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APPLICATION OF HOLT'S LINEAR MODEL IN FORECASTING MATERNAL MORTALITY FOR TUNISIA

Smartson. P. NYONI[1], Thabani NYONI[2]
[1]Independent Researcher & Medical Doctor, Harare, Zimbabwe
[2]Independent Researcher & Health Economist, Harare, Zimbabwe

Abstract
This study uses annual time series data on MMR for Tunisia 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 0.1 respectively based on minimum MSE. The results of the study indicate that MMR will fall from around 37 in 2024 to about 28 deaths per 100 000 live births in 2035. We implore authorities to direct more resources towards the implementation of quality improvement strategies.

Keyword(s): - Exponential smoothing, Forecasting, Maternal Mortality Ratio

Introduction

Maternal mortality is a public health problem of international concern. A maternal death is defined as the demise of a woman while she is pregnant or within 42 days after the pregnancy termination resulting from any cause connected to or aggravated by the pregnancy or its management, but not from unintentional or incidental causes (WHO, 2023). According to WHO statistics for 2020, maternal mortality is reaching unprecedented levels. Nearly 287,000 women died during or after pregnancy or childbirth; almost 95% of maternal deaths occurred in low- and middle-income countries (WHO, 2024). The maternal mortality ratio (MMR) in Tunisia has declined from 62 in 2000 to 37 in 2020 (WHO, 2023). The situation in Tunisia indicates that MMR has reduced, but not enough in relation to the level of effort required and the objectives set (Tunisa Ministry of Health, 2017). Direct causes of maternal death include excessive bleeding, sepsis and hypertensive disorders. Most of these maternal deaths are preventable in 80% of cases, even in situations where countries have few resources (Tunisia Ministry of Health, 2017) The objective of this paper is to model and forecast MMR for Tunisia using Holt's linear method. The findings of this paper are envisioned to stimulate an appropriate national response so that further reduction of preventable maternal deaths is achieved.

Literature Review

Author(s)	Objective(s)	Methodology	Key finding(s)

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Amara et al. (2025)	to determine cost of Caesarean section using TDABC in a tertiary-level government hospital in Tunisia	-conducted a retrospective costing study using Time-Driven Activity Based costing (TDABC) at the Maternity Department of Farhat Hached University Hospital Center to estimate the cost of caesarean delivery	The total cost of caesarean delivery in our study was 1,610.83TND (US$573.04). Personnel costs were the largest cost drivers. The second highest cost was for medical consumables and medicines and investigations ranked third
Jena et al. (2025)	To estimate the pooled magnitude of neonatal mortality and its association with maternal and child health care in SSA	Systematic review	Neonatal mortality in SSA remains high. Maternal health services such as exposure to antenatal care and institutional delivery and child health services such as early initiation of breastfeeding were related to reducing the burden of neonatal mortality
Lukwa et al. (2024)	To evaluate the effectiveness and value of value-based healthcare interventions in improving maternal health outcomes in Sub-Saharan Africa	Systematic review	The results suggest that VBHC can significantly improve maternal health, evidenced by successful implementations like obstetric units in Sierra Leone and integrated care in South Africa, which improved outcomes and cost-effectiveness
Magdoud et al. (2024)	to determine the Maternal Mortality Ratio (MMR) in the governorate of Tunis	Secondary data analysis	The postpartum period was the most critical. In fact, 83, 33 % of maternal

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	and to identify the main causes of maternal death		deaths occurred postpartum. Hemorrhage was the main etiology in 20.8% of cases
Baig et al. (2023)	To Investigate maternal mortality in Southeast Asia, Europe and Africa	Literature review	-Inadequate care is one of the major causes of maternal mortality in majority of regions across the globe -The three delays model plays a significant role in the higher maternal mortality rate
Konlan et al. (2023)	To identify factors that influence women's decision for a CS are synthesized to clarify policy initiatives that improve care	Systematic review	The prevalence of CS was 2.1% to 18.5% of all live births as the socioeconomic status (SES) and demographic factors that influence the rate of CS were higher SES, education, and age; place of birth; urban residence; and women headed household
Mlambo et al. (2023)	to investigate the macro determinants of maternal mortality in Southern African Development Community (SADC) states	A panel data estimation (Generalized Method of Moments) covering the period from 2005–2019 was used to examine how various factors affect maternal mortality	The econometric analysis reveals a significant positive impact of fertility, GDP per capita and HIV on maternal mortality
Okonji et al. (2023)	To assess maternal mortality patterns by age and country in Sub-Saharan Africa	The demographic and health survey data were used for the study	The study found that the patterns of death vary across different countries

