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Infant mortality rates in Ghana: progress toward sustainable development goal 3

Solomon Opoku¹, Zakariya Kuupah Adama^{2*} and Sabina Abuga¹

Abstract

Infant mortality remains a critical measure of national health performance and socio-economic development. In Ghana, despite sustained public health interventions, infant mortality rates (IMRs) continue to reflect persistent inequalities and systemic challenges. This study models historical trends in Ghana's IMR from 1960 to 2022 and provides forecasts up to 2030 to support data-driven health planning. Using annual data from the World Development Indicators, an ARIMA model was used to analyze the time series. After achieving stationarity through first-order differencing, the ARIMA (1, 1, 4) model was selected as the best based on AIC, BIC, and AICC criteria. The results reveal a consistently decreasing trend in infant mortality, with projections showing a decline from 30.68 deaths per 1,000 live births in 2023 to 24.68 per 1,000 live births by 2030. Forecast accuracy was confirmed with a mean squared error (MSE) of 0.079 and a mean absolute percentage error (MAPE) of 0.657. However, the projected rate remains slightly below the SDG 3 target for under-five mortality but still exceeds the target for neonatal mortality. The study concludes that while progress has been made, the current pace of improvement is insufficient. It calls for strengthened, equity-focused health strategies and demonstrates the value of ARIMA modeling as a practical tool for forecasting and policy planning in low- and middle-income countries.

Keywords Infant mortality, Ghana, ARIMA, Sustainable development goals, Public health policy

Introduction

Infant mortality remains one of the most critical indicators of a nation's public health capacity, encapsulating the broader socio-economic, environmental, and general determinants of child survival [1]. In Sub-Saharan Africa, and particularly in Ghana, this issue continues to demand urgent attention. Despite significant progress in reducing infant mortality over the past decades, Ghana still faces formidable challenges in meeting Sustainable Development Goal (SDG) 3: ensuring healthy lives and promoting well-being for all at all ages [2]. Although SDG

3.2 does not set a specific benchmark for infant mortality, it targets reducing neonatal mortality to at least 12 deaths per 1,000 live births and under-five mortality to at least 25 per 1,000 by 2030, implying that infant mortality must also decline substantially to align with these broader child survival goals. Historical data indicate substantial regional and socio-demographic variations in infant mortality rates (IMRs), with patterns reflecting enduring structural, cultural, and healthcare delivery disparities [3, 4].

Although SDG 3.2 specifically targets reductions in neonatal mortality to ≤ 12 deaths per 1,000 live births and under-five mortality to ≤ 25 deaths per 1,000 live births by 2030, infant mortality remains a critical and closely related indicator. Defined as the probability of dying within the first year of life, infant mortality is strongly correlated with both neonatal and under-five

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mortality in Sub-Saharan Africa, including Ghana (UNICEF, 2023; Ghana Statistical Service, 2022). We use infant mortality here as a proxy because it offers a longer historical time series, enabling robust modeling. To further illustrate the policy relevance, we include a simple scenario analysis: if Ghana sustains the current annual reduction of about 3%, the IMR is projected to reach 24.7 deaths per 1,000 live births by 2030. However, if the pace of reduction were accelerated to 5% annually, the IMR would decline further to 21.4 deaths per 1,000 live births, thereby improving the likelihood of achieving the survival target. These projections highlight the sensitivity of future outcomes to the assumed rate of decline, emphasizing the importance of sustained and accelerated efforts. We also recognize that rates are not uniform across Ghana northern regions such as Upper West and Northern consistently report higher infant mortality than the south, a disparity that has implications for targeted interventions.

Infant mortality refers to the number of deaths of children under one year of age per 1,000 live births within a given year. In Ghana, it is a critical indicator of national health performance, reflecting the quality of maternal and child healthcare services, socio-economic conditions, and the effectiveness of public health interventions [5, 6]. Despite notable progress, infant mortality remains a public health concern, particularly in rural and underserved regions where access to skilled birth attendants, postnatal care, and neonatal services is limited [5]. Common causes of infant deaths in Ghana include birth asphyxia, neonatal infections, low birth weight, malnutrition, and preventable diseases such as pneumonia and malaria [7]. To address these challenges, the government has implemented programs such as the Community-Based Health Planning and Services (CHPS), the Free Maternal and Child Healthcare Policy, and national immunization campaigns (GHS, 2022). While these efforts have contributed to a gradual decline in infant mortality from over 60 deaths per 1,000 live births in the 1990s to around 32 per 1,000 in 2022 further targeted, data-driven, and equity-focused interventions are essential to accelerate progress and meet global child survival targets [6].

