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# Forecasting progress: analyzing the trajectory of under-five child mortality for Ghana, Niger, Nigeria, and Sierra Leone towards SDG3 using ARIMA time series model

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## Abstract
This study employs the AutoRegressive Integrated Moving Average (ARIMA) model to forecast under-five mortality rates in Ghana, Niger, Nigeria, and Sierra Leone for the years 2030 and 2031. Using World Bank Indicators data from 1967 to 2021, the study evaluates these countries' progress toward achieving Sustainable Development Goal 3 (SDG 3), which aims to reduce under-five mortality to less than 25 deaths per 1,000 live births by 2030. The objective is to provide data-driven insights into future mortality trends, supporting policymakers and healthcare professionals in designing targeted interventions to accelerate progress. The results reveal distinct mortality patterns among the four countries. Ghana, Nigeria, and Sierra Leone exhibit a consistent decline in under-five mortality, while Niger shows a non-continuous decreasing trend, indicating potential stagnation or reversal. Projections for 2030 estimate mortality rates of 30.5 per 1,000 live births in Ghana, 109.5 in Niger, 84.5 in Nigeria, and 64.3 in Sierra Leone. By 2031, these rates are expected to reach 28.9 per 1,000 live births in Ghana, 110.4 in Niger, 81.7 in Nigeria, and 59.8 in Sierra Leone. The findings indicate that Ghana is on track to meet SDG 3, provided that sustained and enhanced healthcare interventions are implemented. However, Nigeria, Niger, and Sierra Leone remain off-target, requiring significant reductions in mortality rates to meet the SDG 3 benchmark. These projections offer valuable evidence for policymakers, emphasizing the need for urgent and data-driven strategies to combat under-five mortality in these nations.

**Keywords** AutoRegressive integrated moving average (ARIMA) model, World bank indicators, Sustainable development goal 3 (SDG3), Ghana, Niger, Nigeria, Sierra Leone, Trends in mortality rates

## Introduction
Child mortality, especially among children under five years old, stands as a key worldwide health indicator, offering information on the overall health of societies and the effectiveness of their healthcare systems. Despite tremendous progress during the Millennium Development Goals (MDGs) era, the persistence of under-five mortality (U5M) shows its enduring significance and the need for sustained attention. A 30-year trend analysis in Ghana highlights that U5M remains high, falling short of the expected rate of decline required to meet the 2030 SDG target of 25 deaths per 1,000 live births. Socioeconomic disparities persist, with household wealth, maternal age, number of surviving children, and postnatal healthcare attendance identified as critical determinants of child survival [16].

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Factors that strongly predict under-five mortality include mothers' educational level, the presence of co-wives, age, and marital status. According to Kanmiki et al. [10], Ghanaian mothers who have achieved primary or junior high school education were 45% less likely to encounter under-five deaths than mothers with no formal education at all. Monogamous women were 22% less likely to incur under-five fatalities than moms in polygamous marriages. Similarly, moms who were between the ages of 35 and 49 were nearly eleven times more likely to encounter under-five deaths than those below the age of 20. Also, women who were married had a 27% lower probability of experiencing under-five mortality than those who were single, divorced, or widowed. In Nigeria, regional disparities significantly impact child survival, accounting for 30% of neonatal mortality, 37.1% of infant mortality, and 39.9% of under-five mortality. Other key factors include rural residence, infrastructural development, contraceptive use, and birth spacing of at least two years. Direct influences on child survival include female sex, singleton births, and maternal age at delivery [4].

From 1990 to 2015, the global community accomplished considerable advancements in lowering under-five mortality. During this 25-year period, the under-five mortality rate experienced a dramatic drop from 90.6 deaths per 1,000 live births in 1990 to 42.5 deaths per 1,000 live births in 2015. Simultaneously, the annual number of under-five mortality globally reduced from 12.7 million to 5.9 million, demonstrating tremendous achievements in healthcare, nutrition, and living circumstances and reflecting a substantial global commitment to boosting child survival [20]. While these results are notable, continuous focus on global health programs remains vital for further lowering infant mortality and reaching sustainable development goals.

The West African region grapples with a substantial problem of under-five mortality, mostly related to infectious diseases such as pneumonia, sepsis, tetanus, diarrhea, malaria, AIDS, measles, and meningitis. Notably, only Niger and Senegal have attained the Millennium Development Goal objective, and Cape Verde has achieved Sustainable Development Goal target 3.2, boasting an under-five mortality rate of 17 per 1,000 live births [17]. Additionally, in Sierra Leone, approximately 9% of children succumb to mortality before reaching the age of five. Protective factors include maternal breastfeeding, maternal age above 20 years, and proper birth spacing, as they significantly lower child mortality risks. On the other hand, male gender and very small size at birth are associated with increased under-five mortality risks in Sierra Leone [11].

From 1993 to 2014, under-five mortality in Ghana shifted, with the poorest households displaying the lowest rates. Maternal education was a consistent factor, and rural people faced increased risks. Gender discrepancies were also evident, with males suffering greater mortality rates. However, overall, under-five mortality dropped, showing the need for focused treatments [5]. Similarly, despite poverty alleviation and health policies in Ghana, household wealth remains a significant determinant of child survival [16].

Economic factors also play a critical role in child mortality rates. A study analyzing data from India, Bangladesh, and Pakistan from 1973 to 2021 found a strong long-term relationship between income levels and child mortality rates. As GDP per capita increased, child mortality consistently declined over five decades [18].

Nutritional status is another crucial determinant of child survival, with malnutrition and stunting posing severe risks. In Kenya's Korogocho slum, 52% of children were severely stunted, with household food insecurity, male gender, and ethnicity being common risk factors for worsening stunting. Exclusive breastfeeding, however, was associated with a lower likelihood of transitioning to severe stunting [15]. Similarly, studies across Sub-Saharan Africa show that maternal education, household wealth, and media exposure significantly reduce the likelihood of child stunting, whereas rural residence, high birth order, and childhood illnesses increase the risk [19].

