



MATERNAL MORTALITY FORECASTING FOR SAO TOME AND PRINCIPE USING HOLT'S LINEAR METHOD

Smartson. P. NYONI 1,

Thabani NYONI 2

1Independent Researcher & Medical Doctor, Harare, Zimbabwe

2Independent Researcher & Health Economist, Harare, Zimbabwe

Abstract

This study uses annual time series data on MMR for Sao Tome and Principe from 1985 to 2023 to predict future trends of MMR over the period 2024 to 2035. The study utilizes Holt's double exponential smoothing model. The optimal values of smoothing constants α and β are 0.7 and 0.3 respectively based on minimum MSE. The results of the study indicate that MMR will decline from around 70 in 2024 to levels below 10 deaths per 100 000 live births by 2035. Therefore, we encourage authorities to address major drivers of maternal deaths.

Keywords: Exponential smoothing, Forecasting, Maternal Mortality Ratio.

Introduction

Sao Tome & Principe (STP), is a Sub-Saharan Island country in the Gulf of Guinea. The country's overall fertility rate is around 4.4 births per woman and the unmet need for contraception is 33.7% (Sao Tome and Principe, 2023). STP level of poverty is high, with 66.2% of the population living on less than two euros per day, which is a major barrier to achieve universal health coverage (STP, 2018; MICS-STP-2014). The country already reached two out of four 90/90/80/80 targets and milestones for maternal and newborn health, with 95.4% women receiving the service of a skilled birth attendant at birth and 91% newborns obtaining first postnatal care within the first 24 h after birth (Sao Tome and Principe, 2023; UNICEF, 2020). Maternal mortality ratio for STP declined from 158.3 maternal deaths per 100,000 live births to 74 per 100,000 live births



in 2014, but the reduction was not enough to meet the Millennium Development Goal number five (UNDP, 2018; STP, 2018; STP, 2015). This paper models and forecasts MMR for STP using Holt's linear method. The study results will guide policy making, planning and allocation of resources to the maternal and child health program.

Literature Review

Author(s)	Objective(s)	Methodology	Key finding(s)
Becerra et al. (2026)	to identify and analyze maternal complications associated with adolescent pregnancy, with a particular focus on the Latin American context	qualitative and descriptive approach	adolescent pregnancy in Latin America and the Caribbean entails significant medical risks and negatively affects the integral development of adolescents, a situation that is aggravated by the lack of access to health services, education and by factors such as poverty
Mackin et al. (2026)	to understand how levels of MNH care are organized in different country contexts	Scoping review	Three or four levels of MNH facility care were most commonly reported. Linking maternal and newborn facility care to community connections is an important consideration to ensure equitable access to routine and emergency care
Marks & Castro (2026)	To examine how MWHs have been implemented across Latin America, analyzing their evolution, the specific needs they address in different countries, and their impact on maternal and neonatal health outcomes throughout the region	Systematic review	The evolution of MWHs suggests that they address a spectrum of needs beyond their original purposes, such as providing culturally responsive maternal support and psychosocial and early childhood support
Tsushima et al. (2026)	To determine the long-term incidence of dysglycemia and dyslipidemia after GDM and evaluated	Prospective cohort study	postpartum weight change may help identify women at higher risk of subsequent metabolic abnormalities, particularly dysglycemia, in



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	whether postpartum changes in body mass index (BMI) independently predicted these outcomes		this high-risk population, although causal relationships cannot be inferred from this observational study
Yue et al. (2026)	to perform an umbrella review to summarize the current evidence to provide a reference for clinicians and future research	Systematic literature review	This review offers a thorough overview of the current evidence linking SLE, SS and APS to pregnancy and assisted reproductive outcomes. It identifies existing gaps and proposes future research directions
Cresswell et al. (2025)	To obtain updated evidence on causes of maternal death is needed to accelerate progress	Systematic review	Globally, the most common cause of maternal death was hemorrhage (27%; 80% uncertainty interval 22–32), followed by indirect obstetric deaths (23%, 18–30), and hypertensive disorders (16%, 14–19). The proportion of hemorrhage deaths varied substantially by region and was highest in sub-Saharan Africa and Western Asia and Northern Africa.
Quiroz-Acuña et al. (2025)	To assess maternal mortality trends in LAC women from 1997 to 2019, providing key insights to address this issue.	ecological observational time-series study	Despite overall progress, regional differences in maternal mortality persist across Latin America and the Caribbean. These variations highlight the importance of strengthening maternal health systems, improving access to skilled birth attendance, and ensuring quality prenatal and postnatal care
Silvana et al. (2025)	To describe the factors influencing the reduction of maternal mortality during the 2022–2024 management period at Tartagal Hospital (HT)	Participatory Action Research (PAR) with a qualitative-quantitative analysis. Twelve meetings and interviews were conducted with the	intercultural, comprehensive, and territory-based management of pregnancy and childbirth led to a reduction in maternal mortality beginning in 2022. Teamwork and intersectoral collaboration optimized available resources, consolidating a sustainable and



