1: REM**
50.28***	16.79***	1520.43***
R^2 Within	0.63	0.63
R^2 Between	0.05	0.05
R^2 Overall	0.3	0.29

Note: ** significant at 5%, and ***significant at 1% significance level

Parentheses indicate robust standard error

Source: Authors' calculations based on data from [2] and World-Bank [69]

models, confirming the significant role of economic growth in improving child health. Similarly, DTP1 coverage demonstrated a robust negative effect on U5MR, where a 1% increase in DTP1 coverage led to a reduction of approximately 0.63–0.67 in U5MR

In line with prior studies [84], these results reinforce the role of effective governance and improved healthcare infrastructure in lowering child mortality. Moreover, increased PGDP implies enhanced availability of infrastructure and resources to deliver healthcare services and immunisation programs effectively.

In the country-wise analysis, the MLR model was employed to generate the results presented in Table 4. Notably, PGDP showed a consistent negative and statistically significant effect on U5MR in 18 of the 19 LICs, with Chad being the exception. In Burundi, Central African Republic, Guinea-Bissau, Rwanda, and Sierra Leone, the effect of PGDP on U5MR was particularly strong. These findings align with earlier research that associates economic growth with improved child health outcomes through mechanisms such as better access to healthcare, nutrition, and sanitation [85]. Further, the robust standard errors and the F values is presented in S4 Appendix.

For DTP1, significant negative effects on U5MR were observed in Chad, Democratic Republic of Congo, Ethiopia, Liberia, Malawi, Niger, and Uganda, suggesting that enhanced immunisation coverage substantially improves child survival. However, a surprising and significant positive association was found in the Central African Republic and Malawi. This counterintuitive result may stem from several underlying factors such as vaccine administration quality, public health infrastructure weaknesses, or regional instability [86]. For example, past studies have

Table 4 MLR results accessing the impact on U5MR in every LIC presented

Countries	**Variables**				**R^2**	**F value**
	Constant	**PGDP**	**DTP1**	**ΔGHE**		
Burkina Faso	379.48*	-0.14***	-1.832	-4.921	0.92	57.58***
Burundi	222.55	-0.553***	-0.175	0.222	0.81	22.55***
Central African Republic	103.904**	-0.166***	1.513**	2.65	0.79	20.22***
Chad	258.942***	-0.009	-2.003***	-15.539	0.74	15.28***
Democratic Republic of Congo	191.879***	-0.14***	-0.377***	14.123	0.98	226.21***
Ethiopia	197.444***	-0.065***	-1.242***	0.59	0.98	208.11***
Gambia	-40.179	-0.074**	1.68	0.15	0.35	2.91*
Guinea	184.406***	-0.072***	-0.189	3.101	0.87	37.35***
Guinea-Bissau	252.869***	-0.19***	-0.36	-1.384	0.92	57.95***
Liberia	235.653***	-0.116***	-0.824**	-9.074	0.79	19.84***
Madagascar	139.027***	-0.122***	-0.129	-3.953	0.77	17.41***
Malawi	-351.636*	-0.173***	5.451***	-0.524	0.57	7.19***
Mali	236.375***	-0.133***	-0.178	-15.49*	0.93	73.56***
Mozambique	426.82**	-0.095*	-3.012	-39.475	0.46	4.58**
Niger	279.562***	-0.121**	-1.045***	-0.413	0.96	145.09***
Rwanda	323.419**	-0.169***	-1.57	4.054	0.92	61.57***
Sierra Leone	332.057***	-0.150**	9	-0.571	0.73	14.46***
Togo	117.367***	-0.076***	0.252	-2.485	0.86	33.24***
Uganda	340.044***	-0.074***	-2.343***	-8.828	0.91	51.74***

Source: Authors' calculations based on data from UNICEF [2] and World-Bank [69]