Healthcare access, particularly vaccination and maternal healthcare utilization, plays a critical role in child survival. A study on time to under-five mortality found that vaccinated children had a significantly lower risk of death, while children of mothers working in agriculture and those living in rural areas faced higher mortality risks. Additionally, children from male-headed households and those who were non-anemic had lower mortality rates, whereas delayed breastfeeding initiation increased the risk of death [9]. Examining the causes of child mortality reveals that neonatal conditions remain the primary contributors. In Ethiopia, perinatal asphyxia (18%), prematurity (16%), and diarrheal diseases (12.5%) were the leading causes of death, with post-neonatal deaths primarily resulting from diarrheal diseases, respiratory infections, malnutrition, and HIV. Alarmingly, 61.6% of under-five deaths occurred at home, highlighting gaps in healthcare access and emergency care [1].

Nigeria, a significant actor in the West African area, has observed substantial changes in childhood death rates over the years. Data from [14] reveal rates of 200.72, 156.86, 128.05, and 132.02 per 1,000 live births in 2003, 2008, 2013, and 2018, respectively. This demonstrates a tremendous improvement, with the chance of a child not reaching their fifth birthday reducing from one in five in 2003 to one in seven in 2018. Looking ahead, predictions indicate a projected under-five mortality rate of 102.17 in 2023.

This article contributes to the understanding of the general context of under-five mortality, with a specific focus on Ghana, Niger, Nigeria, and Sierra Leone. By applying complex statistical models and drawing on data ranging from 1967 to 2021, the study tries to anticipate under-five child death rates in these nations for the years 2030 and 2031. The findings aim to inform policymakers and healthcare professionals, delivering insights that can guide targeted initiatives and strategies to accelerate progress toward Sustainable Development Goal 3 (SDG 3) in the designated African states.

## Methods

### Data

This study used data from World Bank Indicators. With its World Development Indicators (WDI) database, the World Bank offers a comprehensive collection of economic, social, and environmental statistics. A vast array of indicators covering several facets of development, such as gender equality, economic growth, poverty, education, and health, are included in the WDI. The World Bank's own research, international organizations, and national statistical offices are just a few of the places the data comes from. The dataset included in this study contains mortality rates pertaining to children under the age of five, spanning the years 1967 through 2021. The focus of the investigation centers on the countries of Ghana, Niger, Nigeria, and Sierra Leone. The dataset serves as a vital source for exploring and grasping trends and variations in child mortality within the defined temporal and regional parameters. The study applied the ARIMA (AutoRegressive Integrated Moving Average) time series model to project death rates into the future, specifically forecasting rates for the years 2030 and 2031. This approach was selected to thoroughly evaluate and analyze the projected trends in under-five mortality rates, delivering significant insights into the trajectory of such rates over the defined period. The researcher can investigate the trajectory of child mortality and assess the trend's characteristics in 2031, which is a year following the implementation of Sustainable Development Goal 3, aimed at a large reduction in children under the age of five fatalities. The ARIMA model is taken into account since it employs lagged moving averages to smooth time series data and predicts future values based on past values. Because it just requires historical data, models non-stationary data, and is typically not designed for long-term forecasting, the ARIMA time series model is ideal for short-term forecasting.

The AutoRegressive Integrated Moving Average (ARIMA) model is a widely recognized statistical tool for time series forecasting, particularly in public health research. Its effectiveness in projecting under-five mortality rates has been well established in various studies, making it a suitable choice for this research. Eke and Ewere [8] conducted a study titled Modeling and Forecasting Under-Five Mortality Rate in Nigeria using Auto-Regressive Integrated Moving Average Approach, which applied the ARIMA model to predict under-five mortality rates in Nigeria up to the year 2030. The study concluded that the ARIMA (2,1,1) model was appropriate for short-term forecasting, providing valuable insights into mortality trends and assisting in the assessment of progress toward health-related Sustainable Development Goals (SDGs).

Similarly, Adeyinka and Muhajarine [3], in the study Time Series Prediction of Under-Five Mortality Rates for Nigeria: Comparative Analysis of Artificial Neural Networks, Holt-Winters Exponential Smoothing, and AutoRegressive Integrated Moving Average Models, utilized the ARIMA model to forecast under-five mortality rates. The research emphasized the ARIMA model's capability to handle non-stationary data through differencing, making it an effective tool for analyzing and predicting mortality trends based solely on historical data. Moreover, Mwijalilege et al. [13] compared the performance of ARIMA and ARFIMA models in the study Comparing ARFIMA and ARIMA Models in Forecasting Under-Five Mortality Rate in Tanzania. The findings indicated that the ARIMA model effectively captured short-term trends in mortality rates, further reinforcing its suitability for short-term forecasting in public health contexts.

These studies collectively highlight the appropriateness of the ARIMA model for forecasting under-five mortality rates. Its reliance on historical data, ability to model non-stationary time series, and effectiveness in capturing short-term trends make it a valuable tool for projecting mortality rates and assessing the potential impact of health interventions over specific periods. Given these advantages, the ARIMA model is the optimal choice for this study's projections into 2030 and 2031.

### Statistical analysis

Before analyzing the data, the downloaded data was first edited and arranged in a single Excel sheet with years and mortality rates for each country. There was a diagrammatic presentation using tables and graphs. Although there are many electronic tools for data analysis, Excel and R were employed in this case. The ARIMA time series model and the Random Walk with Drift Model were used to project death rates into the future, specifically forecasting rates for the years 2030 and 2031.

### The ARIMA model

In univariate ARIMA modeling, it is first required that the data be either stationary or can be transformed to be stationary. The model identification, model estimation, model diagnosis, and forecasting procedures make up the Box-Jeckins ARIMA technique.

According to Aue and Horváth [6], when a time series data set's mean, variance, and covariance are stationary, they stay the same over the course of time.

The properties of the data remain constant over time. The Stationarity of the data is assessed using the time series plot, a correlogram graph that displays the ACF and the PACF together, and the Augmented Dickey-Fuller test (ADF) which is the formal test for identifying stationarity in the data.

The ARIMA model incorporates the AR, MA, and I elements. It is made up of three parts: the moving average component, the differences component, and the weighted sum of prior values and mistakes. The *p*, *d*, and *q* ARIMA model can be expressed as follows:

$$X_t = \Phi_1 X_{t-1} + \Phi_2 X_{t-2} + \cdots + \Phi_p X_{t-p} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q} + \delta^d X_t \tag{1}$$

The fitted ARIMA models were selected using the Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC), and Akaike's Bias Corrected Information Criteria (AICC). The model with the smallest value of these criteria is the best model for prediction.

