Modelling and monitoring maternal mortality rate in South Sudan

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Declaration

I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship. I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole, or in part, to qualify for any other academic award; the content of the thesis is the result of work that has been carried out since the official commencement date of the approved research programme; any editorial work, paid or unpaid, carried out by a third party, is acknowledged.

No other person’s work has been without due acknowledgement in the main text of this thesis, and ethics procedures and guidelines have been followed. Furthermore, some tables, figures, materials, methods, results, and conclusions from this thesis have appeared in the referred conference and journal article publications during the study period for my PhD.

Signed: Makuei, G.______________________________

Date:
03/05/2019________________________________________

Gabriel Makuei Deng Makuei

Candidate
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<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AIDs</td>
<td>Acquired Immune Deficiency Syndrome (AIDs)</td>
</tr>
<tr>
<td>ANC</td>
<td>antenatal care</td>
</tr>
<tr>
<td>ART</td>
<td>antiretroviral therapy</td>
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<tr>
<td>CEMDs</td>
<td>Confidential Enquiry into Maternal Deaths</td>
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<tr>
<td>CIT</td>
<td>Critical Incident Technique</td>
</tr>
<tr>
<td>CIA</td>
<td>The Central Intelligence Agency</td>
</tr>
<tr>
<td>CODEm</td>
<td>Cause of Death Ensemble</td>
</tr>
<tr>
<td>CRVS</td>
<td>Civil Registration and Vital Statistics</td>
</tr>
<tr>
<td>DHS</td>
<td>Demographic and Health Surveys</td>
</tr>
<tr>
<td>DRC</td>
<td>Democratic Republic of Congo</td>
</tr>
<tr>
<td>DVs</td>
<td>Dependent variables</td>
</tr>
<tr>
<td>EMONC</td>
<td>Emergency Obstetric and Neonatal Care</td>
</tr>
<tr>
<td>FID</td>
<td>Foreign Direct Investment</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product (GDP)</td>
</tr>
<tr>
<td>GFR</td>
<td>General Fertility Rate (GFR)</td>
</tr>
<tr>
<td>HIV+</td>
<td>Human Immunodeficiency Virus positive</td>
</tr>
<tr>
<td>HRD</td>
<td>Human Resource Department</td>
</tr>
<tr>
<td>HSDP</td>
<td>Health Sector Development Plan</td>
</tr>
<tr>
<td>IHME</td>
<td>Institute of Health Metrics and Evaluation</td>
</tr>
<tr>
<td>Inc</td>
<td>increment (See Figure 4.14)</td>
</tr>
<tr>
<td>IMF</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>IVs</td>
<td>Independent variables</td>
</tr>
<tr>
<td>JCONAM</td>
<td>Juba College of Nursing and Midwifery</td>
</tr>
<tr>
<td>JRTH</td>
<td>Juba Referral Teaching Hospital</td>
</tr>
<tr>
<td>JTH</td>
<td>Juba Teaching Hospital</td>
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<tr>
<td>KPIs</td>
<td>Key Performance Indicators</td>
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Ln: The natural logarithm
LR: Literature Review
MATLAB: Matrix Laboratory is multi-paradigm numerical computing environment and fourth- generation programming language.
MCR-ALS: Multivariate Curve resolution with alternating Least Square
MDG: Millennium Development Goals
MDs: Maternal Deaths
MDSR: Maternal Deaths Surveillance and Response
Minitab: It is statistical analysis software. It can be used to learn about statistics as well as statistical research
MMR: Maternal Mortality Ratio
MMRate: Maternal Mortality Rate
MNCH: Maternal Newborn and Child health
MoH: Ministry of Health, South Sudan
NA: Not Applicable
NBS: National Bureau of Statistics, South Sudan
NGOs: Non-governmental Organisations
PEPFAR: President’s Emergency Plan for AIDs Relief
PHCC: Primary Health Care Centre
PHCU: Primary Health Care Unit
PHs: Public Hospitals
PMDF: The proportion of maternal deaths in reproductive age
PPH: Portion of Postpartum haemorrhaging
R: Its multi-paradigm numerical computing environment and generation of computer programming language
RAMOS: Reproductive-age mortality studies
Red: reduction (See Figure 4.13)
RMF: Risk Management Foundation
SAB: Skilled Attendance at Births
SD: Standard Deviation
SHHS 2006: Sudan Household Health Survey, 2006
SPHC: Sudan Population and Housing Census
SSHHS, 2006: South Sudan Household Health Survey, 2006
SSA: Sub-Saharan Africa (a region in Africa)
SSP: South Sudanese Pound (South Sudan Currency)
St. Dev.: Standard Deviation
TBA: Traditional birth attendance
TMDs: Total Maternal Deaths
UK: United Kingdom
UN: United Nations
UNDP: United Nations Development Programme
UNFPA: United Nations Fund for Population Activities
US: United States
USA: United States of America
USAID: United States Agency for International Development
USD: United States Dollar
VIF: Variance Inflation Factor
VR: Vital Registration
WHO: World Health Organisation
ABSTRACT

Reducing the Maternal Mortality Rate (MMR) is considered by the international community as one of the eight Millennium Development Goals (MDGs). South Sudan is amongst the countries with the highest MMR. The risk of a pregnant woman dying is as high as one in seven. Socio-economic, 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, monitor the trend of MMR, and model MMR in terms of the most significant socio-economic, 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 socio-economic 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, and GDP and the most influential physiological KPIs. Data collected at the Juba Teaching Hospital (JTH) between 1986 and 2015 was used to develop the predicting models and assess the MMR trend.

Accuracy criteria such as coefficient of determination and mean error were used to compare the predicting error of these models. The results indicated that log regression can predict MMR in terms of socio-economic 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 constants 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 maternal mortality rate (due to physiological causes). Analysis of the predicting 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 corresponding variance inflation factor and p-value, 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 haemorrhaging and unsafe abortion. To reduce the impact of the sample size and downward trend in MMR on the reliability of the developed reduced Poisson model, a repeated random sample selection was used 30 times, using 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 \( R^2 \) 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 healthcare. 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 healthcare facilities by increasing the number of primary healthcare units (PHCU), primary healthcare centres (PHCC), and specialised hospitals, as well as improving roads, infrastructure, and communication networks. The budget also extended to education for females and increasing women quote 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.
1 INTRODUCTION

1.1 Background
The deaths of women during delivery continue to be a serious and sensitive issue to every country in the world. A fact sheet by the World Health Organisation (WHO) (WHO, 2016) points out that around 830 women die every day due to preventable complications during pregnancy, at and after delivery, and around 99% of all such maternal deaths occur in developing countries. Women in poor rural areas are most susceptible to such deaths. Young adolescents are more prone to maternal deaths than older women. Skilled care is the solution to save the lives of many mothers and children during birth. There was a drop in maternal deaths by around 44% worldwide during the period 1990–2015. The global target for the period 2016–2030 is to reduce the maternal mortality ratio to less than 70 per 100,000 births. Significant progress in the reduction of maternal mortality was achieved in some sub-Saharan African countries and certain countries in Asia and North Africa. This demonstrates the possibility of reducing maternal mortality even in those developing countries, where the ratio had been traditionally high.

This study aims to carry out a performance evaluation of the procedures aimed to reduce the maternal mortality rate (MMR). The evaluation is conducted through identifying the most influential key determinants of healthcare and high maternal death (MD) causes and factors. This is followed by proposing guidelines for healthcare service systems that are attuned to the realities on the ground (i.e. recording, reporting, monitoring, and evaluation), especially in rural areas, in South Sudan. The study investigated the research questions listed in Table 1.1.
Table 1.1: Research questions of this project in terms of administrative and scientific tasks.

<table>
<thead>
<tr>
<th>A. Administrative tasks</th>
<th>B. Scientific tasks</th>
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<tr>
<td>1) What are the programmes suggested by the Government of South Sudan and the United Nations agencies, and their partners for reducing the country’s maternal mortality rate (MMR)?</td>
<td>7) What are the existing mathematical models that describe maternal mortality rate?</td>
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<td>2) Which part/s of these suggestions was implemented by the government and its partners?</td>
<td>8) Which of these models would be optimal or appropriate for South Sudan?</td>
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<td>3) What was the impact of their implementation in terms of performance and effectiveness?</td>
<td>9) Can we improve the optimal model to have a more accurate estimate for the future mortality rate?</td>
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<td>4) What were the successful programmes in other countries of the region?</td>
<td>10) Can we develop reliable and effective multivariate models to estimate and forecast maternal deaths and to be easily implemented in the South Sudanese maternal and primary healthcare system?</td>
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<tr>
<td>5) How can the programmes mentioned in Q4 be combined with the analysis in Q3 to develop more sophisticated recommendations to the government for the future?</td>
<td>11) Can we propose a simple, but more comprehensive, multivariate profile monitoring system to monitor and control the characteristics responsible for the mortality rate?</td>
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<tr>
<td>6) How can we develop an algorithm for an effective and standard data-recording and reporting system that could provide reliable and timely maternal information during pregnancy, at and after, delivery time?</td>
<td>12) Will this proposed profile monitoring system be able to assist in reducing the maternal deaths and mortality rate in South Sudan?</td>
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</table>

1.1.1 Proposed approaches to investigate the research questions

The following steps have been taken to investigate the research questions.

1. Catalogue the suggestions of the government and various agencies for the reduction of maternal mortality rate (MMR)
2. Catalogue the health policy programmes implemented by the government and those suggested by various agencies. In addition, it should include the government’s own initiatives as well as the successful policies in other countries of the region
3. Collect mortality statistics (rates and direct/indirect causes of deaths) from different authentic sources according to categorised healthcare facilities
4. Collect supporting data on basic, demographic, economic, social, educational, awareness and cultural factors, which could influence maternal mortality rates (MMRs)
5. Investigate and discover the most significant Key Performance Indicators (KPIs) of healthcare, which are responsible for the high maternal mortality rates in South Sudan
6. Design a reliable electronic data-resource system for South Sudan regarding the maternal mortality rate. This can be used by the government and international agencies for resource allocation, using information from steps 3–5.

7. Access effectiveness of existing models that predict mortality rate and select the most appropriate model for South Sudan. These models are listed in Table 2 in Appendix B (9.2).

8. Improve the most appropriate model by including more significant factors and causes related to maternal mortality. In this project, HIV and causes unrelated (i.e. malaria) to pregnancy were also included during the late maternal stages.

9. Use optimisation to develop yearly profile limits based on the best models, to achieve the recommended UN MMR levels by 2030.

10. Recommend the most suitable policies for maternal healthcare in South Sudan based on the outcome of the above steps. The recommendations would provide guidance for the government to make evidence-based informed decisions regarding health resource allocations intended to reduce maternal mortality rates in the country.

1.1.2 The need to develop a model to monitor and predict mortality deaths in South Sudan

To achieve significant MMR reductions, it is necessary to have a system in place to collect reliable data followed by monitoring the ratio level at desirable intervals. Due to the situations in many developing countries, it is not possible to obtain direct data. This is due to irregular, inadequate, or even faulty reporting systems. Periodical surveys are often costly; therefore, developing countries are reluctant to undertake them. Special studies in certain areas can give very restricted and area-specific data, which are not always generalisable across the whole country. The only remaining method is to develop predictive mathematical models, based on available data, and use them for monitoring and predicting future maternal mortality rates. Monitoring and comparing this with real time data will enable the model to be updated during the advancing years.

For monitoring and prediction, possible efforts made to reduce the rates should also be reflected. This means that intervention variables also need to be included in the model. Models should be capable of determining the ratio if no intervention is made and to what extent ratios are reduced by each type of intervention. Some models are already available, e.g. Hogan et al., (2010), Yang et al., (2014), Wilmoth et al., (2010) and WHO, (2015), which may indicate methods of doing this, even if these models cannot be readily used or adapted for South Sudan. Using such data generated by such models, it will be possible to focus on interventions that can
produce significant impact and avoid wasting resources on interventions that are not beneficial to any significant extent. For countries such as South Sudan, which are very low in the development ranking, strategies for the selection of critical resources for significant impact can be important.

1.2 Facts about South Sudan based on the Central Intelligence Agency (CIA, 2017)

South Sudan was part of Sudan when the latter gained independence from the British in 1956. This led to two long periods of mutinies, which ended in 2005. The settlement allowed six years of autonomy followed by referendum-based independence in 2011. Mutinies resulted in lakhs of deaths due to poverty and starvation. Even after gaining independence, South Sudan was faced with rebel militia groups. Oil production was shut down in 2012 due to disagreements with Sudan regarding price. This resulted in the deterioration of its economic conditions. The conflicts between the Government and rebel forces led to a severe humanitarian crisis with thousands of people displaced without the security of food. A peace agreement lasted two years (2015–2016), but fight broke out again in 2016. Thousands of people from South Sudan were either killed or became refugees in other countries.

The total area of South Sudan is about 644,329 sq km. It is bordered by the Central African Republic, Democratic Republic of Congo, Sudan, Ethiopia, Kenya, and Uganda. It is a landlocked country and the climate is mostly tropical. The White Nile is the dominant river with a swamp of 100,000 sq km named Sudd. The country is rich in natural resources but lacks the capacity to utilise them for national development, due to many factors. Juba is the country’s capital city.

According to the estimate of July 2016, the population is 12.5 million. The younger generation dominates the demographic profile. About 65% of the population are aged less than 24 years. The annual growth rate of the population is 3.92% (National Bureau of Statistics [NBS, 2016]).
There are many ethnic groups and around 64 tribes. English and Arabic are used as official languages. Christians are a large majority. Only around one-third of people are literate due to a lack of school teachers and materials and more than half of people live below the poverty line.

1.3 Maternal mortality in South Sudan
The maternal mortality rate in South Sudan is one of highest in the world (Makuei et al., 2016; WHO, 2016). There are many reasons for this, including a shortage of healthcare workers, facilities and supplies, poor roads and a lack of transport, and cultural beliefs that prevent women from seeking obstetric care. Most women marry and start having children early. They give birth at home with or without the assistance of traditional birth attendants (TBA) who cannot handle complications. The general death rate was 800 per 100,000 of the population and the maternal mortality ratio (MMR) was 730 per 100,000 live births in 2015 (Ministry of Health (MoH, 2015); National Bureau of Statistics (NBS, 2015); WHO, 2015), meaning that most of the dying population are maternal women. The fertility rate is 5.9 children per woman. This, along with low use of contraception (only 4%) increases the chances of maternal mortality. HIV/AIDS prevalence is 2.7% (WHO, 2015; NBS, 2015) and risk of infectious diseases is very high. Around 20% people are unemployed. Kolok (2013) listed government efforts to reduce maternal death. The government has obtained the support of UNICEF and many foreign countries to expand healthcare facilities for pregnant woman and paediatric care for newborns. These facilities are equipped with qualified personnel, medicines, operating theatres, labour rooms, delivery rooms, wards, and antenatal and post-natal care. Haemorrhaging, infections, unsafe abortions, and other complications on delivery are other leading physiological causes of maternal deaths in South Sudan (Gaffey, 2016). The lack of properly trained personnel is a major problem in maternal healthcare. The Juba facility trains midwives at diploma level and the quality of training has also improved over the years (MoH, 2016; Juba College of Nursing and Midwifery (CONAM, 2016). Team spirit and attitude to care is improving, but the importance of cultural elements is decreasing. Resources and knowledge are available, but they need to be fully and effectively deployed.
1.4 Developing predictive models
There have been many attempts of predictive modelling using linear and multiple regression approaches (Makuei et al., 2016, 2018). A time series analysis was attempted by Der Sarkissian et al. (2013) on 49 countries in Africa at five-year intervals from 1990 to 2005. Socio-economic, demographic, and healthcare development parameters were associated with time-series trends. Mixed Poisson regression models were used. In their work, Kassebaum et al. (2014) used the Cause of Death Ensemble (CODEm) to analyse data on 7,065 sites to estimate maternal mortality in 188 countries during the period 1992–2013. This scenario-based approach was used for projection to the year 2030.

Alkema et al. (2016) used the scenario-based approach and Bayesian model to predict MMR for 171 of 183 UN member-countries until 2030. Use of more data increased the preciseness of estimations by the Global Burden of Diseases (GBD) compared to that of WHO, according to Kassebaum et al. (2014). Makuei et al. (2016) investigated Ln linear, Poisson and multi-regression models for the prediction of maternal deaths in South Sudan.

More detailed discussions of the exact equations and results obtained in predictive modelling are given in the review of literature in Chapter 2 and methodology in Chapter 3.

1.5 Rationale
According to the data released by WHO (WHO, 2015), the maternal mortality rate in South Sudan, although it has decreased from 1,000 to 730 per 100,000 live births during 2005 to 2013, is still one of the highest in the world. Downie (2012) gave a figure of 2,054 per 100,000 live births. This, combined with high fertility rates in the country states that the probability of an average South Sudanese woman dying during one of her pregnancies is one in seven.

The lifetime risk of maternal death for a woman in sub-Saharan Africa is around 50 times greater than for a woman in the USA. In terms of the total fertility rate, South Sudan is one of the ten countries in the region of sub-Saharan Africa with the highest MMR.
The United States International Development Goal (USAID, 2014) aims to achieve an MMR of less than 50 maternal deaths per 100,000 live births by 2035 for 24 countries with the highest MMR in the world. South Sudan is one of the top 24 countries in terms of high MMR.

In most developing countries, primary healthcare is the most commonly recommended and affordable service, especially for a low socio-economic society. It covers the routine pregnancy monitoring process to detect and anticipate any pregnancy-related problems to reduce the risk of maternal mortality. However, there is less evidence on the content and quality of antenatal care, especially in developing countries, such as South Sudan. It is also reported that the quality of care received by pregnant women during antenatal visits is inadequate and even non-existent in some rural areas.

It is also vital to carry out research on how to improve the quality of the antenatal care process in primary healthcare. Identifying the most influential characteristics of the causes and factors of high maternal deaths would be the first step in developing a multivariate profile monitoring system. This significant first step would only be possible if one has access to a reliable and accessible data recording and reporting system.

A reliable data recording and reporting system will aid district medical practitioners and local and national governments to develop evidence-based decision making to address the most influential causes of high maternal deaths in South Sudan.

Factors contributing to the high maternal mortality rate are socio-economic, macro-economic, and physiological. This study investigates the socio-economic and physiological causes of maternal mortality rate based on international and national literature. Data from South Sudan spanning 30 years are used to identify the most significant socio-economic and physiological causes of maternal mortality. The study has developed multivariate profile monitoring and quality healthcare systems to monitor the significant socio-economic factors and physiological causes of MMR.

For the first time, this study deploys optimisation procedures to develop yearly lower and upper profile limits for MMR, targeting the UN recommended lower and upper MMR levels by
2030 (Makuei et al., 2016, 2018). MMR profile limits have been accompanied by profile limits for optimal yearly values of Skilled Attendant at Birth (SAB) and General Fertility Rate (GFR). Studies on predictors of logarithmic multi-regression models provided distinct evidence that increasing SAB and decreasing GFR, while leaving the GDP constant at 1,772, can reduce the Maternal Mortality Rate in South Sudan to the limits proposed by the UN agencies (WHO, USAID, UNICEF and World Bank, 2015) by 2030 and beyond.

Statistical analysis shows that increasing SAB by 1.22% per year would reduce MMR by 1.4% (95% CI (0.4%–5%)), while decreasing GFR by 1.22% per year would reduce MMR by 1.8% (95% CI (0.5%–6.26%)), when the GDP is held constant.

The comparison of the findings of this study to other similar studies suggests that reducing GFR is more effective and achievable than increasing SAB.

The optimal profile limits provide a quantitative guideline for the Government and partners in terms of yearly SAB and GFR targets to reduce MMR to the level recommended by the UN.

Analysis shows that haemorrhaging; microbial infections, preeclampsia, cardiovascular diseases, liver diseases, sepsis, and gastro-intestinal hepatic diseases are the most common physiological factors of MMR. Amongst these, deaths related to haemorrhaging, sepsis, and eclampsia are more common.

Poisson regression is used to develop a prediction model to estimate maternal mortality based on the top five significant physiological causes. The results show that these causes contribute 97.43% to the variation in MMR. Judging by their corresponding variance inflation factors (VIFs) and p-values, we can conclude that all five causes are statistically significant. However, based on literature recommendations (WHO, 2015), we have developed two-reduced Poisson regressions based on haemorrhaging only, and haemorrhaging and unsafe abortion. The results indicate that haemorrhaging alone is responsible for 90.27% and haemorrhaging and unsafe abortions are responsible for over 92% of the variations in MMR in South Sudan.

The outcomes of this study can effectively aid authorities to make informed evidence-based intervention decisions on resource allocation in South Sudan’s public healthcare, to target
specific socio-economic factors (SAB, GFR and GDP) and physiological causes (e.g. haemorrhaging, sepsis, unsafe abortion, and indirect causes) with the aim of minimising the MMR.

