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Driving down child mortality in the SAARC: the impact of GDP, healthcare, and vaccination

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This study investigates the determinants of under-five mortality rate (U5MR) in South Asian Association for Regional Cooperation (SAARC) countries from 2000 to 2020, focusing on the roles of per capita gross domestic product (PGDP), Diphtheria-Tetanus-Pertussis (DTP1) immunisation coverage, and government healthcare expenditure (GHE). Despite global progress in reducing child mortality, disparities persist in SAARC countries, where economic, healthcare, and immunisation factors influence child survival. The research employs a panel regression analysis using a fixed effects model to assess the impact of these variables on U5MR across seven SAARC nations (excluding Afghanistan due to insufficient and inconsistent data), as well as multiple linear regression (MLR) for a country-specific explanation. Results reveal that both PGDP and DTP1 coverage are inversely related to U5MR, highlighting the importance of economic growth and immunisation programs in reducing child mortality. However, while the associations between PGDP, GHE, and DTP1 with U5MR were not statistically significant in the panel model, the country specific MLR analysis revealed statistically significant relationships in some cases. In fact, GHE presents mixed results, indicating that healthcare expenditure alone may be insufficient without effective allocation. The study's findings emphasise the need for region-specific policies to address healthcare inequalities and expand immunisation programs, providing practical recommendations for SAARC policymakers to achieve sustainable improvements in child health outcomes.

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Introduction

Child mortality, particularly the under-five mortality rate (U5MR), remains a critical health challenge for many nations. Despite significant progress in reducing global child mortality, millions of children under the age of five continue to fall victim to preventable diseases such as malaria, pneumonia, diarrhoea, and neonatal complications. Improving health outcomes for children under five has been a central goal of international organisations, including the United Nations, as outlined in the Sustainable Development Goals (UNICEF, 2024b). However, the disparities in child mortality between regions and countries continue to present a significant challenge, particularly in low- and middle-income regions like South Asia.

The South Asian Association for Regional Cooperation (SAARC), comprising Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka, has experienced both progress and ongoing struggles in reducing U5MR. Since 1990, the region has experienced a significant reduction in child mortality, with countries like Sri Lanka leading the way by implementing effective healthcare policies and infrastructure improvements (Jayathilaka et al. 2021; UNICEF, 2024b; WHO, 2020). Conversely, countries such as Pakistan and Afghanistan continue to struggle with higher U5MR due to socio-economic disparities, insufficient healthcare infrastructure, and uneven distribution of health resources (Nadeem et al. 2021; Tharwani et al. 2023).

Economic growth and public health interventions are widely recognised as crucial drivers of child survival, but the relative contributions of specific factors such as per capita gross domestic product (PGDP), immunisation coverage, and government healthcare expenditure (GHE) are still under debate. Economic growth, reflected by PGDP, is generally linked to improved healthcare access and resources, yet its impact on child mortality varies significantly across countries (Ahmmed et al. 2021; Murad et al. 2023). Immunisation programs, particularly the Diphtheria, Tetanus, and Pertussis Dose One (DTP1) vaccine, have been critical in preventing common childhood diseases, though gaps in vaccine coverage persist in underserved areas (Das et al. 2015; UNICEF, 2024b). Additionally, government healthcare expenditure has a direct impact on healthcare infrastructure, which is vital for reducing U5MR, but disparities in health spending continue to affect outcomes (Bokhari et al. 2007; Rahman et al. 2018).

This study aims to examine the influence of PGDP, DTP1 vaccine coverage, and GHE on U5MR in SAARC countries and thereby hold significance in multiple ways. Firstly, this study provides a focused and detailed analysis of the key factors affecting U5MR in the SAARC region, by drawing specific attention towards examining the combined impact of PGDP, DTP1 and GHE on child mortality. Secondly, the study is unique in its use of a regional approach, offering an in-depth look at each SAARC country individually. This differentiation from broader global studies highlights the specific challenges and successes within the region, thus providing more actionable insights for policymakers. Thirdly, by spanning across two decades (2000–2020) and utilising a comprehensive panel dataset, the study provides an in-depth, longitudinal analysis of the trends affecting child mortality in South Asia.

Accordingly, this study not only contributes to the academic understanding of U5MR across SAARC countries but also provides practical, region-specific policy recommendations addressing both economic and healthcare-related factors. By deepening the understanding of socio-economic and healthcare influences on U5MR in South Asia, this study offers customised policy solutions tailored to the unique challenges of the region. In doing so, it holds the potential to assist SAARC nations in achieving sustainable improvements in child health outcomes.

Literature Review

The Fig. 1 illustrates the number of publications conducted in the SAARC region from 1993 to 2024, focusing on the associations between independent variables - GHE, PGDP, and DTP1 and the dependent variable-U5MR.

Despite the fact that scholarly attention towards GHE and U5MR has been relatively steady since 1993 up to 2001, a diversion of scholarly attention towards the impact of PGDP and DTP1 on U5MR is seen from 2005 onwards. Additionally, a clear hype is seen in overall research related to U5MR in year 2021, converging a higher focus towards the impact of PGDP and GHE on U5MR, reflecting a growing interest in addressing child mortality in the region.

Overall, the number of publications has increased in recent years, highlighting a growing scholarly focus on U5MR and its related factors in SAARC countries. However, varying levels of

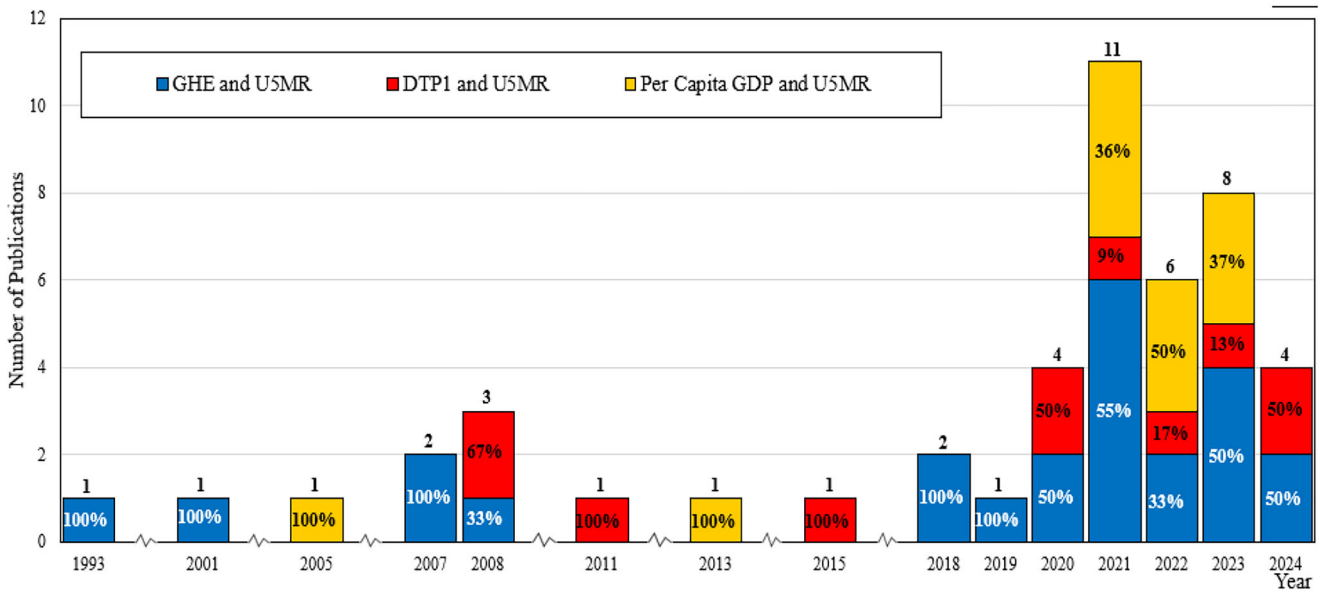

Fig. 1 Number of publications reviewed by research country context. Source: Authors' compilation based on literature.

research across different determinants suggest that issues like government health expenditure and vaccine impact have received uneven attention, potentially due to data constraints and changing research priorities.

Trends in Under-Five Mortality. Significant disparities remain, particularly between high-income and low-income countries. In 2019, for instance, the U5MR in high-income countries was seven times lower than in low-income countries, where all South Asian countries fall under, highlighting the inequality in health outcomes (Saeidi et al. 2015). The primary causes of child mortality in low-income regions include preventable diseases such as lower respiratory infections, malaria, and diarrhoea (Sharrow et al. 2022; WHO, 2024).

South Asia, particularly, has made a notable impact, with a 72% reduction in U5MR between 1990 and 2022 (UNICEF, 2024b). Despite these improvements, South Asia continues to face challenges, particularly in countries like Pakistan and Afghanistan, where high child mortality remains prevalent due to socio-economic disparities (Naz et al. 2021). In fact, lack of education regarding healthcare needs and the unavailability of sufficient liquidity in the said countries continue to fuel this burden whilst negatively contributing towards the overall child-mortality rate in the South Asian region.

Economic Growth and Child Mortality (PGDP and U5MR). Economic growth, as reflected by PGDP, has been widely acknowledged as a crucial factor in improving child health outcomes. Higher PGDP often translates into better access to healthcare services, improved living standards, and reduced malnutrition, all of which contribute to lower U5MR (Ahmmed et al. 2021; Murad et al. 2023). For example, studies have shown that in Bangladesh, higher PGDP has significantly contributed to reducing U5MR by enabling families to afford better healthcare and nutrition (Ahmmed et al. 2021; Ghosh et al. 2016).

However, the impact of economic growth on child mortality is not uniform across all regions. In some SAARC countries, such as India, the relationship between PGDP and U5MR has been less clear. While India's economy has grown substantially, the decline in U5MR has not kept pace, suggesting that economic growth alone is insufficient to address the complexities of child mortality (Parihar, 2021). Factors such as healthcare access, maternal education, and socio-economic inequalities play a critical role in shaping child health outcomes, often surpassing the direct effects of PGDP (Azam et al. 2023; Fagbamigbe et al. 2022).

