



UTILIZING FORECASTS GENERATED BY HOLT'S LINEAR METHOD TO INFORM MATERNAL HEALTH POLICY IN SUDAN

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 Sudan 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 0.9 and 0.1 respectively based on minimum MSE. The results of the study indicate that MMR will continue to fall but still remain high throughout the out of sample period. Therefore, we encourage authorities to address major drivers of maternal mortality and direct more effort towards quality improvement programs across the country.

Keywords: Exponential smoothing, Forecasting, Maternal Mortality Ratio.

Introduction

Sudan is known for reporting high maternal mortality rates and in 2017 MMR stood at 295 deaths per 100,000 live births (Callister & Edwards, 2017). According to the WHO, the conflict in Sudan has aggravated the risk of gender-based violence, with more than three million women and girls already at risk before the fighting began, a number expected to have increased to 4.2 million (World Health Organization, 2023; Miskeen, 2024). Maternal healthcare in conflict-affected countries, such as Sudan poses many challenges that are made worse by ongoing military conflict. Women of reproductive age living near high-intensity conflicts have three times higher mortality than women in peaceful settings (Onambele et al., 2022; Souza et al., 2010; Yamin, 2008). The military conflict in Sudan has worsened healthcare challenges by destroying crucial



infrastructure, including clinics and hospitals, and disrupting supply chains for medical supplies (Khogali & Homeida, 2023; Pattanshetty et al., 2023). The conflict has made it even more difficult for women to access maternal health services thereby increasing maternal mortality and morbidity risk (McLean & Abuelaish, 2020; Al Gasseer et al., 2004; Omer et al., 2014). This paper models and forecasts MMR for Sudan using the double exponential smoothing technique. The findings of this paper are anticipated to facilitate crafting of policies and strategies that will effectively control maternal mortality across the country.

Literature Review

Author(s)	Objective(s)	Methodology	Main finding(s)
Osman et al. (2026)	to identify the prevalence and determinants of facility delivery among pregnant women in Somalia using data from the 2020 Somalia Demographic and Health Survey (SDHS)	cross-sectional study	Facility delivery remains low in Somalia. Wealth status, ANC attendance, and perceived distance to health facilities were key determinants of facility delivery, alongside residence type, parity, and early marriage
Ara et al. (2025)	to summarize the frequencies of sociodemographic characteristics, parity distribution, antenatal care patterns, and causes of death among maternal mortality	Conducted a retrospective study which analyzed maternal mortality at Rangpur Medical College Hospital, Bangladesh, in 2024, reviewing 4,741 birth records with 83 maternal deaths	-Among 83 maternal deaths, majority of deaths occurred among women aged 16–25 (41%) and those from low socioeconomic backgrounds (72.2%). - Parity distribution showed 49.39% had 1–2 children, while 73.4% received no antenatal care (ANC), highlighting gaps in healthcare access. - Eclampsia (37.35%) and obstetric hemorrhage (26.50%) were the predominant cause of maternal deaths.
Elhassan et al. (2025)	To investigate the patterns of adverse maternal and neonatal outcomes and their correlation with ANC use and socioeconomic profile	cross-sectional study	the rate of adverse maternal outcomes was high and was influenced by obstetric and socioeconomic profiles



Hussein et al. (2025)	to quantify the perinatal mortality rate (PMR) and identify key determinants within two major referral hospitals in Mogadishu	hospital-based, cross-sectional study	this study revealed a severe, localized crisis of perinatal mortality in Mogadishu, driven overwhelmingly by stillbirths
Ladu et al. (2025)	to better understand the relationship between maternal malnutrition and adverse birthing outcomes (neonatal mortality, premature delivery, stillbirth, and low birthing weight) in South Sudan	retrospective chart review utilized t-test analysis to determine the relationship between maternal malnutrition and adverse birthing outcome (ABOs). Maternal malnutrition was determined by measurements of mid upper arm circumference (MUAC) values (232-300mm) and hemoglobin levels (9.5-15.0mg/dL) during labor and delivery	results suggest that maternal malnutrition is a contributing factor to neonatal ABOs and subsequently the high neonatal mortality rate in South Sudan. The absence of anemia in malaria-positive mothers suggest a mechanism in which the fetus is primarily affected by the infection
Singh & Swain (2025)	to explore the factors influencing CDMR and its effect on maternal and fetal outcomes	Prospective cohort study	The prevalence of CDMR was 21.35%, which was relatively higher than the World Health Organization's recommended guidelines
Aweis et al. (2024)	To shed light on the trends of the maternal mortality ratio (MMR) and obstetric transition in Somalia over the last two decades	This was a descriptive study comparing aggregate secondary data from the 2006 Multiple Indicator Cluster Survey and the 2020 Somali Health and Demographic Survey to show the transition	A 44% reduction of the MMR from 1044 to 692 per 100 000 live births was observed comparing the two surveys
Miskeen (2024)	to investigate the impact of conflict on maternal health in Sudan	Mixed methods approach	-Most women did not have access to healthcare services (86.6%), and out of the total sample, 93 (24%) experienced adverse outcomes -The factors associated with adverse effects were parity (OR 1.78, CI [1.15–2.75], p-value