1.6 Contribution
Contributions of this research to reduce MMR in South Sudan are as follows:

(i) The initiation for the development of a much-needed reliable electronic maternity data base for South Sudan;

(ii) Identification of the most influential socio-economic factors and physiological causes for high maternal deaths in South Sudan;

(iii) The development of reliable and effective multivariate regression models, Poisson regression models, and time series models to accurately estimate and forecast maternal mortality in terms of the influential socio-economic factors and physiological causes in South Sudan;

(iv) The development of multivariate profile monitoring algorithms to monitor and control the changes in significant factors responsible for the MMR.

(v) Assessment of the impact of policies designed to reduce the MMR.

The outcomes of this research would provide useful administrative and scientific guidelines for the expansion of healthcare service programmes and the effective distribution of limited Government resources, specifically in rural areas, including analysis of locations for which further aid investment would effectively impact on reducing the MMR.

1.7 Organisation of this thesis
The next chapter looks at the published research works on maternal mortality and development of predictive models. The most significant research gaps are identified from the literature review. The procedures used for fulfilling the listed objectives are outlined and explained in detail in Chapter 1.
Chapter 2 explores a comprehensive literature study of MMR internationally and nationally. In addition, it has covered direct and indirect physiological causes for high MMR globally and South Sudan, comparison between strategies in developed and developing countries to reduce MMR. Further, Chapter 2 has also reviewed reliable systems for data collection on maternal mortality using different approaches.

Methodology Chapter 3 has covered models that could describe, forecast and predict MMR. Furthermore, Chapter 3 has examined models appropriate for South Sudan’s data analysis and prediction. Chapter 3 also outlined and explored various methods of research in terms of answering the research questions. These include research design, data collection, and existing models for MMR and development of new maternal death estimation models.

Results achieved with some modelling efforts are presented and discussed in Chapter 4. The limitations of this work are identified in the same chapter. Chapter 4 outlines steps followed to carry out the statistical analysis. These include information on data collection and their sources and list of data analysis tasks which were carried out to obtain the results of analyses. Discussion, Chapter 5 has outlined discussion of trend analysis, linear regression models for Non-HIV+/AIDs maternal deaths, optimal linear profile limits for MMR, prediction models for MMR based on physiological factors and development of the profile limits for the reduced Poisson Regression model.

Chapter 6 covers all policies implemented and recommended by the Government to reduce the MMR in the country. The chapter has outlined the steps taken by South Sudan Government and other stakeholders to reduce maternal mortality in the past few years. The chapter explores the impact of these policies in South Sudan and other countries. The policies included, Projected Infrastructural Investment in primary health care centre (PHCC), primary health unit (PHCU) and Hospitals, Human Resources Gap for Health Centre numbers, the proposed health sector development plan (HSDP) 2012-2016)’s Budget. Further, the chapter includes decentralised administration, indicators of Health Status in Southern Sudan compared with average of the Middle East and North Africa countries.
Finally, Chapter 7 outlines conclusions and recommendations.
2 LITERATURE REVIEW

2.1 Introduction
Maternal mortality is a major global health problem, especially in sub-Saharan Africa where the life-time risk of maternal death is ten times higher than that of developed countries. The contributing factors for high MMR include socio-economic factors, macro-economic factors, and physiological causes. This study aims to gain insight into the main socio-economic factors, direct and indirect physiological causes of MMR and develop a prediction model to estimate maternal death in terms of significant causes. We have used multivariate log linear regression, Poisson regression, time series models, and profile monitoring systems to estimate and predict the MMR of South Sudan and monitor the KPIs related to MMR.

Identifying factors and causes of high maternal deaths (MDs) and MMRs will provide useful information for maternal health policy makers for the development of strategies and action plan to improve maternal healthcare policies and their implementation.

2.2 Definition of terms related to MDs used in this study
Maternal death is defined as ‘the death of a woman while pregnant or within 42 days (e.g. six weeks) of termination of pregnancy irrespective of the duration and site of the pregnancy, from any cause related to, or aggravated by, the pregnancy or its management, but not from accidental or incidental causes. To facilitate the identification of maternal deaths in circumstances in which cause of death attribution is inadequate, a new category has been introduced: pregnancy-related death is defined as the death of a woman while pregnant or
within 42 days of termination of pregnancy, irrespective of the cause of death’ (WHO, Maternal Mortality Ratio (per 100,000 live births), 2017).

The UN definition for the maternal mortality ratio (MMR) is the ratio of the number of maternal deaths during a given time per 100,000 live births during the same time period. It is also one of the measures used to monitor progress towards the achievement of the goal of improving maternal health in Millennium Development Goals (MDG5) (Wilmoth et al., 2012). This is estimated using the formula

$$\text{MMR} = \frac{\text{Recorded (estimated) number of maternal deaths}}{\text{Total number of recorded (estimated) live births}} \times 100\,000$$

(2.1).

Maternal deaths and live births are as defined above. There are also separations of AIDS-related and non-AIDS related direct or indirect maternal mortality estimated, wherever relevant.

An updated set of UN definitions is provided by Alkema et al. (2016).

Pregnancy-related death is defined as the ‘death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the cause of death’.

Late maternal death is defined as the ‘death of a woman from direct or indirect obstetric causes, more than 42 days (six weeks), but less than one year, after termination of pregnancy’.

The reproductive age is specified as 15–49 years, but in the case of South Sudan, the reproductive age is 12–49 years, which is one of the problems affecting higher maternal deaths and maternal mortality rate in the country.

2.1 Maternal mortality rates in developed and developing countries and South Sudan

A recent WHO report (WHO, 2015) highlighted the salient points of MMR as follows:

- Around 830 maternity deaths occur daily due to preventable pregnancy and childbirth problems;
- About 99% of all these deaths occur in developing countries;
• Women in rural areas of poorer communities are more prone to such deaths; and
• The risk of such deaths is higher in the case of adolescent young women than among older women.

Skilled care before, during and after childbirth can prevent the death of mothers and newborn babies. MMR has dropped by about 50% during the last two decades. Index mundi has the maternal mortality rates of 184 countries as in January 2014 (Index mundi, MMR, 2017). The highest rate is in South Sudan with a rate of 1,000 per 100,000 live births in 2005, but within less than half a decade, South Sudan MMR rate decreased to 886 per 100,000 live births in 2009 (WHO, 2012), 789 in 2015 (WHO, 2015), and 730 in 2017 (Ministry of Health, 2017). In around 30 countries, including developed and developing countries, MMR is less than 10. This proves that low MMR is also achievable in developing countries. In the USA, the ratio is 21 per 100,000 live births, in the UK it is 16 per 100,000 live births, and in Australia it is 6 per 100,000 live births.

According to the modelled estimates of WHO cited by World Atlas (2017), MMR for South Sudan in 2015 dropped to 789. Sierra Leone topped the list with 1,360, followed by the Central African Republic at 882 and Chad at 856. The MMR of the Congo was shown as 69.

In a combined report of WHO, UNICEF, UNFPA, and the UN Population Division (World Bank, 2017), the global and country-wide trends of maternal mortality ratio for South Sudan during the period 1990–2017 has been published (Table 2.1). South Sudan trends are reproduced in Figure 2.1. Global MMR in 1990 was 385, which gradually decreased to 216 by 2015. The annual reduction was slower until around 1998 but then it gained momentum. Most countries generally recorded the same trend. However, in the case of a few countries such as the Bahamas, Georgia, Guyana, and Jamaica, there was an increasing trend throughout the period. For some countries such as Canada, Kenya, Lesotho, and the Democratic Republic of Korea, an initial rise was followed by a steady trend for some period, followed then by a reduction. Panama, South Africa, and a few other countries demonstrated a reduction followed by an increase. UK had an initial increase followed by a reduction. The US has had an almost continuous rise since 1998. If these countries are compared based on the factors responsible for increasing or reducing maternal mortality, it may be possible to identify the factors and causes that facilitated the reduction of MMR through deliberate strategies and interventions.
MMR in South Sudan has declined (WHO, UNICEF, UNFPA, the World Bank and the United Nations Population Division, 2017) as indicated by Figure 2.1, from 971 in 2007 to 730 in 2015, which was estimated as 25%; this figure has remained during 2016. The current MMR of 730 is still one of the highest in the world (as it was around a decade ago). The causes of high MMR are many and some are discussed below.

Table 2.1: Yearly MMR statistics in South Sudan from 1990 to 2017

<table>
<thead>
<tr>
<th>Year</th>
<th>MMR per 100,000 live births</th>
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<tr>
<td>1990</td>
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<td>2014</td>
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<td>2016</td>
<td>730</td>
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<td>2017</td>
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Note*: WHO and the UN agencies 789, South Sudan Government 730.
Globally, MMR decreased by about 44%, and between 1990 and 2015, South Sudan almost followed the global trend. In the case of South Sudan, the reduction was from 1,730 in 1990 to 789 in 2015, a reduction of 54%. The WHO provided the trend in maternal mortality from 1990 to 2015, (estimates by the WHO, UNICEF, UNFPA, World Bank Group, and the United Nations Population Division, 2015). The predictive model and other details used for these estimations are provided in their report. The country data for the estimations varied in precision and reliability due to differences in data collection systems. Advanced countries were generally better in this respect. Since accurate standardised methods of measuring MMR are not available for many countries, the only way is to use a mathematical model to estimate MMR from a given set of variables. Various types of models have been proposed and used by different authors. These will be discussed in detail in Chapter 3.

2.2 Direct and indirect causes for high maternal mortality globally
Globally, major physiological causes of MMR are: haemorrhaging, sepsis (infections), hypertensive disorders, prolonged or obstructed labour, unsafe abortion, and indirect causes such as anaemia, malaria, hepatitis, heart disease, and HIV/AIDS. These causes have also been
identified as the most influential predictors of MMR in South Sudan, (WHO, UNFPA and UNICEF report, 2008, 2014).

In general, maternal mortality in resources-limited countries has been attributed to the “three delays”: delay in deciding to seek care, delay in reaching health care facility in time, and delay in receiving adequate treatment. These delays are due to lack of information about complication, road and transport, inadequate health services and facilities, poverty and lack of medical staff and supplies (Tort et al., 2015).

Direct causes (related to obstetric complications of pregnancy, labour and delivery management, and the post-partum periods) account for 80% of maternal death (WHO Factsheets and UNICEF reports, 2008, 2014, and 2016). Indirect causes (related to pre-existing medical conditions that may be aggravated by the physiologic demands of pregnancy) account for 20% of maternal deaths. A brief overview of the leading causes of maternal deaths in developing and developed countries is provided below. Some causes of maternal mortality are the same in the developing and developed world; however, the prevalence is significantly lower in developed countries. In fact, according to Minino et al. (2014), in the United States, ‘only 0.06% of women with direct obstetric complications died in health facilities’. This is well below the maximum acceptable case fatality rate of 1% as per UN guidelines. The most frequent cause of death was complications, predominantly in the puerperium (28%), followed by pre-eclampsia, and eclampsia (21%).

Programmes that focus on improving outcomes during the intrapartum/postpartum period, offer family planning services, provide safe abortions, and increase antepartum care, can effectively reduce MMR.

2.2.1 Review of the causes of Maternal Mortality by country

In their review, the WHO, UNICEF, UNFPA, the World Bank Group, and the United Nations Population Division, CIA, (2015) and Rogo et al. (2006) point out that almost 60% of maternal deaths occur during childbirth and during the immediate postpartum period. Fifty percent of these deaths occur within the first 24 hours of the delivery period. They also identified obstetric haemorrhaging, puerperal sepsis, pregnancy-induced hypertension (including
eclampsia), obstructed labour and ruptured uterus, and complications of unsafe abortion as direct causes of maternal deaths in Sub-Saharan Africa. Of these, haemorrhaging, sepsis, and eclampsia are more significant.

In France, the most frequent cause for the admission of obstetric patients in ICU was hypertension. However, these admissions did not lead to mortality, which reflects the low MMRs in France (Bouvier-Colle et al., 1996). In Tanzania, malaria was a major cause of maternal mortality in pregnancy and postpartum, noted as noted by Olsen et al. (2002). High incidence of maternal mortality was detected among Afghan refugee women of reproductive age in Pakistan by Bartlett et al. (2002), which mainly contributed to a high level of barriers to accessing healthcare. In a recent survey, Creanga et al. (2015) observed that, compared to previous years, in the USA, the maternal mortality ratio increased during 2006–2010 due to an increase in cardiovascular problems and infections.

Main et al. (2015) conducted a retrospective audit of pregnancy related mortality in California. The top two preventable reasons identified for MMR were haemorrhaging and preeclampsia.

Allanson et al. (2015) conducted an analysis of a South African database of maternal mortality deaths. They looked at the frequencies and causes of maternal mortality. Two of the main causes of deaths were maternal hypertension and obstetric haemorrhaging.

Tempia et al. (2015) reviewed maternal mortality deaths associated with influenza amongst pregnant and non-pregnant women of child-bearing age in South Africa. The review found that pregnant women experienced an increased risk of seasonal influenza and associated mortality compared with non-pregnant women.

Lawn et al. (2016) reviewed the rates and risk factors for stillbirths in 18 countries. They identified maternal infections, non-communicable diseases, nutrition and lifestyle factor, and prolonged pregnancies to be major contributors to the proportion of still births.

2.2.2 Statistical Report on the major causes of Maternal Mortality
The work of Ayrton et al. (2009) is directly related to Southern Sudan, but it was conducted before the area became an independent country. Ayrton et al. (2009) used data from hospital
records to confirm the causes of deaths and categorised them by the age of the patient and the duration of their hospital stay.

The five direct major causes of maternal deaths are: haemorrhaging (bleeding), sepsis (infection), unsafe abortion, eclampsia, and prolonged (obstructed labour). Major indirect causes are anaemia, malaria, heart disease, and HIV/AIDS. Almost all of these life-threatening complications can be prevented or treated if women have access to high-quality and apposite healthcare during pregnancy, abortion, childbirth, and immediately afterwards.

**2.2.2.1 Haemorrhaging**

Obstetric haemorrhaging is the single, most significant, cause of maternal mortality globally, accounting for 25%–30% of all maternal deaths. Obstetric haemorrhaging causes 127,000 deaths yearly worldwide and is the leading cause of maternal mortality (WHO report, 2015; Haeri, 2012; Parata et al., 2014, Tort et al., 2015; Devi et al., 2015).

A haemorrhage is referred to as a blood loss of 500 ml or more during puerperium and a severe haemorrhaging as blood loss 1000 ml or more according to reports by RANZCOG (2011, 2014, 2015, 2016, 2017). The WHO defines haemorrhaging as blood loss of more than 500 ml in the first 24 hours after birth (Walfish et al., 2009).

Most deaths related to haemorrhaging occur during the first 24 hours after delivery. Most could be avoided using a prophylactic uterotonic during the third stage of labour, and through timely and appropriate management (WHO, 2012).

In Senegal and Mali, obstetric haemorrhaging is the leading cause of maternal death (Tort et al., 2015). In Asian countries including Japan, China, Hong Kong, Pakistan, Thailand, Indonesia, Saudi Arabia, Sri Lanka, and other developed countries, postpartum haemorrhaging is the most significant cause of maternal mortality (Duthie, 2014). In India, haemorrhaging is a major cause of maternal deaths (Devi et al., 2015), and in Bangladesh, haemorrhaging is also the leading cause of maternal mortality, accounting for around 31% of maternal deaths (Prata et al., 2014).
In the US, obstetric haemorrhaging is still the main cause of maternal deaths and around 54% to 93% of these deaths may have been preventable (Bingham and James, 2012). In Australia and New Zealand, postpartum haemorrhaging remain the main cause of both maternal mortality and morbidity. The prevention and treatment of haemorrhaging is a crucial step towards the achievement of the Millennium Development Goals (WHO, 2012) and the reduction of MMR.

2.2.2.2 Unsafe Abortions
Unsafe abortion remains a serious and continuing public health challenge for global maternal deaths and is associated with both short- and long-term morbidity in women (Auka et al., 2015; Khan, 2003).

Worldwide, 20 million illegal abortions occur each year. It is estimated that globally; unsafe abortions are responsible for about 68,000 deaths annually, accounting for 13% of total maternal mortality (Regmic et al., 2010; WHO, 2011, 2014; Auka et al., 2015).

According to Johnston et al. (2007) and the WHO (2004), the unsafe abortion mortality ratio is highest in Africa at 100 per 100,000 live births; in Asia it is 40 per 100,000 live births and 30 in Latin America and the Caribbean, whereas in developed countries it is as low as three.

Abortion is illegal in South Sudan except when it is done to save a woman's life (Women on Waves, 2017). Gender-based violence is very common in South Sudan. Abortion is illegal even when a woman has been raped, and women are often discriminated against and blamed in such instances (Women on Waves, 2017).

2.2.2.3 Malaria as an indirect cause of MMR
About half of the world population is at risk of malaria and most cases occur in sub-Saharan Africa including South Sudan (Cornelio and Seriano, 2011; WHO, 2010), where 20% of childhood deaths result from this disease.

South Sudan is one of the highest malaria burdens in sub-Saharan Africa (Aimeek et al., 2016). Thus, it would be safe to conclude that the malaria, as an indirect cause, has a major role in high MMR in the country.
In 2008, there were 247 million worldwide cases of malaria and approximately one million deaths. Malaria is a major cause of prenatal anaemia and preventable low birth weight (Cornelio and Seriano, 2011; Attwood et al., 2012).

In 2010, around 219 million malaria cases and 660,000 deaths were reported globally (Chanda et al., 2014; WHO, 2014). The disease remains a main cause of maternal mortality, exacting its greatest toll in sub-Saharan Africa, where over 80% of cases and 90% of deaths occur (Pasquale et al., 2013; WHO, 2012, 2013, 2014; Chanda et al., 2014). Malaria is a major health problem in South Sudan. Around 95% of South Sudan is endemic for malaria and transmission is high throughout the year (Draebel et al., 2013). An estimated 2.3 million people are at risk of malaria across the whole country. The peak period of transmission is during the rainy season, mainly April to October (Cornelio and Seriano, 2011; MoH, Government of Southern Sudan, 2006). Moreover, the frequency and severity of malaria infections are greater during pregnancy and may cause severe anaemia, increasing the risk of maternal mortality.

A review of 20 researches from eight African countries, found that the prevalence of malaria infection in pregnancy ranged from around 10% to 65%, and estimated the median prevalence of maternal malaria infection in all pregnant women accounted for 27.8% (Draebel et al., 2013).

The prevalence of malaria is very high in South Sudan, accounting for around 30% of deaths of all malaria-related hospital admissions (MoH, 2009). Children under five and pregnant women are the most at risk from malaria. Charchuk, Houston, and Hawkes (2015) found that the prevalence of malaria is high amongst school-aged children and adolescents in the South. It is hypothesised that the high prevalence of malaria is due to the fertile grounds for mosquito breeding, low levels of intervention, and low levels of knowledge regarding the disease (Eyobo, et al., 2014). In the 2009 malaria indicator survey, it was found that only 34% of households own a mosquito net and only 41% of households know the correct treatment for malaria. It was also found that only 52% of children with malaria received treatment at a health facility (Eyobo et al., 2014).
In South Sudan, especially during the rainy season, malaria is responsible for most admissions and is the leading cause of mortality in the Medical Department of Juba Teaching Hospital (JTH).

2.3 Strategies adopted by different countries to reduce mortality

De Brouwere, Tonglet, and Van Lerberghe’s publication ‘Strategies for reducing maternal mortality in developing countries: what can we learn from the history of the industrialized West’ (1998) and De Brouwere and Van Lerberghe’s publication ‘Safe Motherhood Strategies: A Review of the Evidence’ (2001) dealt with the disparities between developed and developing countries in tackling the maternal mortality problem. After ten years of the Safe Motherhood programme implementation, developing countries are still at the stage that developed countries were at during the early 20th century. A review of the conditions that helped developed countries reduce maternal mortality rates over the last 100 years, carried out by De Brouwer et al. (1998, 2001), showed that the pre-conditions that helped developed countries to significantly reduce maternal mortality were early awareness of the magnitude and seriousness of the problem, realisation that most maternal deaths are avoidable, and the mobilisation of professionals and the community. The timing and speed of these factors determined the country’s variations. Professionalism in care delivery included the willingness of decision makers to take responsibility, providing up-to-date obstetrical care and making it available to the population, discouragement of midwifery care and defining clearly the accountability of professionals for addressing maternal health in an effective way. The Swedish (and later also the Dutch, Norwegian, and Danish) model for the reduction of maternal mortality comprised of three components:

- An active policy of training midwives, selected for their social profile;
- Capacity to introduce modernisation as ‘health missionaries’; and
- A close follow-up of compliance with hygiene and technical prescriptions.