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Nnadi et al. (2022)	to estimate the effect of maternal mortality on economic development in Sub-Sahara African region. Cross-sectional data analysis of selected member countries in the region under focus was employed using double-log econometric model	Cross-sectional data analysis of selected member countries in the region under focus was employed using double-log econometric model	The explanatory variables in the model were statistically significant at 5% level while other coefficients like maternal mortality, exports and imports conform to the apriori expectations and impacted negatively on the overall GDP
Limam et al. (2021)	to assess the availability, utilization, and quality of emergency obstetric care services in the Governorate of Sousse (Tunisia)	a cross-sectional study was conducted among public health facilities which performed deliveries in Sousse in 2017. Data were collected by consulting clinical records and registers and interviewing staff using WHO EmOC tools	The study concluded that raising maternity facilities to a minimum level of basic EmOC status would be a major contributing step towards maternal mortality reduction
Musarandega et al. (2021)	to identify the leading causes of maternal deaths using the international classification of disease – 10th revision, for maternal mortality (ICD-MM)	Systematic review	Obstetric hemorrhage, hypertensive disorders in pregnancy, non-obstetric complications, and pregnancy-related infections are the leading causes of maternal deaths in SSA
Ghardallou et al. (2019)	to determine the frequency and the indications of obstetric referrals in a Tunisian tertiary care maternity and to	a descriptive study was undertaken among women referred to Farhat Hached University Hospital in Sousse,	Most of the indications for referrals (95.8%) did not conform to the list of referral indications of the

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	assess the conformity of referral mechanisms with the National Perinatality Programme (NPP) guidelines	Tunisia with antenatal complications requiring urgent delivery and those referred while in labor or with immediate postpartum complications. The ICD-10 was used to code recorded indications and diagnoses for referrals	NPP. Twenty-eight diagnoses were retained after referrals: the most common of which were prolonged pregnancy (29.5%) and premature rupture of membranes (19.3%). In 41% of women, reasons for referral did not match with diagnoses established at the time of the patients' admission to hospital
Girum and Wasie (2017)	to identify correlates of maternal mortality in developing countries	Systematic review	Maternal mortality is correlated with multiples of socio-economic factors, health care system associated factors, disease burden and their complex interactions
Singh et al. (2016)	To assess how countries in regions of the world where maternal mortality is highest - South Asia and Sub-Saharan Africa - are performing with regards to providing women with vital elements of the continuum of care	-Used Demographic and Health Survey data -descriptive and multilevel regression analyses were conducted on four key elements of the continuum of care - at least one antenatal care visit, four or more antenatal care visits, delivery with a skilled birth attendant and postnatal checks for the mother within the	—Results indicated that a major drop-out (more than 50%) occurs early on in the continuum of care between the first antenatal care visit and four or more antenatal care visits. Few women (less than 5%) who do not receive any antenatal care go on to have a skilled delivery or receive postnatal care

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		first 24 hours since birth	

Methodology

This study utilizes an exponential smoothing technique to model and forecast future trends of MMR for Tunisia. 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

$A_t=\mu_t + \rho_t \mathbf{t} + \varepsilon_t$

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

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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 Tunisia 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	0.100
Forecast performance measures	
Mean Absolute Error (MAE)	4.669181
Sum Square Error (SSE)	3231.963779
Mean Square Error (MSE)	82.870866
Mean Percentage Error (MPE)	0.120938
Mean Absolute Percentage Error (MAPE)	7.187351

Residual Analysis for the Applied Model

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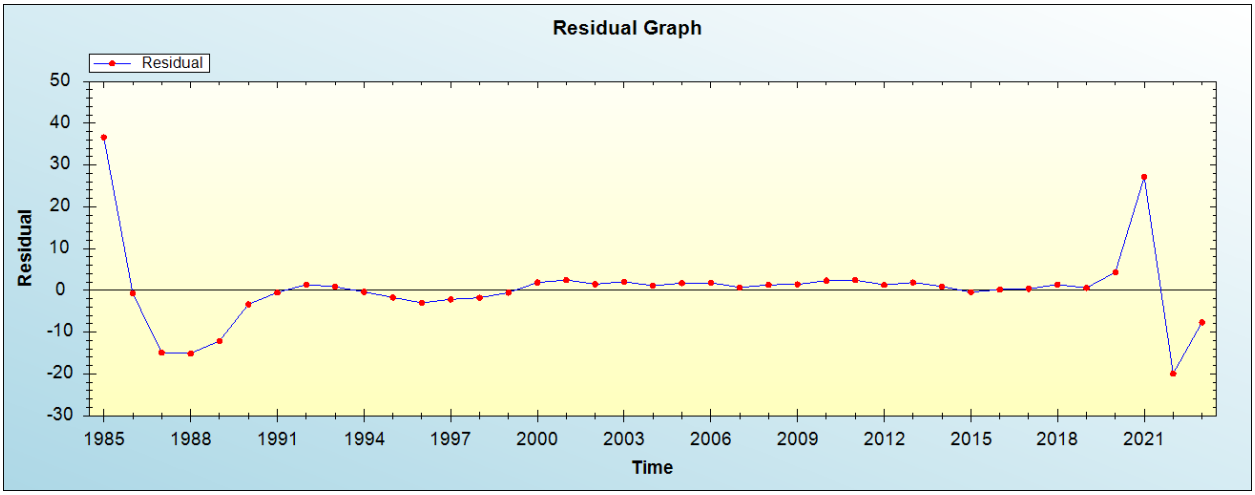