Modern American Journal of Medical and Health Sciences

ISSN (E): 3067-803X

Volume 2, Issue 7, July 2026

Website: usajournals.org

This work is Licensed under CC BY 4.0 a Creative Commons Attribution 4.0 International License.

			0.010), gestational age (OR 2.10, CI [1.36–3.25], p-value 0.002), access to healthcare (OR 2.35, CI [1.48–3.72], p-value 0.001), and delivery mode (OR 1.68, CI [1.05–2.69], p = 0.030)
Sheikh et al. (2024)	to investigate the factors hindering women from giving birth at healthcare facilities in major towns in Somalia, where most of the health facilities in the country are concentrated	-A community-based health survey was carried out in 11 major towns in Somalia between October and December 2021 -Applied logistic regression	The study found that home delivery is high in major towns in Somalia and is associated with a lack of understanding of the importance of health facility delivery, not using ANC, and not receiving consultancy about where to give birth
Manamo et al. (2023)	to examine the socio-economic differentials of under-five mortality in Botswana within the framework of equality and equity	The was based on the data from 2001 and 2011 Botswana Population and Housing Censuses and the 2017 Botswana Demographic Survey. One census method was used to indirectly estimate under five mortalities for different socio-economic groups using Princeton west model life tables.	socio-economic disparities in under-five mortality disfavoring the worse-off exist in all the selected socio-economic variables
Chacha et al. (2022)	review the current cardiac obstetrics practice, gaps, and potential areas of improvement.	Systematic review	With an increasing number of women with pre-existing cardiac conditions becoming pregnant, the contribution of CVD to maternal mortality is also growing. Consequently, there is a need for accurate diagnosis and appropriate care of pregnant women with CVD to minimize adverse outcomes
Hassan et al. (2022)	To study maternal and fetal outcome of postdate pregnancy in Wad Madani	Observational, descriptive cross-sectional hospital-based	Researchers concluded that postdate pregnancy is vulnerable for



	maternity teaching hospital, Wad Madani, Gezira State 2020	study was conducted in Wad Madani maternity teaching hospital which located in Wad Madani city, Gezira state in central zone of Sudan within the period from March to September 2020 and covered postdate pregnant women	considerable undesired maternal and fetal outcomes which should not be ignored
Isaacson et al. (2021)	to evaluate the prevalence and outcome of twin pregnancies in Botswana	Quantitative analysis	Adverse birth outcomes are common among twins in Botswana, and are often severe
Mohamed et al. (2021)	to determine whether the health crisis in Comoros is attributable to the consequences of the chronic political instability	semi-structured interviews with key informants	political instability and lack of proper leaders' hip from the Government undermine the establishment of health policies which contributed dramatically to the decline in health performance
Aden et al. (2019)	To explore and describe causes and contributing factors concerning maternal deaths in the Bosaso District, Puntland State of Somalia	Data was collected using an adapted Verbal Autopsy tool. In 2017 30 cases of maternal deaths occurring in 2016 in the Bosaso District were reviewed. Information was assessed by three independent reviewers who classified the cause of death and the contributing factors	Direct obstetric deaths accounted for 28 cases. Among these, hemorrhage was the leading cause, followed by eclampsia, sepsis and obstructed labor. Two cases were indirect obstetric deaths, caused by anemia. All three types of delay were frequent among the studied cases. Delay in deciding to seek care was found in 25 cases, delay in reaching care in 22 cases and delay in receiving health care in 24 cases
Apary & Amongin (2020)	to assess quality of maternal health services (MHS) at Juba Teaching Hospital, South Sudan	This cross-sectional research study was done among women of reproductive age at a time of taking their	Women were satisfied with maternal healthcare services. Level of education and monthly family earnings were



Modern American Journal of Medical and Health Sciences

ISSN (E): 3067-803X

Volume 2, Issue 7, July 2026

Website: usajournals.org

This work is Licensed under CC BY 4.0 a Creative Commons Attribution 4.0 International License.