In Pakistan, the relationship between economic growth and child mortality is more positive, with studies indicating that higher PGDP is associated with lower U5MR. However, disparities in income distribution and healthcare access have limited the full potential of economic growth to reduce child mortality in rural and underserved areas (Azam et al. 2023; Nadeem et al. 2021). These findings suggest that while economic growth is a critical factor in improving child health, focused investments in healthcare and social infrastructure are necessary to achieve significant reductions in U5MR (Bango and Ghosh, 2023). Moreover, a cross-country study across low-income nations revealed that the relationship between PGDP and under-five mortality is significantly influenced by contextual factors such as healthcare infrastructure and income inequality, offering a valuable global reference point for interpreting the region-specific patterns observed in this SAARC-focused analysis (Rajapakse et al. 2025).

Government Healthcare Expenditure and Child Mortality (GHE and U5MR). GHE plays a crucial role in shaping child health outcomes, particularly in low- and middle-income countries where most South Asian countries reside. Higher GHE enables governments to invest in healthcare infrastructure, improve access to medical services, and provide essential interventions such as immunisation and maternal healthcare (Rahman et al. 2018). Several studies have shown a significant inverse relationship between GHE and U5MR, indicating that higher healthcare spending leads to lower child mortality rates (Bokhari et al. 2007; Rajapakse and Jayathilaka, 2025; Ullah et al. 2021).

However, in the SAARC region, healthcare spending has been uneven. For instance, Bangladesh has relatively low healthcare expenditure compared to other South Asian countries, yet it has managed to achieve significant improvements in child health due to efficient use of resources and effective public health programs (Osman, 2008; UNICEF, 2024b). In contrast, Pakistan continues to struggle with high U5MR despite increases in healthcare expenditure, highlighting the need for more effective resource allocation and healthcare infrastructure improvements (Ullah et al. 2021).

Sri Lanka stands out in the region for its successful healthcare policies and investments, which have led to one of the lowest U5MR rates in South Asia (Jayathilaka et al. 2021). The country's high GHE, combined with a well-functioning primary healthcare system, has contributed significantly to its success in reducing child mortality (Amarasiri de Silva et al. 2001; Raina et al. 2023). This suggests that healthcare expenditure, when combined with efficient delivery of services, can have a significant impact on child health outcomes.

Immunisation and Child Mortality (DTP1 Vaccine and U5MR). Immunisation programs, particularly the DTP1 vaccine, have been critical in reducing child mortality globally. Vaccination protects children from life-threatening diseases and strengthens their immune systems, thereby improving survival rates (Andre et al. 2008; Crespo et al. 2011). The DTP1 vaccine has been especially effective in South Asia, where immunisation programs have contributed to a significant reduction in under-five deaths (Das et al. 2015).

However, disparities in vaccine coverage persist across the SAARC region. In Pakistan and Afghanistan, for example, low immunisation rates have been linked to high U5MR due to factors such as poor healthcare infrastructure, lack of access to vaccines, and political instability (Memon et al. 2023; Naz et al. 2021). In contrast, Sri Lanka has achieved near-universal DTP1 vaccine coverage, which has played a crucial role in reducing child mortality rates (UNICEF, 2024b; WHO, 2020). These differences highlight the importance of expanding immunisation programs and addressing the barriers to vaccine access in underserved regions.

Regional Focus on SAARC Countries. Within the SAARC region, there are significant variations in U5MR and its determinants. Sri Lanka, for instance, has made remarkable progress in reducing child mortality through effective healthcare policies, high GHE, and comprehensive immunisation programs (Jayathilaka et al. 2021; Raina et al. 2023). In contrast, Pakistan and Afghanistan continue to face high U5MR due to socio-economic inequalities, inadequate healthcare infrastructure, and low immunisation coverage (Nadeem et al. 2021; Naz et al. 2021).

Bangladesh has also made significant progress in reducing U5MR despite limited healthcare expenditure, due to its emphasis on improving public health services and ensuring equitable access to healthcare (Osman, 2008; Rahman et al. 2018). However, the country still faces challenges in reaching remote areas and ensuring consistent vaccine coverage (UNICEF, 2024b).

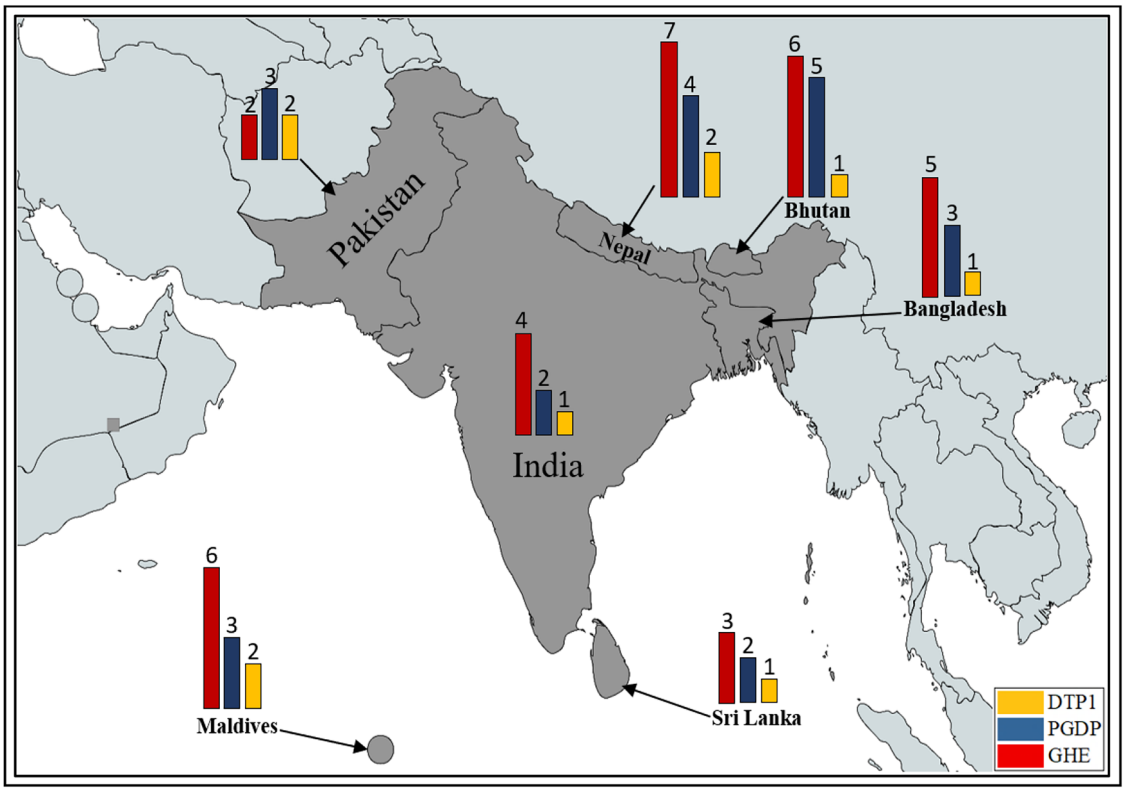

Fig. 2 Number of publications by research country context. Source: Authors' compilation based on literature.

Nepal and Bhutan have made progress in reducing child mortality but continue to face challenges related to healthcare access and economic development (Basra et al. 2024; Ghimire et al. 2019). These countries would benefit from increased investments in healthcare infrastructure and expanded immunisation programs to further reduce U5MR.

Figure 2 provides a breakdown of research publications conducted related to SAARC countries, focusing on the associations between PGDP, GHE, DTP1 vaccination, and U5MR.

In Bangladesh, research is relatively balanced across PGDP and GHE, with fewer studies on DTP1. Bangladesh's significant progress in reducing U5MR has encouraged more research attention on its healthcare systems and economic factors (Khan et al. 2024). In contrast, India and Sri Lanka face challenges in data availability, limiting comprehensive studies on the long-term effect of PGDP on U5MR due to inadequate datasets. This hinders longitudinal analyses necessary to understand the full impact of economic factors on child mortality (Khan et al. 2024). Despite India's moderate research on GHE, there is sparse focus on DTP1, similar to Sri Lanka. Both countries deal with social and economic hurdles that hinder substantial reductions in U5MR, shifting the focus toward non-economic factors (Khan et al. 2024).

Bhutan and Nepal have a strong emphasis on PGDP and GHE as influential factors in U5MR, with Bhutan leading in terms of publications on GHE, while Nepal has the highest focus on PGDP. Maldives demonstrates a balanced approach, with an increased focus on DTP1, suggesting attention to vaccine coverage as a factor affecting U5MR, although other countries like India and Bangladesh pay less attention to this relationship due to inconsistent data (O'Brien and Lemango, 2023; Path, 2024; UNICEF, 2024a; WHO, 2024; Wigley et al. 2022).

Across all SAARC countries, research on DTP1 remains sparse due to data inconsistencies and fluctuations in vaccination rates (O'Brien and Lemango, 2023; Wigley et al. 2022). This has led to limited exploration of DTP1's direct impact on U5MR, as more attention is given to coverage rates rather than outcomes, especially in countries like Sri Lanka, where investigations have focused more on the percentage of zero-dose children rather than analysing the direct effects of DTP1 on U5MR (O'Brien and Lemango, 2023; Path, 2024; UNICEF, 2024a). Government health expenditure is a major focus, particularly in Bhutan, Maldives, and Bangladesh, reflecting its perceived importance in reducing child mortality rates (Matthews et al. 2023; Shaikh and Singh, 2017). However, data limitations and a lack of comprehensive datasets continue to challenge comparative studies in countries like Sri Lanka and India, where attention often shifts to other socio-economic factors influencing U5MR (Khan et al. 2024).

Theoretical Framework. This study integrates multiple theories to explain how economic growth, healthcare expenditure, and immunisation influence child mortality (U5MR) in SAARC countries. Key frameworks include the Social Determinants of Health, Human Capital Theory, Ecological Systems Theory, the Biomedical Model, and Demographic Transition Theory. These perspectives collectively highlight the interplay of socio-economic, medical, and policy-related factors affecting child health outcomes, particularly in SAARC countries.

Social Determinants of Health Framework. The Social Determinants of Health Framework emphasises that social, economic and environmental factors play a crucial role in shaping health outcomes (Marmot, 2005). According to this theory, factors such as income, education, and living conditions directly impact an individual's ability to access healthcare services, including essential vaccinations. In the context of SAARC countries, disparities in these social determinants explain the uneven progress in reducing U5MR. For instance, in countries like Pakistan and Afghanistan, lower income levels and limited healthcare infrastructure worsen child mortality rates, despite global advances in

public health interventions (Nadeem et al. 2021; Naz et al. 2021). This framework supports the notion that higher PGDP leads to better health outcomes by improving access to quality healthcare and living conditions. However, as noted in previous studies, economic growth alone is insufficient to reduce child mortality unless it is accompanied by social investments that address disparities in access to healthcare and education (Murad et al. 2023).