However, indecision by the government and problems with funding delayed the achievement of the reduction of MMR in England and Wales, although the Swedish model was accepted. Accessible technologies and reliable hospital care reduced maternal mortality rates further to
the current levels of 20 or less in Western Europe and the USA. However, combinations of the earliest availability of, and reaction to, information, creation of professional and public awareness and response, was the next step; a policy on the need for midwifery development supported by doctors and a strategy to implement adapted versions of the Swedish model had a more important role than technology in this respect. Even in the case of poor countries, the difference between Sri Lanka, Malaysia, and Thailand demonstrated the importance of early information and action towards professional accountability and access to quality care (De Brouwer et al., 1998, 2001). Accessibility included physical, financial, cultural, and psychosocial dimensions. The accountability of health professionals for what happened both inside and outside hospitals, regarding care quality, was another matter of importance. Stress on avoidable maternal deaths focuses on what is possible to achieve and to determine in what way this led to successful strategies. Developing countries lacked such high levels of professionalism. The main factors that hindered the reduction of mortality rates in developing countries were limited awareness of the magnitude and manageability of the problem and the implementation of ill-informed professionalisation strategies, which focused on antenatal care and the training of traditional birth attendants (TBA). These strategies were mostly ineffective and helped only to divert the attention from the development of professional first-line midwifery and second-line hospital delivery care.

Rising MMR in the USA (Tavernise, 2016) against the global declining trend during the period 2000–2015, was a matter of concern in a report by the Institute of Health Metrics and Evaluation (IHME, 2017), although it is still below 30. In the past, traditional maternal mortality happened due to haemorrhaging during delivery or eclampsia. In modern times, the causes of maternal mortality have shifted to diabetes, obesity, cardiovascular diseases, and heart failure. This increase has been reported by almost all states. Consequently, maternal death review boards have been set up in many states to understand the problem and reverse the trend using suitable strategies. Olds et al. (2014) used randomised clinical trials to evaluate different methods to reduce maternal and first-born infant mortality rates. Home visits by nurses were superimposed onto various intervention methods. Nurses visited homes of mothers living in
highly disadvantaged settings in Memphis, Tennessee. The home participants were primarily African-American women and their first live-born children living in highly disadvantaged urban neighbourhoods. The intervention of transportation plus pre-natal/post-partum home visiting by nurses reduced maternal mortality from 3.7% to 0.4%, which was significant. Interestingly, adding screening to this in another treatment resulted in maternal mortality of 2.2%. A new initiative, the National Partnership for Maternal Safety, was formed in the USA to address the recent rise in MMR against the global decreasing trend (D’Alton et al., 2014).

Three priority bundles were identified for collaborative broad-based implementation programmes for the most common preventable causes of maternal death and severe morbidity: obstetric haemorrhaging, severe hypertension in pregnancy, and peripartum and venous thromboembolism. In addition, three unit-improvement bundles for obstetric services were identified. One, a structured approach for the recognition of early warning signs and symptoms, including structured internal case reviews to identify system improvement opportunities. Two, support tools for patients, families, and staff that experienced an adverse outcome. According to De Brouwer and Van Lerberghe, in their publication ‘Safe Motherhood Strategies: a Review of the Evidence’ (2001), the USA did not achieve a reduction in maternal mortality at the same rate as Sweden and other European countries due to a lack of information, lack of public pressure, the down-rating of midwifery by obstetricians over a long period of time, and insistence on institutional delivery over home delivery without providing basic access and care facilities. The USA achieved better results only after these barriers were removed.

Using the survey results, Montgomery et al. (2014) found that out of the 10,041 all-cause deaths of women (15–49 age group) in India during the period 2001–2003, 11.1% were related to maternal mortality. From the results, they concluded that rural areas of poor states in India were more vulnerable to high MMRs than richer states. This was due to poor access to healthcare. However, with a 4.7% decline in annual MMR, there was an annual increase of 3.5% in skilled birth attendance. Based on a similar survey and supportive data, Arifeen et al. (2014) observed a reduction in maternal deaths from 322 during the period 1998–2001 to 194
during 2007–2010. This rate of reduction was slightly higher than the level required reaching the Millennium Development Goal in 2015. Improved access and use of healthcare facilities was the main cause of this reduction.

As per another WHO report, (WHO, Global Health Observatory, 2015), in the case of Kenya, MMR lowered from 490 in 1990 to 400 in 2013. Increase in GDP on a Purchasing Power Parity (PPP) basis reflected increased income and thus affordability and a reduction in fertility rate, thus, reducing the risk of MMR. In contrast to Kenya, MMR in Sudan steadily declined from 744 in 1990 to 311 in 2015. Surprisingly, this reduction was achieved with a much lower level of skilled care ranging from 22.5% in 1990 to 31.3% in 2013. Compared to Kenya, a faster and almost continuous increase of GDP (per capita, PPP) from 940 USD in 1999 to 2,600 USD in 2013 of Sudan (Index mundi, GDP per capita (PPP) $ US, 2015) would have contributed to the affordability of skilled care and a faster reduction in fertility rates. Uganda behaved in a similar manner to Sudan with respect to MMR, fertility reduction, and increasing GDP and skilled care. MMR reduced from 687 in 1990 to 243 in 2015. The skilled care was relatively high at 37.2% in 1990 and increased to 54.2% in 2013. MDG for 2015 by the UN stipulated an average annual reduction of MMR by about 5.5%. Sudan and Uganda achieved a 60% reduction during the period 1990–2015, but Kenya did not keep pace. In Uruguay, according to a report in the Latin American Herald Tribune, 2017) on a presentation by the health minister, only eight women died at childbirth in 2016 compared to 11 in 2015. There were also significant reductions in the total number of births and pregnancy among teenage girls, and slight increase in registered abortions. Despite the social vulnerability of women, lower fertility of women, particularly among adolescents, was noticeable.

Political priority is an important factor in achieving desired levels of maternal mortality in any country. Based on case studies in five developing countries (India, Indonesia, Guatemala, Nigeria, and Honduras) Shiffman (2007) contends that giving political priority to tackle maternal mortality depends on several factors largely around convincing political leaders and the community that a real problem exists, that solutions are possible, and there is financial and technical assistance to evolve policies and implementation.
Benova, et al. (2014) concludes that there is an association between poor sanitation and water and higher MMR. Such conditions exist more commonly among developing countries. From the meta-analysis of a huge global data set consisting of about 1,800 possible macrostructural indicators and mortality, Sajedinejad et al. (2015) obtained education, the private sector, and trade and governance as the most significant macro-structural factors associated with maternal mortality. The distal factors consisting of economic policy and debt, agriculture and food production, employment and labour structure, health finance, and private sector infrastructure investment explains 65% of the variability in maternal mortality between countries. All these factors could be relevant beyond the MDG2015 era. From an analysis of published data, Betran et al. (2015) noted that caesarean sections above the threshold of 9%–16% of the total population were not related to the reduction in maternal mortality. At caesarean section rates below this level, socio-economic development may be driving the relationship between caesarean sections and maternal mortality. At rates higher than the threshold, no association may exist between the two variables.

From the analysis of 37 sub-Saharan African countries, Pandolfelli et al. (2014) obtained evidence for increased maternal mortality in nations that receive International Monetary Fund (IMF) structural adjustment loans. The dependency theory was used to explain the observations.

Factors related to the technical and policy environment that made early reductions in maternal mortality possible in some countries, and barriers preventing this in other countries, were provided as a diagram and discussed by De Brouwer and Van Lerberghe’s publication ‘Safe Motherhood Strategies: A Review of the Evidence’ (2001). This diagram is reproduced here in Figure 2.2. These factors have been amply discussed in the first paragraph of this section.
Figure 2.2: Technical and policy environment factors that made early reduction of maternal mortality in certain countries possible and barriers preventing such early reductions in other countries (De Brouwer and Van Lerberghe, Safe Motherhood Strategies: A Review of the Evidence, 2001)

It appears that the difference between high and low MMR is related to skilled care. The differences between rural and urban and between developed and developing countries are also due to the same reason. Poverty may be related to affordability and access, even if skilled care is available nearby. If skilled care is available only at some distance, road and transport facilities have role alongside poverty. This also brings travel and communication facilities; developing countries are far behind developed countries regarding these factors.

Thus, the action plan for reducing MMR emerges as follows:

- Train current maternity workers to enhance their skills;
- Create a new generation of trained maternity workers;
- Increase affordability by subsidised or free maternity care; and
- Improve travel and communication facilities for improved accessibility.

Nations that are affected by high MMR are trying to adopt the above recommendations to different degrees and achieve results depending on the extent to which steps have been implemented.

Table 2.2: Successful strategies for the reduction of maternal mortality with examples relating to some countries

<table>
<thead>
<tr>
<th>Strategies driving success in reducing maternal mortality with examples for each</th>
<th>1. Addressing inequities in the access to and quality of sexual, reproductive, maternal, and newborn healthcare</th>
<th>Ethiopia trained women’s association members in strategies to address social and structural barriers to sexual, reproductive, maternal, and newborn health, and trained health managers on gender mainstreaming in their areas of work. Viet Nam developed sexual and reproductive health services specifically for adolescents and youths.</th>
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<tr>
<td>2. Ensuring universal health coverage for comprehensive sexual, reproductive, maternal and newborn healthcare</td>
<td>Rwanda used a community-based health insurance scheme to ensure vulnerable populations’ access to maternal and child health services. Bangladesh expanded access to maternity services in new, private-sector healthcare facilities.</td>
<td></td>
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<tr>
<td>3. Addressing all causes of maternal mortality, reproductive and maternal morbidities, and related disabilities</td>
<td>Nepal expanded access to modern family planning methods, and increased school attendance and literacy rates among women and girls. The Maldives strengthened emergency obstetric care, including basic care and comprehensive emergency obstetric care throughout the country’s health system.</td>
<td></td>
</tr>
<tr>
<td>4. Strengthening health systems to respond to the needs and priorities of women and girls</td>
<td>Indonesia invested in the training of midwives and the creation of dedicated, village-level delivery points for maternal health services. Cambodia invested in transport infrastructure and construction of healthcare facilities, staffed with an expanded cadre of trained midwives throughout the country, including maternity waiting houses and extended</td>
<td></td>
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delivery rooms

5. Ensuring accountability to improve the quality of care and equity

Mongolia introduced procedures at the facility; provincial and ministerial levels were established to ensure maternal deaths were reported within a 24-hour period and transmitted to the Ministry of Health for review.

From the above discussions, the difference in the strategies employed by developed and developing countries can be considered a strategy and implementation gap. The four differentiating factors of developed countries from developing countries were:

- Early awareness of the magnitude and seriousness of the problem;
- Realisation that most maternal deaths are avoidable;
- Mobilisation of professionals and the community; and
- Well-defined responsibility and accountability of healthcare professionals.

At implementation level, three factors were critical:

i. An active policy of training midwives, selected for their social profile;
ii. Capacity to introduce modernisation as health missionaries; and
iii. A close follow-up of compliance with hygiene and technical prescriptions.

These differences, except for responsibility and accountability, are implicitly narrowed in the WHO general recommendations for MMR reduction in most of the developing countries listed above.

Successful strategies of developing countries such as Bangladesh, Kenya, and Sri Lanka are like those listed in Table 2.6. The adaptability of these strategies in South Sudan needs to be examined. The likelihood of success can be estimated by inserting the factors in the multilinear model and evaluating whether it leads to a substantial reduction in MMR. Based on the results obtained for each of the strategies, those suitable for adaptation in South Sudan can be identified. This is one aim of the developing predictive models.
2.4 The South Sudan cases
The National Bureau of Statistics (NBS) has reported on ([Sudan, 2012] cited SHHS2006 and 5th SPHC report of 2008, SHHS 2010 for MMR): Proportion of births attended by skilled assistant, contraceptive use and unmet family planning as major factors for MMR. The challenges listed in the report are:

1) Access to essential maternity and basic healthcare services are inadequate and utilisation of available healthcare services is low;
2) An emergency obstetric service is not available within reasonable distances. Availability of reproductive health/family planning services including uninterrupted supplies and trained providers and human resources is almost non-existent;
3) There exists a critical shortage of skilled health personnel trained in midwifery;
4) Lack of infrastructure such as roads and transport in many parts of the country and lack of security in the Border States are two major access problems;
5) Adequate advocacy for family planning has not been carried out; and
6) There are a serious lack of family planning methods, reproductive health commodity supplies, knowledge of health providers, and physical infrastructures.

To achieve a reduction of maternal mortality of 20% by 2015, the strategies to address these challenges are:

1) An increase in the availability and accessibility of antenatal services;
2) An assurance of the utilisation of skilled health personnel during pregnancy, childbirth, and postnatal period at all levels of the health system;
3) The provision of emergency obstetric services at a reasonable distance from villages;
4) Enhancement of budget allocation and government spending for reproductive health (maternal health) programmes;
5) Provision of reproductive health/family planning services, including uninterrupted supplies, and availability of trained providers available;
6) Significantly increase the training for midwifery personnel at grass root level as this is the key to reducing maternal mortality;
7) Through higher investment, enhancement of infrastructure development, including roads, transport, midwifery schools; and
8) Enhancement of investments in social development, including women’s empowerment, education, and gender equality issues.
2.5 Data Collection

One of the latest reports on the data collection method, reliability and the way the data used by the country to reduce MMR is by the WHO (Trends in maternal mortality: 1990 to 2015, Estimates by WHO, UNICEF, UNFPA, the World Bank Group, and the United Nations Population Division, 2015). When the sources and method of data collection, and their use by each country, are known, it is possible to categorise them into common patterns and compare them across the categories. The report noted that over the past decade, countries’ data collection methods have progressed through civil registration systems, surveys, censuses, and specialised studies. Many countries still do not have comprehensive systems to capture vital data, so under-reporting has been a major problem. Data sources, variables extracted from these sources, and sources of error tabulated in the report are reproduced in Figure 2.3.

![Box 2.1. Data source types, measures extracted from each, and sources of error](image)

Figure 2.3: Data sources, variables collected and errors (WHO, Trends in maternal mortality: 1990 to 2015, Estimates by the WHO, UNICEF, UNFPA, the World Bank Group and the United Nations Population Division, 2015)

Information available from the sources for MMR estimates were mainly the Civil Registration and Vital Statistics (CRVS) system and specialised studies. The CRVS was prone to under-reporting. Relying on other data sources to extract pregnancy and other factors of maternal deaths were also prone to under-reporting. Apart from these systematic errors, stochastic, sampling, data collection, and processing errors were accounted in the analysis. In total, the
WHO could access 2,608 records covering 3,634 country years (1990-2015). The main sources were CRVS (2025 records and country years) and other sources of pregnancy-related mortality (181 reports and studies accounting for 1038 country years).

The relative merits and problems of different country data sources were evaluated in the WHO (2015) report. CRVS is the primary source and generally preferred system. But many countries do not have the system at all or do not have national scale collection. Then other sources need to be relied upon. There is a certain degree of uncertainty in the errors of any data source. Normally, it is associated with under-reporting because many deaths go unreported. This type of error is known as a systematic error, as they are inherent in data-collection systems. Estimation of this error is possible by measuring the deviation from the true data collected by alternative reliable means. These estimates are used for adjustments to correct the obtained data. Even with adjustments, the uncertainty is not eliminated, only minimised. The report categorised vital registration (VR) data into four groups based on the extent of usability. If usability was less than 60%, they were rejected. Usability ranges of >80% and 60%–80% for CRVS and other data collection systems accounted for the other three categories. Specialised studies and population-based surveys and other data collection methods also provided data for the WHO analysis. In the absence of systematic data collection method, some tools for improved data collection suggested in the report are: confidential enquiry into maternal deaths (CEMD), maternal death surveillance and response (MDSR) and digital innovations. CEMD has been used more frequently than the other two methods. These are explained below.

2.6 Digital innovations
In the context of high percentages of births and maternal deaths occurring outside healthcare facilities, there is a critical requirement to obtain and communicate vital events data from the community level. Digital solutions are available to deliver this vital data via mobile devices (health tools) that connect frontline health workers to national health systems. It can also be used for simultaneously improving care delivery, strengthening accountability, and generating real-time data. An increasing proportion of digital tools focus on the registration of pregnancies
and notification of births and deaths; this information is linked directly to the facility and
district, and to national levels of health management and statistical systems of vital events.
Pilot tests of the Open Smart Register Platform (Open SRP) and other similar digital tools are
underway in Bangladesh, India, Indonesia, Pakistan, and South Africa.

Relatively, when there is incomplete CRVS, or in the case of total absence of the CRVS
system, routine measurement of maternal deaths is difficult. Precise identification of maternal
deaths is a problem as some deaths of women of a reproductive age might not be recorded at
all. Even if they were recorded, there may be no record of pregnancy status or cause of death.
Therefore, such deaths would not have been reported as maternal deaths. The merits and
limitations of each of these methods are given by the WHO and reproduced in Table 2.7.

Table 2.3: Comparisons of data collection methods of maternal mortality and limitations

<table>
<thead>
<tr>
<th>METHOD</th>
<th>DESCRIPTION</th>
<th>LIMITATIONS</th>
</tr>
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<tbody>
<tr>
<td>Civil registration and vital statistics (CRVS) system</td>
<td>Routine registration of births and deaths. Maternal mortality statistics should be obtained through vital registration data.</td>
<td>Even in a perfect system of complete coverage and identified causes of all deaths on standard medical certificates, maternal deaths may be missed or misclassified due to the absence of active case finding.</td>
</tr>
<tr>
<td>Household surveys</td>
<td>Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS) use the direct method of ‘sisterhood’ using household survey data. Information is obtained by interviewing a representative sample of respondents about the survival of all their siblings including details of age of all siblings, the number who are alive or dead, age at the time of death and year of death of those</td>
<td>Only pregnancy-related deaths, and not maternal deaths, are identified. Estimates have wide confidence intervals, thus reducing the scope for trend analysis. A retrospective, rather than a current, maternal mortality estimate of about five years prior to the survey and analysis is very complicated.</td>
</tr>
</tbody>
</table>
dead, and among sisters of reproductive age, how many died during pregnancy, delivery, or within two months of pregnancy.

**Census**

A limited number of questions can be added in a national census to produce estimates of maternal mortality. There are no sampling errors as the entire population of women are covered. Thus, it allows a more detailed break-down of the results such as trend analysis, geographic distribution, and social strata.

Identification of deaths in the household in a relatively short reference period of 1–2 years to provide recent maternal mortality estimates is possible. Census is conducted at 10-year intervals and therefore has limitations on the monitoring of maternal mortality. Census needs to be combined with verbal autopsy to obtain information on maternal mortality from pregnancy-related deaths.

Adjustment of results for characteristics such as completeness of death and birth statistics, and population structures, may be required to obtain reliable estimates.

**Reproductive-age mortality studies (RAMOS)**

Identification of, and investigation into, the causes of all deaths of women of reproductive age in a defined area or population using multiple sources of data such as interviews of family members, CRVS, healthcare facility records, burial records, and traditional birth attendants (TBAs).

This requires multiple sources of data and this itself is a limitation. Interviews and reviews of facilities are the only ways to estimate maternal death. In the absence of a reliable registration system, this is one way of obtaining MMR estimations. Inadequate identification of all maternal deaths or all deaths lead to underestimation, especially in predominantly home
delivery systems, number of births, the nature of live births may not be accurate.

**Verbal autopsy**

It is useful to assign cause of death through interviews with family members when medical certification does not include this information. Verbal autopsies may be conducted as part of a demographic surveillance system of research institutions for periodical collection of records of births and deaths among small populations such as a district. This may also be combined with household surveys or a census. There are special versions, with software to identify the diagnosis. Thus, verbal autopsy is a suitable, inexpensive method for routine use in populations in which no other method of assessing the cause of death exists.

Misclassifications of causes of deaths, early pregnancy maternal deaths, and ectopic or abortion-related deaths, are not identified. Accuracy depends upon the knowledge of the family members interviewed regarding causes of death, the interviewer’s skills, and the competence of physicians for diagnosis and coding. The detailed procedure involves long interviews and can be done only in research, but not for practical use. The population level use of this method with software helps to eliminate this limitation.

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A Commission on Information and Accountability for women’s and children’s health was formed by WHO in December 2010 (WHO, Commission on Information and Accountability for Women's and Children's Health, 2017). The aim was to develop a framework to ensure that promises of resources for women’s and children’s health are kept and that results are measured. For this purpose, a core set of indicators for results and resources were identified. An action plan was proposed to improve health information systems. Opportunities to improve access to information through information technology were also explored. The objectives of the Commission were related to the collection and sharing of data from reliable sources, results for global reporting, and the national purposes of oversight and accountability. Two working groups of professionals, one for resources and the other for results, assisted the Commission.
2.7 Maternal Mortality data-collection methods adopted in different countries

From the above discussions regarding the comparative merits and limitations of each method, accuracy, reliability, and validity depend on the method of data collection. CRVS, supported by a general 10-year census and CEMD may be good systems. As most countries follow the 10-year census system, a few additional questions in the format may give indicative data. CVRS provides further confirmation with specific data on maternal mortality. CEMD, as an occasional method, can be used as a cross-check to supplement CRVS data with more accurate estimates. Generally, developed countries have CRVS and some of them e.g. Wales, in the UK, have systematic CEMD as their sources so can provide more precise estimations. Developing countries are rapidly progressing towards more precise data-collection methods.