Factors including poverty, healthcare inequities, malnutrition, and inadequate access to essential services continue to contribute to preventable infant deaths in Ghana [8]. Although efforts under initiatives like the Millennium Development Goals initially drove reductions in infant mortality, Ghana did not achieve MDG 4 by 2015, as infant mortality rates stagnated in some regions and even increased [9]. According to data from the World Development Indicators, Ghana's infant mortality rate declined significantly from 80 deaths per 1,000 live births in 1990 to 33.4 deaths per 1,000 live births in 2020, reflecting national-level progress but masking persistent regional

and socio-economic disparities. Adama et al. [10] asserts that although child mortality is declining, further efforts are required to accelerate the reduction. The period from 1960 to 2022 has seen Ghana navigate multiple demographic transitions and health policy shifts. Early studies underscore stark rural-urban disparities in IMRs, with children in rural areas facing significantly higher mortality risks than their urban counterparts [3, 11]. These discrepancies are further intensified by regional imbalances; for instance, children in the Upper Regions, irrespective of urban status, consistently exhibit elevated mortality risks compared to their peers in Greater Accra [12].

Ethnic and cultural factors have also been implicated in the spatial and temporal heterogeneity of infant mortality. Drawing on data from the Ghana Demographic and Health Surveys (GDHS), [4] demonstrated that children born to Mole-Dagbani, Grussi, Gruma, Dagarti, and Fanti mothers had significantly higher mortality risks compared to those of Asante descent. However, these ethnic disparities were largely attenuated upon controlling for socioeconomic and biodemographic variables, suggesting that structural inequalities rather than cultural predispositions primarily drive the observed patterns. Contemporary analyses emphasize the multiplicity of determinants influencing infant mortality. Dwomoh et al. [13] highlight how multiple births, maternal labor force participation, and health-seeking behaviors significantly influence mortality risk, while [14] attributes improvements in survival to increased utilization of skilled birth attendants, particularly between 2003 and 2008. Similarly, maternal education, parity, and antenatal care access remain consistent predictors of infant mortality [15, 16].

In response to ongoing challenges, the government has implemented key policy frameworks, including those specifically targeting infant and newborn mortality. One such targeted intervention is the National Newborn Health Strategy and Action Plan, first launched in 2014 and revised in 2019, which aims to reduce neonatal and infant deaths through improved skilled delivery, essential newborn care, neonatal resuscitation, and strengthened postnatal services. While broader policies such as the Community-Based Health Planning and Services (CHPS) initiative and the Free Maternal Healthcare Policy have contributed to improvements in maternal and child health, infant mortality rates have remained largely stagnant [17]. Reaching the SDG 3.2 target of fewer infant and child deaths per 1,000 live births by 2030 will require not only renewed political commitment but also structural reforms in the delivery and equity of health services. The Ministry of Health has acknowledged persistent barriers, including health system fragmentation, geographical disparities, and socio-economic inequality, which continue to undermine progress [18]. To address these gaps, community-based health programs have been

scaled up in recent years to improve healthcare access at the grassroots level [19]. Nevertheless, structural issues such as inadequate sanitation, high burden of infectious diseases, and child malnutrition remain significant contributors to infant mortality [20].

Despite modest but consistent national reductions in IMR since the late 1980s [2], the pace of decline remains insufficient to meet the SDG 3 target of reducing infant mortality 2030. The integration of HIV/AIDS services with maternal and child health programs has shown promise in improving outcomes [21], and evidence from comparable middle-income settings like Brazil indicates that structured primary healthcare initiatives can significantly reduce IMR [22]. However, implementation fidelity, equitable healthcare financing under Ghana's National Health Insurance Scheme, and perceptions of healthcare quality remain persistent challenges [23]. Furthermore, macro-level health financing frameworks such as the Sector-Wide Approaches (SWAps) introduced in the 2000s have yielded modest improvements in infant mortality by enhancing aid effectiveness and public expenditure efficiency [24]. Yet, these gains risk erosion without complementary data-driven forecasting mechanisms and targeted intervention strategies tailored to the specific risk profiles of subpopulations.

While Ghana has demonstrated both commitment and capacity to reduce infant mortality, future progress depends on effectively translating policy into action, addressing persistent inequalities, and aligning the health system with the ambitions of SDG 3. However, existing research often focuses on isolated determinants, overlooking the broader, systemic, and forward-looking perspectives necessary for sustained improvement. To bridge this gap, the present study models infant mortality trends in Ghana from 1960 to 2022 and forecasts outcomes through 2030 using an ARIMA time series approach. By integrating historical patterns, socio-demographic dynamics, and health system indicators, the study provides a data-driven foundation for evidence-based policymaking. It emphasizes the need for regionally disaggregated, equity-oriented health planning and demonstrates how predictive analytics can support strategic decision-making toward achieving SDG 3.