Human Capital Theory. The Human Capital Theory emphasises the role of investments in health and education in improving individual and societal well-being (Becker, 2007). This theory suggests that higher GHE strengthens healthcare infrastructure, enhances preventive care, and improves service quality, reducing U5MR. In SAARC countries, where healthcare systems are often underfunded, increasing GHE could directly influence child survival rates by expanding healthcare services access for vulnerable populations (Aziz et al. 2021). Increased healthcare spending in countries like Sri Lanka and Maldives has led to significant improvements in child health outcomes, with these countries achieving some of the lowest U5MR in the region (Jayathilaka et al. 2021; Raina et al. 2023). On the other hand, in countries where healthcare expenditure remains low, such as Pakistan and Bangladesh, child mortality rates continue to be high due to inadequate healthcare resources and infrastructure (Osman, 2008; Ullah et al. 2021). Human Capital Theory thus highlights GHE's role in long-term societal benefits, notably better child health outcomes.

Bronfenbrenner's Ecological Systems Theory. Bronfenbrenner's Ecological Systems Theory offers a multi-layered approach to understanding child mortality by considering the interaction between individual, household, community, and societal factors (Hoffman and Kruczek, 2011). In this framework, a child's health is shaped by biological, medical, and socio-economic factors, including income, healthcare infrastructure, and policies. This theory is particularly relevant to the study of U5MR in SAARC countries, where socio-economic disparities and healthcare access vary widely between urban and rural areas. For instance, rural areas in Pakistan and Afghanistan experience higher child mortality due to limited access to healthcare and lower immunisation rates, as compared to more urbanised regions (Nadeem et al. 2021; Naz et al. 2021). In contrast, countries like Sri Lanka, which have more equitable distribution of healthcare services, have achieved better health outcomes (Jayathilaka et al. 2021). As such, Bronfenbrenner's theory links regional disparities to macro-level policies and micro-level household factors shaping child health.

Biomedical Model. The Biomedical Model focuses on the biological and medical factors that directly impact child health outcomes, particularly the role of immunisation in preventing disease (Suzuki, 2013). Immunisation, such as the administration of the DTP1 vaccine, is one of the most effective biomedical interventions for reducing U5MR. Research has shown that widespread vaccination significantly reduces vaccine-preventable diseases and lowers child mortality (Andre et al. 2008; Das et al. 2015). In SAARC countries, the DTP1 vaccine has been a critical tool for preventing diphtheria, tetanus, and pertussis, all of which are major contributors to child mortality (Das et al. 2015). However, disparities in vaccine coverage remain, with countries like Sri Lanka achieving near-universal coverage, while Pakistan and Afghanistan, struggle with low immunisation rates due to political instability, poor infrastructure, and vaccine supply issues (Memon et al. 2023; Naz et al. 2021). As such, the Biomedical Model emphasises immunisation's vital role in improving child health, especially in low- and middle-income countries.

Demographic Transition Theory. Demographic Transition Theory links economic progress to shifts in birth and death rates, suggesting that as a country develops, both birth rates and child mortality rates decline (Caldwell et al. 2006). In the context of SAARC countries, it explains the reduction in U5MR in countries like Sri Lanka and Maldives, which have experienced sustained economic growth and improvements in healthcare access (Jayathilaka et al. 2021; Raina et al. 2023). As these countries progress through the demographic transition, lower fertility rates and improved healthcare services contribute to the steady decline in child mortality. However, some SAARC countries, such as Pakistan and Afghanistan, are still in earlier stages of the demographic transition, where high birth rates and high child mortality rates coexist (Nadeem et al. 2021). This highlights the importance of targeted policy interventions that accelerate healthcare improvements and ensure that economic growth translates into better child health outcomes.

Figure 3 presents the theoretical framework underpinning this study, developed based on the reviewed literature and relevant

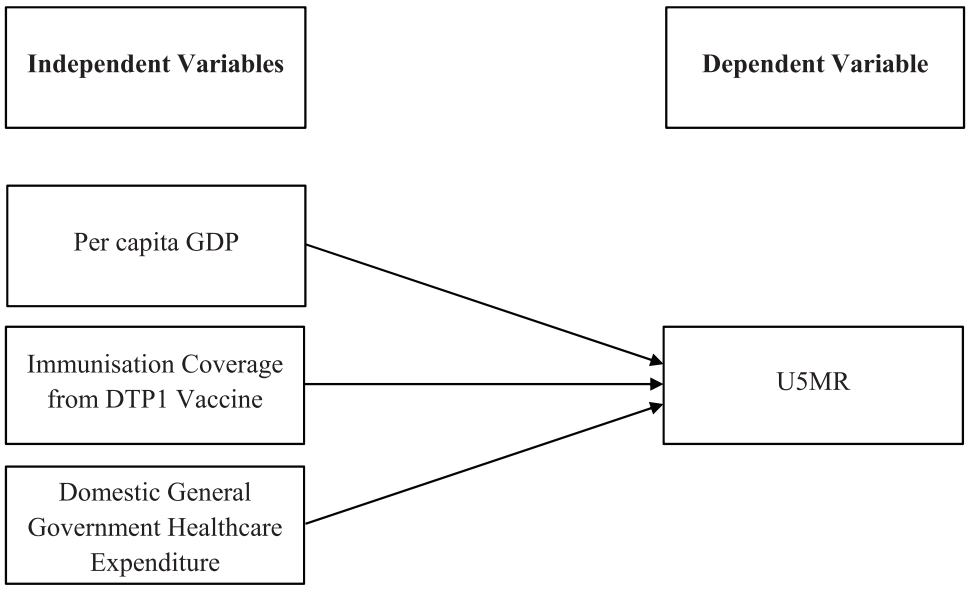

Fig. 3 Conceptual Framework. Source: Authors' composition.

theoretical foundations. Accordingly, the following hypotheses are proposed: First, higher PGDP is expected to be associated with lower U5MR, as economic growth improves access to healthcare and enhances living conditions. Second, increased GHE is hypothesised to be negatively associated with U5MR, as greater investment in healthcare infrastructure and service delivery promotes better health outcomes and facilitates higher immunisation coverage. Finally, it is hypothesised that DTP1 vaccine coverage will be inversely related to U5MR, as the vaccine provides protection against common childhood diseases, contributing to reduced child mortality.

Methodology

The Fig. 4 denotes the overview of the workflow adopted in conducting this study. This study employs a quantitative research approach utilising a panel dataset from 2000 to 2020 to investigate the impact of three key determinants, PGDP, DTP1 vaccine, and GHE, on the U5MR in SAARC countries. The countries analysed in this study include Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. Due to issues in data availability, Afghanistan was excluded from the analysis (UNICEF, 2024b; WorldBank, 2024).

Data Sources. Table 1 denotes a snapshot of the key variables related to the study along with the respective data sources. The study used a panel dataset covering data for a period of 20 years from 2000–2020 (Appendix 1), providing a comprehensive view of the long-term trends in child mortality and its determinants across the SAARC region. The STATA software version SE was used to conduct effective and efficient analysis of data.

The trends related to the behaviour of U5MR and DTP1 vaccine coverage among the 7 SAARC countries is indicated in Fig. 5.

According to Fig. 5, Sri Lanka maintains the lowest U5MR trend among the SAARC nations, despite notable hikes in year 2004 and year 2009. The overall U5MR trend in Sri Lanka is complemented by the DTP1 coverage trend shown by Sri Lanka, which tops the overall SAARC nations. Similarly, it could be observed that Maldives which denotes the lowest DTP1 coverage across the SAARC nations being the country with the highest U5MR amongst the SAARC. Figure 6 denotes the trend of PGDP and GHE for SAARC nations from 2000–2020.

According to Fig. 6, Maldives sets the lead in terms of PGDP and GHE in the SAARC region. This lead by Maldives together with the DPT 1 trend (denoted in Fig. 5) complements why Maldives remain to be second in terms of lowest U5MR statistics recorded in the SAARC region.

Stationarity and Stability Tests. Before conducting the regression analysis, stationarity tests were performed using the Levin-Lin-Chu (LLC) unit root test to check whether the data series for U5MR, DTP1, and GHE were stationary. The results showed that these variables were non-stationary, as their p-values exceeded the significance level, where U5MR was 0.6807, PGDP was 0.0015, DTP1 was 0.0682 and GHE, which was 0.5990. To address this issue, differencing transformations were applied: third differences for U5MR (ΔΔΔU5MR), first differences for DTP1 (ΔDTP1), and second differences for GHE (ΔΔGHE). After these transformations, all variables passed the stationarity test, ensuring reliable results to proceed with the regression analysis.

Additionally, stability tests were conducted to confirm the robustness of the regression model. The eigenvalues were found to lie within the unit circle, confirming that the panel vector autoregression (VAR) model met the stability conditions (Choi et al. 2009). These stability tests ensured that the data and model were fit for subsequent analysis. The outcomes of both the stationery and stability tests are mentioned in Appendix 2.

Specification Tests. After conducting the stationarity and stability tests, specification tests were performed to identify the most appropriate model for the study. First, the Breusch-Pagan test was carried out, which indicated that the random-effects model was preferable for the dataset than Pooled Ordinary Least Squares (POLS) model as the p-value was 0.00, further rejecting H0, which is the POLS model, and accepting H1, which is random-effects model. Subsequently, the Hausman test was conducted, and its results suggested that the fixed-effects model was suitable for this analysis than the random effects model, as the p-value was 0.00, further rejecting H0, which is the random effects model, and accepting H1, which is the fixed-effects model. To further confirm the model choice, the F-test was employed, which demonstrated that the fixed-effects model was a better model than the POLS model, again due to the p-value being 0.00, further rejecting H0, which is the pooled ordinary least squares model and accepting H1, which is the fixed-effects model. Based on the results of these three specification tests, the fixed effects model was selected as the most appropriate method for analysing the data in this study where the majority of the favour lies (Appendix 3).