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		healthcare team, along with 10 validated surveys administered to obstetric inpatients (10/12/24), and an analysis of hospital databases	effective model for maternal health. However, the greatest challenge lies in maintaining and increasing funding to ensure the continuity of this policy
Nigenda and Serván-Mori (2024)	To discuss the relationship between the availability of human resources for health and the maternal mortality ratio for the period 1990–2021 in Latin America	used secondary data from a global source to show patterns in the relationship between these two aspects and identify gaps in the Latin American and Caribbean regions	Although variations in maternal mortality rate cannot be explained solely through the provision of health personnel, it is important to consider that it is critical to find new modalities on how human resources for health could integrate and create synergies with other resources to increase systems capacity to deliver care according to conditions in each country
Vasconcelos et al. (2024)	to identify the factors affecting perinatal and neonatal deaths in Sao Tome & Principe (STP), the smallest Central Africa country	Institution-based prospective cohort study	Factors such as having a high-risk pregnancy score, meconium-stained amniotic fluid, prolonged rupture of membranes, being transferred from another unit, and an instrumental-assisted vaginal delivery increased 4– to 9-fold the risk of stillbirth and neonatal deaths
Vasconcelos et al. (2023)	to identify the determinants for adequate ANC utilization considering the number and timing of ANC contacts and screening completion	hospital based cross-sectional study	Maternal age, residence and type of pregnancy planning were the determinants for adequate ANC utilization
Vasconcelos et al. (2022)	to fill the gaps in ANC screenings with a focus on how to improve neonatal outcomes in Sao Tome & Principe	retrospective hospital-based study	
Critto et al. (2022)	To examine the effects of a pandemic influenza virus on cause-specific maternal mortality time	-conducted a population-based natural experiment from national vital	Over this 38-year study, the MMR decreased by 58.6% (69.5 to 28.8 deaths/100,000 live births), transitioning from



	series, Argentinian statistics	using vital	records of maternal deaths between 1980 and 2017 -applied Join-point regression models	direct obstetric causes (67.0 to 21.1/100,000 live births; 68.4% decrease) to indirect causes (2.6 to 7.7/ 100,000 live births; 196.2% increase)
Hill et al. (2009)	To assess the feasibility of measuring maternal mortality in countries lacking accurate birth and death registration through national population censuses by a detailed evaluation of such data for three Latin American countries		Applied established demographic techniques	The PRMRs for Honduras (2001), Nicaragua (2005) and Paraguay (2002) were 168, 95 and 178 per 100 000 live births, respectively. Surprisingly, evaluation of the data for Nicaragua and Paraguay showed overreporting of adult deaths, so a downward adjustment of 20% to 30% was required

Methodology

This study utilizes an exponential smoothing technique to model and forecast future trends of MMR for Sao Tome and Principe. In exponential smoothing forecasts are generated from the smoothed original series with the most recent historical values having more influence than those in the more distant past as more recent values are allocated more weights than those in the distant past. This study uses the Holt's linear method (Double exponential smoothing) because it is an appropriate technique for modeling linear data.

Holt's linear method is specified as follows:

Model equation

$$A_t = \mu_t + \rho_t t + \varepsilon_t$$

Smoothing equation

$$S_t = \alpha A_t + (1-\alpha) (S_{t-1} + b_{t-1})$$

$$0 < \alpha < 1$$

Trend estimation equation

$$b_t = \beta (S_t - S_{t-1}) + (1-\beta)b_{t-1}$$

$$0 < \beta < 1$$

Forecasting equation

$$f_{t+h} = S_t + hb_t$$

A_t is the actual value of MMR at time t



ε_t is the time varying **error term**

μ_t is the time varying mean (**level**) term

ρ_t is the time varying **slope term**

t is the trend component of the time series

S_t is the exponentially smoothed value of MMR at time t

α is the exponential smoothing constant for the data

β is the smoothing constant for trend

f_{t+h} is the h step ahead forecast

b_t is the trend estimate (slope of the trend) at time t

b_{t-1} is the trend estimate at time $t-1$

Data Issues

This study is based on annual MMR in Sao Tome and Principe for the period 1985– 2023. The out-of-sample forecast covers the period 2024 – 2035. All the data employed in this research paper was gathered from the World Bank online database.

