



MATERNAL MORTALITY ESTIMATION FOR SOUTH SUDAN USING THE MULTILAYER PERCEPTRON

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Abstract

This research article employs annual time series data on MMR for South Sudan from 1985 to 2023 to predict future trends of MMR over the period 2024 to 2035. The forecast evaluation criteria of the applied model indicate that the ANN (12, 12, 1) model is stable. The neural network model projections revealed that MMR will remain very high hovering around 952 deaths per 100 000 live births throughout the out of sample period. Therefore, we encourage the government to address major drivers of maternal mortality and direct more resources towards quality improvement initiatives.

Keywords: ANN, Forecasting, Maternal Mortality Ratio.

Introduction

According to the World Health Organization in ICD-10, maternal death is defined as “the death of a woman while pregnant or within 42 days (six weeks) of termination of pregnancy regardless of the duration and the site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management but not from accidental or incidental causes” (Abawi, 2016; WHO, 2016). Direct causes include excessive bleeding, hypertensive disorders and sepsis. Death emanating from pre-existing medical condition or disease that developed during pregnancy and was aggravated by physiologic effects of pregnancy is classified as indirect obstetric death. Maternal mortality remains a public health issue in South Sudan because of its negative effects on the family and community as a whole (Makuei, 2016; Tort et al. 2016; WHO, 2008). Factors associated with maternal mortality in South Sudan include socio economic factors,



macroeconomic factors and physiological causes (WHO, 2008). The impact of the Gross Domestic Product (GDP), the General Fertility Rate (GFR), and the Skilled Attended at Births (SAB) on MMR in South Sudan has been investigated and results indicate that the most significant predictor influencing MMR is SAB followed by GFR and GDP. The objective of this paper is to model and forecast MMR for South Sudan using a machine learning approach. The findings will assist in planning and allocation of adequate resources to the maternal and child health program so that preventable maternal deaths are further reduced.

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.
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,	retrospective chart review utilized t-test analysis to determine the relationship between maternal malnutrition and adverse birthing outcome (ABOs).	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



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	stillbirth, and low birthing weight) in South Sudan	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	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
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



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Hassan et al. (2022)	To study maternal and fetal outcome of postdate pregnancy in Wad Madani maternity teaching hospital, Wad Madani, Gezira State 2020	Observational, descriptive cross-sectional hospital-based 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	Researchers concluded that postdate pregnancy is vulnerable for 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 infants for routine immunization services in June to July 2015	Women were satisfied with maternal healthcare services. Level of education and monthly family earnings were 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



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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
Madzimbamuto et al. (2014)	To determine the underlying causes of maternal deaths reported in 2010, to categorize contributory factors and to prioritize appropriate interventions based on the identified causes, to prevent further deaths.	Case-notes for maternal deaths were reviewed by a panel of five clinicians, initially independently then discussed together to achieve consensus on assigning contributory factors, cause of death and whether each death was avoidable or not at presentation to hospital. Factors contributing to maternal deaths were categorized into organizational/management, personnel, technology/equipment/supplies, environment and barriers to accessing healthcare	The high number of contributory factors demonstrates poor quality of care even where deaths were not avoidable: 14/23 (61%) of direct deaths were considered avoidable compared to 12/32 (38%) indirect deaths. Highest ranking categories were: failure to recognize seriousness of patients' condition (71% of cases); lack of knowledge (67%); failure to follow recommended practice (53%); lack of or failure to implement policies, protocols and guidelines (44%); and poor organizational arrangements (35%). Half the deaths had some barrier to accessing health services



Alvarez et al. (2009)	to describe and determine different factors associated with the maternal mortality ratio in Sub Saharan countries	An ecological multi-group study compared variables between many countries in Sub Saharan Africa using data collected between 1997 and 2006. The dependent variable was the maternal mortality ratio, and Health care system-related, educational and economic indicators were the independent variables. Information sources included the WHO, World Bank, UNICEF and UNDP	Education and an effective and efficient health system, especially during pregnancy and delivery, are strongly related to maternal death
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Methodology

The Artificial Neural Network (ANN) approach, which is flexible and capable of nonlinear modelling; will be applied in this study. The ANN is a data processing system consisting of a large number of highly interconnected processing elements in architecture inspired by the way biological nervous systems of the brain appear like. Since no explicit guidelines exist for the determination of the ANN structure, the study applies the popular ANN (12, 12, 1) model based on the hyperbolic tangent activation function. This paper applies the Artificial Neural Network (ANN) approach in predicting annual maternal mortality ratio (MMR) for South Sudan.