Accordingly fixed-effects model was deemed as a much better model approach as it controls country-specific unobserved factors that do not change over time. Furthermore, as this study breaks down the SAACR region into a country-specific evaluation, the fixed-effects model helps examine relationships between the independent variable and the dependent variable in different countries over several years. Moreover, this model helps eliminate the bias from unobserved, time invariant characteristics.

Panel Regression Analysis. With the variables confirmed to be stationary and the random-effects model deemed inappropriate, the study proceeded with the panel regression using the fixed effects model. This regression model was used to assess the impact of per capita GDP, DTP1 immunisation coverage, and government healthcare expenditure on U5MR across SAARC countries as a whole. Later, a multiple linear regression analysis was conducted to assess each country individually.

The following panel regression equation was employed:

$$\Delta\Delta\Delta U5MR_{it} = \beta_0 + \beta_1 \ln\mathrm{PGDP}_{it} + \beta_2 \Delta DTP1_{it} + \beta_3 \Delta\Delta GHE_{it} + \varepsilon_{it} \quad (1)$$

where:

ΔΔΔU5MR is the third difference of the under-five mortality rate for country **i** at time **t,**

lnPGDP represents per capita gross domestic product,

ΔDTP1 refers to the first difference of immunisation coverage (DTP1 vaccine),

ΔΔGHE is the second difference of government healthcare expenditure as a percentage of GDP, and

$\boldsymbol{\varepsilon_{it}}$ is the error term.

The regression analysis aimed to determine whether higher PGDP, increased DTP1 vaccine, and higher GHE are associated with lower U5MR. The fixed effects model was selected to account for time-invariant country-specific effects and to mitigate multicollinearity issues. Further, Variance Inflation Factor (VIF) analysis was conducted to justify normality, no multicollinearity, and no endogeneity, where the results remained below the threshold of 5. Moreover, the issue remains non-problematic. This method allowed for a robust analysis of the relationships between the independent variables and U5MR across the SAARC

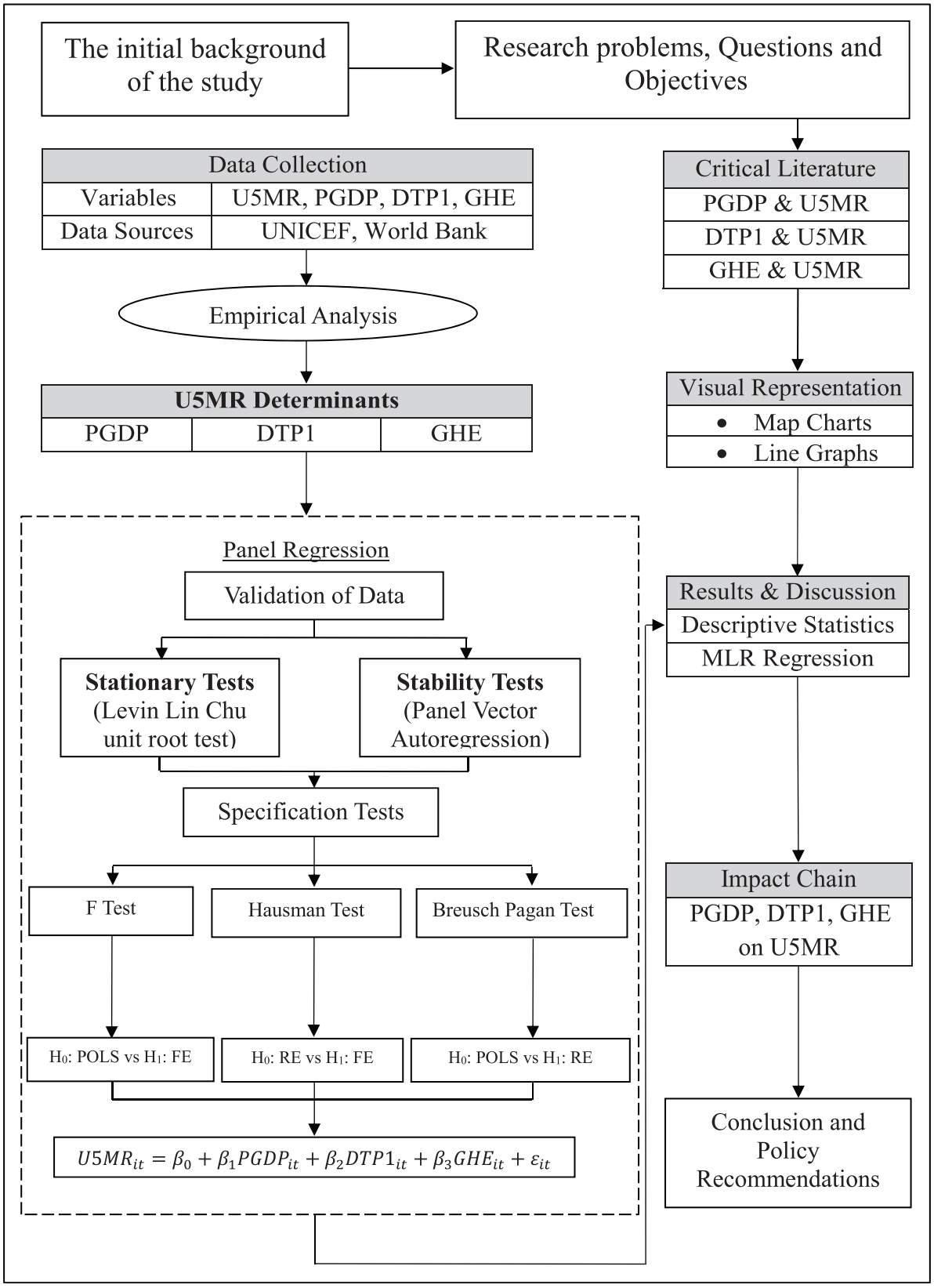

Fig. 4 Workflow of the study. Source: Authors' composition.

Table 1 Description of Variables and Data Sources.

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

Source: Authors' illustrations based on (UNICEF, 2024b) and (WorldBank, 2024).

region.

$$\Delta\Delta\Delta U5MR_t = \beta_0 + \beta_1 \mathrm{lnPGDP}_t + \beta_2 \Delta DTP1_t + \beta_3 \Delta\Delta GHE_t + \varepsilon_t \quad (2)$$

where:

ΔΔΔU5MR is the third difference of the under-five mortality rate for country **i** at time **t,**

lnPGDP represents per capita gross domestic product,

ΔDTP1 refers to the first difference of immunisation coverage (DTP1 vaccine),

ΔΔGHE is the second difference of government healthcare expenditure as a percentage of GDP, and

ε_{it} is the error term.

The MLR model was used to generate results, which was 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. Equation was included to assess the country-specific impact of PGDP, DTP1 and GHE on U5MR.

Data Analysis Procedure. The data analysis was conducted following a structured procedure to ensure comprehensive results. First, descriptive statistics were computed for each variable, covering both the overall dataset and individual SAARC countries. These statistics included measures of central tendency such as mean and median, as well as measures of variability like standard deviation. The descriptive statistics provided a clear overview of the data distribution and variability across different countries, allowing for a deeper understanding of the dataset.

Following the descriptive analysis, a panel regression analysis was performed using the fixed effects model to estimate the effects of PGDP, DTP1 immunisation coverage, and GHE on the U5MR. The regression results included coefficients, p-values, and R-squared values, which were used to assess the significance of the independent variables and the overall goodness-of-fit of the model. The panel regression analysis helped uncover the relationship between economic, healthcare, and immunisation factors and child mortality across the SAARC region.

Lastly, a trend analysis was employed to visualise how U5MR evolved over the 21-year study period in each SAARC country. The predicted values of U5MR were plotted against time to illustrate the shifts in child mortality rates during the study period, highlighting the impact of PGDP growth, DTP1 immunisation coverage, and changes in GHE on U5MR. This trend analysis provided valuable insights into the progress and challenges faced by each country in reducing child mortality.

Results

The results of the analysis provide important insights into the relationship between PGDP, DTP1 vaccine, GHE, and the U5MR across SAARC countries, as factors influencing child mortality in the region.

Descriptive Statistics. The descriptive statistics for the study variables; U5MR, PGDP, DTP1 vaccine coverage, and GHE, reveal significant variations across SAARC countries from 2000 to 2020 (Appendix 4). Countries such as Sri Lanka and the Maldives exhibited lower U5MR, reflecting their more advanced healthcare systems and higher immunisation coverage (Jayathilaka et al. 2021; UNICEF, 2024b). In contrast, countries like Pakistan and Afghanistan showed much higher U5MR rates, likely due to socio-economic disparities, lower healthcare expenditure, and challenges in immunisation coverage (Nadeem et al. 2021; Naz et al. 2021).

For example, Sri Lanka's U5MR was consistently lower compared to Pakistan, highlighting the efficacy of Sri Lanka's healthcare policies (Jayathilaka et al. 2021). Similarly, while Bangladesh had relatively low GHE, its focus on efficient public health programs resulted in a significant reduction in U5MR, underlining the importance of effective healthcare delivery even in resource-constrained environments (Osman, 2008; Rahman et al. 2018). These descriptive statistics set the stage for further analysis of the relationships between these variables.

Multiple Linear Regression Results. Table 2 presents the results obtained through multiple linear regression (MLR), breaking down the results by country, the analysis reveals some interesting country-specific nuances and offer evidence of significant relationships between the independent variables lnPGDP, ΔDTP1 vaccine coverage, and GHE and U5MR. Specifically, the findings indicate that both PGDP and DTP1 vaccine coverage are inversely related to U5MR across SAARC countries, suggesting that economic growth and improved immunisation coverage contribute to lower child mortality rates.