The model's performance was assessed using the Ljung-Box test, the mean square error (MSE) and the mean absolute percentage error (MAPE).

This formula yields the Ljung-Box test statistic at lag q:

$$LB(q) = n(n+2)\sum_{k=1}^{q} \frac{r_k^2}{n-k} \tag{2}$$

$LB(q)$ is the Ljung-Box test statistic at lag $q$, $n$ is the number of observations, and $r_k^2$ is the sample autocorrelation function (ACF) of the residuals at lag $k$.

The null hypothesis is rejected if the Ljung-Box test statistic is considerably higher than the chi-square critical value at a selected significance level (e.g., 0.05). This implies that the residuals show a large amount of autocorrelation, indicating that the time series data is not random noise.

The formula for calculating MSE is:

$$MSE = \frac{\sum (Y - \overline{Y})^2}{n} \tag{3}$$

The total number of data points is $n$, the true or observed values of the time series data are $Y$, and the predicted values are $\overline{Y}$.

A smaller mean square error indicates a better fit to the data.

The mean absolute percentage error is calculated using the equation below:

$$MAPE = \frac{1}{n} * \sum \left( \left| \frac{Y_i - \overline{Y}}{Y_i} \right| \right) * 100 \tag{4}$$

Where $n$ specifies the overall number of observations, $Y_i$ denotes the value that was actually observed, and is $\overline{Y}$ the value that is anticipated.

There is a perfect fit when the value of MAPE is zero.

## Results and discussion

### Trends in under-five mortality in Ghana, Niger, Nigeria, and Sierra Leone

The time series of the annual mortality rate for children under five in Ghana, Nigeria, Niger, and Sierra Leone are displayed in Fig. 1. Mortality rates are shown as ordinates, and years are shown as an abscissa. The pattern and behavior of the data over time may be seen and examined using this method. A visual examination of the charts of the four nations indicates non-stationarity in the time series data, which is shown by a declining trend.

### Stationarity and autocorrelation analysis of under-five mortality rates in Ghana, Niger, Nigeria, and Sierra Leone

The partial autocorrelation function (PACF) and the autocorrelation function (ACF) for the time series data are shown in Fig. 2 of the correlograms below. The findings demonstrated that, for all four countries, there is a very strong ACF for the time lags, which gradually decreases in size until it approaches zero (0). The ACF shows that there is a non-stationarity trend in the time series data. The PACF plot, on the other hand, is around one at time lag 1 and is all below zero from lag 2 to lag 17. This demonstrates even more how non-stationary the data are. It is clear that there is no stationarity in any of the time series data from the four countries. Before creating the model, this can be fixed by modifying the series using the differencing technique to stabilize the variance. The ADF test was conducted after the first differentiation, and the *p*-values for Ghana, Niger, Nigeria, and Sierra Leone were, respectively, 0.08204, 0.8115, 0.03241, and 0.5482. With the exception of Nigeria, all of the *p*-value computation results were more than the significance level of 5%, therefore we were unable to rule out the null hypothesis that the first difference is not stationary. Consequently, it appears that the data series are