2.7.1 Maternal Mortality data-collection methods in South Sudan

South Sudan only became an independent state in 2011 and national sample surveys and census reports are mainly what exist. Healthcare records available e.g. the Sudan Household Health Survey (2006), the Health Facility Monthly reports (2010), the May Not Require Hospitalisation strategy* (2007), and the Strategic Management Information System* (2009) have been cited as data sources, in relation to maternal mortality reduction strategies in Sudan, (2011). Another source is the Department of Statistics, at the Juba Teaching Hospital (JTH), Juba, South Sudan (NBS, 2015). However, some of the latest reports available on this site are more than 10 years old. Many reports belonged to former Sudan, of which South Sudan was a part. The reliability and accuracy of these data may not be very high.

Furthermore, in this study we designed a questionnaire table for collecting data regarding maternal mortality information based on records and reports obtained from the Juba Teaching Hospital for the period 1986–2015 as in Appendix C.

2.8 Chapter summary

The aim of this research is to provide answers to address technical and scientific tasks regarding the prevalence and reduction of maternal mortality in South Sudan. Administrative
tasks were related to current policies, strategies, and their effectiveness, in terms of reduction in maternal mortality in the country over the years. Scientific questions were related to utilisation of available data to estimate and predict maternal mortality due to relevant causes and strategies. Predictability facilitates comparative evaluation of various strategies in reducing maternal mortality to the desired level and selects the best combinations of the most successful strategies. The available literature on the topic was critically and comprehensive reviewed to enable undertaking of these tasks in terms of systematic research and modelling approaches.

As a first step, the definitions of maternal mortality and related terms, frequently used in published works, were outlined, and the most suitable definitions applicable to this research were selected.

The extent of the problem at global, regional and country levels, reported mainly by the WHO and other international agencies were reviewed. Barring some exceptions, developed countries are already at very low levels of MMR <100. Some developing countries have also achieved this level. However, MMR levels in most developing countries are high to very high with very low probability of achieving the MDG2015 goal of MMR reduction. Examples of the strategies implemented by more successful developing countries show that the achievement of targets is not beyond the capability of developing nations. In this respect, the policies, strategies and processes adopted by developed countries for rapid reduction of MMR in the early 20th century shows the difference between developed and developing countries rather explicitly. However, instead of copying them, developing countries can try to adapt them to their respective contexts. Strategies such as antenatal screening and training of local nurses and midwives have doubtful effectiveness at least in some contexts. The merits and limitations of each strategy for specific country’s contexts require evaluation for adaptation.

South Sudan has one of the highest MMRs in the world, although it has significantly declined over the years. Some more specific policies and strategies are required for full effectiveness. The above comparison with developed and successful developing countries can provide a clue.
3 Methodology

3.1 Introduction
Methods of research differ considerably in the way they answer research questions and techniques used to analyse data. Since no methods are inherently better than others, the selection of methods is crucial for answering research questions appropriately. Understanding the relationship between the method and issues of the study is, therefore, vital in conducting social and scientific research. This chapter discusses the methods deployed to answer the research questions.

3.2 Research design
Methods of conducting research in general applied different research contexts are described in standard textbooks by Creswell (2013), Saunders et al. (2009), Sekaran and Bougie (2011), Greener (2011), Denscombe (2010), Crotty (1998), and many others. From these sources, the aspects related to this study are described below.

Generally, there are two approaches in research: qualitative and quantitative. For the qualitative approach, no numerical data are collected. Textual statements and other information are analysed using content or thematic analysis methods to derive conclusions. Very often, it is used as an additional method for increasing the validity of quantitative research. For the quantitative approach, numerical data are collected using experiments, questionnaire surveys, and other methods. There are established statistical data analysis procedures to process quantitative research data described in standard statistical text books. As this study involves
only mathematical/statistical modelling and optimising using quantitative data, only the quantitative approach was utilised.

3.3 Data collection and their sources
In this study we have designed a questionnaire table for data collection based on maternal mortality information and records and reports obtained from the Juba Teaching Hospital (JTH) as exhibited in Appendix C. The data available in various authentic sources such as the Department of Statistics at the Juba Teaching Hospital, the National Bureau of Statistics (NBS), the Ministry of Health (MoH), and the United Nations’ organisations (WHO, UNICEF, UNDP, UNFPA, USAIDs), and their partners, were used for this purpose. The period of collecting data was August to October 2015. Furthermore, the data collected were: the monthly, quarterly, and yearly data of maternal deaths and causes from the records available at JTH, and the yearly data of maternal death factors from the records of the NBS, MoH, and the UN agencies were used, from the period 1986–2015. Data also include socio-economic factors (SAB, GFR, and GDP) and physiological factors of direct and indirect causes that were used as independent variables (IVs) (See Eq. 3.15, Table 3.2, and Eq. 3.16).

3.3.1 List of data used in this project
- Maternal deaths reports and records, South Sudanese population by age group, and other related data;
- The most influential socio-economic factors for high maternal deaths and mortality rates in South Sudan, e.g. skilled attendance at births (SAB), general fertility rate (GFR), and gross domestic product (GDP);
- The most influential physiological causes for high maternal deaths and the MMR in South Sudan, e.g. haemorrhaging, hypertension, infections, unsafe abortion, indirect causes including (malaria, HIV/AIDs, anaemia, and heart disease); and
- Economic data on infrastructure aimed to reduce MMR.

3.3.2 Data cleaning and reliability tests – Elimination of outliers, Cronbach’s reliability test
In large-scale data, odd values that are either too low or too high compared to other values in the data set may occur. These are called outliers and can be detected by standard procedures from scatter plots or box plots with fences. Such values need to be removed ensure consistency
of data and its analysis. This procedure was adopted in the case of outliers found in this research.

Cronbach’s alpha (Cronbach, 1951) is a test for internal consistency indicating how closely a set of items are related to a group. The value of alpha increases when correlations between the items increase; it is calculated by the formula:

$$\alpha = \frac{k}{k-1} \left(1 - \frac{\sum_{i=1}^{k} \sigma_{y_i}^2}{\sigma_x^2}\right)$$  \hspace{1cm} (3.1)$$

Where \(K\) is the number of items such that \(X = Y_1 + Y_2 + Y_3 \ldots \ldots + Y_k\), \(\sigma^2_x\) is the variance of the observed total test scores, and \(\sigma^2_{y_i}\) is the variance of component \(i\) for the current sample of persons. Other simplified formulas are also used for estimations. Most of the statistical software has this estimation included in them. The theoretical value of Cronbach’s alpha ranges from 0 to 1, generally, a value of 0.7 is used as the minimum threshold value (Nunnally and Bernstein, 1994), although, sometimes lower values are also accepted. This test was employed in this work as the minimum threshold value was set at 0.7.

### 3.4 Research Process

The following steps were undertaken to investigate our research questions:

Identification of Key Performance Indicators (KPIs): In this step, the current recommended characteristics of maternal deaths and maternal mortality rates (MMRs), e.g. factors and causes, were reviewed as discussed earlier in the Systematic Review chapter.

The KPIs were then analysed through descriptive statistics, time series, and regression modelling.

### 3.5 Time series models

Time series plot and trend analysis are often used to observe patterns and structures in data over time. For this project we used Statistical Package R and Minitab to carry out trend analysis and model fitting to HIV+/AIDS, Non-HIV+/AIDS, and total maternal mortality rates (Makuei et al., 2016).
Assessing the temporal trends over the study period of 1986 to 2015 was one of the aims of the study. Time series analyses were carried out to monitor the trends.

Monthly data relating to HIV/AIDs maternal deaths, Non-HIV/AIDs maternal deaths, total maternal deaths (TMD), live births, and total deliveries were obtained from the Juba Teaching Hospital records.

Statistics summaries, including descriptive statistics, means, standard deviations and box plots, and time series were produced for yearly trends of HIV/AIDs, non-HIV/AIDs, and total MMR from 1986 to 2015. The analysis was carried out using statistical packages MINITAB version 17, R, and Excel.

A linear trend model was fitted to the three-time series of HIV+/AIDs MMR, non-HIV+/AIDs MMR, and total MMR. The model had the general form of

\[ Y_t = a + b*t \]  

(3.2)

Where \( Y_t \) is the mortality rate considered, \( b \) is the linear regression coefficient and \( t \) is the year.

### 3.6 Existing prediction models


In most reported research descriptive statistics, Pearson’s correlation, joint point regression, multivariate linear regression, and Poisson regression have been used to analyse mortality data. However, the last two were rejected by Hogan et al. (2010) in favour of spatial-temporal regression. In this project, the suitability of different regression models were tested in terms of fulfilling the aims and objectives of our research more efficiently, and the best models were selected. The aim of this study is to measure the effect of changes in the KPIs as well as changes in the health policies of the Government on MMRs in different regions of South Sudan during the study period.
The available estimation models in the literature were those of Hogan et al. (2010), Yang et al. (2014), WHO/UNICEF/UNFPA/World Bank/UNPD (2014), Hill et al. (2001), and Wilmoth et al. (2010). These models are discussed in the next sections. Here, only the merits and disadvantages are explained to justify the selection of models for this research.

3.6.1 The model used by Hogan et al. (2010)
Hogan et al. (2010) tested different regression methods and determined that spatial-temporal regression was the best for modelling maternal mortality. They used the model

\[ \ln (\mu_{a,i,t}) = \beta X_{a,i,t} + M_{a,i,t} + e \] (3.3)

Where \((\mu)\) is the maternal death rate, \((a)\) is age, \((i)\) is the country and \((t)\) is the year. \(X_{a,i,t}\) is a vector of covariates that explains variation in maternal mortality rates. Substantial variation in the MMR is not explained by these covariates, and the unexplained component \(M_{a,i,t}\) varies systematically over time and across countries. The parameter \((e)\) is an error term.

The model was estimated in two stages: first it was estimated as a simple linear model \(\beta X_{a,i,t}\) and then it was extended to use as a spatial-temporal local regression model to estimate \(M_{a,i,t}\). In this study, spatial factor \((i)\) represented different regions. However, due to a lack of separated data for individual regions, we used ‘\(i\)’ to represent the country, although GFR, GDP per capita, HIV prevalence, neo-natal mortality, female education, and lack of SAB were considered. The preliminary investigation indicated that, in South Sudan, lack of socio-economic factors (SAB, GFR, and GDP) and physiological causes, e.g. haemorrhaging, hypertension, sepsis (infections), prolonged (obstructed labour), unsafe abortion, and indirect cause, e.g. anaemia, malaria, HIV/AIDS, and heart disease, are key factors for high MMR. Therefore, the effect of these predictors as a strategic variable to reduce mortality was tested.

3.6.2 The model used by Yang et al. (2014)
Yang et al. (2014) used a Poisson regression model with a specified year and direct physiological causes of death as the covariate. This enabled one to obtain different equations for different years, possibly reflecting changes in health policies. Furthermore, the Poisson
regression model used by Hogan et al. (2010) is more useful in terms of mathematical simplicity and considering several causes of death. This model is given as:

$$\ln (\lambda) = \alpha + \beta_1 \text{year} + \beta_2 C_1 + \beta_3 C_2 + \beta_4 C_3 + \beta_5 C_4 + \beta_6 C_5$$

(3.4).

Where \(\lambda\) is the mortality rate, \(\beta\) values are coefficients, and \(C\) terms are causes of death. Using the Wald Chi-square test, the author identified five causes as being significant. In this research, deploying such equations for the period of study resulted in a set of equations with different numerical values for the coefficients. Therefore, the MMR trend over the study period reflected the impact of the government’s health policies. These were correlated with other factors such as GDP, women’s education, and skilled attendance. Adding more factors, this model can be adapted for our project and it seems more suitable than the earlier equation used by Hogan et al. (2010) for answering the research questions 7, 8, and 9.

When available data on maternal death cannot be directly used due to unreliability, the multiple regression model for target years could be used, according to the criteria in the WHO report regarding data quality. The regression model of the WHO has two parts: a linear regression to predict maternal deaths due to direct and indirect causes, except AIDS when pregnancy was a substantial aggravating factor. In the second part, AIDS-related maternal deaths out of total AIDS deaths, which can be categorised as indirect maternal deaths, are estimated. The model has five predictor variables: haemorrhage, sepsis (infections), prolonged (obstructed labour), unsafe abortion, and indirect causes (anaemia, malaria, HIV/AIDS, and heart disease) as in Eq. (3.16).

### 3.6.3 The model used by Hill et al. (2001)

The regression model developed by Hill et al. (2001) has the following form:

$$\ln(\frac{PMDF}{1-PMDF})=-8.289-0.0141*\text{TRATT}+1386*\ln \text{GFR}+0.682*\text{FSE} +0.719*\text{LASSAME}-0.684*\text{goodVR}-0.0197*\text{HIVAIDS}$$

(3.5).

The values in parenthesis are the corresponding t-values for coefficients. All variables except HIV/AIDS were significant at p=0.01.
Where GFR is general fertility rate, TRATT is the percentage of deliveries supported by a skilled attendant at the birth; HIV/AIDS effects are also included. If this does not need to be included, the term can be assigned a zero value. FSE is a dummy variable to identify the former socialist Europe. LASSAME is another dummy variable to identify Latin America, Africa, and West and South Asia. When estimating for a single country, the dummy variables can be assumed to be zero. PMDF is the proportion of maternal death in reproductive age. PMDF is estimated as

\[ PMDF = \frac{\text{Maternal deaths}}{\text{All deaths of females 15–49}} \] (3.6).

The specificity of the term to reproductive age makes PMDF a better and more reliable estimate than MMR. Expressing MMR in terms of proportion facilitates logic modelling. The estimated PMDF ranges between 0 and 1. The model can be applied for countries for which limited, and/or unreliable data are available, as in the case of South Sudan. The term PMDF needs to be explained in detail. It is related to the methods of data collection used in the equation. The proportion of deaths of women of a reproductive age due to maternal causes (PMDF), rather than the MMR, has several advantages. This enables modelling based on the logit \[ \text{[Ln (PMDF/[1-PMDF])]} \] in which there is no risk of predicted values falling outside that range. The predicted PMDF can then be applied to study the effect of many factors. The estimates will be consistent with other demographic information about maternal mortality. The PMDF estimate makes full use of the limited data. In the cases of countries with good overall death registration but uncertain cause-of-death reporting, a model-based estimate of PMDF can be applied to evaluate the effect of many factors by modelling only the distribution of such deaths by cause, not their number. In the case of sisterhood data, which is the most frequently available type of information about maternal mortality in high-mortality settings, it is more likely to provide more robust measures regarding PMDF than of MMR. A large majority of nationally representative data sets are on sister survival, mostly collected under the auspices of the Demographic and Health Surveys (DHS) programme. This can use sibling history to collect the basic data. Countries were classified into five groups based on the type of data available:
1. Forty-eight countries had reliable good registration systems with the cause of death well identified;
2. Eighteen countries had good registration systems, but with an uncertain cause of death;
3. For 28 countries, sisterhood estimates were used;
4. For 17 countries, data from reproductive age mortality studies were used; and
5. For four countries, other data sources were used.

3.6.4 The model used by Wilmoth et al. (2010)

Wilmoth and co-workers also used the PMDF approach like that of Hill et al. (2001). The Wilmoth model was as follows

\[
\log (\text{PMDF}_{\text{na}}) = \beta_0 + \beta_1 \log (\text{GDP}_i) + \beta_2 \log (\text{GFR}_i) + \beta_3 (\text{SAB}_i) + \alpha_{Cj(i)} + \alpha_{Rk(i)} + \log (1-a_i) + \varepsilon_i
\]  

(3.7).

Where PMDF was the proportion of maternal deaths among all deaths of women of reproductive age (15–49 years) in year i, country j, and geographical region k. GDP was the PPP-based per capita gross domestic product, GFR was the general fertility rate, the yearly number of births per 1,000 women of reproductive age, SAB was the proportion of mothers who had a skilled attendant at the birth, and \( \alpha_c \) and \( \alpha R \) were random intercepts for country j in the geographical region k, respectively. \( a_i \) was the proportion of AIDS deaths among total deaths of women of reproductive age, and \( \varepsilon_i \) was the error term.

Many later publications followed similar multiple linear regression with or without logarithmic transformation. The factors of interest were either inserted as an additional variable or as a variable replacing another less-important variable in the basic equation. The type of data available determined the exact application of these models. In the current work, it was a question whether these factors were adequate to predict South Sudan’s maternal deaths. We investigated the probability of collecting data on all variables possibly associated with maternal deaths as reported in the comprehensive literature review and carried out correlation and regression analysis. From these analyses, combinations of major variables, which explain most variations in maternal deaths, were selected and used in the optimal model. Predictive validity for the regression equation was carried out using standard statistical procedures.
The model is similar to the WHO model below with the same independent variables, but it differs in the number of predictors of variation terms. This equation is explained on c, r and ε terms to include more specifying contexts. The merits and limitations of the WHO equation for South Sudan, as explained later, apply here too. Ahmed et al. (2012) adopted the following from Wilmoth et al. (2010).

3.6.5 The WHO (2015) model

The model has been used for MMR estimation by WHO for South Sudan and other countries. Therefore, the efficacy of WHO model has been proved in more than one way. The following WHO model was used as the base model in this study.

\[
\log (PM)_{na} = a_i - b_1 \log(GDP_i) + b_2 \log(GFR_i) + b_3 \log(SAB_i) + c + r + \epsilon 
\]

(3.8).

where, PM is the proportion of maternal deaths among Non-HIV+/AIDs women of 15–49 age group; na is Non-HIV+/AIDs women of 15–49 age group, GDP per capita is a constant term, GFR is the general fertility rate as live births per women aged 15–49 years, SAB is skilled assistant (i.e. attendance) at birth, c is country variable, r is the regional variable and ε is the error variable.

In the case of South Sudan, GDP data for every year of the study period (1986–2015) is available. However, since GDP is a function of so many economic factors that are not easily adjusted, in this project, the average GDP has been used as a constant factor in the model.

The WHO method is used to estimate MMR for different nations including South Sudan (1980–2015); this facilitates comparison with other countries.

3.7 Development of new Maternal Death Estimation Models

The aim was to develop an effective model to estimate maternal deaths and mortality rates based on the characteristics of maternal deaths that had been recorded and reported between January 1986 and October 2015 at the Juba Teaching Hospital. The intention was to apply the model in rural – urban South Sudanese primary healthcare. The inadequacy of available models for application in a South Sudanese context prompted this work.

First the available models were tested for their suitability with respect to estimation and prediction of MMR. The factors included in various models were examined and compared to
identify the most influential factors and causes of MMR in South Sudan using their corresponding mean errors, the standard error of mean (SE Mean), and p-values. Based on this information, suitable multiple regression models were developed for the estimation and prediction of MMR. Also, models for the analysis of time-series trends and profile modelling were developed (Makuei et al., 2016).

Since the interest was in more than one variable, the model development was based on multivariate Log-linear regression and Poisson regression analyses models available in the literature. These models were applied on both significant economic factors and physiological causes of maternal deaths and mortality rate, respectively. The general model by the WHO was accepted with respect to factors affecting/predictors of MMR. The models were improved by including more significant factors and causes of maternal deaths and MMRs. The best subset approach was deployed to select the best performing subset of independent variables (IVs).

Descriptive statistics, correlation and regression analysis are used to determine the subset of predictors that explain an acceptable level of variations in mortality rates.

Demographic variables, such as GFR and SAB, and economic variables such as GDP were used. Physiological variables included haemorrhaging, sepsis, labour, unsafe abortion, and indirect causes. The descriptive statistics pertaining to these data were estimated.

3.8 Log linear regression and Poisson regression models

3.8.1 Multi-log linear regression model

Regression modelling is a useful technique to model the strength and direction of the relationship between one or more independent variables and a dependent variable. Multiple linear regressions have been utilised to gain insight into the predictors of MMR and the total of maternal deaths (TMD) rate per 100,000 live births. The independent variables that were input into the model include SAB, GFR, GDP, HIV/AIDS, maternal deaths, and non-HIV/AIDS maternal deaths.

In its general form, the linear regression model can be expressed as:

\[ Y = f(X_1, X_2, X_3, \ldots, X_p) + e, \]  

(3.9)
Where $Y$ is the response variable and $X_1, \ldots, X_p$ are $p$ predictors, $f$ is the function that links the predictors to the response and $e$ is error representing the discrepancy in the approximation (Montgomery et al., 2012; Makuei et al., 2016).

Several models for predicting MMR based on different predictors were developed by Makuei et al. (2016).

The Poisson regression model expresses the natural logarithm of the outcome or incident over a period as a linear function of a set of independent variables.

A measure of the goodness of fit for the Poisson regression model is acquired by using the deviance statistic of a partial model against a fuller model.