Further, showing that the logarithm of per capita GDP (lnPGDP) does not exhibit any significant negative effects on under-five mortality (U5MR), which is an unusual finding. However, lnPGDP demonstrates a significant positive impact on U5MR in countries such as Bangladesh and Pakistan, indicating that an increase in GDP is associated with a parallel rise in child mortality. This paradoxical result could be attributed to other socioeconomic factors, such as literacy rates, housing conditions, and the percentage of women employed, which may have outperformed the impact of economic growth on reducing

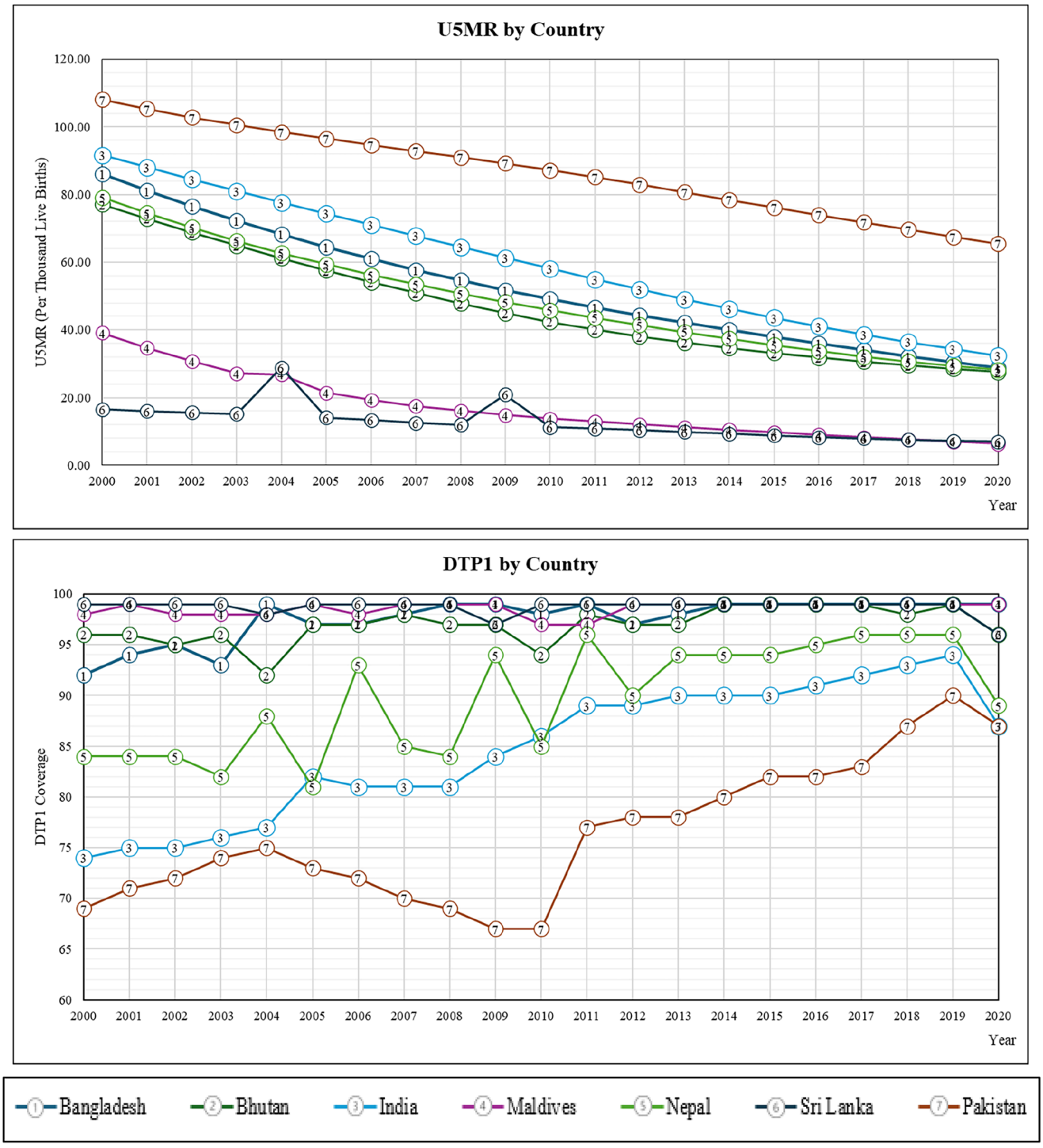

Fig. 5 Average U5MR and DTP1 vaccine trend for SAARC countries from 2000–2020. Source: Authors' illustrations based on (UNICEF, 2024b) and (WorldBank, 2024).

U5MR (Thoa et al. 2013) While economic growth occurred, its benefits did not translate uniformly into improved healthcare outcomes, particularly in rural areas. The country's GHE shows a slow increase, however, it is overshadowed by the high U5MR, contributing to slower progress in child mortality reduction (Naz et al. 2021; Ullah et al. 2021). Additionally, ineffective allocation of healthcare resources seems to hinder efforts to reduce child mortality in these countries.

Examining the acceleration of government healthcare expenditure (ΔΔGHE), the results show a significant negative impact on U5MR in Pakistan, suggesting that as GHE increases, the rate of under-five deaths decreases significantly. This reduction is likely due to better-targeted spending on critical sectors like healthcare and education, which are reliable investments in improving child health outcomes (Anand and Ravallion, 1993). Increased funding accelerates the expansion of hospitals and mobile health units, ensuring that children receive well-timed medical care. Additionally, government projects such as breast-feeding programs influence to improved child nutrition. Which play a crucial role in lowering U5MR. In contrast, India displayed

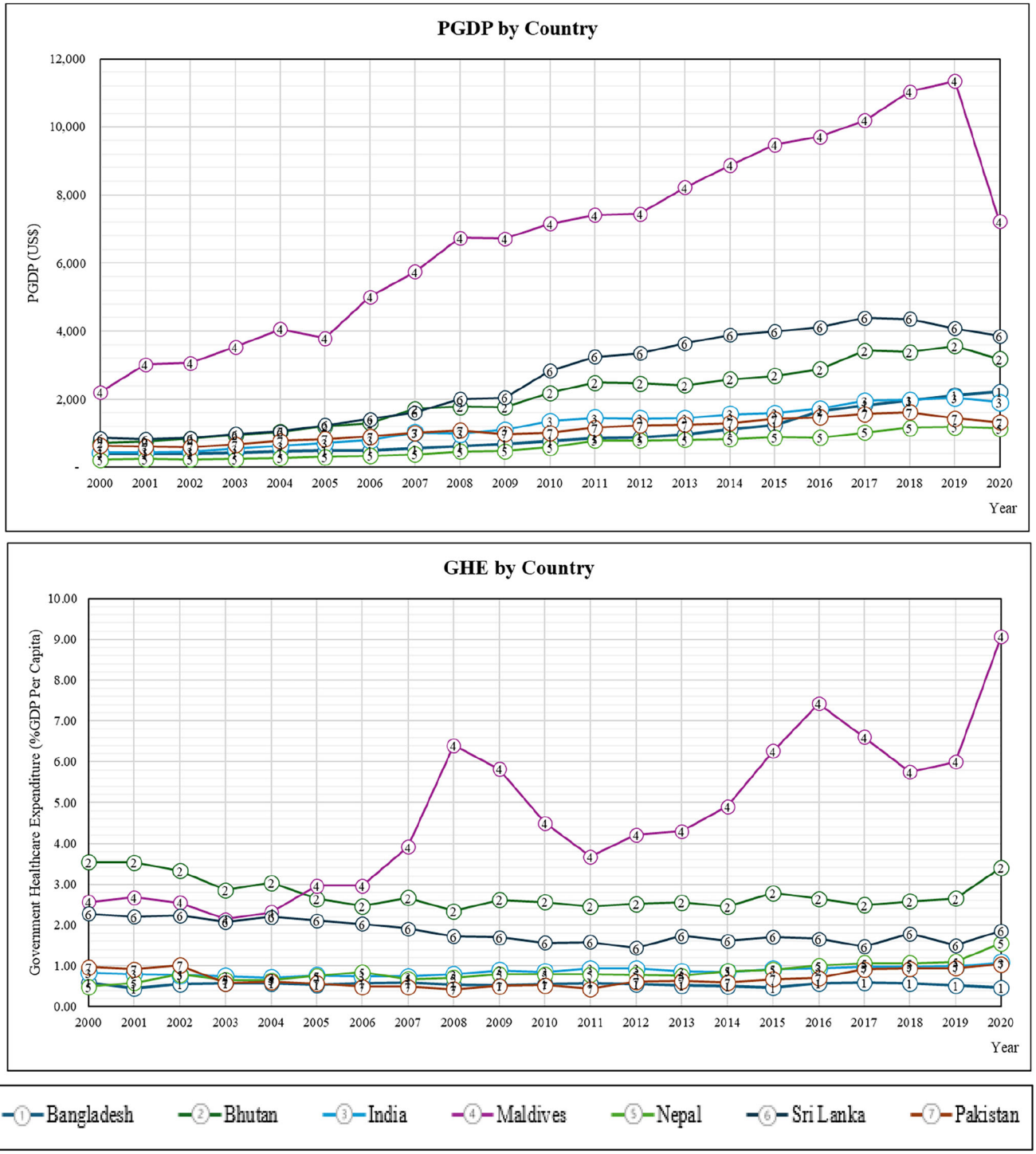

Fig. 6 Average PGDP and GHE for SAARC countries from 2000–2020. Source: Authors' illustrations based on (UNICEF, 2024b) and (WorldBank, 2024).

a significant positive relationship between ΔΔGHE and U5MR, indicating that despite rising healthcare expenditure, child mortality continues to increase. This suggests inefficiencies in the allocation of healthcare resources. The persistent rise in U5MR, despite higher GHE, could be attributed to the misallocation of funds to less impactful sectors, emphasising the need for more effective resource utilisation (Ullah et al. 2021). Funds may be misallocated, due to all funds diverted to administrative expenses, or lost due to corruption. Moreover, short term increases in healthcare spending may not grant immediate reductions in U5MR. Besides, external factors such as war, pandemics, or economic crises can set considerable strain on healthcare systems, leading to sustained or worsening child mortality rates. These challenges contribute to an unexpected positive correlation between government healthcare expenditure and U5MR. Therefore, simply increasing healthcare expenses is not enough. Targeted and well managed sustainable involvements are necessary to ensure a consistent decline in U5MR.

Trend Analysis of U5MR and Independent Variables. The trend analysis provides additional insights into how U5MR has evolved over the 21-year study period across the SAARC region.

Table 2 MLR results assessing the impact on U5MR in every SAARC presented.