Materials and methods

This study utilized data obtained from the World Development Indicators (WDI), a comprehensive and authoritative database that compiles key economic, social, and health statistics from a range of national and international sources. The WDI database serves as a reliable tool for tracking developmental progress and informing evidence-based policy decisions. Specifically, the dataset employed in this study comprises infant mortality rates in Ghana from 1960 to 2022.

To model and project infant mortality rates into the future, specifically for the year 2030, the AutoRegressive Integrated Moving Average (ARIMA) time series model was employed. ARIMA is widely recognized in public health research for its effectiveness in forecasting based on historical data, particularly when analyzing non-stationary time series. The model leverages past values and lagged moving averages to identify patterns and predict future outcomes, making it well-suited for short-term forecasting.

The ARIMA model is advantageous in that it does not require explanatory variables, relying solely on the internal structure of the data series. This makes it a fitting choice for estimating future infant mortality rates where consistent and complete longitudinal covariate data may be limited. Moreover, ARIMA's ability to handle trend and seasonality components through differencing allows it to accommodate the dynamic and evolving nature of public health indicators like infant mortality.

Previous research has validated the ARIMA model's applicability in similar contexts. For instance, [25] in a study titled Modeling and Forecasting Infant Mortality Rate in Nigeria using Auto-Regressive Integrated Moving Average Approach demonstrated the effectiveness of the ARIMA (2,1,1) model in forecasting short-term mortality trends up to the year 2030. The study emphasized the model's practical relevance for tracking progress toward SDG targets. Similarly, [26] conducted a comparative analysis of forecasting methods in Nigeria and reaffirmed the ARIMA model's strength in managing non-stationary data to predict under-five mortality rates. Additionally, [27] assessed the performance of ARIMA and ARFIMA models in Tanzania and concluded that the ARIMA model effectively captured short-term mortality trends, further affirming its utility in public health forecasting.

In the Ghanaian context, [10] applied ARIMA models to predict under-five mortality rates in Ghana, Niger, Nigeria, and Sierra Leone, demonstrating its robustness across countries. However, there is a literature vacuum on the application of ARIMA modeling infant mortality in Ghana. This distinction is important given that infant mortality, which refers to deaths within the first year of life, has distinct causes, dynamics, and policy implications compared to broader under-five mortality. Thus, this study contributes uniquely to the literature by focusing exclusively on infant mortality using time series forecasting in Ghana, helping to fill a methodological and empirical gap.

Although other forecasting techniques, such as exponential smoothing, could be considered, ARIMA was selected due to its statistical transparency, strong performance in similar demographic studies, and the relative ease of interpretability in public health planning. Future

studies could explore hybrid or ensemble models to further strengthen comparative forecasting performance.

Although ARIMA provides a robust data-driven framework for short-term forecasting, it is inherently univariate, relying solely on past values of the dependent variable. As such, it cannot directly account for external factors such as policy interventions, socioeconomic shocks, or changes in healthcare delivery. This limitation implies that the resulting forecasts represent baseline trajectories that may deviate under structural changes or unforeseen shocks. To enhance interpretability, the forecasts are thus presented as reference scenarios rather than definitive predictions.

Given these empirical precedents, the ARIMA model was selected as the optimal forecasting tool for this study. It enabled the researcher to estimate the future trajectory of infant mortality in Ghana, particularly as the country approaches the 2030 target of Sustainable Development Goal 3.2, which calls for ending preventable deaths of newborns and ensuring equitable survival opportunities during the earliest and most vulnerable stage of life.

Statistical analysis

Before conducting the analysis, the dataset downloaded from the World Development Indicators (WDI) was cleaned, edited, and structured in a single Excel sheet. The infant mortality data were organized chronologically by year, covering the period from 1960 to 2022. Each entry corresponded to a specific year and the associated infant mortality rate for Ghana. These steps were performed using Microsoft Excel and the R (version 4.3.2) statistical software environment.

Descriptive analysis was carried out to visualize and understand the historical trends of infant mortality. This included graphical representations to observe patterns over time. Microsoft Excel was used primarily for initial data structuring and exploratory plots, while R was employed for advanced statistical analysis and modeling.

For the time series forecasting, the Auto-Regressive Integrated Moving Average (ARIMA) model was applied to the cleaned data. To ensure robust model selection and validation, the dataset was split into a training set (1960–2009) and a testing set (2010–2022). This allowed for in-sample forecasting and model evaluation by comparing predicted values against actual data in the test period. Once the model was validated for accuracy, out-of-sample forecasting was conducted to project infant mortality trends from 2023 to 2030. This forward-looking analysis supports the study's objective of assessing Ghana's progress toward achieving Sustainable Development Goal 3.2.