Data Issues

This study is based on annual MMR in South 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

ANN Model Summary

Table 1: ANN model summary

Variable	S
Observations	27 (after adjusting endpoints)
Neural Network Architecture:	
Input Layer Neurons	12
Hidden Layer Neurons	12
Output Layer Neurons	1
Activation Function	Hyperbolic Tangent Function
Back Propagation Learning	
Learning Rate	0.005
Momentum	0.05
Criteria:	
Error	0.051796
MSE	62287.558754
MAE	159.362838

Residual Analysis for the Applied Model

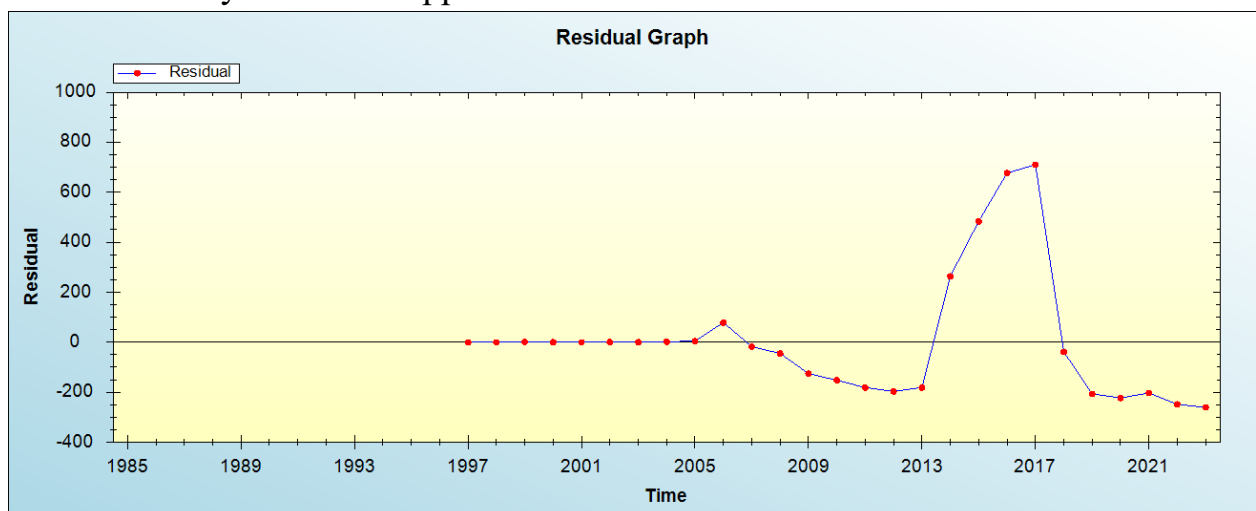


Figure 1: Residual analysis



In-sample Forecast for S

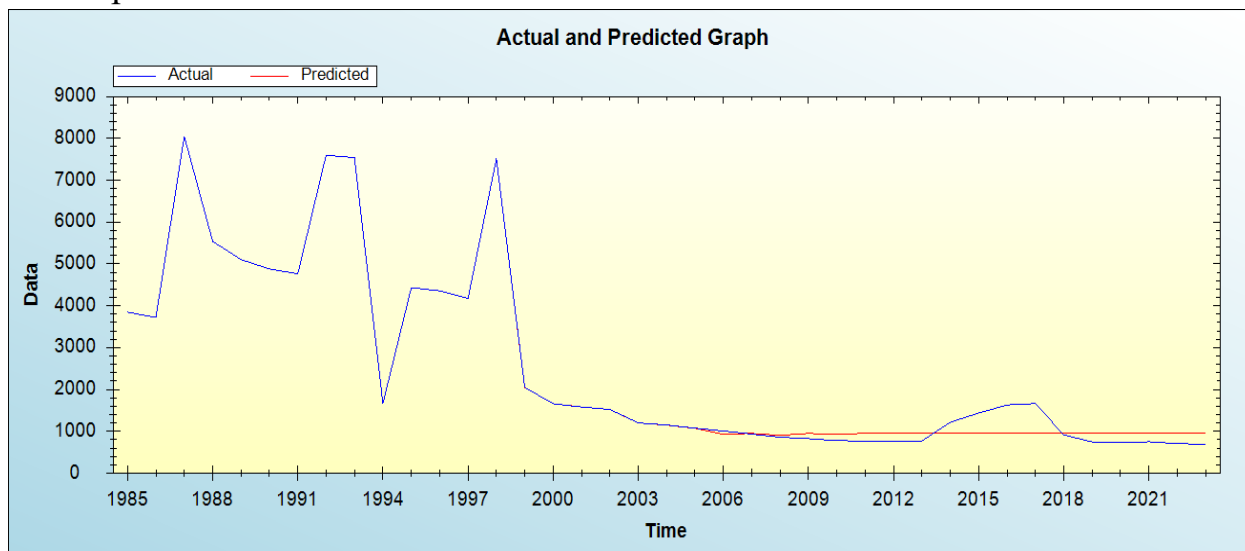


Figure 2: In-sample forecast for the S series

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

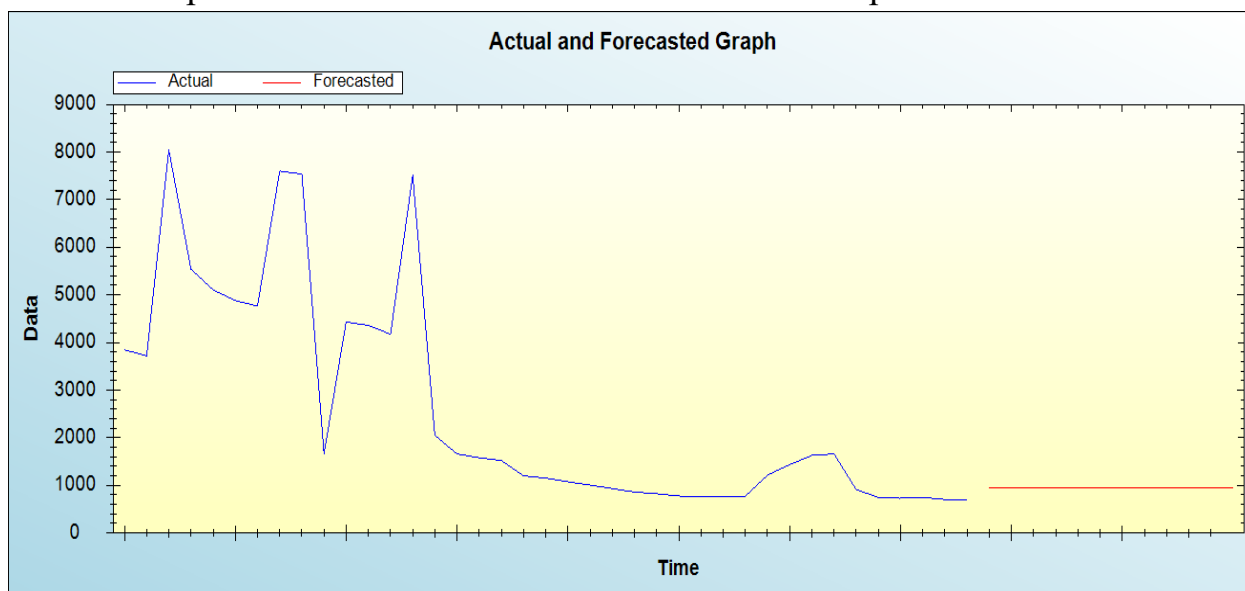


Figure 3: Out-of-sample forecast for S: actual and forecasted graph



Out-of-Sample Forecast for S: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted MMR
2024	952.8233
2025	952.9081
2026	952.6421
2027	952.1948
2028	952.2175
2029	952.3386
2030	952.7413
2031	952.7420
2032	952.7519
2033	952.7978
2034	952.7325
2035	952.7224

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 remain very high around 952 deaths per 100 000 live births over the out of sample period.

Conclusion