The Poisson and Log-linear model with explanatory $Y$ is written as

$$\log(Y) = \alpha + \beta X \quad (3.10)$$

When there is a set of independent variables, then the model becomes

$$\log(Y) = \alpha + \beta X \quad (3.11)$$

Where the row vector $\beta$ represents the coefficient factors and column vector $X$ represents the independent variables (IVs).

For the Poisson regression model, the link function $g$ is the natural logarithm and the model takes the following form:

$$\log(\mathbb{E}(Y)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_p \quad (3.12)$$

The model says that a linear combination of the predictor variables and parameters is related to the natural logarithm of the mean of the outcome variable. Thus, it could be useful for MMR analysis.

We used two-thirds of the yearly data, randomly selected to build the models. The models were then used to predict the remaining ten years’ data. The mean errors and the standard error of the mean (SE Mean) were used to compare the efficacy of the models. The analysis was carried out using Microsoft Excel, R, and Minitab version 17 (statistical-software).
The following two models were the predictive models that best described MMR (based on their respective mean error and SE Mean):

**Ln Regression Equation,** \( R^2 = 77.11\% \)

\[
\text{Ln (Non-HIV/AIDS)} = -20.8 - 8.30 \text{ Log (SAB)} + 8.10 \text{ Log (GFR)} + 5.12 \text{ Log (GDP)}
\]  
(3.13).

**Poisson Regression Equation,** \( R^2 = 79.75\% \), Deviance Statistics = 79.78%

Non-HIV+/AIDS MDs Rate Per 100,000 = \( \exp(Y') \)

\[
Y' = 4.227 - 0.3819 \text{ SAB} + 0.03237 \text{ GFR} + 0.002902 \text{ GDP}
\]  
(3.14).

Table 3.1 Shows error analysis for independent variables of SAB, GFR, and GDP

<table>
<thead>
<tr>
<th>Model</th>
<th>Mean Errors</th>
<th>SE Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Linear regression (1)</td>
<td>0.008</td>
<td>0.171</td>
</tr>
<tr>
<td>Poisson regression (2)</td>
<td>-216</td>
<td>316</td>
</tr>
</tbody>
</table>

Since mean errors and SE mean for the Log-linear regression is much less than Poisson regression, we can conclude that Log-linear regression outperforms Poisson regression in predicting the MMR for South Sudan.

**3.9 Optimisation using Solver Package and MATLAB**

Solver is part of a collection of commands to determine the minimum or maximum value of one cell by changing the values of other cells. With Solver, an optimal (minima or maxima) value could be found for the objective cell, subject to constraints or limits on the values of the predictors. In this study, equation (3.15) was used where Ln (SAB) and Ln (GFR) were optimised for given values of Ln (MMR), while keeping Ln (GDP) constant at 7.480 or GDP = 1,772, which is the average of Ln (GDP) over the period that data were collected.
3.10 Development of multivariate profile monitoring for socio-economic factors

Profile monitoring systems assist and help identify factors related to an observed phenomenon, assess the effect of changing any factor/s on the event, and predict the behaviour of the phenomenon under different situations. In many situations the quality and performance of a process may be better characterised and summarised by the relationship between the response (dependent) variable and one or more explanatory (independent) variables referred to as profile (Yin et al., 2006). The general parametric linear profile model relating the explanatory variables \( X_{i1}, X_{i2}, X_{i3}, \ldots, X_{pi} \) to the response \( Y_{ij} \), is presented by

\[
Y_{ij} = A_{0j} + A_{1j} X_{i1} + \ldots + A_{pj} + \epsilon_{ij}, \quad i=1, 2, 3\ldots n, \quad j = 1,2,3,\ldots k
\]

where \( A_{lj} \) (l = 0,1,2, ...., p) is the regression coefficient. The pair observation \( (X_{li}, Y_{ij}) \) is obtained in the jth random sample, where \( X_{li} \) is the ith design point \( (i = 1,2,3,\ldots, n) \) for the ith explanatory variable \( (i = 1,2,3,\ldots, p) \). It is assumed that the errors \( \epsilon_{ij} \) are independent, identically distributed (i.i. d.) variables with mean zero and variance \( \sigma_j^2 \), when the process is in control. Profile monitoring is used to understand and check the stability of this relationship over time (Kang et al., 2014).

Recently, many practitioners and researchers have used profile monitoring as a new sub-area of statistical process control. They have explored the application of profile monitoring in different disciplines and real life (Gupta S. K. et al., 2010; Gupta S., 2010; Hossenifard et al., 2012; Makuei, 2018). The application of profile monitoring is often focussed on processes with multiple quality characteristics and has also been extended to detect clusters of disease incidence and used in public health surveillance (Grigg et al., 2003; Grigg and Farewell, 2004; Chopra et al., 2009; Woodall et al., 2012; Montgomery, 2014; Woodall et al., 2014; Chou et al., 2016).

In this study, profile monitoring will be used to monitor MMR in South Sudan and assess its variation influenced by SAB and GFR, as described by Makuei et al. (2018).

In this research we have deployed Ln-regression and used 30 years of data to develop the following optimal prediction model for MMR.

\[
\ln (\text{MMR}) = -10 - 1.73 \ln (\text{SAB}) + 2.83 \ln (\text{GFR}) + 0.943 \ln (\text{GDP}) \quad (3.15).
\]
Equation (3.15) indicates that one-unit change in Ln (SAB) will reduce Ln (MMR) by 1.73 units, while one-unit change in Ln (GFR) and Ln (GDP) will increase Ln (MMR) by 2.83 and 0.943, respectively. As the relationships are logarithmic, the effect on actual values of MMR, in terms of maternal death per 100,000 live births, will be several times higher.

Compared to the reduction in MMR, which can be brought about by increasing Ln (SAB), the increasing effect of Ln (GFR) on Ln (MMR) is much higher (1.64 times) than that of Ln (SAB). Meanwhile, the effect that one-unit change in Ln (GDP) has on Ln (MMR) is (0.55 times) less than that of Ln (SAB), Makuei et al., (2018).

This result on GDP is aligned with the finding by Chou et al. (2016), who investigated the relationship between MMR and GDP in 79 developing countries and concluded that per capital GDP was one of the most significant predictor (-0.83) for MMR. Similarly in China, Feng et al. (2010) and Makuei (2016, 2018) observed that GDP per capita was a determinant of crude MMR with an adjusted rate ratio of 0.85–0.86 compared to a crude ratio of 0.66 by Feng et al. (2010). In their study Du et al. (2015), noted that reduction of MMR during the period 1996–2009 in the Guizhou province of China, was negatively related to GDP by Du et al. (2015). In our study, due to lack of the yearly GDP data in South Sudan, the GDP value was held constant at the average GDP over the period of 1986–2015 (Ln [GDP] = 7.480, or GDP= 1772).

3.11 Algorithm for the development of profile limits

Optimisation and time-series plots are often used to optimise and observe optimal values, patterns, and structures in data over time. The predictive equation developed for MMR in the previous step included the variables SAB, GFR, and GDP. We used this equation (3.15) for optimisation. The values of MMR were minimised by changing the values of SAB and GFR. GDP was held constant. The optimised values were then used to establish and plot lower and upper profile limits for the MMR, by Makuei et al., (2016, 2018).

Furthermore, to generate the lower and upper profile control limits for Ln (MMR), the proposed predictive models presented in equation (3.15) and the target minimum and
maximum levels of MMR proposed by the UN agencies; MMR = 70 and MMR = 140 have been used. It was recommended that these limits should be achieved by 2030. The current MMR in South Sudan is about 730 deaths per 100,000 live births.

The following steps were taken to generate the lower and upper profile limits for the yearly target values of SAB and GFR to reduce MMR to the target minimum and maximum levels recommended by UN agencies.

Step 1: To achieve MMR = 140 (the maximum recommended by the UN) from the current value of 730 by 2030; the government should reduce MMR by (approximately) 39 deaths per year (or Ln (MMR) by 0.11 per year). Therefore, the optimisation programme was deployed to obtain the optimal sets of Ln (SAB) and Ln (GFR) for a given Ln (MMR) with the starting value of Ln (730). The Ln (MMR) was then reduced by 0.11, year-on-year. The results in terms of Ln function and numerical values are presented in Tables 4.6 and 4.7. The profile limits are presented in Figures 4.10–4.10b, 4.11–4.11b, and 4.12a–4.12c. It should be noted that the constraint on Ln (SAB) is that it should be greater than the existing maximum (Ln (SAB) = 3.178), as our aim is to increase SAB year-on-year. While the constraint on Ln (GFR) was to be smaller than the existing current minimum value of 5.024, its value should be further reduced.

Step 2: To attain MMR = 70 (the minimum recommended by the UN) from the current value of 730 by 2030, step one was followed except that the target value was changed from 140 to 70 and the decrease in Ln (MMR) was 0.156 per year. The optimisation results in terms of Ln function and numerical values are presented in Tables 4.6 and 4.7. Therefore, developing health policies that target MMR, SAB, GFR profile limits outlined in Table 4.7 would ensure the successful accomplishment of the UN target MMR proposal.
3.12 Developing prediction models based on physiological causes

It is recommended in the literature that the Poisson regression model is the most suitable to describe MMR in terms of the physiological causes, because maternal deaths are countable data (Frome, 1983; Feng et al.; 2010), Loomis, Richardson, and Elliott, 2005; Rodriguez, 2007; Hogan et al., 2010).

As discussed in section 1.3, the top five significant physiological causes are: haemorrhaging, sepsis (infections), prolonged (obstructed labour), unsafe abortion and indirect causes, e.g. anaemia, malaria, and HIV/AIDS. Therefore, Poisson regression has been developed based on these physiological causes.

Since haemorrhaging and hypertension are medically related, the number of non-HIV+/AID maternal deaths (excluding hypertension per 100,000 live births) was modelled using Poisson regression.

To prevent bias towards the downward trend of MMR, two-thirds of the data was selected randomly based on the data partition using Bernoulli distribution with a probability of 0.67 and used to build the model. The remaining one-third of the data was used to assess the efficacy of the model. The analysis was conducted using R, Excel, and the statistical package Minitab version 17. The model, based on all the significant factors together with the corresponding summary, is presented below.

Table 3.2: Summary of the Poisson model based on the major significant causes R² = 97.43%

<table>
<thead>
<tr>
<th>Coef</th>
<th>SE Coef</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6.7833</td>
<td>0.0162</td>
</tr>
<tr>
<td>Haemorrhaging</td>
<td>0.000312</td>
<td>0.000032</td>
</tr>
<tr>
<td>Sepsis (infection)</td>
<td>0.000470</td>
<td>0.000029</td>
</tr>
<tr>
<td>Prolonged (Obstruction)</td>
<td>0.000479</td>
<td>0.000041</td>
</tr>
<tr>
<td>Unsafe Abortion</td>
<td>0.000631</td>
<td>0.000055</td>
</tr>
<tr>
<td>Indirect causes</td>
<td>0.000666</td>
<td>0.000033</td>
</tr>
</tbody>
</table>

Table 53
VIF <10 indicates the independent variable is significant.

Poisson Regression Equation, \( R^2 = 97.43 \):

\[
\text{Non-HIV+/AIDs MDs Rate per 1000} = \exp(Y') \\
Y' = 6.7833 + 0.000312 \text{ Haemorrhaging} + 0.00047 \text{ Sepsis (infection)} + 0.000479 \text{ Prolonged (Obstructed Labour)} + 0.000631 \text{ Unsafe Abortion} + 0.000666 \text{ indirect causes}
\]  

(3.16).

The model summary shows that the selected variables are responsible for 97.43% of the variation in MMR. It also indicates that all the independent variables (IVs) in the model are significant based on their variance inflation factor (VIF) values (less than ten \([10]\)) and p-values (p-<0.05)

### 3.12.1 Proposed reduced Poisson regression model based on haemorrhaging

Even though all the selected causes had a significant impact on the model according to their VIF, the literature review suggests that the most impacted cause is haemorrhaging (WHO, 2014; Makuei et al., 2016). Therefore, in this section we develop the reduced Poisson regression based on haemorrhaging only and the two significant physiological causes of haemorrhaging and unsafe abortion, which can be controlled by the Government regulating and enlightening people in South Sudan about the negative side of unsafe abortion. To overcome the lack of efficacy that may have been caused by the sample size, we repeated the sample random selection 30 times using Bernoulli distribution with a probability of 0.67 to select two thirds of the data to build the models and one third to assess the efficacy. The models fitted to individual samples together with their corresponding mean prediction errors and SE means are provided in Tables 3.3 and 3.5.

The proposed reduced model is based on the average coefficients of the 30 models:

\( B_0 = \text{average of } (B_0) \text{ and } B_1 = \text{average } (B_1). \)

The proposed reduced Poisson regression model based on haemorrhaging with \( R^2 = 90.27\% \) is presented in equation (3.17).

\[
\text{non-HIV/AIDs without Hyperten}_1 = \exp(Y') \\
Y' = 6.264924138 + 0.001505655 \text{ Haemorrhaging}_1
\]  

(3.17).
The results of the proposed reduced Poisson model indicate that haemorrhaging alone accounted for 90.27% of the variation in non-HIV+/AIDs maternal mortality rate (without hypertension – see Table 3.2).

The results of the analysis also indicate that haemorrhaging and unsafe abortion accounted for a significant proportion of non-HIV+/AIDs MDs without hypertension per 100,000 Live Births, \( R^2 = 92.68\% \) of variation in non-HIV+/AIDs MMR (see Table 3.5 and Eq.3.18).

\[
\text{Poisson Regression Equation, } R^2 = 92.68 \\
\text{non-HIV/AIDS without Hyperten}_1 = \exp(Y') \\
Y' = 5.567487 - 0.0161776834 \text{ Haemorrhaging} + 0.066157056 \text{ Unsafe Abortion} \quad (3.18).
\]

### 3.12.2 Assessing the efficacy of the proposed models

As explained above, the data provided by the WHO, UNICEF, UNFPA, the World Bank, and United Nations Population Division Maternal Mortality Estimation Inter-Agency Group in 1986-2015 was modified to obtain a yearly value instead of five-yearly values for independent variables (IVs) of SAB, GFR, and GDP. Further, there were physiological causes of independent variables (haemorrhaging, sepsis, prolonged, unsafe abortion, and indirect cause, e.g. anaemia, malaria HIV/AIDs, and heart disease). The models were then developed using a randomly selected two thirds of the data to overcome the reduction trend of the TMDs over the years (Makuei et al., 2016). The developed model was tested for its efficacy using the remaining one third of data.

To investigate the significant characteristics and identify the model with the fewest prediction errors, multi assessment criteria will be developed. The efficacy of the models will be assessed using accuracy criteria such as: bias and precision and the proportion of correct estimates within 10% of actual maternal death data.

### 3.12.3 Proposed reduced Poisson regression model based on haemorrhaging and unsafe abortion

Even though all the selected causes had a significant impact on the model according to their VIF, the literature’s review suggests that the most impacted cause is haemorrhaging (WHO, 2014; Makuei et al., 2016). Therefore, in this section we develop the reduced Poisson regression based only on haemorrhaging and the two significant physiological causes of
haemorrhaging and unsafe abortion. To overcome the lack of efficacy that may have been caused by the sample size, we repeated the sample random selection 30 times using Bernoulli distribution with a probability of 0.67 to select two-thirds of the data to build the models and one-third to assess the efficacy. The fitted models to individual sample together with their corresponding mean prediction errors and SE means are provided in Tables 3.3 and 3.5.

The proposed reduced models are based on the average coefficients of the 30 models, \( B_0 \) =average of \( (B_0) \) and \( B_1 \) = average \( (B_1) \).

The proposed reduced Poisson regression model based on haemorrhaging with \( R^2 = 90.27\% \) is presented in equation 3.19.

\[
\text{Non-HIV/AIDS without Hyperten}_1 = \exp(Y')
\]
\[
Y' = 6.264924138 + 0.001505655 \text{ Haemorrhaging}_1 \tag{3.19}
\]

The results of the proposed reduced Poisson model indicate that haemorrhaging alone accounted for 90.27% of the variation in non-HIV+/AIDs maternal mortality rate (without hypertension).
Table 3.3: The coefficients of the 30 generated models based on haemorrhaging only together with their corresponding mean and SE mean of prediction errors

<table>
<thead>
<tr>
<th>Model</th>
<th>$B_0$</th>
<th>$B_1$</th>
<th>SE Mean</th>
<th>Mean Error</th>
<th>$R^2$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>6.2170</td>
<td>0.001534</td>
<td>0.0140</td>
<td>75</td>
<td>87.28</td>
</tr>
<tr>
<td>Model 2</td>
<td>6.1057</td>
<td>0.001660</td>
<td>0.0133</td>
<td>9</td>
<td>89.90</td>
</tr>
<tr>
<td>Model 3</td>
<td>6.3251</td>
<td>0.001437</td>
<td>0.0126</td>
<td>-1</td>
<td>89.37</td>
</tr>
<tr>
<td>Model 4</td>
<td>6.1643</td>
<td>0.001616</td>
<td>0.0148</td>
<td>-55</td>
<td>91.45</td>
</tr>
<tr>
<td>Model 5</td>
<td>6.2828</td>
<td>0.001474</td>
<td>0.0140</td>
<td>41</td>
<td>89.04</td>
</tr>
<tr>
<td>Model 6</td>
<td>6.1663</td>
<td>0.001635</td>
<td>0.0440</td>
<td>-195</td>
<td>90.51</td>
</tr>
<tr>
<td>Model 7</td>
<td>6.3197</td>
<td>0.001453</td>
<td>0.0143</td>
<td>-49</td>
<td>89.85</td>
</tr>
<tr>
<td>Model 8</td>
<td>6.3274</td>
<td>0.001437</td>
<td>0.0156</td>
<td>-10</td>
<td>89.65</td>
</tr>
<tr>
<td>Model 9</td>
<td>6.2693</td>
<td>0.001492</td>
<td>0.0144</td>
<td>14</td>
<td>86.87</td>
</tr>
<tr>
<td>Model 10</td>
<td>6.2783</td>
<td>0.001462</td>
<td>0.0136</td>
<td>102</td>
<td>89.05</td>
</tr>
<tr>
<td>Model 11</td>
<td>6.4035</td>
<td>0.001405</td>
<td>0.0164</td>
<td>-197</td>
<td>91.56</td>
</tr>
<tr>
<td>Model 12</td>
<td>6.4629</td>
<td>0.001347</td>
<td>0.0175</td>
<td>-232</td>
<td>95.44</td>
</tr>
<tr>
<td>Model 13</td>
<td>6.2768</td>
<td>0.001534</td>
<td>0.0144</td>
<td>-287</td>
<td>90.99</td>
</tr>
<tr>
<td>Model 14</td>
<td>6.1070</td>
<td>0.001670</td>
<td>0.0157</td>
<td>-45</td>
<td>91.43</td>
</tr>
<tr>
<td>Model 15</td>
<td>6.2278</td>
<td>0.001580</td>
<td>0.0139</td>
<td>-216</td>
<td>90.03</td>
</tr>
<tr>
<td>Model 16</td>
<td>6.3152</td>
<td>0.001442</td>
<td>0.0132</td>
<td>24</td>
<td>89.21</td>
</tr>
<tr>
<td>Model 17</td>
<td>6.3997</td>
<td>0.001371</td>
<td>0.0142</td>
<td>-61</td>
<td>91.18</td>
</tr>
<tr>
<td>Model 18</td>
<td>6.2488</td>
<td>0.001496</td>
<td>0.0129</td>
<td>117</td>
<td>89.24</td>
</tr>
<tr>
<td>Model 19</td>
<td>6.1228</td>
<td>0.001660</td>
<td>0.0141</td>
<td>-79</td>
<td>88.50</td>
</tr>
<tr>
<td>Model 20</td>
<td>6.0960</td>
<td>0.001664</td>
<td>0.0138</td>
<td>46</td>
<td>90.27</td>
</tr>
<tr>
<td>Model 21</td>
<td>6.2833</td>
<td>0.001480</td>
<td>0.0151</td>
<td>1</td>
<td>89.77</td>
</tr>
<tr>
<td>Model 22</td>
<td>6.2237</td>
<td>0.001516</td>
<td>0.0134</td>
<td>152</td>
<td>91.09</td>
</tr>
<tr>
<td>Model 23</td>
<td>6.2842</td>
<td>0.001460</td>
<td>0.0144</td>
<td>93</td>
<td>89.64</td>
</tr>
<tr>
<td>Model 24</td>
<td>6.4349</td>
<td>0.001352</td>
<td>0.0137</td>
<td>-165</td>
<td>89.22</td>
</tr>
<tr>
<td>Model 25</td>
<td>6.4364</td>
<td>0.001336</td>
<td>0.0148</td>
<td>-67</td>
<td>93.96</td>
</tr>
<tr>
<td>Model 26</td>
<td>6.2014</td>
<td>0.001580</td>
<td>0.0155</td>
<td>-96</td>
<td>90.95</td>
</tr>
<tr>
<td>Model 27</td>
<td>6.1016</td>
<td>0.001682</td>
<td>0.0149</td>
<td>-92</td>
<td>90.27</td>
</tr>
<tr>
<td>Model 28</td>
<td>6.2170</td>
<td>0.001518</td>
<td>0.0151</td>
<td>136</td>
<td>91.53</td>
</tr>
<tr>
<td>Model 29</td>
<td>6.2441</td>
<td>0.001506</td>
<td>0.0131</td>
<td>85</td>
<td>90.23</td>
</tr>
<tr>
<td>Model 30</td>
<td>6.3568</td>
<td>0.001399</td>
<td>0.0136</td>
<td>25</td>
<td>92.48</td>
</tr>
</tbody>
</table>

| Sample Mean(μ) | 6.264924138 | 0.001505655 | 0.015389655 | -34.55 | 90.44   |

Table 3.4 presents the summary of the prediction errors for the proposed reduced Poisson model based on haemorrhaging only
Table 3.4: Prediction errors

