

## MODELLING AND MONITORING MATERNAL MORTALITY RATE IN SOUTH SUDAN

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Reducing the maternal mortality rate (MMR) is considered by the international community as one of the eight Millennium Development Goals. South Sudan is among the countries with the highest MMR. The risk of a pregnant woman dying is as high as one in seven. Socioeconomic, macroeconomic and physiological factors have been found to contribute to high mortality rates. This study deployed statistical analysis tools to identify and rank the key performance indicators (KPIs) responsible for high MMR in South Sudan, to monitor the trend of MMR and to model MMR in terms of the most significant socioeconomic, macroeconomic and physiological KPIs. Time-series analysis was used to monitor the MMR trend. The results of this analysis indicated that there was a general declining trend in HIV/AIDS, non-HIV/AIDS and total maternal mortality rate during the period of study. However, the decline in HIV/AIDS maternal mortality rate is much slower than the non-HIV/AIDS maternal mortality rate. Trend analysis also shows that non-HIV/AIDS MMR accounts for about two-thirds of the total MMR.

Skilled assistant at birth (SAB), general fertility rate (GFR) and gross domestic product (GDP) were identified as the most significant socioeconomic predictors of MMR in South Sudan. The most influential physiological KPIs were identified as haemorrhaging followed by indirect causes (anaemia, malaria, HIV/AIDS and heart disease), sepsis (infection), prolonged (obstructed) labour and unsafe abortion.

Logarithmic multi-regression and Poisson regression models were used to model MMR in terms of SAB, GFR, GDP and the most influential physiological KPIs. Data collected at the Juba Teaching Hospital between 1986 and 2015 were used to develop the prediction models and assess the MMR trend.

Accuracy criteria such as the coefficient of determination and mean error were used to compare the prediction error of these models. The results indicated that log

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regression can predict MMR in terms of socioeconomic factors with fewer mean prediction errors.

Results also show that logarithmic multi-regression models provide distinct evidence that increasing SAB and decreasing GFR (while leaving the GDP constant at 1772) could reduce MMR in South Sudan by 2030 to the lower and upper target levels proposed by UN agencies.

The statistical analysis shows that increasing SAB by 1.22% per year would reduce MMR by 1.4% (95% CI [0.4%–5%]), and decreasing GFR by 1.22% per year would reduce MMR by 1.8% (95% CI [0.5%–6.26%]).

The numerical results indicate that the top five physiological causes contributed 97.43% to the variation in MMR (due to physiological causes). Analysis of the prediction errors shows that Poisson regression can describe MMR in terms of physiological factors more accurately than the log regression model. Therefore, Poisson regression was used to assess the impact of physiological causes on MMR.

Judging by their variance inflation factors and  $p$ -values, the conclusion is that all five causes are statistically significant. However, based on literature recommendations, the study developed two reduced Poisson regressions based on haemorrhaging only, and on haemorrhaging and unsafe abortion. To reduce the impact of the sample size and downward trend in MMR on the reliability of the reduced Poisson model developed, a repeated random sample selection was used 30 times, using the Bernoulli distribution, with a probability of 0.67 to randomly select two-thirds of the data to build the models and one-third to assess the efficacy. The proposed reduced model was developed based on the average coefficients of the 30 models.

The findings indicate that the proposed reduced Poisson regression model with an  $R^2$  of 90.27% can predict MMR for a given level of haemorrhaging with a mean error of  $-34.5517$  and a 0.0151 standard error of the mean. Moreover, the reduced model based on haemorrhaging and unsafe abortion explains 92.68% of the variation in MMR due to physiological causes.

For the first time, this study deployed optimisation procedures to develop lower and upper yearly profile limits for maternal mortality rates, targeting the UN recommended lower and upper MMR levels by 2030. The MMR profile limits were accompanied by optimal yearly values of SAB and GFR level profile limits. The study also developed yearly optimal profile limits for MMR due to physiological causes of haemorrhaging and unsafe abortion, accompanied by a yearly optimal level of haemorrhaging and unsafe abortion.

This study generated a database. Having access to the electronic database and optimal level predictors that significantly influence the maternal mortality rate will aid the Government in making informed evidence-based decisions on resource allocation and intervention plans to reduce the risk of maternal death.

The project also investigated and outlined the steps taken by the South Sudan Government and international agencies to reduce MMR during the past few years. The recommended policies, implemented policies and the impact of implemented policies

in South Sudan and other countries that aim to reduce MMR have been thoroughly explored.

The Government has taken positive steps to reduce MMR by targeting these KPIs. The lack of properly trained personnel is a major problem in maternal health care. Thus, the Government has implemented policies to increase the number of health professional students and graduates.

The analysis also shows that the health development plan had a budget increase of 87% for the period 2012–2016. The increased budget was used to significantly improve health-care facilities by increasing the number of primary health-care units, primary health-care centres and specialised hospitals, as well as improving roads, infrastructure and communication networks. The budget also extended to education for females and increasing the quota of women in all Government institutions. These policies were responsible for the significant downward trend in MMR, especially between 2013 and 2017. A list of recommendations for administrative strategies and policies has been provided.

This project has contributed to new knowledge and practice by producing a simple, yet effective, system for monitoring and improving the antenatal care process as well as reliable and effective models to forecast South Sudanese MMR which might be applied in other countries.

Parts of this research have been published in [1–3].

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