The ARIMA model

In univariate ARIMA modeling, it is essential that the time series data be stationary or capable of being

transformed into a stationary form. The Box-Jenkins ARIMA methodology involves four key stages: model identification, estimation, diagnostic checking, and forecasting. According to [28], a time series is considered stationary when its mean, variance, and covariance remain constant over time. This implies that the statistical properties of the data do not change throughout the observed period. To assess stationarity, several techniques are employed, including visual inspection through time series plots, the use of correlograms displaying the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF), and the Augmented Dickey-Fuller (ADF) test, which serves as a formal statistical test for stationarity.

The ARIMA model combines three key components: AutoRegressive (AR), Moving Average (MA), and Integration (I). It captures the underlying patterns in a time series by accounting for past values (AR), past forecast errors (MA), and differencing to achieve stationarity (I). An ARIMA model is typically denoted as ARIMA(p, d, q), where p represents the order of the autoregressive terms, d the degree of differencing, and q the order of the moving average terms. The general form of the ARIMA(p, d, q) model is expressed as follows:

$$Q_t = \Phi_1 Q_{t-1} + \Phi_2 Q_{t-2} + \dots + \Phi_p Q_{t-p} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \dots + \theta_q \varepsilon_{t-q} + \delta^d Q_t \quad (1)$$

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 :

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

$LB(q)$ 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:

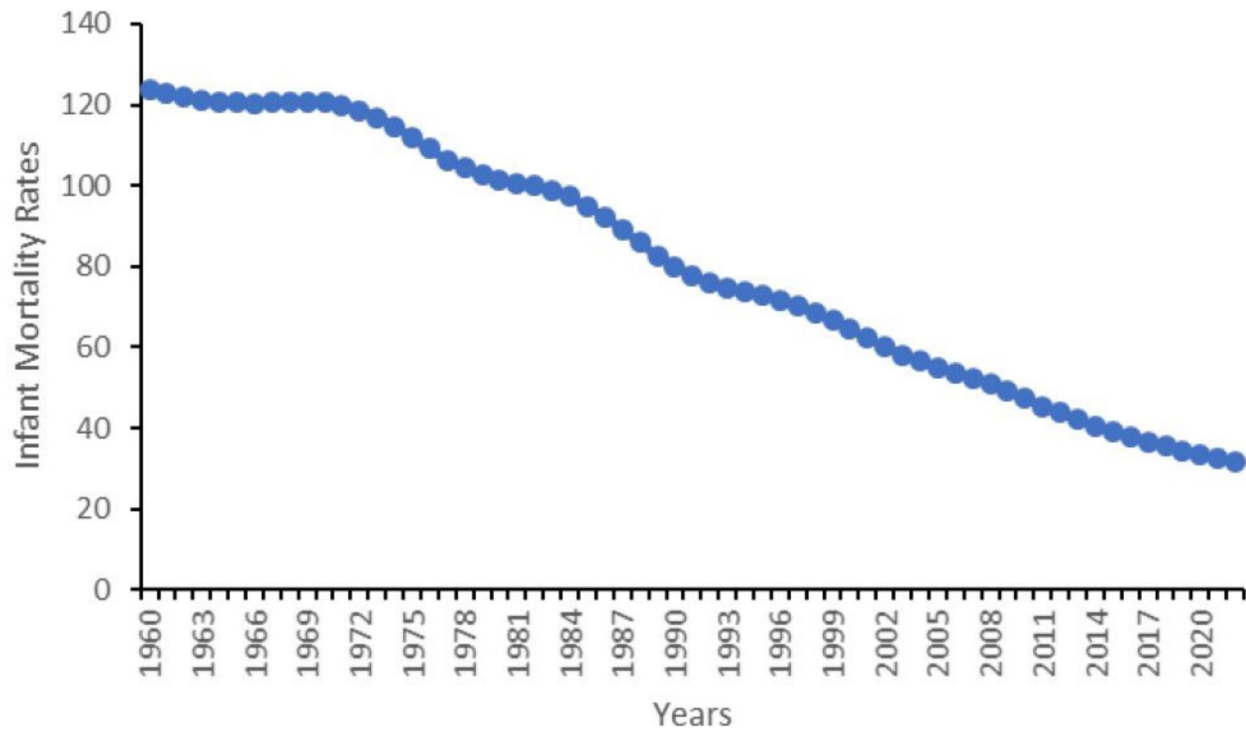


Fig. 1 Trends of infant mortality in Ghana

$$MSE = \frac{\sum(T - \bar{T})^2}{n} \quad (3)$$

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

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

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

$$MAPE = \frac{1}{n} * \sum \left(\left| \frac{T_i - \bar{T}}{T_i} \right| \right) * 100 \quad (4)$$

Where n specifies the overall number of observations, T_i denotes the value that was actually observed, and is \bar{T} the value that is anticipated.

