

ANNUAL MATERNAL MORTALITY RATE ESTIMATION FOR MADAGASCAR USING THE DOUBLE EXPONENTIAL SMOOTHING MODEL

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ABSTRACT

This study uses annual time series data on MMR for Madagascar 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 0.8 and 0.5 respectively based on minimum MSE. The results of the study indicate that MMR will continue on a downward path but still remain very high over the out of sample period. Therefore, we encourage health authorities to adopt the suggested 5-fold policy prescription.

Keywords: Exponential smoothing, Forecasting, Maternal Mortality Ratio.

INTRODUCTION

Maternal mortality is a critical global public health issue. Nearly 800 women die each day from preventable causes related to pregnancy or childbirth (WHO, 2023). Hemorrhage, hypertensive disorders, and sepsis are responsible for over 50% of maternal deaths worldwide (Khan et al. 2006). In Sub-Saharan Africa, 65% of maternal deaths from hemorrhage occur following delivery (Campbell et al. 2006; Li et al, 1996). Maternal mortality affects low-middle countries more than the developed countries. According to the WHO, at the global level, the maternal mortality ratio in 2020 was estimated at 233 per 100,000 live births (WHO, 2020). However, during the recent years, a significant decline of maternal mortality ratio at the global level was noted, with a reduction of 34.3% between 2000 and 2020, an average rate of reduction of 2.9% per year (WHO, 2023; WBG, 2023; WHO, 2020). Madagascar is no exception, with an estimated maternal mortality rate of 408 deaths per 100,000 live births (INSTAT, 2021). The country struggles with significant disparities in access to healthcare, particularly in rural areas (INSTAT & ICF, 2022). The objective of this paper is to model and forecast MMR for Madagascar using the double exponential smoothing model. The findings will be essential for policy making, planning and allocation of resources to the maternal and child health program in order to further low preventable maternal deaths across the country.

LITERATURE REVIEW

Author(s)	Objective(s)	Methodology	Main finding(s)
Bemanana et al. (2025)	To examine whether regional variations in the intensity of multidimensional poverty are associated with the maternal mortality ratio (MMR)	Cross-sectional study	A strong positive correlation was observed between the intensity of multidimensional poverty and MMR ($r = 0.642$, $p < 0.001$), explaining 41.2% of the variation. Rural regions exhibited significantly higher multidimensional poverty index (MPI) and MMR values

			than urban ones. A one-point increase in MPI was associated with an average rise of 24 maternal deaths per 100,000 live births
Bemanana et al. (2025)	to assess the association between ANC quality and maternal mortality rate (MMR), focusing on regional disparities and exploring potential non-linear relationships in Madagascar	conducted a retrospective ecological study using publicly available data from Madagascar's 22 regions. ANC indicators included blood pressure monitoring, blood and urine tests, iron supplementation, and antiparasitic treatment	Considerable disparities were observed in ANC coverage across regions. Linear models revealed no significant association between ANC indicators and MMR ($p > 0.05$). However, GAM identified significant non-linear relationships for blood pressure monitoring ($p < 0.0045$) and blood testing ($p < 0.0055$), suggesting potential threshold effects
Franke et al. (2024)	to determine the cost-effectiveness of a non-governmental organization (NGO)-run inter-facility referral system for emergency obstetrical and neonatal care in rural Southern Madagascar by analyzing the characteristics of cases referred through the intervention as well as its costs	Researchers performed a descriptive and a cost-effectiveness analysis, including a one-way deterministic sensitivity analysis	the inter-facility referral system was a very cost-effective intervention
Razakamanana et al. (2023)	to identify the relationship between health expenditures and maternal and child mortality in Madagascar and the potential bottlenecks in the flow of funds for maternal and child health	Using panel data, fixed and random effect models for the 22 regions of Madagascar over the period 2010 to 2017 were used. Then bottlenecks related to the flow of funds for maternal and child health were identified	Equipment endowments contributed more to health improvement and would be more effective than monetary financing
Muriithi et al. (2022)	to identify these contributing factors and assess the frequency of their reporting in published literature	Systematic review	findings indicate that health facility-level factors were the most frequently reported contributing factors to maternal deaths in Africa
Andrianantoandro et al. (2021)	to identify and analyze the factors that influence the utilization of maternal services, specifically, the use of antenatal care (ANC) during pregnancy and the use of skilled birth attendants (SBAs) at delivery	used quantitative and qualitative approaches	The use of maternal healthcare services is starting to gain ground, although many women and their relatives still use traditional caregivers at the same time. Relatives play a crucial role in maternal healthcare seeking