<table>
<thead>
<tr>
<th>Model</th>
<th>B₀</th>
<th>B₁</th>
<th>SE Mean</th>
<th>Mean Error</th>
<th>R² %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poisson regression</td>
<td>6.264924138</td>
<td>0.001505655</td>
<td>0.0151</td>
<td>-34.55172414</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.5: The coefficients of the 30 generated models based on haemorrhaging and unsafe abortion together with their corresponding mean and SE mean of prediction errors

<table>
<thead>
<tr>
<th>Model</th>
<th>B₀</th>
<th>B₁</th>
<th>SE Mean</th>
<th>Mean Error</th>
<th>R² %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>5.4061</td>
<td>-0.0023788</td>
<td>0.06257</td>
<td>0.0230</td>
<td>-0.8769</td>
</tr>
<tr>
<td>Model 2</td>
<td>5.6403</td>
<td>-0.0221698</td>
<td>0.08886</td>
<td>0.0225</td>
<td>-0.3471</td>
</tr>
<tr>
<td>Model 3</td>
<td>5.4061</td>
<td>-0.0023796</td>
<td>0.012679789</td>
<td>0.0170</td>
<td>-0.415</td>
</tr>
<tr>
<td>Model 4</td>
<td>5.2981</td>
<td>-0.0179986</td>
<td>0.07430974</td>
<td>0.0257</td>
<td>-0.62307</td>
</tr>
<tr>
<td>Model 5</td>
<td>5.3897</td>
<td>-0.0178987</td>
<td>0.06380989</td>
<td>0.0230</td>
<td>-0.77</td>
</tr>
<tr>
<td>Model 6</td>
<td>5.3075</td>
<td>-0.0164988</td>
<td>0.06630879</td>
<td>0.0253</td>
<td>-0.55</td>
</tr>
<tr>
<td>Model 7</td>
<td>5.3075</td>
<td>-0.0164998</td>
<td>0.06130875</td>
<td>0.0253</td>
<td>-0.55</td>
</tr>
<tr>
<td>Model 8</td>
<td>5.6066</td>
<td>-0.0225988</td>
<td>0.09025967</td>
<td>0.0183</td>
<td>-0.57059</td>
</tr>
<tr>
<td>Model 9</td>
<td>5.3075</td>
<td>-0.0164978</td>
<td>0.06937865</td>
<td>0.0253</td>
<td>-0.55</td>
</tr>
<tr>
<td>Model 10</td>
<td>5.3897</td>
<td>-0.0178997</td>
<td>0.07386975</td>
<td>0.0230</td>
<td>-0.7667</td>
</tr>
<tr>
<td>Model 11</td>
<td>5.3908</td>
<td>-0.0181979</td>
<td>0.0749785</td>
<td>0.0229</td>
<td>-0.7667</td>
</tr>
<tr>
<td>Model 12</td>
<td>5.6213</td>
<td>-0.0193998</td>
<td>0.0404975</td>
<td>0.0176</td>
<td>-0.64118</td>
</tr>
<tr>
<td>Model 13</td>
<td>5.2881</td>
<td>-0.0179988</td>
<td>0.07507897</td>
<td>0.0257</td>
<td>-0.62308</td>
</tr>
<tr>
<td>Model 14</td>
<td>5.3897</td>
<td>-0.0178987</td>
<td>0.0738657</td>
<td>0.0230</td>
<td>-0.7667</td>
</tr>
<tr>
<td>Model 15</td>
<td>5.6213</td>
<td>-0.0122990</td>
<td>0.04049095</td>
<td>0.0176</td>
<td>-0.64118</td>
</tr>
<tr>
<td>Model 16</td>
<td>5.2981</td>
<td>-0.0179977</td>
<td>0.07500978</td>
<td>0.0257</td>
<td>-0.62308</td>
</tr>
<tr>
<td>Model 17</td>
<td>5.3897</td>
<td>-0.0178969</td>
<td>0.07490776</td>
<td>0.0230</td>
<td>-0.7667</td>
</tr>
<tr>
<td>Model 18</td>
<td>5.3908</td>
<td>-0.0181979</td>
<td>0.07500997</td>
<td>0.0229</td>
<td>-0.7667</td>
</tr>
<tr>
<td>Model 19</td>
<td>5.2981</td>
<td>-0.0135898</td>
<td>0.05530875</td>
<td>0.0257</td>
<td>-0.62308</td>
</tr>
<tr>
<td>Model 20</td>
<td>5.8944</td>
<td>-0.0121969</td>
<td>0.05030876</td>
<td>0.0217</td>
<td>0.2556</td>
</tr>
<tr>
<td>Model 21</td>
<td>5.8528</td>
<td>-0.0121979</td>
<td>0.04970897</td>
<td>0.0195</td>
<td>-0.03333</td>
</tr>
<tr>
<td>Model 22</td>
<td>5.9706</td>
<td>-0.0121999</td>
<td>0.049708567</td>
<td>0.0257</td>
<td>0.08571</td>
</tr>
<tr>
<td>Model 23</td>
<td>5.9706</td>
<td>-0.0138784</td>
<td>0.05530789</td>
<td>0.0257</td>
<td>0.08571</td>
</tr>
<tr>
<td>Model 24</td>
<td>5.8944</td>
<td>-0.0225972</td>
<td>0.090207658</td>
<td>0.0217</td>
<td>0.2556</td>
</tr>
<tr>
<td>Model 25</td>
<td>5.6066</td>
<td>-0.0121971</td>
<td>0.090205674</td>
<td>0.0183</td>
<td>-0.570588</td>
</tr>
<tr>
<td>Model 26</td>
<td>5.9706</td>
<td>-0.0192897</td>
<td>0.07670786</td>
<td>0.0257</td>
<td>0.08571</td>
</tr>
<tr>
<td>Model 27</td>
<td>5.4061</td>
<td>-0.0121861</td>
<td>0.04470875</td>
<td>0.0225</td>
<td>-0.8769</td>
</tr>
<tr>
<td>Model 28</td>
<td>5.8811</td>
<td>-0.0121977</td>
<td>0.05020786</td>
<td>0.0218</td>
<td>0.2</td>
</tr>
<tr>
<td>Model 29</td>
<td>5.9706</td>
<td>-0.0220981</td>
<td>0.08960798</td>
<td>0.0257</td>
<td>0.0851</td>
</tr>
<tr>
<td>Model 30</td>
<td>5.8528</td>
<td>-0.0279951</td>
<td>0.089609567</td>
<td>0.0195</td>
<td>-0.03333</td>
</tr>
<tr>
<td>Sample Mean (B₀)</td>
<td>5.567487</td>
<td>-0.0161777683</td>
<td>0.066157056</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The final model was based on B₀ = average of (B₀), B₁ = average (B₁) and B₂ = average (B₂)

30 models together with their corresponding mean errors and SE means are given in Table above

The results of the analysis indicate that Haemorrhaging and Unsafe Abortion accounted for a significant proportion of non-HIV+/AIDs MDs without Hypertension per 100,000 Live Births, R² = 92.68%. None of the other independent variables featured in the final model.

Poisson Regression Equation, R² = 92.68
Non-HIV/AIDS without Hyperten_1 = \exp(Y')

\[ Y' = 5.567487 - 0.0161776834 \text{Haemorrhaging} + 0.066157056\text{Unsafe Abortion} \quad (3.20). \]

### 3.13 Chapter summary

The methodologies followed in this research are described in this chapter. Various models described in the comprehensive literature study were examined for applicability in South Sudanese context. As none of them were fully suitable, alternative models for estimation and prediction of MMR and time-series analysis were developed and validated using standard procedures. Further, a multivariate profile monitoring algorithm was developed to monitor the MMR in South Sudan. The results obtained are described in Chapter 4.
4 RESULTS

4.1 Introduction
This chapter presents statistical results based on the methods outlined in the previous chapter.

4.2 Trend Analysis
Time-series plots and summary statistics including means, standard deviations, and box plots have been produced for yearly levels of HIV+/AIDs maternal deaths, non-HIV+/AIDs maternal deaths, and total MMR from 1986 to 2015, and are presented in Table 4.1 and Figures 4.1 and 4.2.

A linear-trend model was fitted to each individual time series of HIV+/AIDs MMR, non-HIV+/AIDs MMR, and the total MMR. The fitted models are presented in Table 4.2 and Figures 4.3–4.6. The slopes of the models were compared to the slope of the total maternal mortality rate model.

The results in Table 4.1 and Figures 4.1–4.6 indicate that the mean HIV+/AIDs MMR for the period of 1986 to 2015 were almost one third of the total MMR. The balance of the MMR was attributed to non-HIV+/AIDs-related causes. Furthermore, the results of this analysis indicate that there has been 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 compared to non-HIV+/AIDs maternal mortality rate (Makuei et al., 2016). Therefore, there is a possibility that soon, the HIV+/AIDs-based MMR will be a bigger contributor to the overall MMR compared to non-HIV+/AIDs based MMR, if nothing has been done.
The summary statistics for the three-time series by year groupings are shown in Table 4.1 with the comparison graph in Figure 4.3.

Table 4.1: Summary statistics for yearly HIV+/AIDs, Non-HIV+/AIDs and total maternal mortality rate by year grouping

<table>
<thead>
<tr>
<th>Variable</th>
<th>Year</th>
<th>N</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV+/AIDs MMR</td>
<td>1986-2008</td>
<td>23</td>
<td>1236.46</td>
<td>504.41</td>
<td>1950.81</td>
<td>468.66</td>
</tr>
<tr>
<td></td>
<td>2009-2015</td>
<td>7</td>
<td>285.67</td>
<td>145.31</td>
<td>434.45</td>
<td>87.02</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>30</td>
<td>1014.61</td>
<td>145.31</td>
<td>1950.81</td>
<td>579.21</td>
</tr>
<tr>
<td>Non-HIV+/AIDs MMR</td>
<td>1986-2008</td>
<td>23</td>
<td>2816.27</td>
<td>1051.71</td>
<td>5042.02</td>
<td>1246.42</td>
</tr>
<tr>
<td></td>
<td>2009-2015</td>
<td>7</td>
<td>793.64</td>
<td>121.09</td>
<td>2990.03</td>
<td>1018.60</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>30</td>
<td>2344.32</td>
<td>121.09</td>
<td>5042.02</td>
<td>1466.39</td>
</tr>
<tr>
<td>Total MMR</td>
<td>1986-2008</td>
<td>23</td>
<td>4052.73</td>
<td>1752.85</td>
<td>5602.24</td>
<td>1103.99</td>
</tr>
<tr>
<td></td>
<td>2009-2015</td>
<td>7</td>
<td>1079.31</td>
<td>266.41</td>
<td>3424.48</td>
<td>1087.05</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>30</td>
<td>3358.94</td>
<td>266.41</td>
<td>5602.24</td>
<td>1674.88</td>
</tr>
</tbody>
</table>

Figure 4.1: Comparison of HIV+/AIDs, Non- HIV+/AIDs and total MMR by Year Grouping

The results in the Table 4.1 indicate that between the periods of (1986 -- 2008) and (2009 – 2015) the decline in HIV+/AIDs maternal mortality rate has been higher (28.3%) compared with the decline in the Non-HIV+/AIDs MMR (60.2%). This confirms the findings from the trend analysis which are presented in Figures 4.2 and 4.3. However, the numerical and
graphical comparisons given in Table 4.1 and Figure 4.1 show a significant reduction in mortality rate during the period 2009–2015.

Figure 4.2: Box plots for yearly HIV+/AIDs, non-HIV+/AIDs and total MMR during the period 1986–2015.

Table 4.2: Time-series models fitted to yearly HIV+/AIDs, non-HIV+/AIDs and total MMR

<table>
<thead>
<tr>
<th>Time Series</th>
<th>Linear Trend Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV+/AIDs MMR</td>
<td>Yt = 1337 - 20.8t</td>
</tr>
<tr>
<td>Non-HIV+/AIDs MMR</td>
<td>Yt = 4585 - 144.6t</td>
</tr>
<tr>
<td>Total MMR</td>
<td>Yt = 5992 - 165.3t</td>
</tr>
</tbody>
</table>

Plot 4.3 presents the three-time series, which are shown in Figure 4.3.
Figure 4.3: Trend Comparisons for yearly HIV+/AIDs, non-HIV+/AIDs, and total maternal mortality during the period 1986–2015

Figure 4.4: Trend analysis for yearly HIV+/AIDs MMR during the period 1986–2015

Figure 4.5: Trend analysis for yearly non-HIV+/AIDs MMR during the period 1986–2015
Figure 4.6: Trend analysis for total yearly maternal mortality rate during the period 1986–2015 Table 4.2 and Figures 4.4–4.6 indicate that the HIV+/AIDs MMR linear trend model has a slope of 20.8, the non-HIV+/AIDs MMR linear trend model has a slope of 144.6, and the Total MMR linear trend model has a slope of 165.3. These results indicate that the difference between the slopes of the non-HIV+/AIDs MMR and the Total MMR series is much less than the difference between the slopes of the HIV+/AIDs MMR and the Total MMR series. Taking into consideration the declining trend in the three-time series and the differences in the slopes of non-HIV+/AIDs MMR and the Total MMR and HIV+/AIDs MMR and the Total MMR, it would be safe to conclude that the HIV+/AIDs MMR is declining at a much slower rate compared to the non-HIV+/AIDs MMR

4.3 Development of predicting models for MMR in terms of healthcare Key Performance Indicators (KPIs)

To develop the predicting models, we first summarise the data on the economical KPIs.

4.3.1 Healthcare indices-related predictors of MMR

The mean and standard deviation of the four significant economic predictors over the entire period of 1986–2015 are summarised in Table 4.1.
Table 4.3: Summary Statistics for the dependent and independent variables in this study during the period 1986–2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-HIV+/AIDs Maternal Deaths</td>
<td>28.27</td>
<td>19.90</td>
</tr>
<tr>
<td>Skilled Attendant at Birth (SAB) (% of Births)</td>
<td>15.98</td>
<td>2.28</td>
</tr>
<tr>
<td>General Fertility Rate (GFR) (Per 1,000 Women of Reproductive Age)</td>
<td>179.90</td>
<td>22.67</td>
</tr>
<tr>
<td>Gross Domestic Product (GDP) (Per Capita in USD)</td>
<td>1256.43</td>
<td>360.74</td>
</tr>
</tbody>
</table>

4.3.2 Impact of independent variables SAB and GFR on MMR

A Ln regression was fitted to the data to predict the number of non-HIV+/AIDs Maternal Deaths between 1986 and 2015 based on the SAB, GFR, and GDP using all the data.

\[
\text{Ln (MMR)} = -1.63 -0.06 \times \text{Ln (SAB)} + 0.02 \times \text{Ln (GFR)} +0.002 \times \text{Ln (GDP)}
\] (4.1).

Statistical analysis indicates that, for a unit increases in Ln (GFR), Ln (Non-HIV+/AIDs) maternal deaths will increase by .02. Also, for a unit increases in Ln (GDP), Ln (non-HIV+/AIDs) MMR will decrease by.002. Further, for a unit increase in Ln (SAB), Ln (Non-HIV+/AIDs) will decrease by -0.06, (see Table 4.4).

Table 4.4: Parameter estimates for the Log-regression model using all the data.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>B</th>
<th>SE</th>
<th>95% Wald CI</th>
<th>Hypothesis Test</th>
<th>Exp(B)</th>
<th>95% Wald CI for Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>LB</td>
<td>UB</td>
<td>Wald</td>
<td>df</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>-1.63</td>
<td>2.4722</td>
<td>-</td>
<td>3.215</td>
<td>0.435</td>
<td>1</td>
</tr>
<tr>
<td>SAB</td>
<td>-0.06</td>
<td>0.0805</td>
<td>-0.218</td>
<td>0.098</td>
<td>0.552</td>
<td>1</td>
</tr>
<tr>
<td>GFR</td>
<td>0.02</td>
<td>0.0075</td>
<td>0.005</td>
<td>0.034</td>
<td>6.945</td>
<td>1</td>
</tr>
<tr>
<td>GDP</td>
<td>0.002</td>
<td>0.0003</td>
<td>0.001</td>
<td>0.002</td>
<td>36.579</td>
<td>1</td>
</tr>
<tr>
<td>(Scale)</td>
<td>1a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fixed at the displayed value

As mentioned earlier, to establish Log-linear and Poisson regression models, we randomly selected two-thirds of the yearly data to build the predicting models. The models were then
used to predict the remaining ten years’ data for Total non-HIV+/AIDs Maternal Death (TMDs). The analysis was carried out using Microsoft Excel, R and Minitab version 17 statistical packages.

The results of the prediction errors are presented in Table 4.5, and Figures 4.7 and 4.8. Table 4.5 indicates that the mean error percentage and the SE Mean for the Ln linear regression are much smaller than Poisson regression. Therefore, we can conclude that Ln linear regression outperforms Poisson regression in predicting the morality data for South Sudan.

The results of error analyses are forming the following regression models:

**Ln Linear Regression Equation, \( R^2 = 77.11\% \)**

\[
\text{Ln (Non-HIV/AIDS)} = -20.8 - 8.30 \log \text{(SAB)} + 8.10 \log \text{(GFR)} + 5.12 \log \text{(GDP)}
\] (4.2).

**Poisson Regression Equation, \( R^2 = 79.75\% \)**

\[
\text{Non-HIV+/AIDs MDs Rate Per 1000} = \exp(Y')
\]

\[
Y' = 4.227 - 0.3819 \text{SAB} + 0.03237 \text{GFR} + 0.002902 \text{GDP}
\] (4.3).

**Table 4.5:** Presents error analysis based on the two-thirds and one-third of yearly data for independent variables (IVs) of SAB, GFR, and GDP.

<table>
<thead>
<tr>
<th>Model</th>
<th>Mean Errors</th>
<th>SE Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Linear regression (1)</td>
<td>0.008</td>
<td>0.171</td>
</tr>
<tr>
<td>Poisson regression (2)</td>
<td>-216</td>
<td>316</td>
</tr>
</tbody>
</table>

The dependent variable: Non-HIV+/AIDs MDs (TMDs)

![Figure 4.7](image)

Figure 4.7: Presents actual and estimated values of one-third of non-HIV/AIDs MDs based on the independent variables SAB, GFR, and GDP, using Ln linear regression.
4.4 Development of profile limits:

The following prediction model is used to develop profile limits for MMR in terms of SAB and GFR.

\[
\ln(MMR) = -10 - 1.73 \ln(SAB) + 2.83 \ln(GFR) + 0.943 \ln(GDP) \quad (4.4)
\]

In this research, MATLAB, Minitab, R and Excel Solver are used to obtain optimal values of \(\ln(SAB)\) and \(\ln(GFR)\) for a given value of \(\ln(MMR)\) while keeping \(\ln(GDP)\) constants at 7.480 (GDP=1772), which is the average of \(\ln(GDP)\) during the period that the data were collected. Furthermore, to generate the lower and upper profile control limits for \(\ln(MMR)\), the proposed predictive models presented in equation (4.4) and the target minimum and maximum levels of MMR proposed by the UN agencies; MMR = 70 and MMR = 140 have been used. It was recommended that these limits should be achieved by 2030. The current MMR in South Sudan is around 730 deaths per 100,000 live births.

The following steps were taken to generate the lower and upper profile limits for yearly target values of SAB and GFR to reduce MMR to the target minimum and maximum levels recommended by UN agencies.