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

Results

Trends of infant mortality in Ghana

Figure 1 presents the annual trend of infant mortality in Ghana. From the graph, the x-axis represents the years, and the y-axis shows the infant mortality rate. The behavior of the data can be seen through the trend. According to a visual analysis of the data, infant mortality shows a downward trend between 1960 and 2022, suggesting non-stationarity.

Table 1 Stationarity analysis of infant mortality data

	ADF (<i>p</i> -value)	KPSS (<i>p</i> -value)
Before Differencing	0.23	0.01
After 1st Differencing	0.04	0.10

Stationarity analysis of infant mortality data

From the trend analysis in Fig. 1 above, it was observed that there is non-stationarity in the study data. A rigorous test to identify stationarity confirmed this. Both the Augmented Dickey-Fuller Test (ADF) and Kwiatkowski-Phillips-Schmidt-Shin Test (KPSS) test were used for this study as presented in Table 1. The p -values for the ADF and KPSS on the initial time series data were 0.23 and 0.01 respectively. While the KPSS result revealed a non-stationarity, the ADF test suggested stationarity. To resolve this disagreement, transformation (differencing) technique was applied. After first differencing the p -values for the ADF and KPSS were 0.04 and 0.1 respectively. Both results indicate stationarity in the transformed data. This was further tested by constructing a trend analysis graph and the autocorrelation analysis and all results pointed to stationarity in the transformed data.

Model specification and selection

Four models were fitted using the autocorrelation and partial autocorrelation functions as shown in Table 2. Among the models are ARIMA (1,1,4), ARIMA (1,1,2), ARIMA (1,1,3), and ARIMA (1,1,1). In the ARIMA (1,1,4), While the moving average terms indicate that

Table 2 Fitted ARIMA models for infant mortality rates in Ghana

Model	AIC	BIC	AICC
ARIMA(1,1,4)	-9.95	1.40	-7.99
ARIMA(1,1,2)	4.19	11.75	5.07
ARIMA(1,1,3)	-2.59	6.86	-1.22
ARIMA(1,1,1)	20.91	26.58	21.43

Table 3 95% Confidence intervals for in-sample forecasts by ARIMA model

Year	Observed	Forecast	Confidence interval
2010	47.3	47.5	47.14–47.84
2011	45.5	45.8	44.80–46.71
2012	43.8	44.0	42.12–45.94
2013	42.1	42.3	39.08–45.58
2014	40.6	40.7	35.79–45.69
2015	39.2	39.2	32.38–46.11
2016	37.9	37.8	28.90–46.78
2017	36.6	36.5	25.40–47.66
2018	35.5	35.3	21.88–48.71
2019	34.4	34.1	18.37–49.90
2020	33.4	33.0	14.88–51.22
2021	32.5	32.0	11.42–52.64
2022	31.6	31.1	7.99–54.15

the series' current value is impacted by the previous four shocks, the model suggests that the series' present value is influenced by the first most recent past values. With the order of differencing (I) 1, the series is stable after the first differencing. The ARIMA (1,1,2) model suggests that the present value of the series is dependent on the most recent past values. The order of differencing (I) is 1, and the moving average terms show that the series' current value is influenced by the most recent past two shocks. ARIMA (1,1,3) model implied that the present value of the series is dependent on one of the recent historical values. The order of differencing (I) is 1, and the moving average terms show that the series' current value is influenced by the most recent past three shocks. And ARIMA (1,1,1) implied that the present value of the series is dependent on one of the recent historical values. The order of differencing (I) is 1, and the moving average terms show that the series' current value is influenced by the most recent past one shock. The best ARIMA model was chosen from the fitted ARIMA models based on AIC, AICC, and BIC values. The model with the fewest AIC is deemed the best, and if the AIC values are the same for more than one model, we consider the BIC or AICC. The AIC values for the ARIMA models were ARIMA (1,1,4) with an AIC value of -9.95, ARIMA (1,1,2) with an AIC value of 4.19, ARIMA (1,1,3) with an AIC value of -2.59, and ARIMA (1,1,1) with an AIC value of 20.91. based on these results, the best model selected for this study was ARIMA (1,1,4) since it had the smallest AIC value.

Table 4 MSE and MAPE results for the in-sample forecast of infant mortalities

Model	MSE	MAPE
ARIMA(1,1,4)	0.079	0.657

Table 5 95% Confidence intervals for out-sample forecasts by ARIMA model

Year	Forecast	Confidence interval
2023	30.68	30.36–30.99
2024	29.76	28.92–30.59
2025	28.83	27.19–30.47
2026	27.91	25.13–30.68
2027	27.03	22.78–31.28
2028	26.20	20.28–32.13
2029	25.43	17.67–33.18
2030	24.68	14.99–34.38

In-sample forecast of the ARIMA model

Table 3 shows the in-sample forecast results for the selected ARIMA model. This was done to assess the performance of the model. The findings demonstrate that the model will perform better since the predicted values are more similar to the observed values. The model's robustness is tested using the diagnostic techniques shown in Table 4.