Figure 1: Residual analysis

In-sample Forecast for A

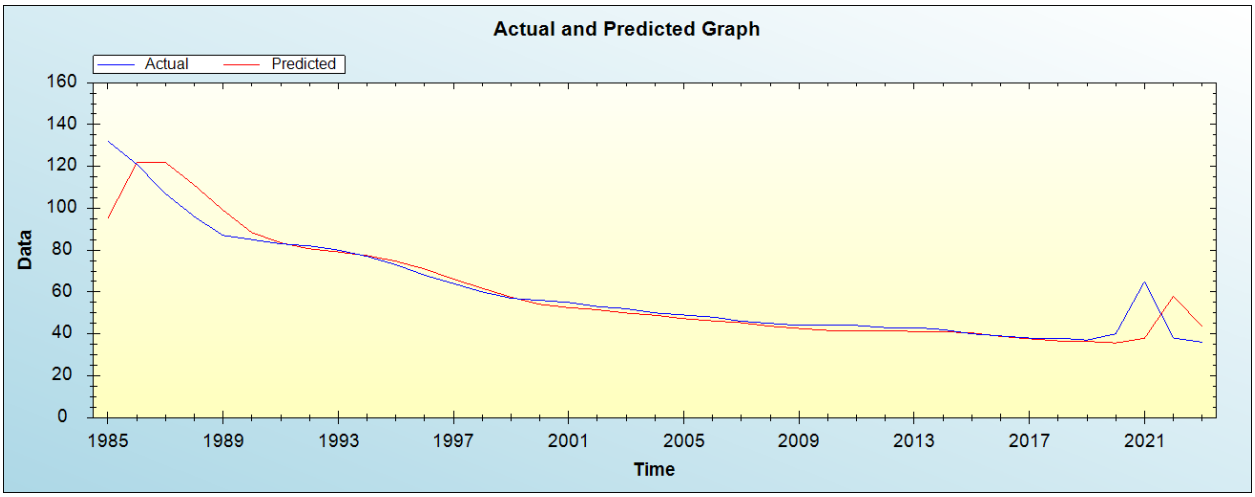


Figure 2: In-sample forecast for the A series

Actual and Smoothed graph for A series

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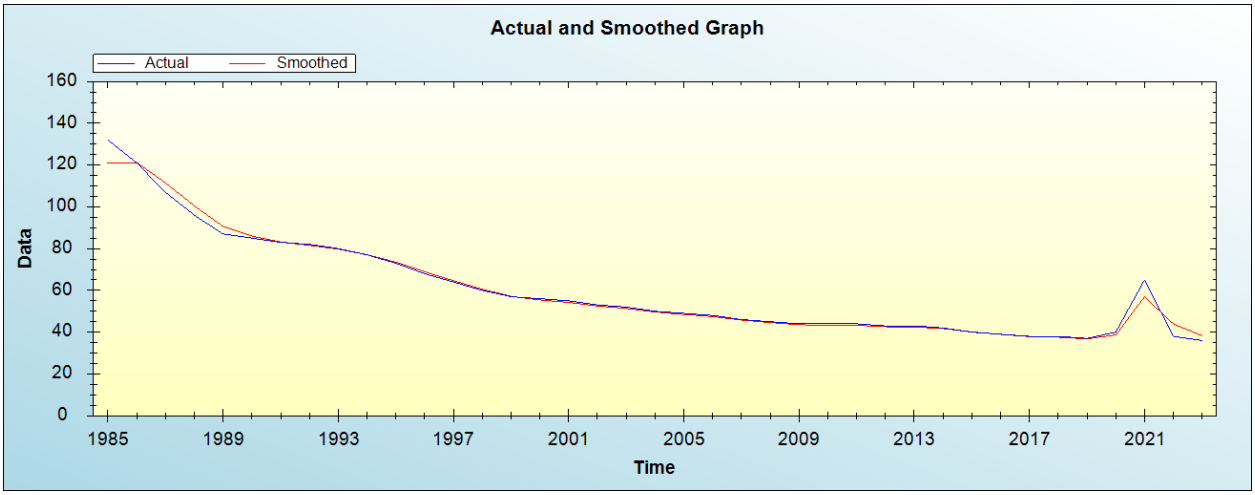