**Step 1:** To achieve MMR = 140 (the maximum recommended by the UN agencies) from the current value of 730 by 2030; the Government should reduce MMR by (approximately) 39 deaths per year (or \(\ln(MMR)\) by 0.11 per year). Therefore, the optimisation programme was deployed to obtain the optimal sets of \(\ln(SAB)\) and \(\ln(GFR)\) for a given \(\ln(MMR)\) with the
starting value of $\ln(730)$. The $\ln$ (MMR) was then reduced by 0.11, year-on-year. The results in terms of $\ln$ function and numerical values are presented in Tables 4.6 and 4.7. The profile limits are presented in Figures 4.9–4.11, 4.12–4.12b, 4.13–4.13b, and 4.15a–4.15c. It should be noted that the constraint on $\ln$ (SAB) is that, it should be greater than the existing maximum ($\ln \{SAB\} = 3.178$), as our aim is to increase SAB year-on-year. While the constraint on $\ln$ (GFR) was to be smaller than the existing current minimum value of 5.024, its value should be further reduced. The results presented in the first three columns of Table 4.7 show that to reduce MMR from 730 to 140 by the year 2030, the Government should increase SAB from the current value of 19 to 50, while the value of GFR should be reduced from the current value of 175 to 97. The five-year break-up values are highlighted in Table 4.7. Thus, for the year 2020, South Sudan should target a reduction in MMR from the current value of 730 to 421 by simultaneously increasing SAB from 19 to 26 and reducing GFR from 175 to 144. By the year 2025, the country should target to have declined MMR from the present value of 730 to 243 by simultaneously increasing SAB from 19 to 36 and reducing GFR from 175 to 118. Moreover, by the year 2030, the Government and stakeholders should target MMR reduction from the current value of 730 to 140 by increasing SAB from 19 to 50 and reducing GFR from 175 to 97.

Step 2: To attain $\text{MMR} = 70$ (the minimum recommended by the UN agencies) from the current value of 730 by 2030, step one was followed except that the target value was changed from 140 to 70 and the reduction in $\ln$ (MMR) was 0.156 per year. The optimisation results in terms of $\ln$ function and numerical values are presented in Tables 4.6 and 4.7. The last three columns of Table 4.7 show that to achieve MMR of 70 by the year 2030, the authorities in South Sudan should reduce GFR from 175 to 75, while increasing SAB from the current value of 19 to 76. The target statistics for 2020 would be MMR=334 with SAB being increased to 30 and GFR reduced to 133. By the year 2025 the government and partners should target to have MMR decreased from the present value of 730 to 153, by simultaneously increasing SAB from 19 to 47 and decreasing GFR from 175 to 101. Therefore, developing health policies that target MMR, the SAB and GFR profile limits outlined in Table 4.7 would ensure the successful accomplishment of the UN target maternal mortality rate proposal.

Statistical analysis shows that increasing SAB by 1.22% per year would decrease MMR by 1.4% (95% CI [0.4%–5%]) while decreasing GFR by 1.22% per year would decrease MMR by 1.8% (95% CI [0.5%–6.26%]), when the GDP is held constant. 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. These findings confirm that increasing SAB and reducing GFR can result in minimising MMR.

The optimisation procedures to attain optimal max Ln (SAB) and min Ln (GFR) values for a given Ln (MMR) level is outlined in the algorithm presented in Figure 4.9, below based on the Equation (4.4)

Profile monitoring algorithmic

\[ \text{Ln (MMR)} = -10 - 1.73 \times \text{Ln (SAB)} + 2.83 \times \text{Ln (GFR)} + 0.943 \times \text{Ln (GDP)} \]  \hspace{1cm} (4.4)

| No | Stop and record max Ln (SAB), min Ln (GFR) and min Ln (MMR) |
| Yes | New Ln (SAB) = Ln (SAB) - Ln (SAB inc)/2 |
|     | New Ln (GFR) = Ln (GFR) + Ln (GFR dec)/2 |
| Ln (MMR) < Ln (Target UN MMR) | New Ln (SAB) =LN (SAB) - LN (SAB inc)/2 |
| Ln (MMR) > Ln (Target UN MMR) | LN (SAB) = initial (SAB) + LN (SAB inc) |
| Ln (GFR) = initial (GFR) - Ln (GFR red) |

Figure 4.9: Calculation of optimal max Ln (SAB) and min Ln (GFR) values for a given MMR level
The following are Ln linear plots for Min Ln (MMR), Max Ln (SAB) and Min Ln (GFR) per 100,000 live births per year.
Figure 4.10: Lower, middle, and upper profile limits for Ln (MMR), Ln (SAB) and Ln (GFR). Ln (MMR) is decreasing by 0.11, 0.129, and 0.156 per year, respectively, to achieve UN-recommended upper, middle, and lower limits of 140, 105, and 70.
Table 4.7: Summary for the optimal values of SAB and GFR for a given MMR when GDP is constant at 1772.

<table>
<thead>
<tr>
<th>Year</th>
<th>MMR Target 140</th>
<th>MMR Target 105</th>
<th>MMR Target 70</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min MMR based on changing per a year</td>
<td>Max values of SAB</td>
<td>Min values of GFR</td>
</tr>
<tr>
<td>2015</td>
<td>730</td>
<td>19</td>
<td>175</td>
</tr>
<tr>
<td>2016</td>
<td>654</td>
<td>20</td>
<td>168</td>
</tr>
<tr>
<td>2017</td>
<td>586</td>
<td>22</td>
<td>162</td>
</tr>
<tr>
<td>2018</td>
<td>525</td>
<td>23</td>
<td>155</td>
</tr>
<tr>
<td>2019</td>
<td>470</td>
<td>25</td>
<td>150</td>
</tr>
<tr>
<td>2020</td>
<td>421</td>
<td>26</td>
<td>144</td>
</tr>
<tr>
<td>2021</td>
<td>377</td>
<td>28</td>
<td>138</td>
</tr>
<tr>
<td>2022</td>
<td>338</td>
<td>30</td>
<td>146</td>
</tr>
<tr>
<td>2023</td>
<td>302</td>
<td>32</td>
<td>128</td>
</tr>
<tr>
<td>2024</td>
<td>271</td>
<td>34</td>
<td>123</td>
</tr>
<tr>
<td>2025</td>
<td>243</td>
<td>36</td>
<td>118</td>
</tr>
<tr>
<td>2026</td>
<td>217</td>
<td>39</td>
<td>114</td>
</tr>
<tr>
<td>2027</td>
<td>195</td>
<td>41</td>
<td>110</td>
</tr>
<tr>
<td>2028</td>
<td>175</td>
<td>44</td>
<td>105</td>
</tr>
<tr>
<td>2029</td>
<td>156</td>
<td>47</td>
<td>101</td>
</tr>
<tr>
<td>2030</td>
<td>140</td>
<td>50</td>
<td>97</td>
</tr>
</tbody>
</table>

The target MMR for 2030 is 140 in the first three columns, 105 in the second three columns, and 70 in the last three columns.
Figure 4.11 presents actual optimal values of yearly MMR, SAB, and GFR to achieve UN targets of 70 and 140 by 2030.
Figure 4.12: Lower and upper profile limits for Ln (MMR), Ln (SAB), and Ln (GFR). Ln (MMR) is decreasing by 0.11 and 0.156 per year, respectively, to achieve UN-recommended upper and lower limits of 140 and 70.

Figure 4.12a: Profile limits for Ln (MMR), Ln (SAB) and Ln (GFR). The target MMR for 2030 is 140.
Figure 4.12b: Profile limits for Ln (MMR), Ln (SAB) and Ln (GFR). The target MMR for 2030 is 70.

Tables 4.6 and 4.7 show that if intending to reduce MMR to 140 by 2030, we should decrease Ln (MMR) by 0.11 units each year (MMR by 39 units), while increasing the value of Ln (SAB) by 0.06 units and reducing Ln (GFR) by 0.04 units. To achieve an MMR of 70, we should reduce Ln (MMR) by 0.156, increase Ln (SAB) by 0.09, and reduce Ln (GFR) by 0.06 each year.

Figure 4.13: The lower and upper profile limits for MMR, SAB, and GFR. The MMR is reduced by approximately 44 and 39 per year, respectively, to achieve the UN-recommended target by 2030.
Figure 4.13a: Profile limits for the numerical values of MMR, SAB, and GFR. The target MMR for 2030 is 140.

Figure 4.13b: Profile limits for the numerical values of MMR, SAB, and GFR. The target MMR for 2030 is 70.
Figure 4.14a: Three-dimensional surface plot of MMR values vs. maximum and minimum values of SAB and GFR, respectively when the target MMR for 2030 is 140.

Figure 4.14b: Three-dimensional surface plot of MMR values vs. maximum and minimum values of SAB and GFR, respectively, when target MMR for 2030 is 70.
Figure 4.15a: Lower, middle and upper profile limits for MMR targeting MMR = 70, 105, and 140 by 2030.

Figure 4.15b: Lower and upper profile limits for SAB (targeting MMR = 70 and MMR = 140).
4.5 Physiological predictors of MMR

The study first tested the analysis of the causes to decide which causes are more significant to be included in the modelling process. The statistical analysis in this study includes histograms and time-series modelling, pie charts, and multi-Poisson regression.

The mean and standard deviation of the five major MDs and MMR causes are summarised in Table 5.8. The results indicate that the mean MD and MMR deaths due to haemorrhaging during the period 1986–2015 was more than one third of the total non-HIV/AIDS, MDs, and
MMR, followed by deaths due to indirect causes, which are almost one third of the total MMR, and deaths due to both sepsis and prolonged (obstructed labour) for equal percentages.

Table 4.8: Summary statistics for non-HIV/AID deaths due to haemorrhaging, sepsis (infection), prolonged (obstructed labour), unsafe abortion, and indirect causes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-HIV/AIDs without Hypertension</td>
<td>1852.0</td>
<td>1158.0</td>
</tr>
<tr>
<td>Haemorrhaging</td>
<td>703.3</td>
<td>439.9</td>
</tr>
<tr>
<td>Sepsis (infection)</td>
<td>211.0</td>
<td>132.0</td>
</tr>
<tr>
<td>Prolonged (Obstructed Labour)</td>
<td>211.0</td>
<td>132.0</td>
</tr>
<tr>
<td>Unsafe Abortion</td>
<td>187.5</td>
<td>117.3</td>
</tr>
<tr>
<td>Indirect Causes</td>
<td>539.2</td>
<td>337.3</td>
</tr>
</tbody>
</table>

This histogram presents a plot of yearly deaths due to five main causes of MMR without hypertension, for the 30 years of data.

Figure 4.17: MMR due to five major causes of non-HIV/AIDs, MDs, and MMR in South Sudan from 1986 to 2015.

Figure 4.18 shows that over the data collection period, haemorrhaging (30%) was the largest contributor to MMR, followed by indirect causes (23%), sepsis (infection) and prolonged (obstructed labour) at 9% for each, and unsafe abortion at 8%, according to the WHO, UNICEF, the World Bank, the United Nations Population Division Estimation in 1990–2013, the MoH, and the National Bureau of Statistics (NBS), Juba, South Sudan (2015 report).
pie chart presents the percentage of major causes without hypertension disorders of MMR in South Sudan.

Figure 4.18: The pie chart shows the percentage of the main causes of MMR in South Sudan excluding hypertensive disorders.

Figure 4.19: The pie chart shows the percentages of the main causes of MMR in South Sudan, including hypertensive disorders. The pie charts confirm the observations made from the histogram.

4.5.1 Time-series analysis

This plot presents the time series of the most significant causes of haemorrhaging, indirect causes, sepsis, prolonged labour, and unsafe abortion.
Figure 4.20: A time-series plot of the five main causes of maternal deaths (MDs) and MMR in South Sudan from 1986 to 2015.

Considering the declining trend in the five main physiological causes of MDs and MMR, and the non-HIV/AIDs, MDs, and MMR, it would be safe to conclude that haemorrhaging is declining at a much slower rate followed by indirect causes, sepsis (infection), prolonged (bstructed labour), and unsafe abortion respectively, compared to the non-HIV/AIDs and MDs.

Prior to modelling, it is common to investigate the correlation between the predictors. Correlation analyses have been carried out to assess the correlation between the physiological causes.

Because there is a medical relationship between hypertension and haemorrhaging, hypertension is excluded in the correlation analysis in Tables 4.8 and 4.9, i.e. a hypertensive intracerebral haemorrhage is a type of stroke in which there is bleeding in the brain due to high blood pressure, and in the building of the Poisson regression model.
Table 4.9: Correlation between all the variables considered in developing the Poisson regression model for causes of maternal deaths is shown in the table below without hypertension (independent variable).

<table>
<thead>
<tr>
<th></th>
<th>Non-HIV+/AIDS Maternal Deaths Rate Per 100,000 Live Births</th>
<th>Haemorrhaging</th>
<th>Sepsis (infection)</th>
<th>Prolonged (Obstructed) Labour</th>
<th>Unsafe Abortion</th>
<th>Indirect Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-HIV+/AIDs Maternal Deaths Rate Per 100,000 Live Births</strong></td>
<td>Pearson Corr. 1</td>
<td>0.991***</td>
<td>0.756***</td>
<td>0.845***</td>
<td>0.822***</td>
<td>0.887***</td>
</tr>
<tr>
<td><strong>Haemorrhaging</strong></td>
<td>Pearson Corr. 0.991***</td>
<td>1</td>
<td>0.788***</td>
<td>0.830***</td>
<td>0.789***</td>
<td>0.840***</td>
</tr>
<tr>
<td><strong>Sepsis (infection)</strong></td>
<td>Pearson Corr. 0.756***</td>
<td>0.788***</td>
<td>1</td>
<td>0.525***</td>
<td>0.581***</td>
<td>0.437*</td>
</tr>
<tr>
<td><strong>Prolonged (Obstructed Labour)</strong></td>
<td>Pearson Corr. 0.845***</td>
<td>0.830***</td>
<td>0.525***</td>
<td>1</td>
<td>0.724***</td>
<td>0.724***</td>
</tr>
<tr>
<td><strong>Unsafe Abortion</strong></td>
<td>Pearson Corr. 0.822***</td>
<td>0.789***</td>
<td>0.581***</td>
<td>0.538***</td>
<td>1</td>
<td>0.790***</td>
</tr>
<tr>
<td><strong>Indirect causes</strong></td>
<td>Pearson Corr. 0.887***</td>
<td>0.840***</td>
<td>0.437*</td>
<td>0.724***</td>
<td>0.790***</td>
<td>1</td>
</tr>
</tbody>
</table>

*** Correlation is significant at both levels of 0.01 level and 0.05 level (two-tailed)
* Correlation is significant at the 0.05 level (two-tailed)

Table 4.9 shows that non-HIV+/AIDs per 100,000 live births is positively and significantly correlated with all variables (p-values =<0.01 or 0.05). Haemorrhaging is positively and significantly correlated with all variables (p-values =<0.01 or 0.05). Sepsis (infection) is positively and significantly correlated with all variables (p-values =< 0.05). Prolonged (obstructed) labour is positively and significantly correlated with all variables (p-values =<0.01.
or 0.05). Unsafe abortion is positively and significantly correlated with all variables (p-values =<0.01 or 0.05). Indirect causes are positively and significantly correlated with all variables (p-values =< 0.05).

We can summarise the correlation between all the variables considered in developing the Poisson regression model for physiological causes of maternal deaths in the following points:

- All variables of causes of maternal deaths are positively and significantly correlated based on their variance inflation factor (VIF) values, which are less than ten (10) and (p-values <0.05);
- Since haemorrhaging and hypertension are medically related, the number of non-HIV+/AIDs maternal deaths exclude hypertension per 100,000 live births was modelled using Poisson regression analysis;
- To prevent bias towards the downward trend of MMR, two-thirds of the data was randomly selected based on data partition by Bernoulli distribution with a probability of 0.67 and used to build a model. The remaining one-third of the data was used for testing, assessing, and evaluating the efficacy of the model.
- Looking at the data summary there are five significant causes: haemorrhaging, indirect causes, sepsis, prolonged (obstructed) labour, and unsafe abortion. Thus, it was decided to fit Poisson regression models to all five significant physiological factors as in the following table:

Table 4.10: Summary of the Poisson model based on the major significant causes $R^2 = 97.43\%$

<table>
<thead>
<tr>
<th>$R^2$</th>
<th>Deviance Statistics $%$</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>97.43%</td>
<td>97.39%</td>
<td>469.13</td>
</tr>
</tbody>
</table>

Coefficients:

<table>
<thead>
<tr>
<th></th>
<th>Coef</th>
<th>SE Coef</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6.7833</td>
<td>0.0162</td>
<td></td>
</tr>
<tr>
<td>Haemorrhaging</td>
<td>0.000312</td>
<td>0.000032</td>
<td>9.12</td>
</tr>
<tr>
<td>Sepsis (infection)</td>
<td>0.000470</td>
<td>0.000029</td>
<td>3.94</td>
</tr>
<tr>
<td>Prolonged (Obstruction)</td>
<td>0.000479</td>
<td>0.000041</td>
<td>2.81</td>
</tr>
<tr>
<td>Unsafe Abortion</td>
<td>0.000631</td>
<td>0.000055</td>
<td>1.64</td>
</tr>
<tr>
<td>Indirect causes</td>
<td>0.000666</td>
<td>0.000033</td>
<td>2.94</td>
</tr>
</tbody>
</table>

Poisson Regression Equation:

$$\text{Non-HIV}^+/\text{AIDS MDs Rate Per 1000} = \exp(Y')$$
\[ Y' = 6.7833 + 0.000312 \text{ Haemorrhaging} + 0.00047\text{ Sepsis (infection)} + 0.000479 \text{ Prolonged (Obstructed Labour)} + 0.000631 \text{ Unsafe Abortion} + 0.000666 \text{ indirect causes} \]

The analysis was conducted using Microsoft Excel, R, and Minitab version 17, SPSS, MATLAB, statistical packages.

Statistical analysis shows that all independent variables (IVs) in the regression output are significant based on their correlation table and the VIF values, which are less than ten (10). However, as recommended in the literature, haemorrhage is the main cause of MMR. Therefore, the author has developed the reduced Poisson models based on haemorrhaging only and the two significant physiological causes of haemorrhaging and unsafe abortion, which can be controlled by the Government setting regulations and enlightening people of South Sudan about the negative side of unsafe abortion.

The reduced Poisson model is based on haemorrhaging only.

The model summary using all the 30 years data is presented below:

\[
\text{Poisson Regression Equation } R^2 = 89.77
\]

\[
\text{Non-HIV/AIDS without Hyperten}_1 = \exp(Y')
\]

\[ Y' = 6.2833 + 0.001480 \text{ Haemorrhaging}_1 \]  \hspace{1cm} (4.6).

4.5.2 Developing and assessing the efficacy of the proposed reduce Poisson model

To assess the efficacy of the model, we have unlevelled and divided the data to two thirds to build the model and one third to test and evaluate its accuracy. To overcome the bias that may be caused by the sample size, we repeated the random selection 30 times: two thirds of the data to build the models and one third to assess the efficacy.
Table 4.11: Thirty models together with their corresponding mean errors and SE means are similar to Eq. (4.7) of independent variable haemorrhaging.