There is a high burden of maternal mortality in South Sudan reflecting the existence of numerous healthcare challenges that remain unresolved or unattended along the continuum of care. In this study we applied a machine learning technique to model and forecast MMR and results indicate that MMR will hover around 952 deaths per 100 000 live births throughout the out of sample period. Therefore, we encourage health authorities to address local drivers of maternal mortality and focus should be given to the implementation of quality improvement initiatives.



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References

1. G. Makuei., M. Abdollahian., and K. Marion (2016). “Modeling maternal mortality rate in South Sudan,” in 15th International Conference on Information and Knowledge Engineering, pp. 107–112, Las Vegas, NV, USA, 2016.
2. J. Tort., P. Rozenberg., M. Traore., P. Fournier., and A. Dumont (2015). “Factors associated with postpartum hemorrhage maternal death in referral hospitals in Senegal and Mali: a cross-sectional epidemiological survey,” BMC Pregnancy Childbirth, vol. 15, p. 235, 2015.
3. K. Abawi (2016). Measuring Maternal Mortality, World Health Organization, Geneva, 2016.
4. WHO (2008). Maternal Mortality: Fact Sheet.
5. WHO (2012). The WHO Application of ICD-10 to Deaths During Pregnancy, Childbirth and Puerperium, WHO, Geneva, 2012.