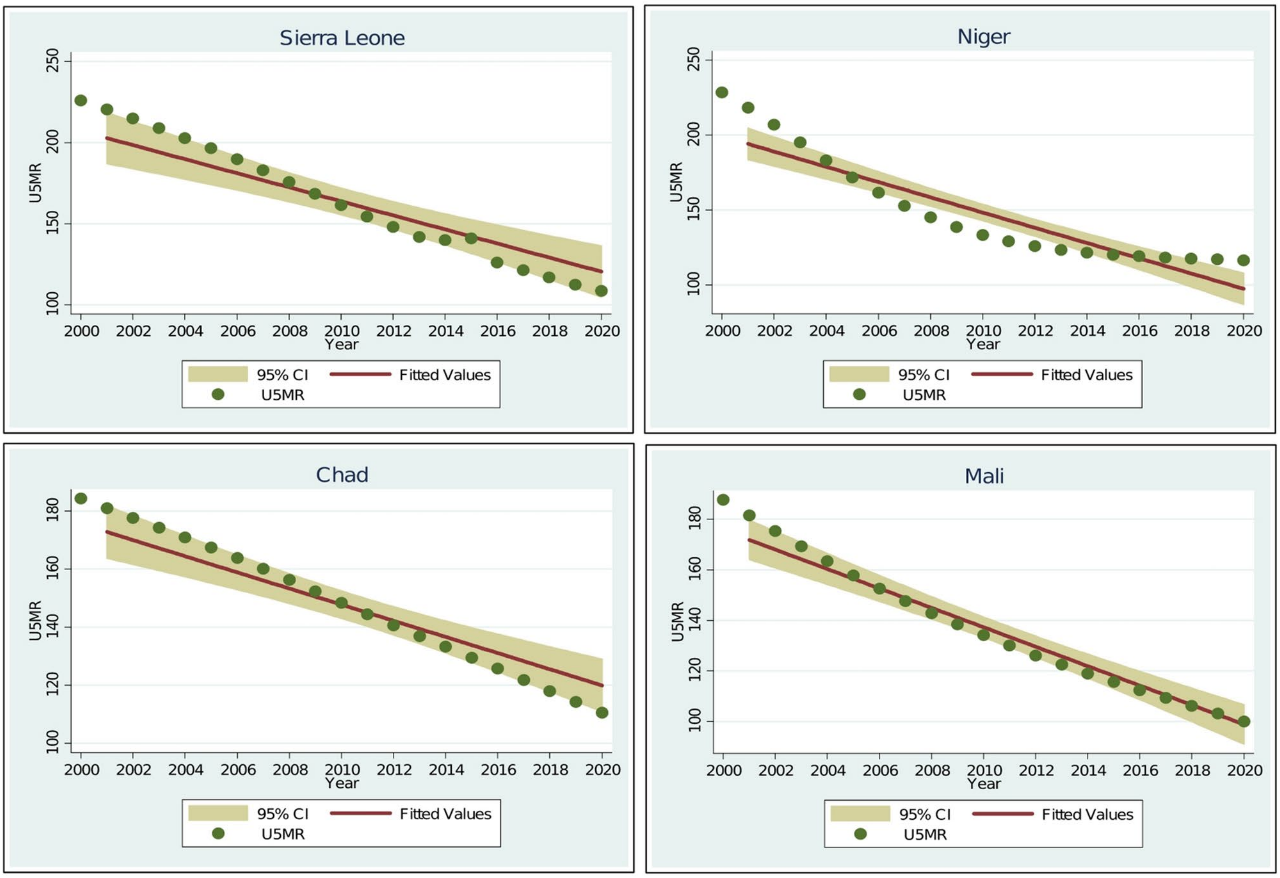

Fig. 4 Predicted values of the top four countries reflecting the highest U5MR among 19 LICs from 2000-2020. Source: Authors' illustration based on data from [2] and World-Bank [69]

shown that poorly timed or improperly administered vaccines may not only be ineffective but could also result in negative outcomes, especially in contexts with malnutrition or weak healthcare systems [87, 88].

In response to this unexpected finding, it is important to consider that in countries facing political instability, logistical constraints, or lack of trained healthcare personnel, the benefits of vaccination programs might be diluted. This reinforces the need to strengthen immunisation supply chains, ensure adherence to recommended vaccine schedules, and improve public trust in immunisation efforts.

Interestingly, the results gained for ΔGHE reflected the impact of U5MR which showed a solid significant negative effect for only one country out of the 19 LICs which is Mali. Prior studies substantiate this claim as it evaluates a negative impact [66]. However, Mali is known to be a large desert country where accessing health services is vastly challenging [89]. Furthermore, even though GHE is utilised, people are still facing problems with U5MR. Moreover, the top four countries reflecting the highest U5MR amongst the 19 LICs taken are shown in Fig. 4.

Moreover, the predicted regression trends illustrated in Fig. 4 and S5 Appendix confirm a steady downward trend in U5MR across LICs, though disparities persist. These results suggest that a one-size-fits-all approach to U5MR reduction may not be effective. Rather, tailored policy interventions are needed to address the unique challenges of each country.

Policy implications

The findings of this study provide strong evidence that U5MR in LICs can be significantly reduced through increased GHE, improved DTP1 vaccination coverage, and policies that translate economic growth into tangible health outcomes. Based on this, several key policy implications emerge, each tailored to the realities faced by LICs.