Figure 3: Actual and smoothed graph for A series

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

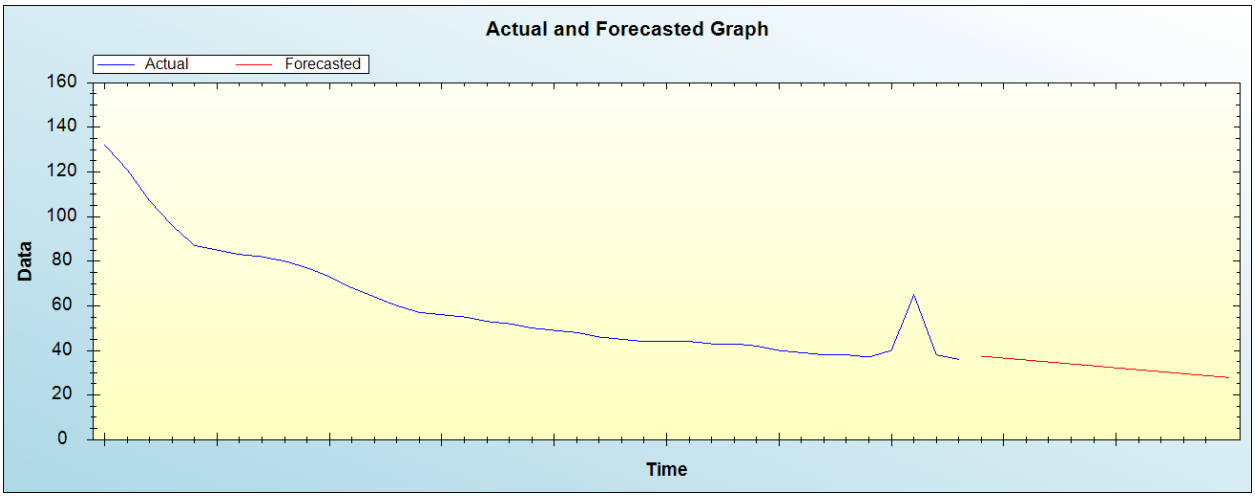


Figure 4: Out-of-sample forecast for A: actual and forecasted graph

Out-of-Sample Forecast for A: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted MMR
2024	37.4201
2025	36.5489
2026	35.6776
2027	34.8064

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2028	33.9351
2029	33.0639
2030	32.1926
2031	31.3214
2032	30.4501
2033	29.5789
2034	28.7076
2035	27.8364

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 continue to fall from around 37 in 2024 to about 28 deaths per 100 000 live births in 2035.

Conclusion

While the Tunisian government has made notable progress in reducing maternal mortality, preventing remaining deaths requires focused action on primary causes, specifically obstetric hemorrhage, hypertensive disorders and sepsis. Utilizing Holt's double exponential smoothing technique, this study projects a sustained reduction in Tunisia's Maternal Mortality Ratio (MMR), decreasing from approximately 37 deaths per 100,000 live births in 2024 to 28 by 2035. To ensure these projected targets are achieved and surpassed, health authorities and public health practitioners should prioritize the following quality improvement interventions:

i. ***Protocol Standardization for Major Obstetric Emergencies:*** Implement and enforce evidence-based clinical guidelines and active management protocols targeting emergency obstetric care, particularly for managing hemorrhage, severe preeclampsia/eclampsia, and maternal sepsis.

ii. ***Capacity Building & Simulation Training:*** Allocate dedicated funding for continuous, simulation-based emergency obstetric training for midwives, nurses, and medical personnel to enhance rapid response and diagnostic accuracy.

iii. ***Strengthening Postpartum Care Audits:*** Institutionalize maternal death and near-miss audits at facility and district levels to identify system failures, monitor referral pathways, and refine service delivery across the care continuum.

iv. ***Resource Supply-Chain Optimization:*** Guarantee uninterrupted access to essential life-saving pharmaceuticals (such as uterotonics, antihypertensives, and parenteral antibiotics) and critical blood products across all secondary and tertiary centers.

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