MSE and MAPE results of the model in-sample forecast

The results for the mean square error (MSE) and mean absolute percentage error (MAPE) of the in -sample forecast (training dataset) results of the model are presented in Table 4. The MSE and the MAPE results were 0.079 and 0.657% respectively. This implies that the model is best for forecast since the errors are small and minimized.

Out-sample forecast by the ARIMA model for infant mortality

Table 5 shows the results of the out-of-sample forecast using the best ARIMA model for Ghana's infant mortality rates. The projections range from 2023 to 2030. According to the ARIMA model results, infant mortality rates in Ghana are on a decreasing trend from 2023 and 2030. The predicted findings show that infant mortality rates will fall from 30.68 per 1000 live births in 2023 to 24.68 per 1000 live births in 2030. This demonstrates that the anticipated values for infant mortality are decreasing till the end of the forecast period.

Comparison of forecasted infant mortality trajectory to SDG 3.2 targets

Figure 2 presents Ghana's forecasted infant mortality trajectory from 2023 to 2030 alongside the SDG 3.2 targets for neonatal (≤ 12 deaths per 1,000 live births) and under-five (≤ 25 deaths per 1,000 live births) mortality.

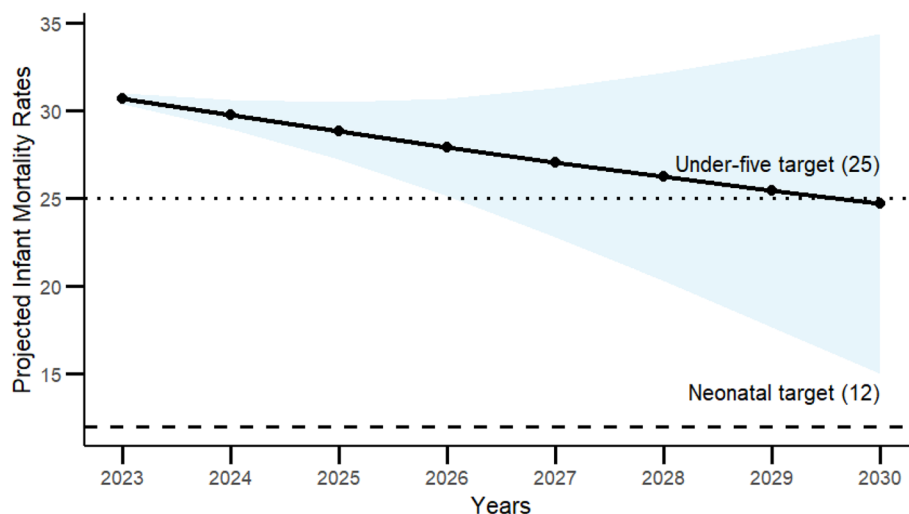


Fig. 2 Comparison of forecasted infant mortality trajectory to SDG 3.2 targets

The forecast indicates a continued decline, reaching 24.68 deaths per 1,000 live births in 2030. This rate remains above the neonatal target but slightly below the under-five target. The shaded ribbon represents the 95% confidence interval, which ranges from 14.99 to 34.38 in 2030, highlighting uncertainty around the estimates. This range implies that, under optimistic scenarios, Ghana could surpass the under-five target earlier, while under pessimistic scenarios, the rate could remain significantly above both targets, necessitating intensified policy action.

Discussion

The time series analysis confirms a sustained decline in Ghana's infant mortality rate, from 47 deaths per 1,000 live births in 2010 to 32 in 2022, consistent with earlier findings that child mortality is decreasing in the region [10]. The predicted findings show that infant mortality rates will fall from 30.68 per 1000 live births in 2023 to 24.68 per 1000 live births in 2030. This demonstrates that the anticipated values for infant mortality are decreasing till the end of the forecast period. While this downward trend reflects significant gains in maternal and child health, the ARIMA-based forecasts suggest that the rate will remain above the Sustainable Development Goal (SDG) 3.2 benchmark for neonatal mortality by 2030, indicating that accelerated progress is required to meet global child survival targets. Ghana still faces enormous challenges in achieving Sustainable Development Goal 3, which aims at ensuring healthy lives and fostering well-being for everyone at all ages [2]. Ghana has had several changes in health policies and demographics between 1960 and 2022. Children in rural regions have much greater mortality risks than their urban counterparts [3, 11]. Again, [9] revealed that Ghana did not achieve the Millennium Development Goals MDG 4 in 2015, as

infant mortality rates stagnated in some regions and even increased in other regions.