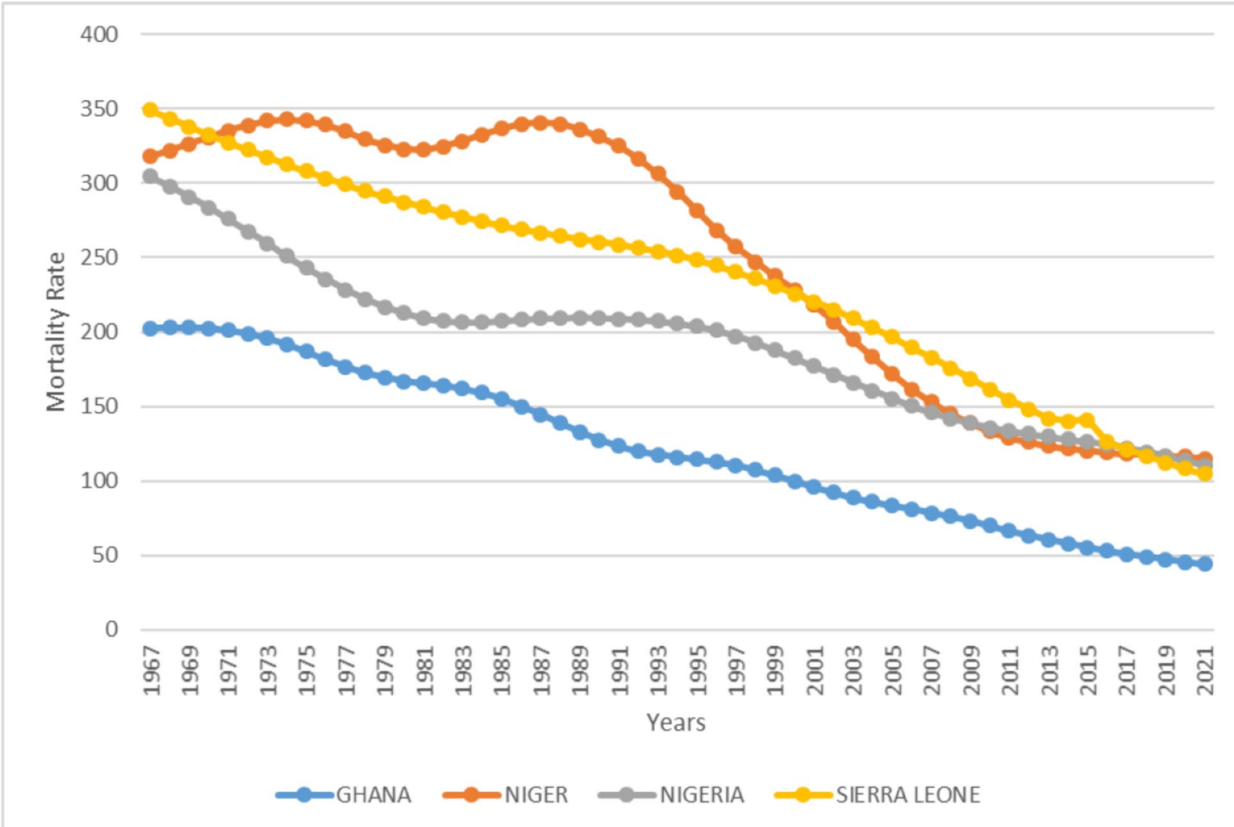


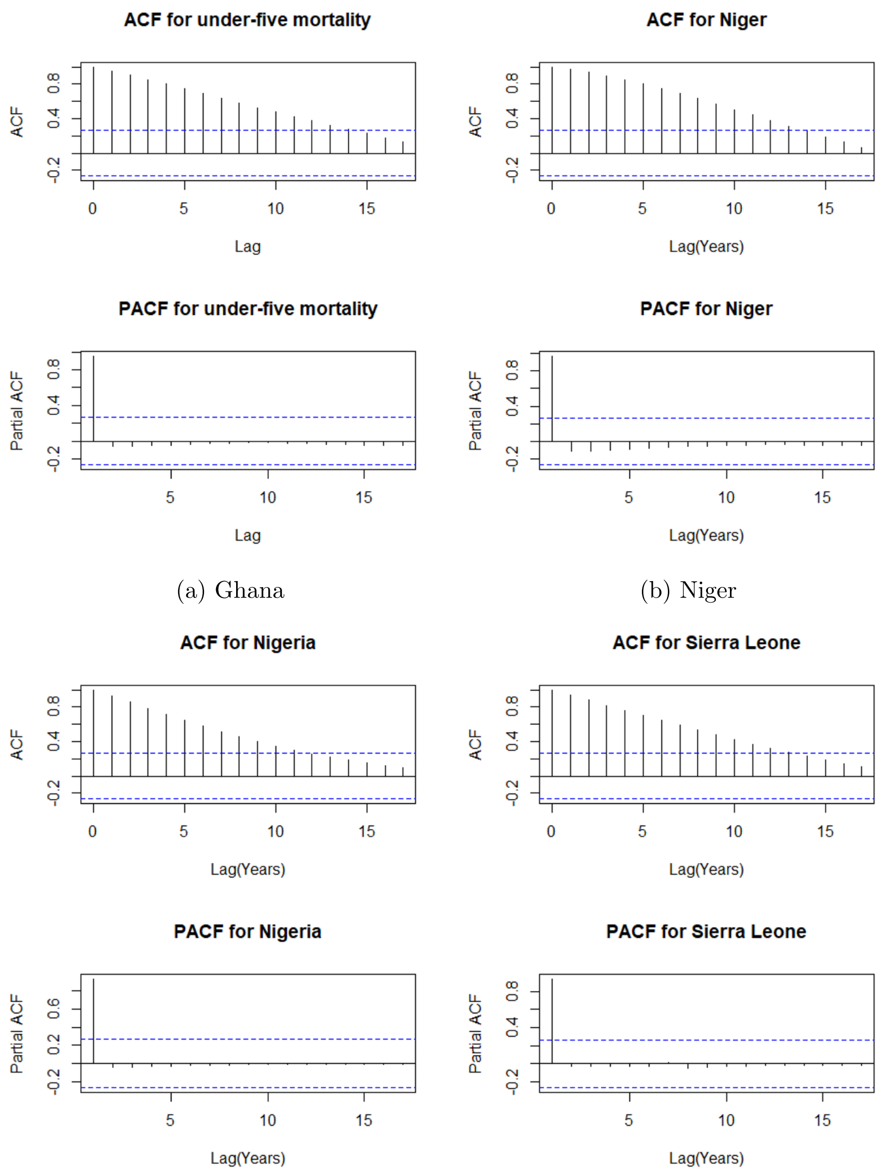

**Fig. 1** Trends in under-five mortality in Ghana, Niger, Nigeria, and Sierra Leone

still non-stationary. To further stabilize the variance, differencing was applied to the data once more. The results of the ADF test indicate that after second differencing, the data was stationary, with *p*-values for Ghana, Niger, and Sierra Leone all falling below the 5 percent significant level. Therefore, the null hypothesis that it is non-stationary is rejected.

#### Model specification

The best model is selected using the auto.arima function, which also chooses the model with the optimal parameter values. Despite the utilization of the auto.arima function, which automatically selects the optimal ARIMA model, other ARIMA models were also fitted using the autocorrelation function and the partial autocorrelation function. AIC, AICC, and BIC values were then utilized to pick the top ARIMA models. The most successful ARIMA models for Ghana, Niger, Nigeria, and Sierra Leone were determined as ARIMA (3,2,1), ARIMA (2,2,3), ARIMA (1,0,0), and ARIMA (0,2,1), respectively. These models were established based on having the lowest values for AIC, BIC, and AICC.

In the example of Ghana, the ARIMA (3,2,1) model implies that the present value of the series is influenced by the three most recent past values. The order of differencing (I) is 2, signaling that the series is already stable after two differences, eliminating seasonality and trend. For Niger, the ARIMA (2,2,3) model proposes that the present value of the series is dependant on the two most recent historical values. The order of differencing (I) is 2, and the moving average terms show that the series' current value is influenced by the most recent past three errors. In the instance of Nigeria, the ARIMA (1,0,0) model comprises a single autoregressive (AR) term, meaning that the first most recent past value drives the series' current value. The order of differentiation is 0 (I=0), and there is no moving average (MA) term, indicating no forecast inaccuracy affecting the series' current value. For Sierra Leone, the ARIMA (0,2,1) model shows that the present value of the series is independent of any previous values. The order of differencing (I) is 2, and the one MA term in the model implies that the most recent forecast inaccuracy has an impact on the series' current value.




(a) Ghana (b) Niger (c) Nigeria (d) Sierra Leone

**Fig. 2** Correlograms for under-five mortality rates in Ghana, Niger, Nigeria, and Sierra Leone

## Model selection criteria for under-five mortality forecasting in Ghana, Niger, Nigeria, and Sierra Leone

The fitted ARIMA models' AIC, AICC, and BIC values for Ghana, Niger, Nigeria, and Sierra Leone were shown in Table 1. The results below indicated that ARIMA(3,2,1), ARIMA(2,2,3), ARIMA(1,0,0), and ARIMA(0,2,1) were the ARIMA models for Ghana, Niger, Nigeria, and Sierra Leone with the lowest AIC, AICC, and BIC, respectively. As a consequence, the top ARIMA models were chosen.