Findings of the study

Exponential smoothing Model Summary

Table 1: ES model summary

Variable	A
Included Observations	39
Smoothing constants	
Alpha (α) for data	0.700
Beta (β) for trend	0.300
Forecast performance measures	
Mean Absolute Error (MAE)	4.866628
Sum Square Error (SSE)	2248.061153
Mean Square Error (MSE)	57.642594
Mean Percentage Error (MPE)	-0.367286
Mean Absolute Percentage Error (MAPE)	3.503931



Residual Analysis for the Applied Model

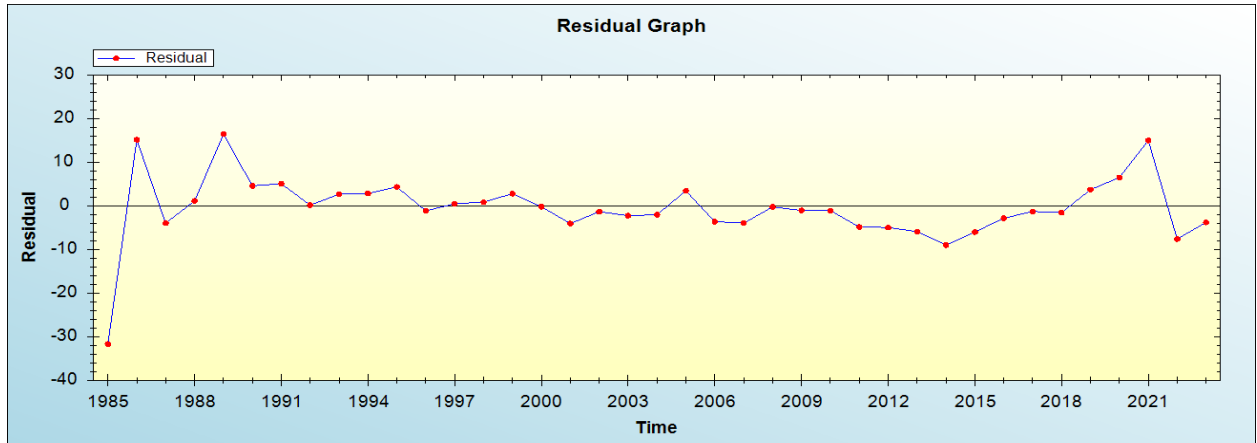


Figure 1: Residual analysis

In-sample Forecast for A

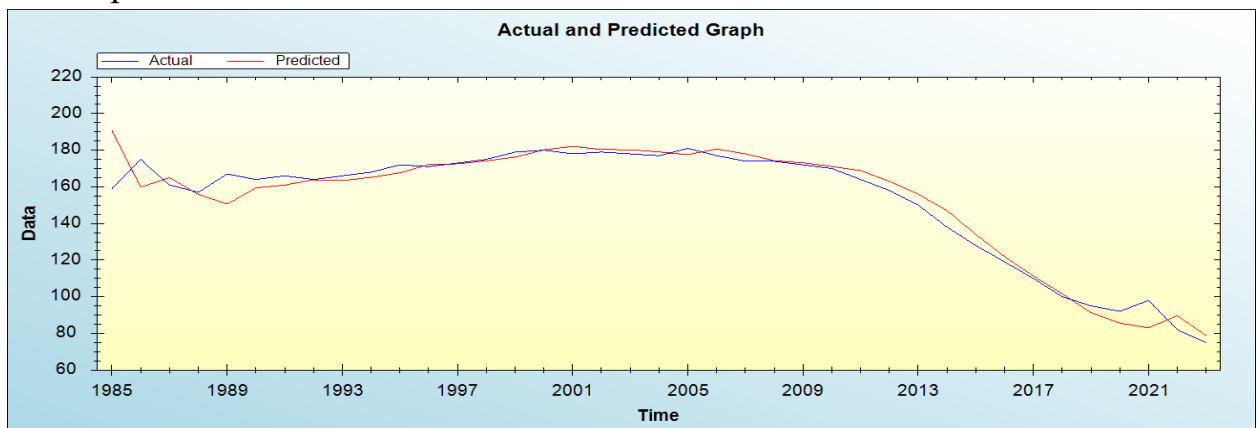


Figure 2: In-sample forecast for the A series

Actual and Smoothed graph for A series

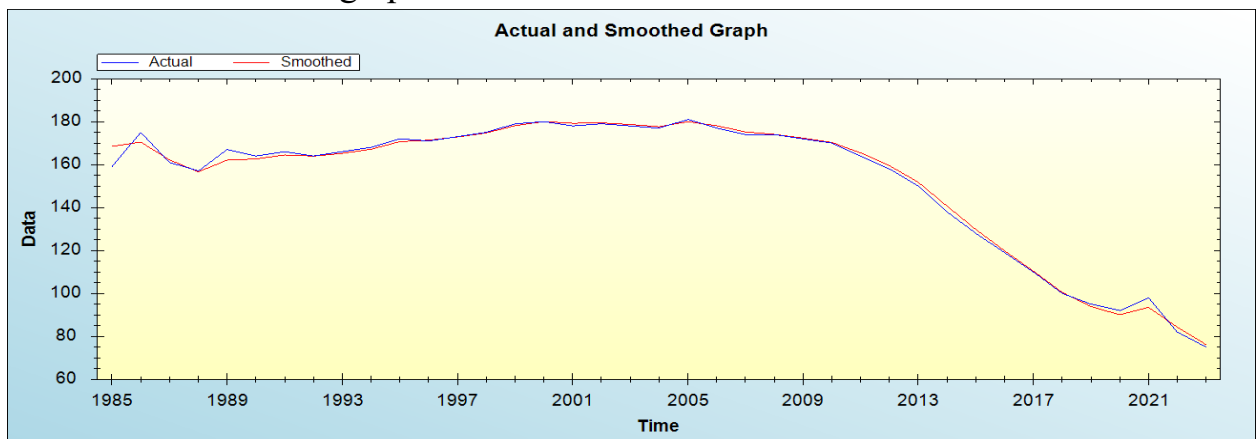


Figure 3: Actual and smoothed graph for A series



Out-of-Sample Forecast for A: Actual and Forecasted Graph

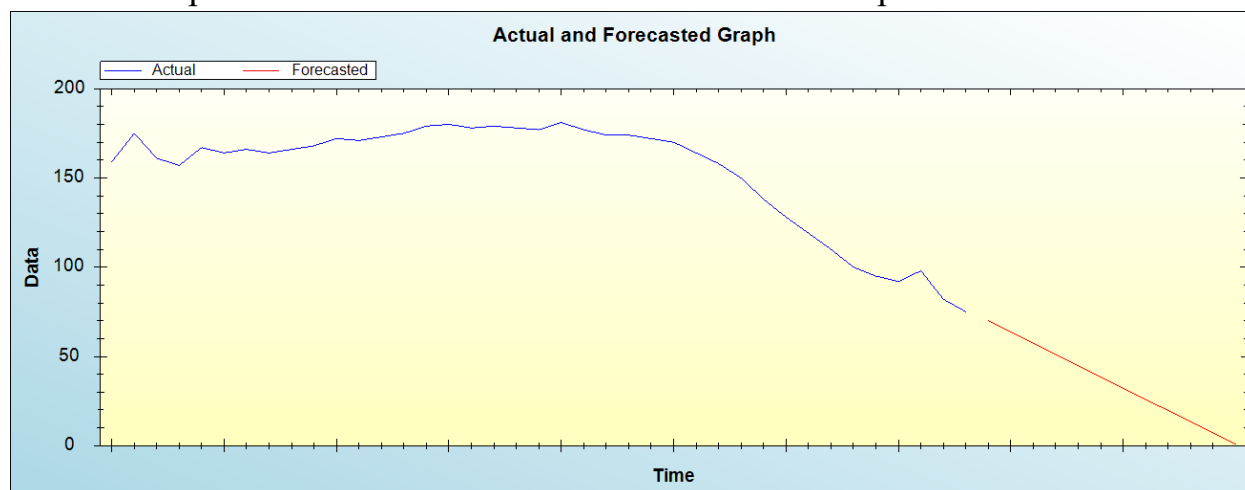


Figure 4: Out-of-sample forecast for A: actual and forecasted graph

Out-of-Sample Forecast for A: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted MMR
2024	69.8644
2025	63.5852
2026	57.3059
2027	51.0266
2028	44.7474
2029	38.4681
2030	32.1888
2031	25.9095
2032	19.6303
2033	13.3510
2034	7.0717
2035	0.7925

The main results of the study are shown in table 1. It is clear that the model is stable as confirmed by evaluation criterion as well as the residual plot of the model shown in figure 1. It is projected that annual MMR will decline from around 70 in 2024 to levels below 10 deaths per 100 000 live births by 2035.



Conclusion

In this study we applied the Holt's linear technique to model and forecast MMR for STP and results indicate that MMR will decline from around 70 in 2024 to levels below 10 deaths per 100 000 live births by 2035. Hence, we implore authorities to address local drivers of maternal mortality.

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