The width of the 95% forecast interval reflects uncertainty in future neonatal mortality trends. In the Ghanaian context, this uncertainty can be linked to specific drivers, such as skilled birth attendance (SBA), post-natal care (PNC) coverage, malaria resurgence, and budgetary shocks. Outcomes shift toward the optimistic bound when coverage and service quality improve, whereas disruptions in funding, disease outbreaks, or regional disparities push projections toward the pessimistic bound. Recognizing these drivers enhances the policy relevance of the forecasts and helps target interventions where they are most needed. Several factors may explain the observed decline. National programs such as the Community-based Health Planning and Services (CHPS) initiative, introduced in 1999 and expanded over the past two decades, have brought basic maternal and child health services closer to rural households, reducing geographical barriers to care [4]. Similarly, the National Health Insurance Scheme (NHIS), launched in 2003, has improved financial access to essential services, particularly for women and children [29]. These interventions, alongside expanded immunization campaigns, improvements in skilled birth attendance, and increased investment in neonatal intensive care units (NICUs) in tertiary facilities, have collectively contributed to reductions in infant mortality. However, progress has not been uniform. Persistent inequities between rural and urban populations [11], disparities in access to quality obstetric care, and high out-of-pocket costs for uninsured households continue to slow the rate of decline.

Ghana's projected decline is broadly consistent with trends in several Sub-Saharan African countries. For example, Kenya's infant mortality rate fell from 46 per 1,000 live births in 2010 to 32 in 2022, while Nigeria

experienced a slower decline from 69 to 54 over the same period (World Bank, 2023). The comparatively faster reductions in Kenya have been linked to expanded immunization coverage, improved neonatal intensive care, and increased skilled birth attendance interventions that could be adapted and scaled in the Ghanaian context to hasten progress.

The ARIMA model demonstrated strong predictive accuracy, with MSE and MAPE values of 0.079% and 0.657%, respectively. This close alignment between predicted and observed values indicates that the model effectively captures historical patterns, with its significant explanatory power and likelihood of success in out-of-sample forecasting supported by the strong agreement between predicted and actual values [30, 31]. These low MSE and MAPE values further confirm that forecast errors are small and well-contained within acceptable limits. In particular, the MSE, which measures the average of the squared prediction errors, is especially sensitive to larger deviations [32], while MAPE values under 10% are generally considered highly accurate in time series forecasting [33]. An observed MAPE of 0.657% therefore suggests that, on average, predicted values deviate from actual observations by less than 1%, representing a very high level of predictive precision. However, as a univariate model, ARIMA relies solely on past infant mortality rates and does not account for explanatory variables such as healthcare access, immunization coverage, or socio-economic conditions. This exclusion introduces the possibility of omitted variable bias, meaning that the model cannot attribute changes to specific determinants or interventions. Consequently, while the forecasts provide valuable baseline trajectories, they should be complemented in future research with multivariate models to support more targeted policy design.

The forecast for 2030 is 24.68 deaths per 1,000 live births, with a wide 95% confidence interval of 14.99–34.38. This range reflects the interplay of Ghana's health system strengths and vulnerabilities. Achieving the optimistic lower bound would likely require scaling up proven interventions such as neonatal resuscitation training, expansion of the Community-Based Health Planning and Services (CHPS) program into underserved northern regions, and increasing National Health Insurance Scheme (NHIS) coverage for poor households. Evidence shows that NHIS enrolment is significantly associated with higher antenatal care utilization, skilled birth attendance, and facility-based delivery, all of which are critical in reducing neonatal and infant deaths [34]. Similarly, [29] demonstrated that NHIS membership lowers the probability of neonatal mortality, highlighting the importance of expanding financial protection in maternal and child health.

At the regional level, studies applying the Lives Saved Tool (LiST) in Northern, Upper West, and Volta regions attribute declines in neonatal mortality to improvements in essential interventions such as skilled birth attendance, neonatal resuscitation, and infection management [35]. However, disparities persist, with higher infant mortality rates consistently reported in rural and northern areas compared to urban and southern regions [11]. These inequalities suggest that unless targeted efforts are intensified in disadvantaged regions, national progress may remain uneven.

Conversely, the pessimistic upper bound of the forecast could result from economic shocks, funding shortfalls, regional service delivery gaps, or stagnation in program implementation. Recent analyses emphasize that health expenditure is a significant determinant of infant mortality in Sub-Saharan Africa, and reductions in funding can slow or even reverse progress [36]. Facility-level studies in Ghana also reveal that preventable causes such as birth asphyxia, prematurity, and neonatal sepsis remain major contributors to mortality, underscoring the importance of sustained investment in quality care [37]. Thus, the confidence interval not only quantifies statistical uncertainty but also maps onto real-world policy contingencies that will determine whether Ghana accelerates or stalls in its progress toward child survival targets.