Strategic allocation of healthcare expenditure

The study emphasises that increased GHE has a significant impact on U5MR in LICs. Policymakers should prioritise healthcare budget allocations that directly strengthen maternal and child health systems. This includes investing in rural health infrastructure, expanding the availability of frontline health workers, and improving access to essential medicines. Moreover, targeted funding should support routine immunisation programs, with a focus on enhancing cold chain infrastructure, training local health personnel, and deploying mobile health units to reach remote areas.

Linking economic growth to child health outcomes

Economic growth, measured by PGDP, should not be treated as an end in itself. The findings emphasise the need to translate PGDP growth into social investment. Conditional cash transfer programs, social safety nets, and targeted nutrition assistance can help ensure that increased income levels result in measurable improvements in child health [90, 91]. By linking economic policies to social welfare goals, LICs can create more inclusive pathways to reducing U5MR and enhancing population well-being.

Improving vaccine delivery and immunisation coverage

DTP1 vaccination coverage emerged as a critical factor in reducing U5MR. However, increasing coverage requires overcoming persistent logistical barriers. LICs should invest in reliable vaccine supply chains, cold storage systems, and tracking technologies [92, 93]. Collaborating with international organisations and NGOs can help bridge resource gaps. In particular, deploying community-based health workers and mobile vaccination units can expand outreach in geographically and socially marginalised areas.

Addressing implementation challenges and governance gaps

The effectiveness of healthcare and economic policies is often constrained by systemic issues such as political instability, corruption, and weak institutional capacity [94]. To address these challenges, LICs must strengthen governance frameworks that promote transparency and accountability in health resource allocation. Public-private partnerships can support infrastructure development, while regional cooperation in procurement and logistics can improve the efficiency of vaccine distribution and health service delivery [95]. Engaging civil society and international development partners is essential to maintain operational continuity in fragile settings.

Tailoring policies to country-specific contexts

Given the diversity of institutional capacities and socioeconomic realities across LICs, policy interventions must be context specific. For example, Sierra Leone, identified as having the highest U5MR among the studied countries, should prioritise expanding rural health services and maternal education. Chad, which reported the lowest U5MR, should continue investing in vaccination monitoring and system resilience. In conflict-affected countries such as the Central African Republic and the Democratic Republic of Congo, interventions must integrate healthcare reform with broader governance strengthening and international support. Meanwhile, countries like Nepal, which show steady immunisation progress, could benefit from focusing on sustaining DTP1 coverage and improving child nutrition programs.

Integrating economic and health policies for sustainable outcomes

The findings advocate for multi-dimensional, data-driven strategies that align economic planning with healthcare delivery. Policymakers should prioritise an integrated approach, linking fiscal expansion, health system strengthening, and community-based interventions to tackle the underlying causes of U5MR [96–98]. Adaptive policymaking, grounded in context-specific evidence, will enable LICs to respond to emerging challenges and make sustainable progress toward equitable child health outcomes.

As such, this study highlights the urgent need for policy approaches that are both evidence-based and context-sensitive. By aligning economic growth with healthcare delivery and immunisation strategies, LICs can make tangible progress in reducing U5MR. Strong governance, local adaptation, and international collaboration will be key to turning these insights into meaningful health outcomes for children.

Limitations and future research directions

This study offers valuable insights into the impact of PGDP, DTP1, and GHE on U5MR in LICs. However, several limitations should be acknowledged to contextualize the findings and guide future inquiry. First, the analysis includes only three explanatory variables, omitting other well-established determinants of child survival such as maternal education, skilled birth attendance, nutrition, sanitation, and healthcare access. This exclusion may introduce omitted variable bias, limiting the model's ability to fully explain variations in U5MR. Future research should consider more comprehensive models incorporating a wider set of socioeconomic and healthcare indicators. Second, the sample is restricted to 19 LICs with available data, the majority from Sub-Saharan Africa. This raises concerns of selection bias, particularly as data-deficient and fragile states with potentially higher child mortality were excluded. Expanding the sample to include LMICs or employing approaches such as propensity score matching, or inverse probability weighting may improve generalizability and allow for meaningful cross-regional comparisons.

Third, although fixed-effects models and lagged variables were used to mitigate endogeneity and reverse causality, residual bias may persist, particularly between PGDP and GHE, which are theoretically and empirically interlinked. Generalized Method of Moments (GMM) estimators were considered but not implemented due to limitations associated with the small number of cross-sectional units ($N=19$) and low within-country variation over time. Future studies with broader panels or access to valid instruments would be better positioned to apply dynamic estimation techniques to enhance causal inference. Fourth, while most variables were confirmed to be stationary at level using unit root tests, GHE required first differencing. Given the limited cross-sectional dimension of the panel, formal cointegration tests were not feasible. Future research using larger samples may explore panel cointegration techniques to assess long-term equilibrium relationships among child mortality determinants more rigorously.