## Residual diagnostics for selected ARIMA models

The residual diagnostic of the ARIMA models chosen for Ghana, Niger, Nigeria, and Sierra Leone are presented in Fig. 3. The ACF of the residuals suggests no substantial autocorrelations. The *P*-values for the Ljung-Box Q test are all substantially over 0.05, implying "non-significance".

**Table 1** Fitted ARIMA models for Ghana, Niger, Nigeria, and Sierra Leone

| MODEL | AIC | AICC | BIC |
|---|---|---|---|
| (a) Ghana | | | |
| ARIMA (3,2,1) | −9.03 | −7.76 | 0.82 |
| ARIMA (2,0,3) | −5.73 | −3.24 | 8.07 |
| ARIMA (3,0,2) | −5.76 | −3.27 | 8.03 |
| ARIMA (1,1,1) | 30.03 | 30.53 | 35.88 |
| ARIMA (3,3,1) | 33.68 | 35.02 | 43.34 |
| (b) Niger | | | |
| ARIMA (2,2,3) | 65.26 | 67.09 | 77.09 |
| ARIMA (2,0,2) | 70.07 | 71.89 | 81.89 |
| ARIMA (2,0,1) | 70.92 | 72.20 | 80.78 |
| ARIMA (1,0,3) | 69.21 | 71.03 | 81.03 |
| ARIMA (1,1,1) | 79.68 | 80.18 | 85.53 |
| (c) Nigeria | | | |
| ARIMA (1,0,0) | 6.5 | 6.74 | 10.44 |
| ARIMA (1,0,1) | 56.16 | 56.98 | 64.12 |
| ARIMA (2,0,3) | 5.64 | 8.07 | 19.56 |
| ARIMA (2,1,0) | 8.49 | 8.98 | 14.40 |
| ARIMA (1,1,1) | 8.49 | 8.98 | 14.41 |
| (d) Sierra Leone | | | |
| ARIMA (0,2,1) | 232.24 | 232.48 | 236.18 |
| ARIMA (0,0,2) | 234.84 | 235.67 | 242.72 |
| ARIMA (2,0,1) | 235.61 | 236.89 | 245.46 |
| ARIMA (1,1,1) | 248.41 | 248.91 | 254.27 |
| ARIMA (2,1,2) | 235.54 | 236.84 | 245.29 |

### In-sample forecasting performance of ARIMA models for Ghana, Niger, Nigeria, and Sierra Leone

Table 2 presents the outcomes of the selected ARIMA models' in-sample forecast. This was done to validate the models. The results show that the models will be able to make better predictions since the in-sample projected values were more closely aligned with the observed values. The robustness of the models is verified using the model validation technique.

### MSE and MAPE results for the in-sample forecast of the ARIMA models

Table 3 displays the findings achieved for mean square error (MSE) and mean absolute percentage error (MAPE) for the in-sample forecast of the ARIMA models fitted. Having a smaller mean square and mean absolute percentage error is an indication that our models are best for the predictions. This implies that the errors are minimized.

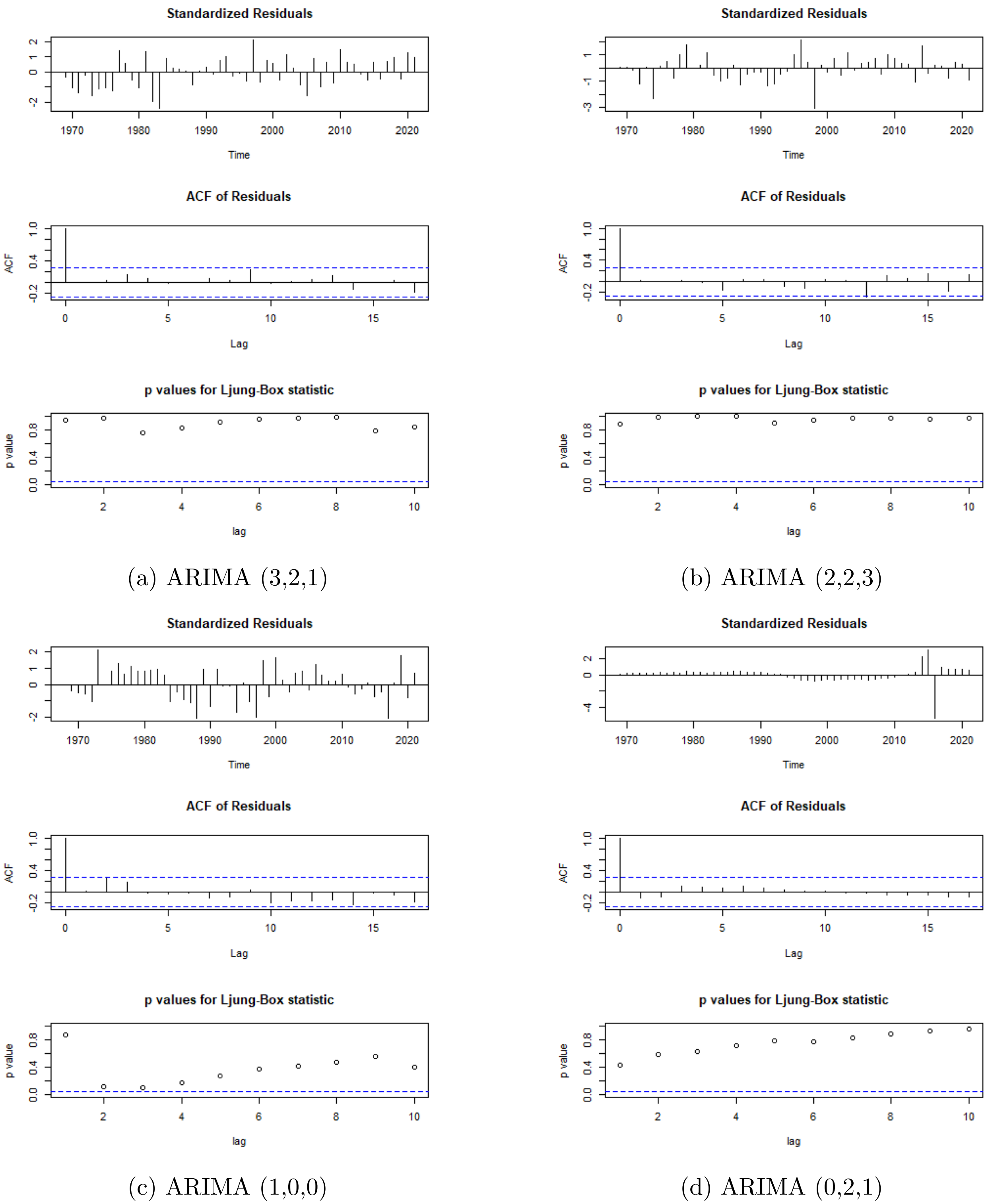
### Out sample forecast by the ARIMA models for Ghana, Niger, Nigeria, and Sierra Leone