		infants for routine immunization services in June to July 2015	associated with maternity care
Akhter et al. (2018)	to present, analyze and interrelate recent data to find barriers to achieving set MDG 5 targets by 2015	literature review has been done as a main method of data collection from Elsevier, Lancet, WHO, UNICEF, BBMS, NIPORT published from 2001 to May 2018	approximately 80% of maternal deaths could be averted if women had access to essential maternity and basic health care services
Makuei et al. (2019)	to identify the significant physiological causes of MMR in South Sudan	Prediction models based on Poisson Regression are then developed to predict MMR in terms of the significant physiological causes. Coefficients of determination and variance inflation factor are deployed to assess the influence of the individual causes on MMR	The results indicate that the most influential predictors of MMR are; hemorrhaging (38%), sepsis (11.5%), obstructed labor (11.5%), unsafe abortion (10%), and indirect causes such as anemia, malaria, and HIV/AIDs virus (29%).
Makuei et al. (2018)	to develop profile limits for the MMR in terms of significant predictors SAB, GFR, and GDP, in Sudan	Logarithmic multi-regression model is used to model MMR in terms of SAB, GFR and GDP. Data from 1986 to 2015 collected from Juba Teaching Hospital was used to develop the model for predicting MMR	The results also indicate that to achieve the UN recommended MMR levels of minimum 70 and maximum 140 by 2030, the government should simultaneously reduce GFR from the current value of 175 to 97 and 75, increase SAB from the current value of 19 to 50 and 76
Oyekale et al. (2018)	To analyze the effect of maternal education and fertility on child survival in the Islands of Comoros	The 2012 Demographic and Health Survey (DHS) data were used. A two-stage probit regression method was used for data analysis	The results showed that about 75% of the children's mothers had given birth to between one and five children, while more than half did not have any form of formal education



Methodology

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

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

Smoothing equation

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

$$0 < \alpha < 1$$

Trend estimation equation

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

$$0 < \beta < 1$$

Forecasting equation

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

X_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 Sudan 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	X
Included Observations	39
Smoothing constants	
Alpha (α) for data	0.900
Beta (β) for trend	0.100
Forecast performance measures	
Mean Absolute Error (MAE)	16.821893
Sum Square Error (SSE)	17360.881378
Mean Square Error (MSE)	445.150805
Mean Percentage Error (MPE)	0.972432
Mean Absolute Percentage Error (MAPE)	3.512376