Addressing these limitations in future research will be essential to building a more robust and comprehensive understanding of the complex, interrelated drivers of child mortality in low-income settings. By leveraging richer datasets, applying stronger causal methods, and expanding geographic scope, future studies can produce deeper, evidence-based insights to inform global child health policy and resource allocation.

Conclusion

This study provides strong evidence that economic and healthcare determinants—specifically PGDP, DTP1 immunisation coverage, and GHE, significantly influence U5MR in LICs. Using both fixed-effects panel regression and country-level multiple linear regression models across 19 LICs from 2000 to 2020, the analysis revealed consistent and compelling patterns. Economic growth, as measured by PGDP, demonstrated a universally strong inverse relationship with U5MR, emphasizing the crucial role of macroeconomic conditions in enhancing child survival. Likewise, DTP1 coverage significantly reduced U5MR in several contexts, though unexpected positive associations in select countries emphasized the need for high-quality, context-sensitive vaccine delivery systems. GHE, while important, revealed mixed results, highlighting that merely increasing healthcare spending without addressing implementation inefficiencies may yield limited returns.

These findings make it clear that efforts to reduce child mortality in LICs must be both integrated and context aware. Economic policies must translate into inclusive healthcare access, immunisation programs must be adapted to address logistical and governance challenges, and healthcare investments must be better targeted to yield measurable outcomes. The study advocates for evidence-based policymaking that aligns macroeconomic strategies with grassroots health interventions. By combining economic development with strategic health system strengthening, LICs can make meaningful and sustained progress in reducing U5MR, moving closer to achieving global child survival targets.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

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Author contributions

R.J. conceptualised the study. A.F., N.S., D.A., R.J. and V.R. contributed to the design and conduction of the study. A.F., N.S., D.A. and A.S. undertook data analysis and interpreted the data. A.F. and N.S. drafted the first manuscript in consultation with V.R. and R.J. All authors critically reviewed, edited, and approved the final manuscript. V.R. took the lead in incorporating the revisions to the paper and helped supervise the study. R.J. supervised the study.

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Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Identifying information/images

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Avelino IC, Van-Dúnem J, Varandas L. Under-five mortality and social determinants in africa: a systematic review. Eur J Pediatrics. 2025;184(2):150.
2. [https://data.unicef.org/].
3. Xie J, Hong Y, Yang J, Yan Y, Fei S. Retrospective analysis of mortality among children under 5 years of age in Huangshi over the period 2002–2022, China. BMC Public Health. 2024;24(1):1431.
4. Burstein R, Henry NJ, Collison ML, Marczak LB, Sligar A, Watson S, Marquez N, Abbasalizad-Farhangi M, Abbasi M, Abd-Allah F, et al. Mapping 123 million neonatal, infant and child deaths between 2000 and 2017. Nature. 2019;574(7778):353–8.