The results of the out-of-sample forecast using the ARIMA models chosen for Ghana, Niger, Nigeria, and Sierra Leone are shown in Table 4. The predicted findings of the ARIMA (3,2,1) which is the selected model for Ghana suggest that the under-five mortality rate goes on declining from 2022 to 2031. The data reveal that the mortality rate declined from 42.5 in 2022 to 30.5 in 2030 and 28.9 in 2031.The results stood in stark contrast to an analysis by Adebanji et al. [2] that established that despite considerable spending, national statistics reveal no notable increase in maternal and neonatal survival throughout the pre- and post-policy eras.

The results for ARIMA (2,2,3) which is the selected ARIMA model for Niger demonstrate that the mortality rate of Niger does not fall continually. It lowers to 2026 and subsequently remains the same for 2027 and 2028 with a death rate of 108.5. The death rate later climbs to 110.4 in 2031. The mortality rate for Nigeria has fallen, according to the ARIMA (1,0,0) forecasts. From 107.8 in 2022 to 84.5 in 2030 and 81.7 in 2031, the death rate fell. According to this, Nigeria's death rate is predicted to reduce until 2031, although this fall would not be enough to fulfill SDG 3. The findings support the research by Eke and Ewere [8], which found that for Nigeria to reach the SDG target for under-five mortality, there must be a drop in under-five mortality of over 300%. Table 4 provided the results for the projected values of the ARIMA (0,2,1) for Sierra Leone. The findings predict a falling mortality rate from 2022 to 2031. The death rate dropped from 99.9 in 2022 to 64.3 in 2030 and 59.8 in 2031. This suggests there is a bigger decline in the rate of death. The results reveal that Sierra Leone still needs to put more effort into meeting SDG 3 in 2030.

## Discussion

The time series analysis of under-five mortality rates for Ghana, Nigeria, Niger, and Sierra Leone reveals a consistent declining trend over time. As depicted in Fig. 1, the mortality rates across all four countries decrease progressively, suggesting improvements in child health outcomes. This downward trajectory aligns with global efforts to reduce under-five mortality, particularly under Sustainable Development Goal 3 (SDG 3), which aims to significantly lower child fatalities by 2030. The observed trend is consistent with the findings of Black et al. [7], who highlighted that sub-Saharan African countries, including Ghana and Nigeria, have made substantial progress in reducing child mortality due to advancements in healthcare, immunization programs, and maternal health services.




(a) ARIMA (3,2,1)

(b) ARIMA (2,2,3)

(c) ARIMA (1,0,0)

(d) ARIMA (0,2,1)

**Fig. 3** Residual diagnostic plots for selected ARIMA models

**Table 2** 95% confidence intervals for in-sample forecasts by ARIMA Models for Ghana, Niger, Nigeria, and Sierra Leone

| Year | Ghana (ARIMA 3,2,1) | | | Niger (ARIMA 2,2,3) | | | Nigeria (ARIMA 1,0,0) | | | Sierra Leone (ARIMA 0,2,1) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Observed** | **Forecast** | **CI** | **Observed** | **Forecast** | **CI** | **Observed** | **Forecast** | **CI** | **Observed** | **Forecast** | **CI** |
| 2012 | 63.4 | 63.8 | 62.6–63.8 | 126.0 | 125.9 | 121.7–128.1 | 131.4 | 131.1 | 129.9–132.3 | 148.0 | 147.0 | 146.7–149.5 |
| 2013 | 60.5 | 61.3 | 58.6–61.3 | 123.4 | 122.7 | 113.5–127.8 | 129.6 | 128.8 | 126.2–131.4 | 141.9 | 141.2 | 140.0–145.6 |
| 2014 | 57.8 | 58.8 | 54.4–58.8 | 121.6 | 120.5 | 104.5–128.5 | 128.0 | 126.5 | 122.2–130.8 | 140.0 | 139.5 | 135.3–144.4 |
| 2015 | 55.4 | 56.5 | 50.2–56.5 | 120.2 | 119.9 | 94.7–129.8 | 126.4 | 124.2 | 117.8–130.5 | 141.0 | 140.9 | 134.5–144.2 |
| 2016 | 53.1 | 54.2 | 45.9–54.2 | 119.1 | 118.9 | 84.4–131.8 | 124.7 | 121.9 | 113.3–130.5 | 126.1 | 126.0 | 120.3–140.8 |
| 2017 | 51.0 | 52.0 | 41.5–52.0 | 118.4 | 118.0 | 73.4–134.4 | 122.4 | 119.6 | 108.5–130.7 | 121.4 | 120.9 | 87.9–137.3 |
| 2018 | 49.1 | 49.9 | 37.0–49.9 | 117.7 | 117.0 | 61.8–137.5 | 119.6 | 117.3 | 103.5–131.0 | 116.8 | 116.0 | 83.6–133.8 |
| 2019 | 47.2 | 47.8 | 32.5–47.8 | 117.0 | 116.0 | 49.8–141.1 | 116.8 | 115.0 | 98.4–131.6 | 112.5 | 111.7 | 79.7–128.6 |
| 2020 | 45.5 | 45.8 | 27.9–45.8 | 116.3 | 115.9 | 37.3–145.3 | 113.8 | 112.7 | 93.0–132.3 | 108.5 | 108.0 | 76.4–125.0 |
| 2021 | 44.0 | 43.8 | 23.4–43.8 | 115.2 | 114.0 | 24.3–149.8 | 110.8 | 110.4 | 87.6–132.2 | 104.7 | 104.0 | 69.8–116.8 |