Residual Analysis for the Applied Model

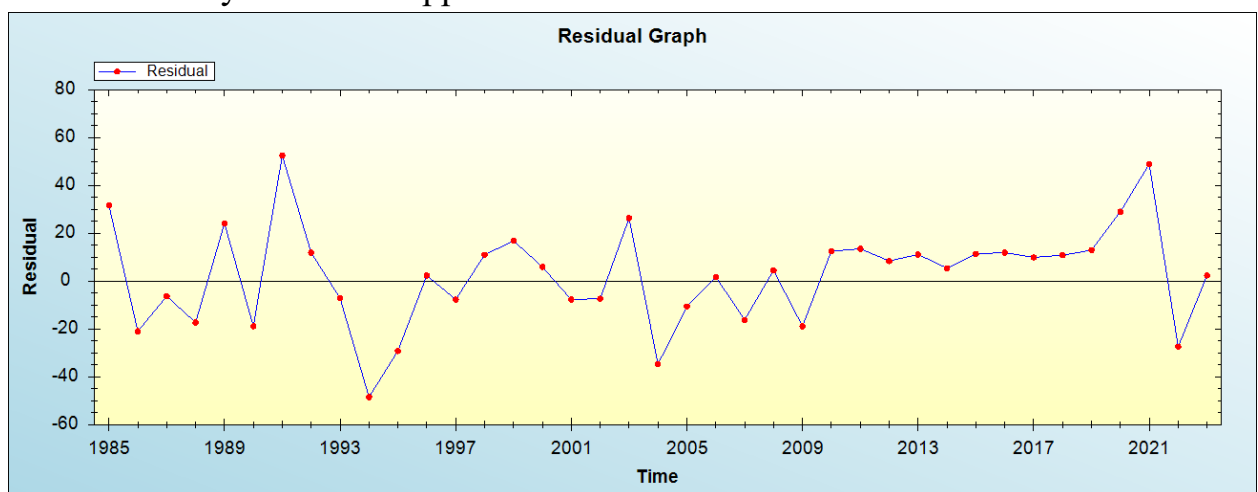


Figure 1: Residual analysis



In-sample Forecast for X

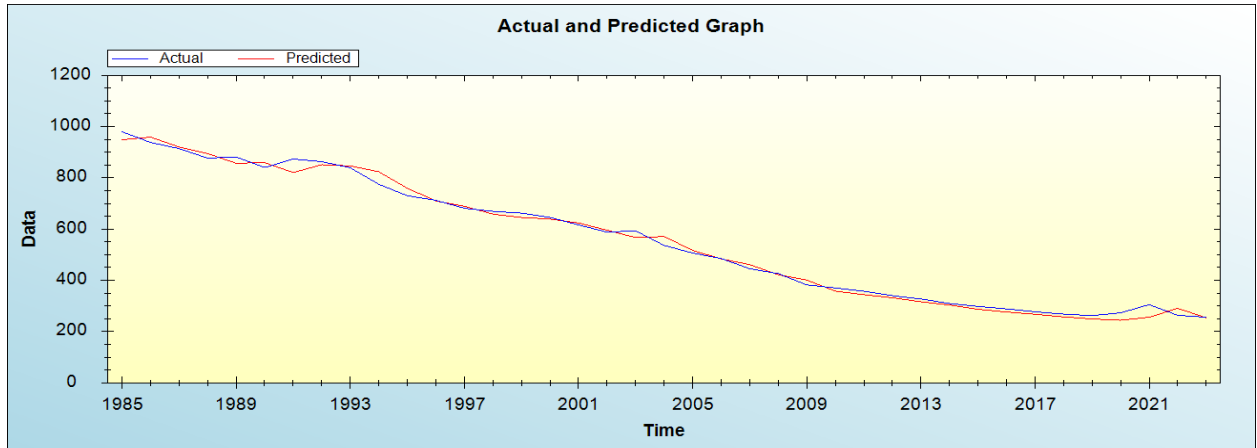


Figure 2: In-sample forecast for the X series

Actual and Smoothed graph for X series

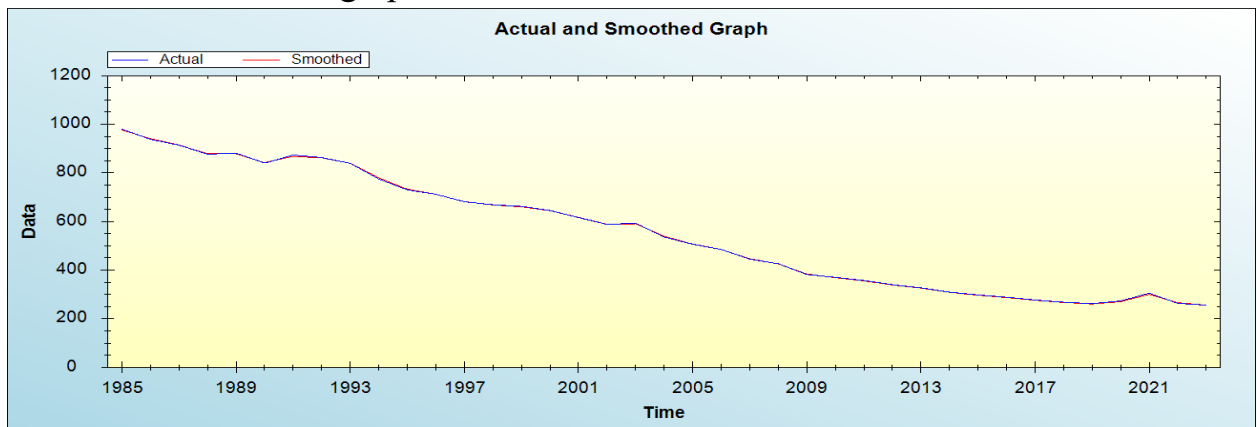


Figure 3: Actual and smoothed graph for X series

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

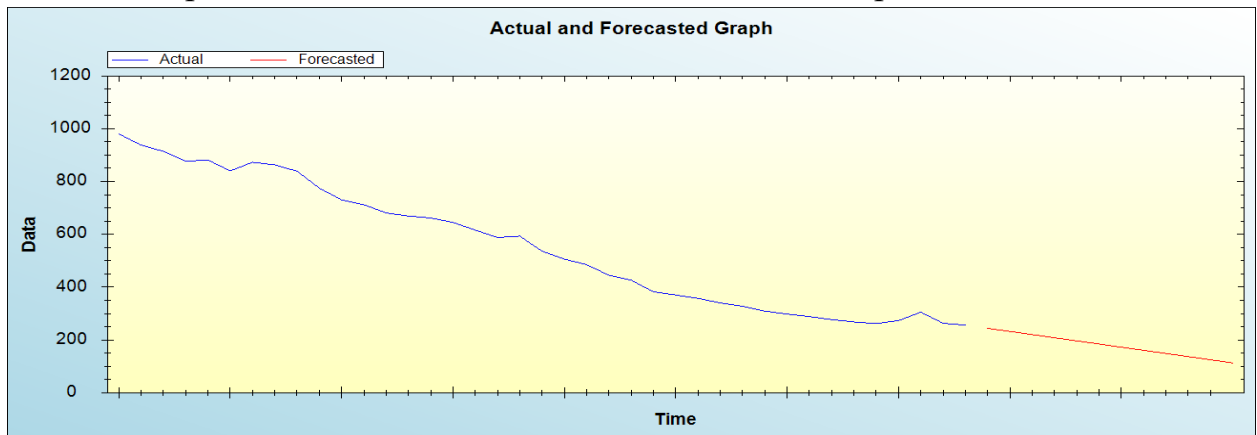


Figure 4: Out-of-sample forecast for X: actual and forecasted graph



Out-of-Sample Forecast for X: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted MMR
2024	243.8442
2025	231.9271
2026	220.0100
2027	208.0930
2028	196.1759
2029	184.2589
2030	172.3418
2031	160.4247
2032	148.5077
2033	136.5906
2034	124.6736
2035	112.7565

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 drop but still remain high over the out of sample period.

Conclusion

The provision of quality maternal healthcare is always a huge challenge in conflict affecting regions. Access of healthcare services is compromised, supply chains are disrupted, in general people flee from conflict areas including qualified medical staff, and there is destruction of medical facilities and other essential infrastructure. In this study we applied the double exponential smoothing technique to model and forecast MMR for Sudan and results indicate that MMR will continue to drop but still remain high throughout the out of sample period. Hence, we encourage authorities to address all factors which are associated with maternal mortality across the country and also prioritize implementation of quality improvement initiatives.



References

1. Al Gasseer N., Dresden E., Keeney G.B., and Warren N (2004). Status of women and infants in complex humanitarian emergencies. *Journal of Midwifery & Women's Health* 49(4):7–13.
2. Callister L.C and Edwards J.E (2017). Sustainable development goals and the ongoing process of reducing maternal mortality. *Journal of Obstetric, Gynecologic & Neonatal Nursing* 46(3).