Vilaplana et al. (2020)	to report maternal morbidities among 1015 women in the district of Ambanja, Madagascar, and to describe the advantages and limitations of a mHealth system	Data were collected using the PANDA (pregnancy and newborn diagnosis assessment) system, an mHealth device that incorporates the WHO recommendations for antenatal care (ANC). Data, including personal and medical information, but also clinical data such as hypertension, anemia or HIV were collected from more than 1000 women attending ANC	The prevalence of anemia in the study population was much higher than previously reported in Sub-Saharan Africa
Ratsiatosika et al. (2019)	to determine the epidemiological and etiological profile of maternal deaths in Madagascar	Researchers conducted a descriptive retrospective study over a 2-year period from January 1st, 2016 to December 31st, 2017 at the Befelatanana Gynecology-Obstetrics Hospital on maternal deaths	Maternal mortality remains a major concern at the Befelatanana Obstetrics Gynecology Hospital. During the study, hypertensive complications were found to be the most common causes requiring adequate management
Salem et al. (2018)	-to assess women's knowledge of obstetric danger signs and factors associated with this knowledge in Ambanja, Madagascar -to evaluate whether the participation in a mobile health (mHealth) project that aimed to provide comprehensive ANC to pregnant women in remote areas influenced women's knowledge of obstetric danger signs	- Applied logistic regression	Knowledge of at least one danger sign varied from 80.9% of women knowing danger sign(s) in pregnancy, to 51.9%, 50.8% and 53.2% at delivery, postpartum and in the newborn, respectively. Participation in the mHealth intervention, higher household income, and receipt of information about danger signs during pregnancy were associated with knowledge of danger signs during delivery, in bivariate analysis; only higher household income and mHealth project participation were independently associated

METHODOLOGY

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

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

Smoothing equation

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

$$0 < \alpha < 1$$

Trend estimation equation

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

$$0 < \beta < 1$$

Forecasting equation

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

M_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 Madagascar 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	M
Included Observations	39
Smoothing constants	
Alpha (α) for data	0.800
Beta (β) for trend	0.500
Forecast performance measures	
Mean Absolute Error (MAE)	7.206746
Sum Square Error (SSE)	4043.263823
Mean Square Error (MSE)	103.673431
Mean Percentage Error (MPE)	0.065940
Mean Absolute Percentage Error (MAPE)	1.258954