**Table 3** MSE and MAPE results for the in-sample forecast

| Country | Ghana | Niger | Nigeria | Sierra Leone |
|---|---|---|---|---|
| Model | ARIMA (3,2,1) | ARIMA (2,2,3) | ARIMA (1,0,0) | ARIMA (0,2,1) |
| MSE | 0.635 | 0.509 | 3.340 | 0.403 |
| MAPE | 1.372 | 0.514 | 1.308 | 0.461 |

A visual examination of the time series data indicates non-stationarity, as mortality rates do not fluctuate randomly but instead follow a structured downward pattern. This sustained reduction is particularly evident in Ghana and Nigeria, where the trend appears more stable, reflecting long-term investments in health infrastructure and policy implementation. These findings align with Liu et al. [12], who found that improvements in healthcare access, economic growth, and interventions like malaria prevention and vaccination programs have significantly contributed to the downward trend in child mortality. Their study further confirmed that countries with stable public health investments tend to exhibit a more predictable decline, which corresponds with the relatively narrow confidence intervals observed in the projections for Ghana and Nigeria.

However, while the overall trend is downward, variations exist across the countries. Niger and Sierra Leone exhibit wider confidence intervals in their forecasts, suggesting greater uncertainty in their mortality trends. This could be attributed to fluctuations in healthcare access, economic instability, or periodic disease outbreaks. The findings resonate with Adebanji et al. [2], which highlighted that high poverty levels, inadequate maternal education, and weak health infrastructure continue to slow progress in some West African nations. This perspective suggests that while the general trend is declining, systemic challenges may hinder sustained reductions in under-five mortality in countries like Niger and Sierra Leone.

The selection of the optimal ARIMA models for forecasting under-five mortality rates in Ghana, Niger, Nigeria, and Sierra Leone provides key insights into the time series characteristics of child mortality in these countries. The use of the auto.arima function, coupled with an evaluation of AIC, AICC, and BIC values, ensured the selection of models that best capture the mortality trends while minimizing prediction errors.

The models selected for each country ARIMA (3,2,1) for Ghana, ARIMA (2,2,3) for Niger, ARIMA (1,0,0) for Nigeria, and ARIMA (0,2,1) for Sierra Leone-highlight variations in the structural dynamics of child mortality across the four nations. Ghana and Niger's models involve higher-order differencing (I=2), suggesting that mortality trends in these countries required adjustments to achieve stationarity, which aligns with studies indicating persistent fluctuations in child mortality due to socioeconomic disparities and healthcare access gaps [16]. The presence of multiple autoregressive (AR) and moving average (MA) terms further supports the complexity of mortality trends in these nations. In contrast, Nigeria's ARIMA (1,0,0) model suggests a more stable mortality pattern that does not require differencing, indicating that past values alone sufficiently explain the trend a finding that resonates with research showing notable reductions in Nigerian child mortality in recent decades due to improved immunization coverage and maternal healthcare utilization [14]. Sierra Leone's ARIMA (0,2,1) model, characterized by a second-order difference and a single MA term, underscores a mortality trend highly influenced by past errors, suggesting potential instability and vulnerability to external shocks, a pattern consistent

**Table 4** 95% confidence intervals for out-sample forecasts by ARIMA models for Ghana, Niger, Nigeria, and Sierra Leone

| Year | Ghana (ARIMA 3,2,1) | | Niger (ARIMA 2,2,3) | | Nigeria (ARIMA 1,0,0) | | Sierra Leone (ARIMA 0,2,1) | |
|---|---|---|---|---|---|---|---|---|
| | Forecast | CI | Forecast | CI | Forecast | CI | Forecast | CI |
| 2022 | 42.5 | 42.1–42.9 | 113.7 | 112.7–114.7 | 107.8 | 106.8–108.9 | 99.9 | 95.8–103.9 |
| 2023 | 40.9 | 40.1–41.9 | 112.1 | 108.7–115.5 | 104.7 | 102.5–107.2 | 95.5 | 89.5–101.4 |
| 2024 | 39.5 | 38.0–40.9 | 110.6 | 103.4–117.8 | 101.9 | 97.3–105.9 | 91.0 | 82.9–99.0 |
| 2025 | 37.9 | 35.8–40.1 | 109.5 | 97.5–121.5 | 98.9 | 93.2–104.8 | 86.5 | 76.2–96.9 |
| 2026 | 36.5 | 33.6–39.4 | 108.8 | 91.3–126.3 | 96.0 | 88.2–103.9 | 82.1 | 69.2–94.9 |
| 2027 | 34.9 | 31.3–38.6 | 108.5 | 85.0–131.9 | 93.1 | 83.1–103.2 | 77.6 | 62.0–93.2 |
| 2028 | 33.5 | 29.0–37.9 | 108.5 | 78.8–138.2 | 90.3 | 77.8–102.7 | 73.2 | 54.7–91.7 |
| 2029 | 31.9 | 26.6–37.4 | 108.8 | 72.6–144.9 | 87.4 | 72.4–102.4 | 68.7 | 47.2–90.2 |
| 2030 | 30.5 | 24.2–36.8 | 109.5 | 66.7–152.3 | 84.5 | 66.9–102.2 | 64.3 | 39.5–88.9 |
| 2031 | 28.9 | 21.7–36.3 | 110.4 | 61.0–159.7 | 81.7 | 61.2–102.2 | 59.8 | 31.7–87.9 |

with previous studies identifying healthcare access challenges and economic disparities as major barriers to child survival in Sierra Leone [11].

The selected models effectively capture country-specific mortality trends, reflecting the impact of historical child survival interventions and persistent structural challenges. These findings underscore the importance of tailored health policies and socioeconomic interventions to sustain and accelerate mortality reductions across West Africa. To ensure the reliability of the selected ARIMA models, an in-sample forecast was conducted, comparing projected values with actual observed values. The results, presented in Table 2, indicate a strong alignment between the predicted and observed mortality rates, confirming the robustness of the models. This validation step is crucial in time series forecasting, as it assesses how well the models capture underlying mortality trends before making future projections.