Countries	Variables				R^2	F value
	Constant	lnPGDP	ΔDTP1	ΔΔGHE		
Bangladesh	−0.1756**	0.0241**	−0.0005	0.0318	0.2767	2.14
P-Values	(0.034)	(0.023)	(0.612)	(0.171)		
Bhutan	0.1937	−0.0257	0.0033	0.0073	0.0302	0.24
P-Values	(0.481)	(0.438)	(0.282)	(0.591)		
India	−0.0670	0.0099	0.0008	0.247**	0.2770	2.09
P-Values	(0.223)	(0.349)	(0.411)	(0.041)		
Maldives	−2.3594	0.2757	−1.7828	0.0124	0.2251	0.53
P-Values	(0.110)	(0.128)	(0.145)	(0.389)		
Nepal	−0.1244	0.0182	0.0002	−0.0917	0.1222	0.78
P-Values	(0.192)	(0.138)	(0.872)	(0.364)		
Pakistan	−0.8328	0.1171*	0.0001	−0.1021*	0.2309	3.07
P-Values	(0.093)	(0.072)	(0.897)	(0.081)		
Sri Lanka	5.7427	−0.8803	−6.7285	2.7064	0.1654	1.07
P-Values	(0.298)	(0.116)	(0.147)	(0.194)		

Note: ** significant at 5%, *significant at 10%. Parentheses indicate robust standard error. First difference (Δ), Second difference (ΔΔ), Third difference (ΔΔΔ) and Logarithm(ln).

The predicted trends in U5MR for the SAARC countries are presented in Appendix 5. These trends reveal that countries with higher levels of economic growth and immunisation coverage have experienced consistent reductions in U5MR, while those with lower GHE or immunisation rates faced slower declines in child mortality.

For instance, Sri Lanka and the Maldives, which maintained high immunisation coverage and experienced robust PGDP growth, saw steady and significant declines in U5MR over the study period (Jayathilaka et al. 2021). Conversely, countries like Pakistan, with relatively lower DTP1 coverage and GHE, exhibited slower progress in reducing child mortality (Das et al. 2015; Nadeem et al. 2021). The trend analysis further emphasises the disparities in healthcare access and economic development across SAARC countries, pointing to the need for targeted interventions in countries that continue to struggle with high U5MR.

Discussion

Impact of Per Capita GDP on U5MR. The negative relationship between PGDP and U5MR emphasises the role of economic growth in improving child health outcomes. Higher PGDP is associated with increased access to healthcare services, improved nutrition, and better living conditions, all of which contribute to lower child mortality rates (Ahmmed et al. 2021). However, the variations in U5MR reductions across SAARC countries suggest that economic growth alone is insufficient to achieve significant improvements in child mortality. For instance, while India has experienced rapid economic growth, disparities in healthcare access and income inequality have limited the impact on U5MR (Azam et al. 2023).

Impact of DTP1 Vaccine Coverage on U5MR. DTP1 vaccine coverage demonstrates a robust negative correlation with U5MR, highlighting the importance of immunisation in reducing preventable childhood diseases. Countries like Sri Lanka and the Maldives, which have achieved near-universal DTP1 coverage, have experienced sharp declines in U5MR (Jayathilaka et al. 2021). In contrast, Pakistan and Afghanistan continue to struggle with high U5MR due to lower vaccine coverage, worsened by political instability and weak healthcare infrastructure (Memon et al. 2023; Naz et al. 2021). These findings are consistent with previous studies that emphasise the critical role of immunisation programs in child mortality reduction (Andre et al. 2008; Das et al. 2015).

Impact of Government Healthcare Expenditure on U5MR. The relationship between GHE and U5MR, while weaker than that of PGDP and DTP1 coverage, still supports the notion that investments in healthcare infrastructure and services are essential for reducing child mortality. Countries that allocate a larger percentage of their GDP to healthcare, such as Sri Lanka, have seen more significant declines in U5MR (Rahman et al. 2018; Raina et al. 2023). However, countries like Bangladesh, which have relatively low GHE but significant reductions in U5MR, suggest that efficient healthcare delivery and public health programs can compensate for limited healthcare spending (Osman, 2008).

Disparities in Child Mortality Across SAARC Countries. Despite the overall progress in reducing U5MR, significant disparities remain across SAARC countries. Sri Lanka and the Maldives stand out as success stories due to their sustained investments in healthcare and high immunisation coverage (Jayathilaka et al. 2021; UNICEF, 2024b). On the other hand, Pakistan and Afghanistan continue to struggle with high child mortality due to socio-economic inequalities, inadequate healthcare access, and poor immunisation coverage (Nadeem et al. 2021; Naz et al. 2021). These findings emphasise the importance of addressing healthcare disparities and expanding public health programs to reach underserved populations.

Comparison of healthcare policies across SAARC nations. Sri Lanka's healthcare policies like universal healthcare and immunisation is leading to significant reductions in U5MR while Maldives also emphasises similar healthcare policies to Sri Lanka, while Sri Lanka benefits from more extensive resources like larger population and higher economic resources but Maldives has similarly reduced U5MR despite its smaller size (Jayathilaka et al. 2021; Rahman et al. 2018).

Bangladesh mainly focuses on cost effective and strong healthcare policies like immunisation campaigns and community health workers (Osman, 2008) while Pakistan shows high U5MR rate due to their inability to conduct suitable healthcare policies like immunisation coverage due to the country's political instability and unequal healthcare access (Naz et al. 2021).

Bhutan's healthcare policy's includes free healthcare with mainly focuses on primary care and child health while Nepal uses

improving access to healthcare services in rural areas and community-based health programs. But when it comes to India's healthcare policies like National rural health mission (NRHM) which mainly focus on primary care and provide underserved healthcare services in rural areas (ORF, 2018). But policies like immunisation has become a challenge to conduct across the nation due to inconsistent infrastructure and vaccine coverage (Azam et al. 2023).

Country-Specific Recommendations for SAARC

Pakistan. Pakistan should significantly increase its government healthcare expenditure to at least 5% of GDP, with a special focus on rural areas where healthcare access is severely limited (Ansari, 2025). Expanding immunisation programs, particularly DTP1 coverage, should be a top priority, aiming for at least 90% coverage by 2025 (Malik and Siddiqui, 2025; UNICEF, 2024c). Given Pakistan's relatively low immunisation coverage and high U5MR, increasing healthcare investment and improving immunisation infrastructure will be critical for reducing child mortality. Public-private partnerships could also be leveraged to build healthcare facilities in underserved regions, improving healthcare delivery for the most vulnerable populations. To ensure effective implementation, deploying mobile health units and training community health workers will help improve immunisation outreach in rural and remote Pakistani areas.

Afghanistan. Afghanistan's healthcare sector was severely weakened following the Taliban's return to power in August 2021, resulting in mass job losses, increased poverty, and a drastic decline in access to medical care. The sudden withdrawal of development aid further destabilised the economy and public health infrastructure, making many healthcare workers to leave the country or abandon their roles (Abbasi, 2024). In this context, rather than setting rigid coverage targets, recommendations must focus on strengthening the foundations of the healthcare system. As such, expanding DTP1 immunisation, especially in rural and conflict-affected regions, should remain a priority, but must be approached through flexible and context-sensitive strategies. These may include the deployment of mobile health units, enhanced collaboration with international humanitarian agencies, and the adoption of digital tracking systems to improve service delivery in inaccessible areas. Moreover, gradually increasing government healthcare expenditure, where feasible, and encouraging public–private partnerships could help rebuild system resilience. Such efforts are essential to ensure that any economic recovery results in meaningful improvements in health outcomes for Afghanistan's most vulnerable populations.

Bangladesh. Bangladesh, despite relatively low government healthcare expenditure, has made significant progress in reducing U5MR through efficient public health programs. To further improve, Bangladesh should focus on increasing GHE to enhance healthcare infrastructure, particularly in rural areas (Rezvi and Hossain, 2022; Sultana et al. 2024). Expanding immunisation programs to cover hard-to-reach areas will help sustain reductions in child mortality. Bangladesh could also benefit from leveraging public-private partnerships to improve healthcare facilities, particularly in urban slums and rural communities, where healthcare access remains limited (Iroz et al. 2024). Targeted outreach programs and immunisation drives using data-driven approaches will help Bangladesh to address remaining gaps in healthcare accessibility.

Sri Lanka. Sri Lanka has been successful in maintaining low U5MR through strong healthcare policies and high immunisation coverage. To sustain this progress, Sri Lanka should continue investing in healthcare infrastructure, particularly in underserved regions, ensuring equitable access to healthcare services across the country (Prinja et al. 2024; Rajapakse and Jayathilaka, 2025). Strengthening its national-level monitoring systems for child health indicators, such as U5MR and immunisation rates, will ensure that progress is tracked efficiently and any gaps in healthcare delivery are addressed promptly. Public-private partnerships could also be explored further to maintain and upgrade healthcare facilities in remote areas. In fact, enhancing telemedicine services and incentivising healthcare professionals to work in underserved areas in Sri Lanka will further strengthen healthcare equity in the country (WHO, 2021).

Maldives. Maldives should continue its focus on high immunisation coverage, which has been a key driver of the country's success in reducing U5MR. However, as a geographically dispersed nation, Maldives should invest more in mobile health units and telemedicine solutions to ensure that healthcare services reach every atoll. Increasing GHE slightly, particularly in preventive healthcare services, will help maintain its low U5MR. The Maldives should also consider forming partnerships with the private sector to improve the delivery of healthcare services in its remote regions, ensuring that all children have access to essential healthcare. In fact, expanding digital health services and strengthening logistics and capitalising on advanced methods such as drone assisted medical supply chains (Haleem, 2023) for vaccine distribution across Maldives will enhance accessibility across remote atolls

Nepal. Nepal needs to focus on increasing both government healthcare expenditure and immunisation coverage, particularly in its mountainous and rural areas, where healthcare access is limited. By investing in healthcare infrastructure and expanding immunisation programs, Nepal can further reduce U5MR. Public-private partnerships should be explored to build healthcare facilities in hard-to-reach areas, while promoting equitable economic growth to ensure that healthcare services are accessible to all segments of the population. Deploying mobile vaccination teams, which is a proven mechanism for improving healthcare accessibility for vulnerable populations (Rabiou et al. 2024) and creating temporary immunisation camps across Nepal will help reach isolated communities more effectively.

Bhutan. Bhutan should continue to invest in its healthcare system, ensuring that its immunisation coverage remains high and U5MR continues to decline. Increasing government healthcare expenditure, particularly in maternal and child health services, will help Bhutan maintain its progress (UNICEF, 2018). Additionally, Bhutan could benefit from implementing a national-level monitoring system to track child health indicators, allowing for timely interventions when healthcare access is compromised in remote areas. In fact, Bhutan could focus efforts on strengthening national immunisation registries and community-based health programs to ensure sustained child health improvements.