5. Wang H, Abbas KM, Abbasifard M, Abbasi-Kangevari M, Abbastabar H, Abd-Allah F, Abdelalim A, Abolhassani H, Abreu LG, Abrigo MRM, et al. Global age-sex-specific fertility, mortality, healthy life expectancy (HALE), and population estimates in 204 countries and territories, 1950–2019: a comprehensive demographic analysis for the global burden of disease study 2019. Lancet. 2020;396(10258):1160–203.
6. Gillani S, Ahmad TI, Wang F, Shafiq MN. Ntenatal care (ANC) coverage, health infrastructure, and postnatal care (PNC) services utilization: A district level analysis of Punjab-Pakistan. IRASD J Econ. 2021;3(3):318–31.
7. Bishai DM, Cohen R, Alfonso YN, Adam T, Kuruvilla S, Schweitzer J. Factors contributing to maternal and child mortality reductions in 146 Low- and Middle-Income countries between 1990 and 2010. PLoS ONE. 2016;11(1):e0144908.
8. Wang F, Gillani S, Nazir R, Razzaq A. Environmental regulations, fiscal decentralization, and health outcomes. Energy Environ. 2024;35(6):3038–64.
9. UNIGME. Levels & Trends in Child Mortality. 2023.
10. Sharrow D, Hug L, You D, Alkema L, Black R, Cousens S, Croft T, Gaigbe-Togbe V, Gerland P, Guillot M, et al. Global, regional, and National trends in under-5 mortality between 1990 and 2019 with scenario-based projections until 2030: a systematic analysis by the UN Inter-agency group for child mortality Estimation. Lancet Global Health. 2022;10(2):e195–206.
11. Levels. & Trends in Child Mortality [https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/un-igme-child-mortality-report-2015.pdf].
12. Ruiz VRL, Navarro JLA, Peña DN. Relationship Between Gross Domestic Product (GDP) and Hidden Wealth Over the Period 2000–2008: An International Study. 2024.
13. Verberi C, Yasar S, Sugozu IH. Capital liberalization, growth and moral hazard: lessons from the global financial crisis. Int Rev Financial Anal. 2023;90:102901.
14. Rose AK, Spiegel MM, Cross-country causes, and consequences of. The 2008 CRISIS: international linkages and american exposure. Pac Econ Rev. 2010;15(3):340–63.
15. Employment. and per capita GDP growth over the past five years [https://obr.uk/box/employment-and-per-capita-gdp-growth-over-the-past-five-years/]
16. World Economic Situation and Prospects. 2014 [https://www.un.org/en/development/desa/policy/wesp/wesp_current/WESP2014_mid-year_update.pdf]
17. Bergen N, Cata-Preta BO, Schlotheuber A, Santos TM, Danovaro-Holliday MC, Mengistu T, Sodha SV, Hogan DR, Barros AJD, Hosseinpoor AR. Economic-Related inequalities in Zero-Dose children: A study of Non-Receipt of Diphtheria–Tetanus–Pertussis immunization using household health survey data from 89 Low- and Middle-Income countries. Vaccines. 2022;10(4):633.
18. Kunyenje CA, Chirwa GC, Mboma SM, Ng'ambi W, Mnjowe E, Nkhoma D, Ngwira LG, Chawani MS, Chilima B, Mitambo C et al. COVID-19 vaccine inequity in African low-income countries. Front Public Health 2023, 11.
19. Chard AN, Gacic-Dobo M, Diallo MS, Sodha SV, Wallace AS. Routine Vaccination Coverage — Worldwide, 2019. *MMWR Morbidity and Mortality Weekly Report*, 2020, 69(45):1706–1710.
20. How does health spending in the U.S. compare to other countries? [https://www.healthsystemtracker.org/chart-collection/health-spending-u-s-compare-countries/#GDP%20per%20capita%20and%20health%20consumption%20spending%20per%20capita,%202022%20(U.S.%20dollars,%20PPP%20adjusted].
21. Global spending on health: rising to the pandemic's challenges [https://www.who.int/publications/i/item/9789240064911]
22. Global expenditure on health. Public spending on the rise? [https://www.who.int/publications/i/item/9789240041219]
23. Levels. & Trends In Child Mortality [https://www.unicef.org/media/47626/file/un-igme-child-mortality-report-2018.pdf].
24. Ng LC, Stevenson A, Kalapurakkel SS, Hanlon C, Seedat S, Harerimana B, Chiliza B, Koenen KC. National and regional prevalence of posttraumatic stress disorder in sub-Saharan africa: A systematic review and meta-analysis. PLoS Med. 2020;17(5):e1003090.
25. Corsi DJ, Subramanian SV. Association between coverage of maternal and child health interventions, and under-5 mortality: a repeated cross-sectional analysis of 35 sub-Saharan African countries. Global Health Action. 2014;7(1):24765.
26. World Population Prospects. [https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/documents/2020/Jan/un_2017_world_population_prospects-2017_revision_databooklet.pdf]