The effectiveness of ARIMA models in capturing under-five mortality patterns aligns with existing research emphasizing the importance of rigorous model validation in demographic and epidemiological forecasting. Studies such as Ntukidem et al. [14] demonstrate the necessity of ensuring that forecast models accurately reflect historical mortality patterns before extending predictions into the future. The strong in-sample performance of the selected models suggests that they will generate reliable forecasts, which is critical for policy planning and intervention strategies aimed at achieving Sustainable Development Goal 3 (SDG 3). Moreover, the ability of the ARIMA models to closely align with historical mortality trends supports findings by Saxena et al. [18], which highlight the long-term relationship between economic stability and child mortality reductions. The validated models can thus serve as effective tools for policymakers to anticipate future mortality trends and design interventions that address both health and socioeconomic determinants of child survival.

Table 3 presents the results for Mean Square Error (MSE) and Mean Absolute Percentage Error (MAPE) from the in-sample forecasts of the selected ARIMA models. These metrics serve as essential indicators of model accuracy, as lower MSE and MAPE values suggest minimal forecast errors, reinforcing the reliability of the models for future predictions. The significance of minimizing these errors is well documented in forecasting literature. Ntukidem et al. [14] highlights that error-based model evaluation, particularly through MSE and MAPE, ensures that predictive models generate outputs that align closely with actual values. This approach is crucial for accurately forecasting under-five mortality trends, enabling policymakers to implement data-driven interventions effectively. Similarly, Saxena et al. [18] emphasizes that models with smaller MSE and MAPE values demonstrate greater precision in capturing long-term trends in child mortality rates. The study underscores the importance of error reduction techniques in enhancing the robustness of predictive models, particularly in demographically dynamic regions where mortality rates fluctuate due to socioeconomic and healthcare-related factors.

The out-of-sample forecasts from the selected ARIMA models for Ghana, Niger, Nigeria, and Sierra Leone provide critical insights into the future trajectory of under-five mortality rates. While some countries are projected to experience a steady decline, others exhibit stagnation or slower reductions, highlighting the persistent challenges in achieving Sustainable Development Goal 3 (SDG 3). For Ghana, the ARIMA (3,2,1) model predicts a significant decline in under-five mortality from 42.5 per 1,000 live births in 2022 to 28.9 in 2031. This trend aligns with broader global patterns of decreasing child mortality due to improved healthcare access and policy interventions. However, the findings stand in contrast to Adebanji et al. [2], which asserts that despite substantial investments in maternal and neonatal healthcare, national statistics do not indicate a proportional improvement in survival rates. This discrepancy suggests that while mortality is decreasing, challenges in service delivery and health policy effectiveness may still hinder accelerated progress.

In contrast, Niger's ARIMA (2,2,3) model predicts an initial decline in mortality until 2026, followed by stagnation from 2027 to 2028 (108.5 per 1,000 live births) and a subsequent increase to 110.4 in 2031. This non-linear trend reflects findings from Sanyang [17], which highlight the persistent burden of infectious diseases such as malaria, pneumonia, and diarrheal illnesses in West Africa. The plateau and eventual rise in mortality could be attributed to structural healthcare deficiencies, economic constraints, and regional disparities in healthcare access.

For Nigeria, the ARIMA (1,0,0) model forecasts a steady decline in under-five mortality from 107.8 in 2022 to 81.7 in 2031. While this reduction is encouraging, it is still insufficient to meet SDG 3's target of less than 25 deaths per 1,000 live births by 2030. This aligns with the research of Eke and Ewere [8], which suggests that Nigeria requires a 300% reduction in under-five mortality to meet global targets. The study further emphasizes the role of regional inequalities, healthcare infrastructure, and socioeconomic conditions in shaping mortality trends.

Sierra Leone's ARIMA (0,2,1) model projects a sharp decline in under-five mortality, from 99.9 in 2022 to 59.8 in 2031. While this represents a substantial improvement, the country still falls short of meeting SDG 3. These findings resonate with Koroma et al. [11], which underscores the impact of maternal age, birth spacing, and exclusive breastfeeding in reducing child mortality. The study also notes that male children and low birth weight infants face higher mortality risks, reinforcing the need for targeted healthcare interventions.

## Conclusion

This study applied the ARIMA model to forecast under-five mortality rates in Ghana, Niger, Nigeria, and Sierra Leone, assessing their progress toward Sustainable Development Goal 3 (SDG 3). The results indicate a continuous decline in under-five mortality for Ghana, Nigeria, and Sierra Leone, while Niger exhibits a non-continuous decreasing pattern, suggesting potential stagnation or reversal. From these findings, Ghana shows promise in achieving SDG 3 if appropriate interventions are strengthened. However, Niger, Nigeria, and Sierra Leone remain off-track. These results underscore the need for sustained policy actions to improve child survival rates across the region.

To accelerate progress toward SDG 3, governments should invest in maternal and child healthcare by expanding neonatal care facilities, immunization programs, and skilled birth attendance. Strengthening healthcare systems is crucial to reducing preventable deaths and ensuring equitable access to essential services. Policymakers should adopt data-driven interventions, utilizing real-time health surveillance systems to monitor child mortality trends and implement targeted strategies in high-risk areas. Evidence-based decision-making will help allocate resources efficiently and address disparities. Community-based health initiatives should be prioritized, focusing on nutrition support, disease prevention, and hygiene education. Empowering local communities through health education and outreach programs can significantly reduce under-five mortality rates. Given their high mortality rates, Niger, Nigeria, and Sierra Leone require urgent interventions. These nations must expand healthcare infrastructure, address health disparities, and enhance access to life-saving medical care to improve child survival rates.

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**Authors' contributions**
Z.K.A and F.O.M. review literature and wrote the introduction and methodology. Z.K.A downloaded the data and cleaned the data per the study requirements. Z.K.A, B.M.B and N.K analysed the data and presented the figures and tables. All authors concluded the paper and reviewed the manuscript F.OM compiled and proofread the paper.

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**Data availability**
This study conducted an analysis using datasets that are accessible to the public. The location of this data can be found at: https://data.worldbank.org.

### Declarations

**Ethics approval and consent to participate**
No ethics approval was necessary as this study relies on publicly accessible secondary data.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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