By focusing on the unique challenges and opportunities present in each country, these customised recommendations provide actionable steps for each SAARC nation. Implementing these strategies will not only help reduce U5MR but also strengthen overall healthcare systems, ensuring that all children have access to life-saving services. The key lies in increasing government healthcare expenditure, expanding immunisation programs, and leveraging public-private partnerships to ensure healthcare delivery is equitable and efficient across all regions.

Conclusion

This study provides a critical examination of the factors driving U5MR across SAARC countries, offering valuable insights into the relationship between economic growth, healthcare expenditure, and immunisation coverage in shaping child health outcomes.

Key Findings and implications. The findings emphasise the complex aspects of child mortality reduction, revealing that while economic growth (PGDP) contributes to improvements in child health, it alone is insufficient to address the deep-rooted disparities in healthcare access and quality. The most significant determinant of child mortality in the region, immunisation coverage (particularly DTP1), emerges as a crucial public health intervention capable of delivering substantial reductions in U5MR. Equally, GHE, though variable in its impact across countries, remains essential for building the healthcare infrastructure needed to support child health improvements, particularly in underserved and rural regions.

The study's emphasis on SAARC countries highlights the unique challenges and opportunities within the region. The stark disparities in U5MR across countries like Sri Lanka, which has made remarkable progress, and Pakistan and Afghanistan, which still face high mortality rates, illuminate the urgent need for targeted policies that address healthcare inequities, expand immunisation programs, and ensure that economic growth translates into tangible health benefits for the most vulnerable populations. By recommending country-specific strategies, this paper not only contributes to the academic understanding of U5MR determinants but also offers practical policy recommendations that are directly applicable to SAARC nations.

Ultimately, this study is an urgent appeal to policymakers, healthcare leaders, and international organisations to prioritise investments in healthcare infrastructure, expand life-saving immunisation coverage, and bridge socio-economic gaps. Only through coordinated, targeted efforts can SAARC countries hope to achieve the ambitious goals set forth by the global health community, including the Sustainable Development Goals, and ensure that every child, regardless of their geographical location or socio-economic status, has the opportunity to survive and thrive. The insights provided by this paper, supported by comprehensive data and rigorous analysis, make it a valuable resource for driving real-world change in reducing child mortality across the SAARC region.

Limitations and future research directions. There are several directions for future research to expand this study, including deeper investigations into the impact of PGDP, DTP1, and GHE on U5MR within the SAARC region, which can help address the limitations identified in the present study. First, future researchers may expand this study by introducing additional variables that can more comprehensively capture the true nature of U5MR such as skilled birth attendance, child nutrition rates, breastfeeding programs, and sanitation levels. Due to the unavailability of consistent and complete data for all seven SAARC countries during the 2000–2020 period, these variables were not included in the current analysis. Moreover, in this study, DTP1 coverage is used as a proxy indicator for immunisation performance. DTP1 is widely recognised as a key metric for identifying "zero-dose" children, those who have not received even a single vaccine dose, making it a valid indicator of immunisation system reach and effectiveness. The impact of other vaccine coverage measures, such as DTP2, DTP3, BCG, Polio, and HEP B, on U5MR in the SAARC area may be further investigated using this methodology as a basis for future studies. Additionally, future research can enhance the comprehensiveness of this analysis by including countries currently excluded due to data limitations. For example, Afghanistan was excluded because decades of conflict and instability have significantly constrained the country's capacity to collect and maintain reliable health data. Moreover, due to the short panel structure and limited availability of strong and valid instruments across all countries, the use of instrumental variables (IV) or system-GMM techniques was not practically feasible in this study. Furthermore, although this study recognises the potential challenges associated with endogeneity and reverse causality, the short time dimension of the dataset limited the feasibility of applying panel cointegration techniques or vector error correction models in the study. This constraint is acknowledged as a key limitation and presents a valuable direction for future research. Subsequent studies could address this gap by employing more advanced causal inference methods and longer panel structures to rigorously assess the directionality of relationships among the core variables.

Data availability

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

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References

Abbasi F (2024) A Disaster for the Foreseeable Future" Afghanistan's Healthcare Crisis. Human Rights Watch. https://www.hrw.org/report/2024/02/12/disaster-foreseeable-future/afghanistans-healthcare-crisis

Ahmmed MM, Babu MA, Ferdosy J (2021) Direct and indirect effects of COVID-19 on maternal and child health in Bangladesh. J Stat Manag Sys 24(1):175–192

Amarasiri de Silva MW, Wijekoon A, Hornik R, Martines J (2001) Care seeking in Sri Lanka: one possible explanation for low childhood mortality. Soc Sci Med 53(10):1363–1372. https://doi.org/10.1016/s0277-9536(00)00425-1

Anand S, Ravallion M (1993) Human Development in Poor Countries: On the Role of Private Incomes and Public Services. Journal of Economic Perspectives 7(1):133–150. https://doi.org/10.1257/jep.7.1.133

Andre FE, Booy R, Bock HL, Clemens J, Datta SK, John TJ, Lee BW, Lolekha S, Peltola H, Ruff TA, Santosham M, Schmitt HJ (2008) Vaccination greatly reduces disease, disability, death and inequity worldwide. Bull World Health Organ 86(2):140–146. https://doi.org/10.2471/blt.07.040089

Ansari I (2025) Pakistan's health spending below 1% of GDP, reveals Economic Survey 2024–25. *The Express Tribune*. https://tribune.com.pk/story/2550010/pakistans-health-spending-below-1-of-gdp-reveals-economic-survey-202425

Azam M, Uddin I, Saqib N (2023) The determinants of life expectancy and environmental degradation in Pakistan: evidence from ARDL bounds test approach. Environ Sci Pollut Res Int 30(1):2233–2246. https://doi.org/10.1007/s11356-022-22338-9

Aziz N, He J, Sarker T, Sui H (2021) Exploring the Role of Health Expenditure and Maternal Mortality in South Asian Countries: An Approach towards Shaping Better Health Policy. Int J Environ Res Public Health 18(21):11514. https://doi.org/10.3390/ijerph182111514

Bango M, Ghosh S (2023) Reducing infant and child mortality: assessing the social inclusiveness of child health care policies and programmes in three states of India. BMC Public Health 23(1):1149. https://doi.org/10.1186/s12889-023-15812-7

Basra M, Patel S, Nepal D, Blavo C (2024) Infant Mortality Screening and Prevention Initiatives in Nepal. Cureus 16(1):e52366. https://doi.org/10.7759/cureus.52366

Becker GS (2007) Health as human capital: synthesis and extensions. Oxford Economic Papers 59(3):379–410. https://doi.org/10.1093/oep/gpm020

Bokhari FA, Gai Y, Gottret P (2007) Government health expenditures and health outcomes. Health Econ 16(3):257–273. https://doi.org/10.1002/hec.1157

Caldwell et al. (2006) *Demographic Transition Theory*. https://doi.org/10.1007/978-1-4020-4498-4

Choi CY, Mark NC, Sul D (2009) Bias Reduction in Dynamic Panel Data Models by Common Recursive Mean Adjustment. SSRN Electronic Journal 72:567–599. https://doi.org/10.2139/ssrn.1434143

Crespo I, Cardenosa N, Godoy P, Carmona G, Sala MR, Barrabeig I, Alvarez J, Minguel S, Camps N, Cayla J, Batalla J, Codina G, Dominguez A (2011)

Epidemiology of pertussis in a country with high vaccination coverage. Vaccine 29(25):4244–4248. https://doi.org/10.1016/j.vaccine.2011.03.065

Das JK, Rizvi A, Bhatti Z, Paul V, Bahl R, Shahidullah M, Manandhar D, Stanekzai H, Amarasena S, Bhutta ZA (2015) State of neonatal health care in eight countries of the SAARC region, South Asia: how can we make a difference? Paediatr Int Child Health 35(3):174–186. https://doi.org/10.1179/2046905515Y.0000000046

Fagbamigbe AF, Adeniji FIP, Morakinyo OM (2022) Factors contributing to household wealth inequality in under-five deaths in low- and middle-income countries: decomposition analysis. BMC Public Health 22(1):769. https://doi.org/10.1186/s12889-022-12988-2

Ghimire PR, Agho KE, Ezeh OK, Renzaho AMN, Dibley M, Raynes-Greenow C (2019) Under-Five Mortality and Associated Factors: Evidence from the Nepal Demographic and Health Survey (2001–2016). Int J Environ Res Public Health, 16(7). https://doi.org/10.3390/ijerph16071241

Ghosh A, Corsi DJ, Subramanian SV (2016) A Tale of Two Bengals: A Comparative Analysis of 23 Indicators of Maternal, Newborn and Child Health. Journal of Development Policy and Practice 1(1):1–17. https://doi.org/10.1177/2455133315612332

Haleem, M (2023). Maldives Republic-Maldives to Integrate Drones Into Medical Supply Chain. https://mvrepublic.com/news/drone-based-medical-supply-chain/#:~:text=The%20government%20is%20gearing%20up,Dr%20Abdulla%20Khaleel%20has%20revealed

Hoffman MA, Kruczek T (2011) A Bioecological Model of Mass Trauma. The Counseling Psychologist 39(8):1087–1127. https://doi.org/10.1177/0011000010397932

Iroz CB, Ramaswamy R, Bhutta ZA, Barach P (2024) Quality improvement in public–private partnerships in low- and middle-income countries: a systematic review. BMC Health Services Research 24(1):332. https://doi.org/10.1186/s12913-024-10802-w

Jayathilaka R, Adikari H, Liyanage R, Udalagama R, Wanigarathna N (2021) Cherish your children: socio-economic and demographic characteristics associated with child mortality. BMC Public Health 21(1):1217. https://doi.org/10.1186/s12889-021-11276-9

Khan et al. (2024) Revisiting Factors Influencing Under-Five Mortality in India: The Application of a Generalised Additive Cox Proportional Hazards Model. International Journal of Environmental Research and Public Health 21(10):1303, https://www.mdpi.com/1660-4601/21/10/1303

Malik MA, Siddiqui MM (2025) A review of childhood immunization coverage in Pakistan. East Mediterr Health J 31(1):6–15. https://doi.org/10.26719/2025.31.1.6