27. Gaffan N, Kpozehouen A, Degbey C, Ahanhanzo YG, Paraïso MN. Effects of household access to water, sanitation, and hygiene services on under-five mortality in Sub-Saharan Africa. Front Public Health 2023, 11.
28. Ekholuenetale M, Wegbom AI, Tudeme G, Onikan A. Household factors associated with infant and under-five mortality in sub-Saharan Africa countries. Int J Child Care Educ Policy. 2020;14(1):10.
29. Prüss-Ustün A, Wolf J, Bartram J, Clasen T, Cumming O, Freeman MC, Gordon B, Hunter PR, Medlicott K, Johnston R. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low- and middle-income countries. Int J Hyg Environ Health. 2019;222(5):765–77.
30. Masia NA, Smerling J, Kapfidze T, Manning R, Showalter M. Vaccination and GDP growth rates: exploring the links in a conditional convergence framework. World Dev. 2018;103:88–99.
31. For every child vaccination. [https://www.unicef.org/media/139216/file/SOWC%20English%20-%20ECARO%20Brief%20.pdf]
32. Cardona M, Millward J, Gemmill A, Jison Yoo K, Bishai DM. Estimated impact of the 2020 economic downturn on under-5 mortality for 129 countries. PLoS ONE. 2022;17(2):e0263245.
33. Marmot M. Social determinants of health inequalities. Lancet. 2005;365(9464):1099–104.
34. Haisma H, Yousefzadeh S, Boele Van Hensbroek P. Towards a capability approach to child growth: A theoretical framework. Matern Child Nutr. 2018;14(2):e12534.
35. Becker GS. Health as human capital: synthesis and extensions. Oxf Econ Pap. 2007;59(3):379–410.
36. Bizzego A, Gabrieli G, Bornstein MH, Deater-Deckard K, Lansford JE, Bradley RH, Costa M, Esposito G. Predictors of contemporary under-5 child mortality in Low- and Middle-Income countries: A machine learning approach. Int J Environ Res Public Health. 2021;18(3):1315.
37. Sanders D, De Ceukelaire W, Hutton B, Sanders D. 19Global Disease Patterns. In: *The Struggle for Health: Medicine and the politics of underdevelopment.* edn. Edited by De Ceukelaire W, Hutton B: Oxford University Press; 2023: 0.
38. Mao W, Watkins D, Sabin ML, Huang K, Langlois E, Ogundeji Y, Fogstad H, Schäferhoff M, Yamey G, Ogbuoji O. Effects of public financing of essential maternal and child health interventions across wealth quintiles in nigeria: an extended cost-effectiveness analysis. Lancet Global Health. 2023;11(4):e597–605.
39. Rahman MM, Alam K, Khanam R. Socio-economic factors affecting high infant and child mortality rates in selected African countries: does globalisation play any role? Globalization Health. 2022;18(1):69.
40. Asumadu-Sarkodie S, Owusu PA. The casual nexus between child mortality rate, fertility rate, GDP, household final consumption expenditure, and food production index. Cogent Econ Finance. 2016;4(1):1191985.
41. 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.
42. Ensor T, Cooper S, Davidson L, Fitzmaurice A, Graham WJ. The impact of economic recession on maternal and infant mortality: lessons from history. BMC Public Health. 2010;10(1):727.
43. Croke K. The political economy of child mortality decline in Tanzania and uganda, 1995–2007. Stud Comp Int Dev. 2012;47(4):441–63.
44. Nwude EC, Chinyere OUR, Sebastine UP UU, and, Nwonye NG. Official development assistance, income per capita and health outcomes in developing countries: is Africa different? Cogent Econ Finance. 2020;8(1):1774970.
45. Annual Health Sector Performance Report. 2016 [https://www.afro.who.int/sites/default/files/2017-08/Sierra%20Leone%20Health%20Sector%20%20Performance%20Report%202016.pdf]
46. Houweling TA, Kunst AE, Looman CW, Mackenbach JP. Determinants of under-5 mortality among the poor and the rich: a cross-national analysis of 43 developing countries. Int J Epidemiol. 2005;34(6):1257–65.
47. Pérez-Moreno S, Blanco-Arana MC, Bárcena-Martín E. Economic cycles and child mortality: a cross-national study of the least developed countries. Econ Hum Biology. 2016;22:14–23.
48. Verguet S, Jamison DT. Estimates of performance in the rate of decline of under-five mortality for 113 low- and middle-income countries, 1970–2010. Health Policy Plann. 2013;29(2):151–63.
49. Sasmoko S, Handayani W, Nassani AA, Haffar M, Zaman K. Do precarious female employment and political autonomy affect the under-5 mortality rate? Evidence from 166 countries. PLoS ONE. 2022;17(6):e0269575.
50. Sodha SV, Cherian T, Lydon P, Lindstrand A, Crowcroft NS, Menning L, Eggers R, Okwo-Bele J-M, O'Brien L. K: Chap. 77 - Immunization in Low- and Middle-Income Countries. In: *Plotkin's Vaccines (Eighth Edition).* edn. Edited by Orenstein W, Offit P, Edwards KM, Plotkin S. Philadelphia: Elsevier; 2023: 1578–1602. e1576.