3. Khogali A and Homeida A (2023). Impact of the 2023-armed conflict on Sudan's healthcare system. *Public Health Challenges* 2(4): e134 DOI 10.1002/puh2.134.
4. McLean M and Abuelaish I (2020). Access to reproductive health care services in countries of conflict: the double impact of conflict and COVID-19. *Medicine, Conflict, and Survival* 36(4):283–291.
5. Miskeen E (2024). Utilization of antenatal care services within the context of COVID-19, security challenges, and an unstable healthcare system at primary health care centers. *International Journal of Women's Health* 31:737–747.
6. Omer A.S., Bezruchka S., Longhi D., Kelly Z., Brown M., and Hagopian A (2014). The effects of household assets inequality and conflict on population health in Sudan. *African Population Studies* 28(3):1216–1232.
7. Onambele L., Ortega-Leon W., Guillen-Aguinaga S., Forjaz M.J., Yoseph A., Guillen-Aguinaga L., Alas-Brun R., Arnedo-Pena A., Aguinaga-Ontoso I., and Guillen-Grima F (2022). Maternal mortality in Africa: regional trends (2000–2017). *International Journal of Environmental Research and Public Health* 19(20): 13146.
8. Pattanshetty S., Bhatt K., Inamdar A., Dsouza V., Chattu V.K and Brand H (2023). Health diplomacy as a tool to build resilient health systems in conflict settings—a case of Sudan. *Sustainability* 15(18).
9. Souza J.P., Cecatti J.G., Faundes A., Morais S.S., Villar J., Carroli G., Gulmezoglu M., Wojdyla D., Zavaleta N., Donner A., and Velazco A (2010). Maternal near miss and maternal death in the world health organization's 2005 global survey on maternal and perinatal health. *Bulletin of the World Health Organization* 88(2):113–119.



Modern American Journal of Medical and Health Sciences

ISSN (E): 3067-803X

Volume 2, Issue 7, July 2026

Website: usajournals.org

This work is Licensed under CC BY 4.0 a Creative Commons Attribution 4.0 International License.

-
10. World Health Organization (2023). Sudan: top UN officials sound alarm at spike in violence against women and girls. New York/Geneva.
 11. Yamin AE (2008). Beyond compassion: the central role of accountability in applying a human rights framework to health. *Health and Human Rights* 10:1–20.