Marmot M (2005) Social determinants of health inequalities. Lancet 365(9464):1099–1104. https://doi.org/10.1016/S0140-6736(05)71146-6

Matthews NR, Porter GJ, Varghese M, Sapkota N, Khan MM, Lukose A, Paddick SM, Dissanayake M, Khan NZ, Walker R (2023) Health and socioeconomic resource provision for older people in South Asian countries: Bangladesh, India, Nepal, Pakistan and Sri Lanka evidence from NEESAMA. Glob Health Action 16(1):2110198. https://doi.org/10.1080/16549716.2022.2110198

Memon Z, Fridman D, Soofi S, Ahmed W, Muhammad S, Rizvi A, Ahmed I, Wright J, Cousens S, Bhutta ZA (2023) Predictors and disparities in neonatal and under 5 mortality in rural Pakistan: cross sectional analysis. Lancet Reg Health Southeast Asia 15:100231. https://doi.org/10.1016/j.lansea.2023.100231

Murad MW, Abdullah ABM, Islam MM, Alam MM, Reaiche C, Boyle S (2023) Determinants of neonatal, infant and under-five mortalities: evidence from a developing country, Bangladesh. J Public Health Policy 44(2):230–241. https://doi.org/10.1057/s41271-023-00413-w

Nadeem M, Adil S, Hunnain F, Nawaz SMN (2021) Predictive model of under-five mortality in developing countries: evidence from multiple indicators cluster survey Punjab. Quality & Quantity 56(3):1463–1480. https://doi.org/10.1007/s11135-021-01185-9

Naz L, Patel KK, Dilanchiev A (2021) Are socioeconomic status and type of residence critical risk factors of under-five mortality in Pakistan? Evidence from nationally representative survey. Clinical Epidemiology and Global Health, 10. https://doi.org/10.1016/j.cegh.2020.11.003

O'Brien KL, Lemango E (2023) The big catch-up in immunisation coverage after the COVID-19 pandemic: progress and challenges to achieving equitable recovery. Lancet 402(10401):510–512. https://doi.org/10.1016/S0140-6736(23)01468-X

ORF (2018) The Road to Universal Health Coverage. https://d1wqtxts1xzle7.cloudfront.net/107224350/The_road_to_universal_health_coverage-libre.pdf?1699412818=&response-content-disposition=inline%3B+filename%3DORF_SPECIAL_REPORT_THE_ROAD_TO_UNIVERSAL.pdf&Expires=1741322079&Signature=hQOKswtNK4fRCNcN6GyE4tIhT3nWN7MFfj-RIxtU~nLHLKEUXmYqua4ZgmSmPfbSLWW3wd6M42ux-FqGuTGKGqzDz~QOUZA8NanSuR7ZSBNk0lA5ems94kYyccgsJKIcjvqfZW5MHfjg8qAl-vLgduKkw0ppBGsoz8Afs5YLR1nCXxVWEcItlmHPdSf5nuBHVDGaK1WpZM2cyCRG34RM-uAzTSWLvSGWBqOT951vhOJTC0BXpS3pXG8UXjK8gdWIxp3mBHgzTR3co7qBPE5uxd1qa4Pc3znMsVVzqSxET5MmJ-kcukvIerEI9KKEulGtRVB61Ei3xc6F4iOXsfjOow__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA

Osman FA (2008) Health Policy, Programmes and System in Bangladesh. South Asian Survey 15(2):263–288. https://doi.org/10.1177/097152310801500206

Parihar S (2021) Predictors of Infant Mortality Rate in India. Journal of Health Management 23(4):758–769. https://doi.org/10.1177/09720634211050472

Path (2024) Zero-dose children: Reaching the. https://www.path.org/our-impact/articles/zero-dose-children-reaching-unreached/

Prinja S, Purohit N, Kaur N, Rajapaksa L, Sarker M, Zaidi R, Bennett S, Rao KD (2024) The state of primary health care in south Asia. The Lancet Global Health 12(10):e1693–e1705. https://doi.org/10.1016/S2214-109X(24)00119-0

Rabiou LM, Oumarou B, Mor D, Abdou M, Ibrahim C, Tamuzi JL, Katoto PDMC, Wiysonge CS, Anya B-PM, Manengu TC (2024) Mobile outreach clinics for improving health care services accessibility in vulnerable populations of the Diffa Region in Niger: a descriptive study. International Journal for Equity in Health 23(1):235. https://doi.org/10.1186/s12939-024-02322-0

Rahman MM, Khanam R, Rahman M (2018) Health care expenditure and health outcome nexus: new evidence from the SAARC-ASEAN region. Global Health 14(1):113. https://doi.org/10.1186/s12992-018-0430-1

Raina N, Khanna R, Gupta S, Jayathilaka CA, Mehta R, Behera S (2023) Progress in achieving SDG targets for mortality reduction among mothers, newborns, and children in the WHO South-East Asia Region. Lancet Reg Health Southeast Asia 18:100307. https://doi.org/10.1016/j.lansea.2023.100307

Rajapakse V, Fernando A, Sudangama N, Adikari D, Sundaram A, Jayathilaka R (2025) Economic and healthcare determinants of under-five mortality in low-income countries. BMC Public Health 25(1):2126. https://doi.org/10.1186/s12889-025-23370-3

Rajapakse V, Jayathilaka R (2025) Surviving the first five years: the economic and healthcare determinants of child mortality in Sri Lanka. Journal of Health, Population and Nutrition 44(1):218. https://doi.org/10.1186/s41043-025-00862-x

Rezvi, MR, & Hossain, MR (2022) Health Financing in Bangladesh: Scarcity and its Impacts. https://doi.org/10.2139/ssrn.4016638

Saeidi et al. (2015) Under-five Mortality in the World (1900–2015). Pediatrics International 3:1093–1095

Shaikh IS, Singh S (2017) On the Examination of out-of-Pocket Health Expenditures in India, Pakistan, Sri Lanka, Maldives, Bhutan, Bangladesh and Nepal. Business: Theory and Practice 18(0):25–32. https://doi.org/10.3846/btp.2017.003

Sharrow D, Hug L, You D, Alkema L, Black R, Cousens S, Croft T, Gaigbe-Togbe V, Gerland P, Guillot M, Hill K, Masquelier B, Mathers C, Pedersen J, Strong KL, Suzuki E, Wakefield J, Walker N, Estimation UNI-aGfCM, its Technical Advisory, G (2022) 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 Glob Health 10(2):e195–e206. https://doi.org/10.1016/S2214-109X(21)00515-5

Sultana S, Hossain ME, Khan MA, Saha SM, Amin MR, Haque Prodhan MM (2024) Effects of healthcare spending on public health status: An empirical investigation from Bangladesh. Heliyon 10(1):e24268. https://doi.org/10.1016/j.heliyon.2024.e24268

Suzuki, H (2013) Biomedical Model. In *The Encyclopedia of Cross-Cultural Psychology* (pp. 142-143). https://doi.org/10.1002/9781118339893.wbeccp056

Tharwani ZH, Bilal W, Khan HA, Kumar P, Butt MS, Hamdana AH, Essar MY, Nashwan AJ, Habib Z, Marzo RR (2023) Infant & Child Mortality in Pakistan and its Determinants: A Review. Inquiry 60:469580231167024. https://doi.org/10.1177/00469580231167024

Thoa NT, Thanh NX, Chuc NT, Lindholm L (2013) The impact of economic growth on health care utilization: a longitudinal study in rural Vietnam. Int J Equity Health 12(1):19. https://doi.org/10.1186/1475-9276-12-19

Ullah I, Ullah A, Ali S, Poulova P, Akbar A, Haroon Shah M, Rehman A, Zeeshan M, Afridi FEA (2021) Public Health Expenditures and Health Outcomes in Pakistan: Evidence from Quantile Autoregressive Distributed Lag Model. Risk Manag Healthc Policy 14:3893–3909. https://doi.org/10.2147/RMHP.S316844

UNICEF (2018) *Maternal, newborn and child health-Bhutan*. UNICEF. https://www.unicef.org/bhutan/wash-water-sanitation-and-hygiene/maternal-newborn-and-child-health/wash-water-sanitation-and-0-0-0#:~:text=it%20with%20them.-,Many%20more%20children%20are%20celebrating%20their%20fifth%20birthday%20than%20a,of%20PNC%20than%20rural%20areas

UNICEF (2024a) *How tracking DTP vaccine dropout rates helps protect children from preventable diseases*. https://data.unicef.org/data-for-action/tracking-dtp-vaccine-dropout-rates-protects-children-from-preventable-diseases/

UNICEF (2024b) *Under-five mortality*. https://data.unicef.org/topic/child-survival/under-five-mortality/
UNICEF (2024c) *WUENIC 2023 Revision-Pakistan*. W. H. Organization. https://www.unicef.org/pakistan/media/6001/file/WUENIC%20Pakistan%202023.pdf.pdf
WHO (2020) Immunization, Vaccines And Biologicals. Vaccine preventable diseases Vaccines monitoring system 2020 Global Summary Reference Time Series: PERTUSSIS
WHO (2021) *Leveraging telehealth for efficient delivery of primary health care in the WHO South-East Asia Region*. R. O. f. S. E. Asia. https://iris.who.int/bitstream/handle/10665/350199/Telehealth-PHC-eng.pdf?utm_source=chatgpt.com
WHO (2024) *Diphtheria tetanus toxoid and pertussis (DTP3) immunization coverage among 1-year-olds (%)* WHO headquarters in Geneva. https://www.who.int/data/gho/data/indicators/indicator-details/GHO/diphtheria-tetanus-toxoid-and-pertussis-(dtp3)-immunization-coverage-among-1-year-olds-(-)
Wigley A, Lorin J, Hogan D, Utazi CE, Hagedorn B, Dansereau E, Tatem AJ, Tejedor-Garavito N (2022) Estimates of the number and distribution of zero-dose and under-immunised children across remote-rural, urban, and conflict-affected settings in low and middle-income countries. PLOS Glob Public Health 2(10):e0001126. https://doi.org/10.1371/journal.pgph.0001126
WorldBank (2024) *The World Bank In Afghanistan*. The World Bank. https://www.worldbank.org/en/country/afghanistan/overview

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Competing interests

The authors declare no competing interests. All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors. Study used the secondary data and necessary clearance was obtained.

Informed consent

No informed consent was needed for this article.

Additional information

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