51. Lanza-León P, Cantarero-Prieto D, Pascual-Sáez M. Exploring trends and determinants of basic childhood vaccination coverage: empirical evidence over 41 years. PLoS ONE. 2024;19(3):e0300404.
52. Patel MM, Clark AD, Sanderson CFB, Tate J, Parashar UD. Removing the age restrictions for rotavirus vaccination: A Benefit-Risk modeling analysis. PLoS Med. 2012;9(10):e1001330.
53. Quinn MK, Edmond KM, Fawzi WW, Hurt L, Kirkwood BR, Masanja H, Muhihi AJ, Newton S, Noor RA, Williams PL, et al. Non-specific effects of BCG and DTP vaccination on infant mortality: an analysis of birth cohorts in Ghana and Tanzania. Vaccine. 2022;40(27):3737–45.
54. Aaby P, Mogensen SW, Rodrigues A, Benn CS. Evidence of increase in mortality after the introduction of Diphtheria-Tetanus-Pertussis vaccine to children aged 6–35 months in Guinea-Bissau: A time for reflection?? Front Public Health. 2018;6:79.
55. Mogensen SW, Andersen A, Rodrigues A, Benn CS, Aaby P. The introduction of Diphtheria-Tetanus-Pertussis and oral polio vaccine among young infants in an urban African community: A natural experiment. EBioMedicine. 2017;17:192–8.
56. Rana RH, Alam K, Gow J. Health expenditure, child and maternal mortality nexus: a comparative global analysis. BMC Int Health Hum Rights. 2018;18(1):29.
57. Sibanda K, Qoko A, Gonese D. Health expenditure, institutional quality, and Under-Five mortality in Sub-Saharan African countries. Int J Environ Res Public Health. 2024;21(3):333.
58. Besnier E, Thomson K, Stonkute D, Mohammad T, Akhter N, Todd A, Rom Jensen M, Kilvik A, Bambra C. Which public health interventions are effective in reducing morbidity, mortality and health inequalities from infectious diseases amongst children in low- and middle-income countries (LMICs): an umbrella review. PLoS ONE. 2021;16(6):e0251905.
59. Adeosun OT, Faboya OM. Health care expenditure and child mortality in Nigeria. Int J Health Care Qual Assur. 2020;33(3):261–75.
60. Ayipe FI, Tanko M. Public health expenditure and under-five mortality in low-income Sub-Saharan African countries. Social Sci Humanit Open. 2023;8(1):100570.
61. Ibukun CO. The role of governance in the health expenditure–health outcomes nexus: insights from West Africa. Int J Soc Econ. 2021;48(4):557–70.
62. Osei B, Kulu E, Appiah-Konadu P. Government health expenditure and child health: empirical evidence from West African countries. Int J Soc Econ. 2024;51(6):786–99.
63. Nixon J, Ulmann P. The relationship between health care expenditure and health outcomes. Eur J Health Econ. 2006;7(1):7–18.
64. Bousmah M-a-Q, Ventelou B, Abu-Zaineh M. Medicine and democracy: the importance of institutional quality in the relationship between health expenditure and health outcomes in the MENA region. Health Policy. 2016;120(8):928–35.
65. Oladosu AO, Chanimbe T, Anaduaka US. Effect of public health expenditure on health outcomes in Nigeria and Ghana. Health Policy OPEN. 2022;3:100072.
66. Wanjiku JM. PUBLIC HEALTH EXPENDITURE AND HEALTH OUTCOMES AN EMPIRICAL STUDY ANALYSIS. In.; 2023.
67. Alexiou C, Trachanas E. Politics, government health expenditure and infant mortality: does political party orientation matter? Int J Soc Econ. 2021;48(12):1810–25.
68. Garcia LP, Schneider IJC, de Oliveira C, Traebert E, Traebert J. What is the impact of National public expenditure and its allocation on neonatal and child mortality? A machine learning analysis. BMC Public Health. 2023;23(1):793.
69. [https://data.worldbank.org/].
70. Guo X, Ren D, Shi J. Carbon emissions, logistics volume and GDP in china: empirical analysis based on panel data model. Environ Sci Pollut Res. 2016;23(24):24758–67.
71. Guo Y, Li B, Duan T, Yao N, Wang H, Yang Y, Yan S, Sun M, Wang L, Yao Y, et al. A panel regression analysis for the COVID-19 epidemic in the united States. PLoS ONE. 2022;17(8):e0273344.
72. MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey LL, Hines JE. Introduction. Occupancy Estimation and modeling. edn.: Elsevier; 2018. pp. 3–26.
73. Choi C-Y, Mark NC, Sul D. Bias reduction in dynamic panel data models by common recursive mean adjustment. Oxf Bull Econ Stat. 2010;72(5):567–99.
74. Voss DS. Multicollinearity. Encyclopedia of social measurement. edn.: Elsevier; 2005. pp. 759–70.
75. Abrigo MRM, Love I. Estimation of panel vector autoregression in Stata. Stata J. 2016;16(3):778–804.
76. Bekun FV. Mitigating emissions in india: accounting for the role of real income, renewable energy consumption and investment in energy. Int J Energy Econ Policy. 2022;12(1):188–92.