Residual Analysis for the Applied Model

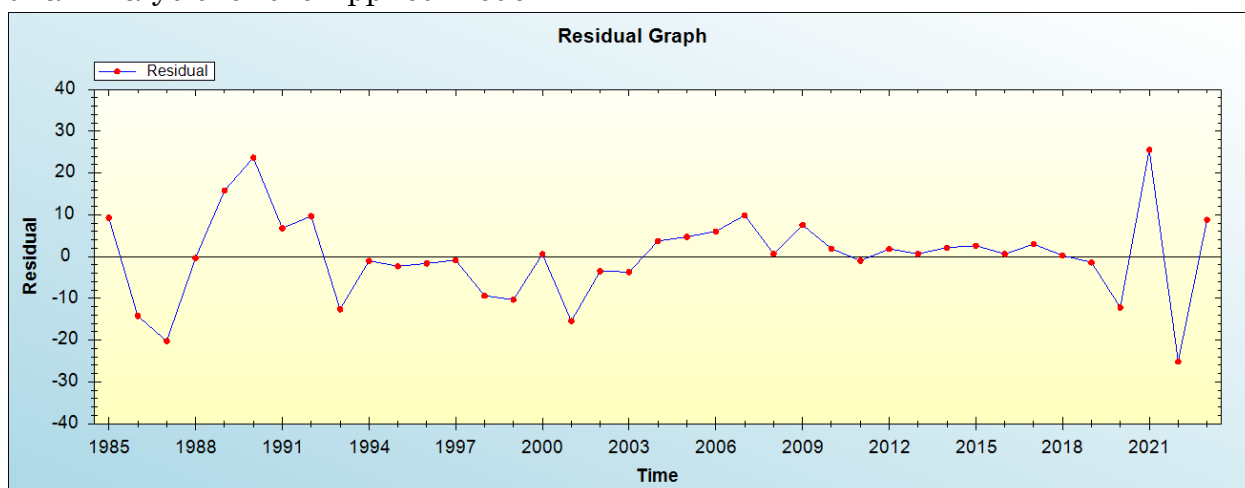


Figure 1: Residual analysis

In-sample Forecast for M

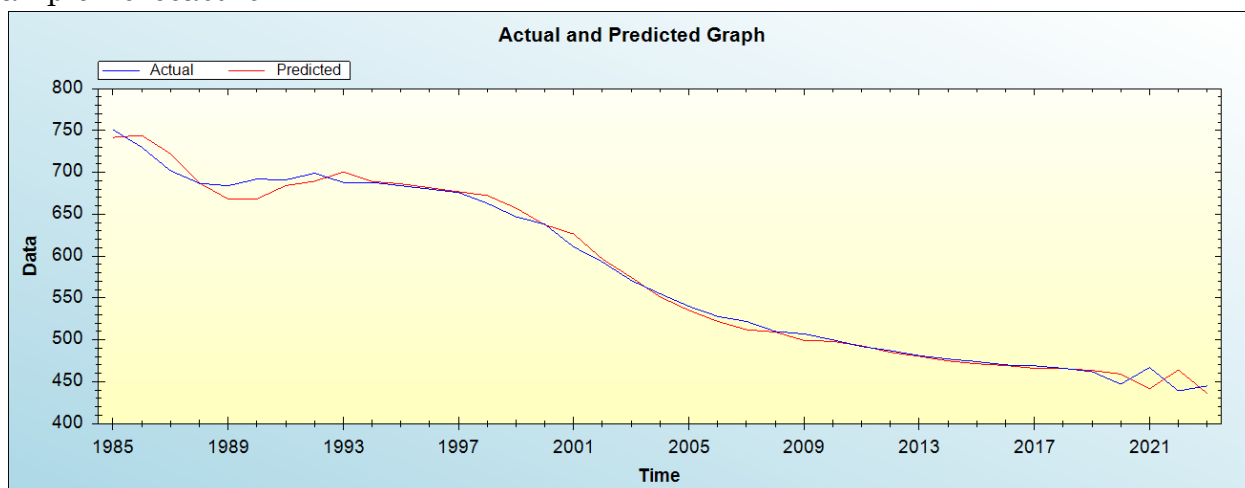


Figure 2: In-sample forecast for the M series

Actual and Smoothed graph for M series

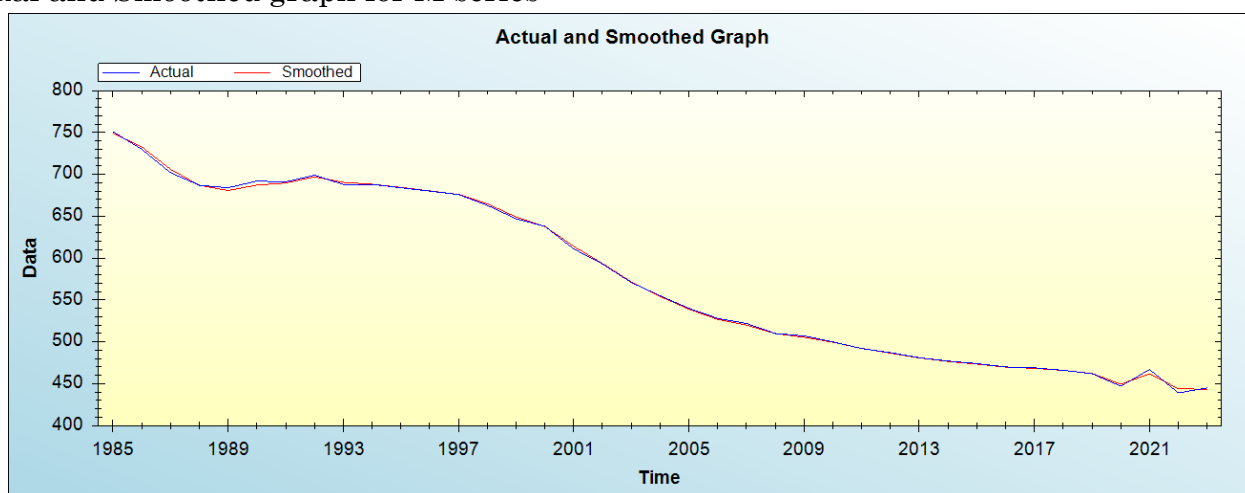


Figure 3: Actual and smoothed graph for M series

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

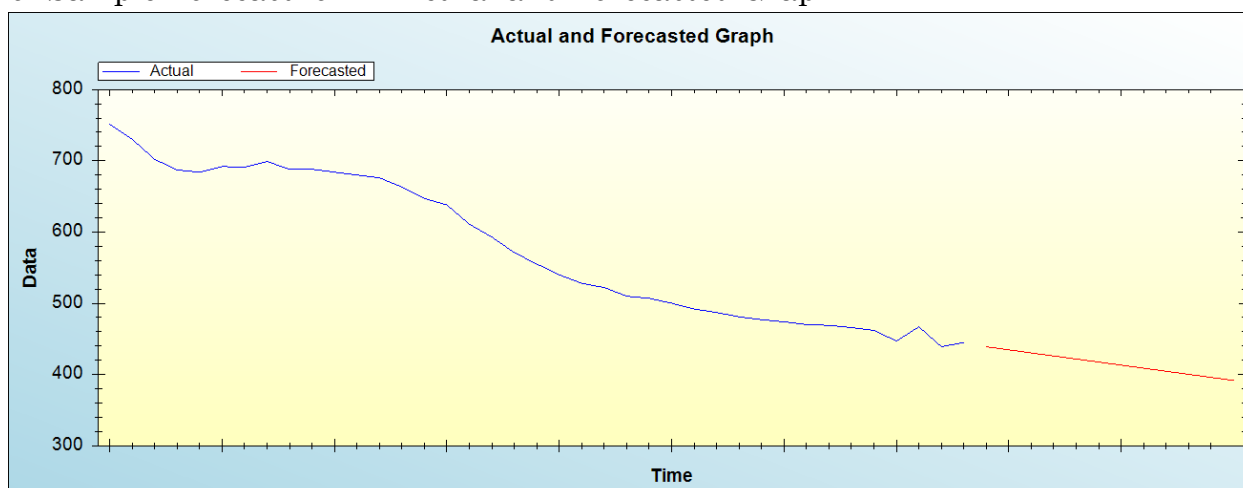


Figure 4: Out-of-sample forecast for M: actual and forecasted graph

Out-of-Sample Forecast for M: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted MMR
2024	438.9446
2025	434.6466
2026	430.3486
2027	426.0506
2028	421.7526
2029	417.4546
2030	413.1566
2031	408.8585
2032	404.5605
2033	400.2625
2034	395.9645
2035	391.6665

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 on a downward trend but still remain very high over the out of sample period.

RECOMMENDATIONS & CONCLUSION

High maternal mortality rates in Madagascar highlights existing gaps in the continuum of care. In addition, it reflects challenges being encountered by pregnant mothers when seeking maternal healthcare services. Rural areas have higher maternal mortality rates due to difficulties in accessing healthcare services during emergency situations as a result of poor road infrastructure. Delays in seeking care due to certain cultural practices contributes significantly to high maternal mortality rates in the rural areas. In this study we forecast MMR and the findings indicate that MMR will continue on a downward path but still remain very high in the out of sample period. Therefore, we encourage the government to adopt the

following policy prescription: : (1) end adolescent pregnancy by enforcing laws that prohibit early child marriage, promote female education and comprehensive sexual and reproductive health education in schools (2) Improve coverage of maternal and child health services across the country (3) improve quality of maternity services (4) ensure availability of adequate medical supplies and medical staff at all levels of the healthcare system and (5) establishing posts for obstetricians at government general or district hospitals particularly at high volume sites so that specialist services are accessed at the first referral level. Alternatively, Registrars undergoing Obstetrics & Gynecology training can be attached at high volume district hospitals under the supervision of provincial consultants.

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