To push the trajectory toward the optimistic bound, interventions should prioritize high-burden areas, particularly in the northern regions. Strategies such as scaling up skilled birth attendance, expanding NICU capacity, strengthening postnatal follow-up systems, and deploying mobile health (mHealth) platforms to remote communities have proven effective in similar settings. Conversely, any reduction in maternal and child health funding, deterioration in service quality, or disruption of primary healthcare delivery could slow or reverse gains, pulling outcomes closer to the pessimistic bound. The findings reinforce the importance of sustained, data-driven investment in maternal and child health, paired with responsive policy frameworks that integrate predictive analytics with real-time health information systems such as DHIMS2. This dual approach can support timely, evidence-based decision-making, ensuring that national strategies remain aligned with both projected trends and emerging challenges.

It is important to recognize that the ARIMA model is descriptive rather than causal. The forecasts are based exclusively on historical IMR data, meaning that any future policy changes, funding shocks, or health crises could alter the projected trend. Consequently, the results are interpreted as baseline expectations under stable conditions. Future research could employ multivariate or hybrid approaches, incorporating exogenous predictors

such as service coverage, budget allocations, and maternal health indicators to improve explanatory power.

Conclusion

This study applied the ARIMA time series modeling approach to analyze and forecast infant mortality trends in Ghana, with the broader aim of assessing the country's progress toward Sustainable Development Goal (SDG) 3. Historical data from 1960 to 2022 indicated a consistent decline in infant mortality, with rates falling from 47 deaths per 1,000 live births in 2010 to 32 in 2022. Forecasts project a continued downward trend, reaching approximately 24.68 deaths per 1,000 live births by 2030. The ARIMA (1,1,4) model was selected as the optimal model based on the lowest AIC value, and its performance was validated through residual diagnostics and low forecast error metrics, including an MSE of 0.079 and MAPE of 0.657%. These results indicate a high degree of predictive accuracy and model adequacy.

Nonetheless, a key limitation of this study lies in its reliance on a univariate ARIMA model, which does not incorporate external explanatory variables such as healthcare access, maternal education, or income levels. While ARIMA offers robust short-term forecasting based on historical patterns, it does not permit analysis of causal relationships. Future research could apply multivariate time series models or econometric approaches to better understand the structural drivers of infant mortality.

While the declining trend is promising, Ghana's projected infant mortality rate still remains above the SDG 3.2 target for neonatal mortality rates of 12 deaths per 1,000 live births and slightly below the under-five mortality target of 25 deaths per 1,000 live births by 2030. This suggests that, despite progress, the current pace of reduction may be insufficient to achieve the global target. Ghana has implemented several key health interventions aimed at improving maternal and child health outcomes, including the Community-Based Health Planning and Services (CHPS) initiative, the Free Maternal Healthcare Policy, the Integrated Management of Childhood Illness (IMCI), and various child immunization programs supported by UNICEF and GAVI. These interventions have contributed to the historical decline in infant mortality and offer a credible basis for sustaining the forecasted progress.

To accelerate reductions in infant mortality, interventions should be aligned with Ghana's current health sector priorities, particularly those outlined in the Health Sector Medium-Term Development Plan (2022–2025). This framework emphasizes strengthening maternal and infant health services, including neonatal resuscitation training, expanding neonatal intensive care units (NICUs), improving skilled birth attendance, and enhancing community-based programs such as

CHPS. Our forecasts highlight the urgency of scaling up these interventions, especially in high-burden northern regions. Linking resource allocation to real-time DHIMS2 data can enable targeted action where infant mortality is most pronounced, improving the likelihood of meeting or surpassing survival targets before 2030.

Additional measures are also recommended, such as improving postnatal care follow-up, strengthening referral systems, deploying mobile health (mHealth) platforms to reach remote communities, and scaling up paid maternity leave and nutrition programs targeted at pregnant women and infants. Collaboration among government agencies, international partners such as WHO, UNICEF, and the World Bank, and local stakeholders will be vital. These efforts should be guided by robust real-time data systems to enable evidence-based targeting of high-risk areas. With sustained and enhanced strategies, Ghana will be better positioned not only to meet but potentially exceed its infant mortality reduction goals ahead of 2030.

Acknowledgements

Not applicable.

Authors' contributions

Z.K.A and S.A. and S.O wrote the main manuscript text. Z.K.A analyse the data and prepared the figures and tables. S.A and S.O proofread the manuscript. Z.K.A. compiled the manuscript in LaTeX.

Funding

No funding was obtained for this study.

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.

Received: 26 May 2025 / Accepted: 5 November 2025

Published online: 15 December 2025

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