77. Baltagi BH. Fixed effects and random effects. The new Palgrave dictionary of economics. edn. London: Palgrave Macmillan UK; 2008. pp. 1–6.
78. Gujarati DN, Porter DC. Basic Econometrics; 2009.
79. Rathnayake S, Jayakody S, Wannisinghe P, Wijayasinghe D, Jayathilaka R, Madhavika N. Macroeconomic factors affecting FDI in the African region. PLoS ONE. 2023;18(1):e0280843.
80. Baiden F, Fleck S, Leigh B, Ayieko P, Tindanbil D, Otieno T, Lawal B, Tehtor M, Rogers M, Odeny L, et al. Prevalence of malaria and helminth infections in rural communities in Northern Sierra leone, a baseline study to inform Ebola vaccine study protocols. PLoS ONE. 2022;17(7):e0270968.
81. Li Z, Hsiao Y, Godwin J, Martin BD, Wakefield J, Clark SJ. With support from the united nations Inter-agency group for child mortality E, its technical advisory g: changes in the Spatial distribution of the under-five mortality rate: Small-area analysis of 122 DHS surveys in 262 subregions of 35 countries in Africa. PLoS ONE. 2019;14(1):e0210645.
82. Hirschhorn LR, Sayinzoga F, Beyer C, Donahoe K, Binagwaho A. Exemplars in Under-5 mortality: Rwanda case study. In.; 2018.
83. Ahinkorah BO, Budu E, Seidu A-A, Agbaglo E, Adu C, Osei D, Banke-Thomas A, Yaya S. Socio-economic and proximate determinants of under-five mortality in Guinea. PLoS ONE. 2022;17(5):e0267700.
84. Makuta I, O'Hare B. Quality of governance, public spending on health and health status in sub saharan africa: a panel data regression analysis. BMC Public Health. 2015;15(1):932.
85. Hategeka C, Tuyisenge G, Bayingana C, Tuyisenge L. Effects of scaling up various community-level interventions on child mortality in burundi, kenya, rwanda, Uganda and tanzania: a modeling study. Global Health Res Policy. 2019;4(1):16.
86. Mouteyica AEN, Ngepah N. Health outcome convergence in africa: the roles of immunization and public health spending. Health Econ Rev. 2023;13(1):30.
87. Aaby P, Benn CS, Nielsen J, Lisse IM, Rodrigues A, Jensen H. DTP vaccination and child survival in observational studies with incomplete vaccination data. Tropical Med Int Health. 2007;12(1):15–24.
88. State of Health Financing in the African Region. [https://iris.who.int/bitstream/handle/10665/101282/9789290232131.pdf?sequence=1&isAllowed=y]
89. Knippenberg R, Nafo FT, Osseni R, Camara YB, Abassi AE, Soucat A. Increasing clients' power to scale up health services for the poor: THE BAMAKO INITIATIVE IN WEST AFRICA background paper to the. World Development Report In.; 2023.
90. James M, Yarlini B, Shahira M, Luke H, Jessica O, Sheila M, David S, Natalia Elena W-R, Atif K. Cash transfers and child nutritional outcomes: a systematic review and meta-analysis. BMJ Global Health. 2020;5(12):e003621.
91. Aizer A, Lleras-Muney A. The safety net and child health and well-being: evidence from the United States and the United Kingdom. *Fiscal Studies* 2024, n/a(n/a).
92. Peck M, Gacic-Dobo M, Diallo MS, Nedelec Y, Sodha SS, Wallace AS. Global Routine Vaccination Coverage, 2018. In: *Morbidity and Mortality Weekly Report.* vol. 68; 2019: 837–942.
93. Jones CE, Danovaro-Holliday MC, Mwinnyaa G, Gacic-Dobo M, Francis L, Grevendonk J, Nedelec Y, Wallace A, Sodha SS, Sugerman C. Routine Vaccination Coverage — Worldwide, 2023. In: *Morbidity and Mortality Weekly Report.* vol. 73; 2024: 978–984.
94. Naher N, Hoque R, Hassan MS, Balabanova D, Adams AM, Ahmed SM. The influence of corruption and governance in the delivery of frontline health care services in the public sector: a scoping review of current and future prospects in low and middle-income countries of South and South-east Asia. BMC Public Health. 2020;20(1):880.
95. George J, Jack S, Gauld R, Colbourn T, Stokes T. Impact of health system governance on healthcare quality in low-income and middle-income countries: a scoping review. BMJ Open. 2023;13(12):e073669.
96. Hajji Adam A, Daba M. Preventing maternal and child mortality: upcoming WHO resolution must galvanise action to tackle the unacceptable weight of preventable deaths. Lancet Global Health. 2024;12(8):e1223–4.
97. Alfvén T. Strengthened health systems and a multisectoral approach are needed to achieve sustainable health gains for children. Acta Paediatr. 2022;111(11):2054–5.

98. Koya CA, Kate W, Regina R, Salim S. The role of governance in implementing sustainable global health interventions: review of health system integration for integrated community case management (iCCM) of childhood illnesses. BMJ Global Health. 2021;6(3):e003257.

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