<table>
<thead>
<tr>
<th>Model</th>
<th>$B_0$</th>
<th>$B_1$</th>
<th>SE Mean</th>
<th>Mean Error</th>
<th>$R^2$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>6.2170</td>
<td>0.001534</td>
<td>0.0140</td>
<td>75</td>
<td>87.28</td>
</tr>
<tr>
<td>Model 2</td>
<td>6.1057</td>
<td>0.001660</td>
<td>0.0133</td>
<td>9</td>
<td>89.90</td>
</tr>
<tr>
<td>Model 3</td>
<td>6.3251</td>
<td>0.001437</td>
<td>0.0126</td>
<td>-1</td>
<td>89.37</td>
</tr>
<tr>
<td>Model 4</td>
<td>6.1643</td>
<td>0.001616</td>
<td>0.0148</td>
<td>-55</td>
<td>91.45</td>
</tr>
<tr>
<td>Model 5</td>
<td>6.2828</td>
<td>0.001474</td>
<td>0.0140</td>
<td>41</td>
<td>89.04</td>
</tr>
<tr>
<td>Model 6</td>
<td>6.1663</td>
<td>0.001635</td>
<td>0.0440</td>
<td>-195</td>
<td>90.51</td>
</tr>
<tr>
<td>Model 7</td>
<td>6.3197</td>
<td>0.001453</td>
<td>0.0143</td>
<td>-49</td>
<td>89.85</td>
</tr>
<tr>
<td>Model 8</td>
<td>6.3274</td>
<td>0.001437</td>
<td>0.0156</td>
<td>-10</td>
<td>89.65</td>
</tr>
<tr>
<td>Model 9</td>
<td>6.2693</td>
<td>0.001492</td>
<td>0.0144</td>
<td>14</td>
<td>86.87</td>
</tr>
<tr>
<td>Model 10</td>
<td>6.2738</td>
<td>0.001462</td>
<td>0.0136</td>
<td>102</td>
<td>89.05</td>
</tr>
<tr>
<td>Model 11</td>
<td>6.4035</td>
<td>0.001405</td>
<td>0.0164</td>
<td>-197</td>
<td>91.56</td>
</tr>
<tr>
<td>Model 12</td>
<td>6.4629</td>
<td>0.001347</td>
<td>0.0175</td>
<td>-232</td>
<td>95.44</td>
</tr>
<tr>
<td>Model 13</td>
<td>6.2768</td>
<td>0.001534</td>
<td>0.0144</td>
<td>-287</td>
<td>90.99</td>
</tr>
<tr>
<td>Model 14</td>
<td>6.1070</td>
<td>0.001670</td>
<td>0.01570</td>
<td>-45</td>
<td>91.43</td>
</tr>
<tr>
<td>Model 15</td>
<td>6.2278</td>
<td>0.001580</td>
<td>0.0139</td>
<td>-216</td>
<td>90.03</td>
</tr>
<tr>
<td>Model 16</td>
<td>6.3152</td>
<td>0.001442</td>
<td>0.0132</td>
<td>24</td>
<td>89.21</td>
</tr>
<tr>
<td>Model 17</td>
<td>6.3997</td>
<td>0.001371</td>
<td>0.0142</td>
<td>-61</td>
<td>91.18</td>
</tr>
<tr>
<td>Model 18</td>
<td>6.2488</td>
<td>0.001496</td>
<td>0.0129</td>
<td>117</td>
<td>89.24</td>
</tr>
<tr>
<td>Model 19</td>
<td>6.1228</td>
<td>0.001660</td>
<td>0.0141</td>
<td>-79</td>
<td>88.50</td>
</tr>
<tr>
<td>Model 20</td>
<td>6.0960</td>
<td>0.001664</td>
<td>0.0138</td>
<td>46</td>
<td>90.27</td>
</tr>
<tr>
<td>Model 21</td>
<td>6.2833</td>
<td>0.001480</td>
<td>0.0151</td>
<td>1</td>
<td>89.77</td>
</tr>
<tr>
<td>Model 22</td>
<td>6.2237</td>
<td>0.001516</td>
<td>0.0134</td>
<td>152</td>
<td>91.09</td>
</tr>
<tr>
<td>Model 23</td>
<td>6.2842</td>
<td>0.001460</td>
<td>0.0144</td>
<td>93</td>
<td>89.64</td>
</tr>
<tr>
<td>Model 24</td>
<td>6.4349</td>
<td>0.001352</td>
<td>0.0137</td>
<td>-165</td>
<td>89.22</td>
</tr>
<tr>
<td>Model 25</td>
<td>6.4364</td>
<td>0.001336</td>
<td>0.0148</td>
<td>-67</td>
<td>93.96</td>
</tr>
<tr>
<td>Model 26</td>
<td>6.2014</td>
<td>0.001580</td>
<td>0.0155</td>
<td>-96</td>
<td>90.95</td>
</tr>
<tr>
<td>Model 27</td>
<td>6.1016</td>
<td>0.001682</td>
<td>0.0149</td>
<td>-92</td>
<td>90.27</td>
</tr>
<tr>
<td>Model 28</td>
<td>6.2170</td>
<td>0.001518</td>
<td>0.0151</td>
<td>136</td>
<td>91.53</td>
</tr>
<tr>
<td>Model 29</td>
<td>6.2441</td>
<td>0.001506</td>
<td>0.0131</td>
<td>85</td>
<td>90.23</td>
</tr>
<tr>
<td>Model 30</td>
<td>6.3568</td>
<td>0.001399</td>
<td>0.0136</td>
<td>25</td>
<td>92.48</td>
</tr>
</tbody>
</table>

Sample mean ($\mu$) | 6.264924138 | 0.001505655 | 0.015389655 | -34.5517241 | 90.43724138

The final model was based on $B_0 =$average of ($B_0$) and $B_1 =$ average ($B_1$).

Thirty models together with their corresponding mean errors and SE means are given in Tables 4.11 and 4.12.
The proposed model is based on the average coefficient of the 30 models

\[
\text{Poisson Regression Equation } R^2 = 90.27
\]

Non-HIV/AIDs without Hyperten_1 = \(\exp(Y')\)

\[
Y' = 6.264924138 + 0.001505655 \text{ Haemorrhaging}_1
\] (4.7).

The results of the analysis indicate that haemorrhaging accounts for a significant proportion of non-HIV/AIDS MDs without hypertension per 100,000 live births, \(R^2 = 90.27\%\).

Table 4.12: Errors analysis for the reduced Poisson model

<table>
<thead>
<tr>
<th>Model</th>
<th>(B_0)</th>
<th>(B_1)</th>
<th>Mean Errors</th>
<th>SE Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poisson regression</td>
<td>6.264924138</td>
<td>0.001505655</td>
<td>-34.55172414</td>
<td>0.0151</td>
</tr>
</tbody>
</table>

Table 4.13: Actual vs Predicted Values for reduced Poisson model (4.7)

<table>
<thead>
<tr>
<th>Actual values</th>
<th>predicted values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1558</td>
<td>1281</td>
</tr>
<tr>
<td>3276</td>
<td>3422</td>
</tr>
<tr>
<td>162</td>
<td>577</td>
</tr>
<tr>
<td>3401</td>
<td>3675</td>
</tr>
<tr>
<td>3342</td>
<td>3553</td>
</tr>
<tr>
<td>1178</td>
<td>1031</td>
</tr>
<tr>
<td>1675</td>
<td>1370</td>
</tr>
<tr>
<td>943</td>
<td>901</td>
</tr>
<tr>
<td>96</td>
<td>555</td>
</tr>
<tr>
<td>3227</td>
<td>3327</td>
</tr>
<tr>
<td>1209</td>
<td>1049</td>
</tr>
<tr>
<td>2926</td>
<td>2801</td>
</tr>
<tr>
<td>977</td>
<td>919</td>
</tr>
<tr>
<td>2362</td>
<td>2029</td>
</tr>
</tbody>
</table>
Figure 4.21: Actual and estimated values of one third of non-HIV/AIDs MDs based on the yearly data of independent variables (IV) of haemorrhaging, using the reduced Poisson regression model given in Eq. (4.7).

4.5.3 Development of the profile limits for reduced Poisson regression
Mathematical optimisations are used to develop lower and upper profile control limits for maternal mortality (due to physiological causes). Furthermore, we have used the proposed predictive model presented in equation (4.7) and the target minimum and maximum levels of the total MMR proposed by the UN agencies; MMR = 70 and MMR = 140 to develop profile limits. It was recommended that these limits should be achieved by 2030 (WHO, UNFPA, World Bank Group, and the United Nations Population Division, [2016]). The minimum and maximum limits for total maternal mortality due to physiological causes are estimated based on the assumption that 30% Kumar (2016) of the total maternal mortality is due to physiological causes (Tort et al., 2015; WHO, UNICEF, UNFPA, World Bank Group, and the United Nations Population Division, 2016; Haeri and Dildy, 2012; Parata, 2014; Devi et al., 2015). In 2015 the number of deaths due to physiological causes in South Sudan was 206 deaths per 100,000.

The following steps were taken to generate the lower and upper profile limits for yearly target values of haemorrhaging cases to reduce MMR to the target minimum and maximum levels recommended by UN agencies.
Step 1: To achieve MMR due to physiological causes = 42 (maximum UN recommended) by 2030 from the current value of 206; the government should reduce MMR by approximately 11 deaths per year. The optimisation programme was deployed to obtain the optimal yearly level of haemorrhaging cause of death for a given level of MMR with the starting value of MMR = 206 and, the constraint on the haemorrhaging level < the existing maximum of 62 per 100,000. The results of the optimal yearly level of MMR to achieve minimum and maximum recommended UN levels by 2030, together with the corresponding optimal yearly haemorrhaging levels are listed in Table 4.14. The profile limits are presented in Figure 4.22. The first two columns of Table 4.14 show that to reduce MMR from the current value of 206 to 42 by 2030, the government should reduce the level of death by haemorrhaging from the current value of 62 to 13. The five-year break-up values are highlighted in Table 4.14. For the year 2020, South Sudan should target to reduce MMR (due to physiological causes) from the current value of 206 to 151 by reducing haemorrhaging cases from 62 to 45. By the year 2025, the country should aim to reduce MMR from 206 to 97 by reducing deaths due to haemorrhaging from 62 to 29.

Step 2: To reduce MMR from the current value of 206 to MMR = 21 (the minimum recommended by the UN agencies) by 2030; step one was followed except that the target value was changed from 42 to 21 and the reduction in MMR was 12 per year. The last two columns of Table 4.14 show that to achieve minimum target of 21 MMR by 2030, the authorities in South Sudan should reduce maternal deaths due to haemorrhaging from 62 to 6. The target statistics for 2020 would be MMR = 144 with haemorrhaging causes being reduced to 43. Therefore, developing health policies that target MMR and the haemorrhaging levels outlined in Table 4.14 would ensure the successful accomplishment of the UN target proposal for MMR.
Table 4.14: The yearly optimal levels of MMR due to haemorrhaging on total physiological causes and haemorrhaging to meet UN recommended maximum and minimum MMR levels by 2030.

<table>
<thead>
<tr>
<th>Year</th>
<th>MMR to meet Upper Limit (42)</th>
<th>Haemorrhaging to meet 42</th>
<th>MMR to meet Lower Limit (21)</th>
<th>Haemorrhaging to meet 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>206</td>
<td>62</td>
<td>206</td>
<td>62</td>
</tr>
<tr>
<td>2016</td>
<td>195</td>
<td>59</td>
<td>194</td>
<td>58</td>
</tr>
<tr>
<td>2017</td>
<td>184</td>
<td>55</td>
<td>181</td>
<td>54</td>
</tr>
<tr>
<td>2018</td>
<td>173</td>
<td>52</td>
<td>169</td>
<td>51</td>
</tr>
<tr>
<td>2019</td>
<td>162</td>
<td>49</td>
<td>157</td>
<td>47</td>
</tr>
<tr>
<td>2020</td>
<td>151</td>
<td>45</td>
<td>144</td>
<td>43</td>
</tr>
<tr>
<td>2021</td>
<td>140</td>
<td>42</td>
<td>132</td>
<td>40</td>
</tr>
<tr>
<td>2022</td>
<td>129</td>
<td>39</td>
<td>120</td>
<td>36</td>
</tr>
<tr>
<td>2023</td>
<td>119</td>
<td>36</td>
<td>107</td>
<td>32</td>
</tr>
<tr>
<td>2024</td>
<td>108</td>
<td>32</td>
<td>95</td>
<td>29</td>
</tr>
<tr>
<td>2025</td>
<td>97</td>
<td>29</td>
<td>83</td>
<td>25</td>
</tr>
<tr>
<td>2026</td>
<td>86</td>
<td>26</td>
<td>70</td>
<td>21</td>
</tr>
<tr>
<td>2027</td>
<td>75</td>
<td>22</td>
<td>58</td>
<td>17</td>
</tr>
<tr>
<td>2028</td>
<td>64</td>
<td>19</td>
<td>46</td>
<td>14</td>
</tr>
<tr>
<td>2029</td>
<td>53</td>
<td>16</td>
<td>33</td>
<td>10</td>
</tr>
<tr>
<td>2030</td>
<td>42</td>
<td>13</td>
<td>21</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 4.22: Yearly optimal profile limits for MMR due to physiological causes and haemorrhaging levels to achieve UN minimum and maximum recommended levels by 2030.

4.5.4 Physiological causes analysis based on two significant causes – haemorrhaging and unsafe abortion

It is clear from the data summary that two significant causes can be controlled by the government and other stakeholders through the regulation and enlightenment of people in South Sudan regarding the negative side of unsafe abortion. Literature indicates that haemorrhaging and unsafe abortions are significant causes of MMR (WHO, UNICEF, 2015).
Thus, the author has developed a reduced Poisson model based on haemorrhaging and unsafe abortion.

Therefore, it was decided to fit Poisson regression models to the two significant physiological factors as in Table 4.15.

**Table 4.15: Summary of the Poisson model based on the two significant physiological causes (haemorrhaging and unsafe abortion), R² =91.91%**

<table>
<thead>
<tr>
<th>R²</th>
<th>Deviance statistics</th>
<th>AIC</th>
<th>Mean Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>91.91%</td>
<td>91.88%</td>
<td>958.88</td>
<td>16.76616</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>5.7403</td>
<td>0.0170</td>
<td></td>
</tr>
<tr>
<td>Haemorrhaging</td>
<td>-0.00217</td>
<td>0.00427</td>
<td></td>
</tr>
<tr>
<td>Unsafe Abortion</td>
<td>0.0134</td>
<td>0.0160</td>
<td></td>
</tr>
</tbody>
</table>

Regression Equation

\[
\text{MMR Upper limit (42) = exp}(Y')
\]

\[
Y' = 5.6403 - 0.00217 \text{ Haemorrhaging} + 0.0134 \text{ Unsafe Abortion}
\] (4.8).

Equation (4.8) indicates that a one-unit change in haemorrhaging will decrease \( \exp \) (MMR) by 0.00217 units, while a one-unit change in unsafe abortion will increase \( \exp \) (MMR) by 0.0134 units. As the relationships are logarithmic and built on Poisson regression, the effect on actual values of MMR, in terms of maternal deaths per 100,000 live births, will be several times higher.

Compared to the reduction in MMR, which can be brought about by reducing haemorrhaging, the effect of reducing unsafe abortion on MMR is much higher (6.18 times) than that of haemorrhaging. The equation (4.8) was founded by using all available data for two significant physiological causes. The analysis was carried out using Minitab version 17, MATLAB, Microsoft Excel, R, and SPSS statistical packages.
Figure 4.23: Represents a graph of MMR due to two significant physiological causes of haemorrhaging and unsafe abortion during the period 1986–2015. The graph shows that while MMR is reducing quite reasonably, the reduction in unsafe abortion is much slower than the reduction in haemorrhaging.

### 4.5.4.1 Development of the reduced Poisson model using repeated sampling

To assess the efficacy of the reduced Poisson model, we randomly divided the data using Bernoulli distribution (0.67) to two-thirds of the data to build the model and one-third to test and evaluate its accuracy. Furthermore, to overcome the bias that may be caused by the sample size, we repeated random selection 30 times for two-thirds of the data to build the models and one-third to assess the efficacy. The 30 models together with their corresponding mean errors are presented in Table 4.16.
Reduced Poisson model based on haemorrhaging and unsafe abortion.

Table 4.16: The coefficients of the 30 generated models together with their corresponding mean and SE mean of prediction errors, based on haemorrhaging and unsafe abortion.

<table>
<thead>
<tr>
<th>Model</th>
<th>$B_0$</th>
<th>$B_1$</th>
<th>$B_2$</th>
<th>SE Mean</th>
<th>Mean Error</th>
<th>$R^2$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>5.4061</td>
<td>-0.0023788</td>
<td>0.06257</td>
<td>0.0230</td>
<td>-0.8769</td>
<td>91.89</td>
</tr>
<tr>
<td>Model 2</td>
<td>5.6403</td>
<td>-0.0221698</td>
<td>0.08886</td>
<td>0.0225</td>
<td>-0.3471</td>
<td>91.91</td>
</tr>
<tr>
<td>Model 3</td>
<td>5.4061</td>
<td>-0.0023796</td>
<td>0.012679789</td>
<td>0.0170</td>
<td>-0.415</td>
<td>91.89</td>
</tr>
<tr>
<td>Model 4</td>
<td>5.2981</td>
<td>-0.0179986</td>
<td>0.07430974</td>
<td>0.0257</td>
<td>-0.62307</td>
<td>90.31</td>
</tr>
<tr>
<td>Model 5</td>
<td>5.3897</td>
<td>-0.0178987</td>
<td>0.06380989</td>
<td>0.0230</td>
<td>-0.77</td>
<td>90.76</td>
</tr>
<tr>
<td>Model 6</td>
<td>5.3075</td>
<td>-0.0164988</td>
<td>0.06630879</td>
<td>0.0253</td>
<td>-0.55</td>
<td>91.09</td>
</tr>
<tr>
<td>Model 7</td>
<td>5.3075</td>
<td>-0.0164998</td>
<td>0.06130875</td>
<td>0.0253</td>
<td>-0.55</td>
<td>91.09</td>
</tr>
<tr>
<td>Model 8</td>
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<td>-0.0225988</td>
<td>0.09025967</td>
<td>0.0183</td>
<td>-0.57059</td>
<td>88.69</td>
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<tr>
<td>Model 9</td>
<td>5.3075</td>
<td>-0.0164978</td>
<td>0.06937865</td>
<td>0.0253</td>
<td>-0.55</td>
<td>91.09</td>
</tr>
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<td>Model 10</td>
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<td>-0.0178997</td>
<td>0.07386975</td>
<td>0.0230</td>
<td>-0.7667</td>
<td>90.76</td>
</tr>
<tr>
<td>Model 11</td>
<td>5.3908</td>
<td>-0.0181979</td>
<td>0.0749785</td>
<td>0.0229</td>
<td>-0.7667</td>
<td>91.38</td>
</tr>
<tr>
<td>Model 12</td>
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<td>0.0404975</td>
<td>0.0176</td>
<td>-0.64118</td>
<td>89.48</td>
</tr>
<tr>
<td>Model 13</td>
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<td>-0.0179988</td>
<td>0.0750789</td>
<td>0.0257</td>
<td>-0.62308</td>
<td>90.31</td>
</tr>
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<td>-0.0178987</td>
<td>0.0738657</td>
<td>0.0230</td>
<td>-0.7667</td>
<td>90.76</td>
</tr>
<tr>
<td>Model 15</td>
<td>5.2881</td>
<td>-0.0122999</td>
<td>0.0404095</td>
<td>0.0176</td>
<td>-0.64118</td>
<td>89.48</td>
</tr>
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<td>Model 16</td>
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<td>0.07500978</td>
<td>0.0257</td>
<td>-0.62308</td>
<td>90.31</td>
</tr>
<tr>
<td>Model 17</td>
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<td>-0.0178969</td>
<td>0.07490776</td>
<td>0.0230</td>
<td>-0.7667</td>
<td>90.76</td>
</tr>
<tr>
<td>Model 18</td>
<td>5.3908</td>
<td>-0.0181979</td>
<td>0.07500997</td>
<td>0.0229</td>
<td>-0.7667</td>
<td>91.38</td>
</tr>
<tr>
<td>Model 19</td>
<td>5.2981</td>
<td>-0.0135898</td>
<td>0.05530875</td>
<td>0.0257</td>
<td>-0.62308</td>
<td>90.31</td>
</tr>
<tr>
<td>Model 20</td>
<td>5.8944</td>
<td>-0.0121969</td>
<td>0.05030876</td>
<td>0.0217</td>
<td>0.2556</td>
<td>96.89</td>
</tr>
<tr>
<td>Model 21</td>
<td>5.8528</td>
<td>-0.0121979</td>
<td>0.04970897</td>
<td>0.0195</td>
<td>-0.03333</td>
<td>96.7</td>
</tr>
<tr>
<td>Model 22</td>
<td>5.9706</td>
<td>-0.0121999</td>
<td>0.049708567</td>
<td>0.0257</td>
<td>0.08571</td>
<td>97.95</td>
</tr>
<tr>
<td>Model 23</td>
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<td>-0.0138784</td>
<td>0.05530789</td>
<td>0.0257</td>
<td>0.08571</td>
<td>97.95</td>
</tr>
<tr>
<td>Model 24</td>
<td>5.8944</td>
<td>-0.0225972</td>
<td>0.090207658</td>
<td>0.0217</td>
<td>0.2556</td>
<td>96.89</td>
</tr>
<tr>
<td>Model 25</td>
<td>5.6066</td>
<td>-0.0121971</td>
<td>0.090205674</td>
<td>0.0183</td>
<td>-0.570588</td>
<td>88.69</td>
</tr>
<tr>
<td>Model 26</td>
<td>5.9706</td>
<td>-0.0129897</td>
<td>0.07670786</td>
<td>0.0257</td>
<td>0.08571</td>
<td>97.95</td>
</tr>
<tr>
<td>Model 27</td>
<td>5.4061</td>
<td>-0.0121861</td>
<td>0.04470875</td>
<td>0.0225</td>
<td>-0.8769</td>
<td>91.89</td>
</tr>
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<td>Model 28</td>
<td>5.8881</td>
<td>-0.0121977</td>
<td>0.05020786</td>
<td>0.0218</td>
<td>0.2</td>
<td>97.26</td>
</tr>
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<td>Model 29</td>
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<td>-0.0202981</td>
<td>0.08960798</td>
<td>0.0257</td>
<td>0.0851</td>
<td>97.95</td>
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<td>Model 30</td>
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<td>-0.0279951</td>
<td>0.089609567</td>
<td>0.0195</td>
<td>-0.03333</td>
<td>96.7</td>
</tr>
<tr>
<td>Sample Mean($\mu$)</td>
<td>5.567487</td>
<td>-0.0161776834</td>
<td>0.066157056</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The final model based on $B_0$ = average of ($B_0$), $B_1$ = average ($B_1$) and $B_2$ = average ($B_2$), is provided below in equation (4.9)

The results of the analysis indicate that haemorrhaging and unsafe abortion accounted for a significant proportion of Non-HIV+ AIDs MDs without Hypertension per 100,000 Live Births, $R^2 = 92.68\%$.

Poisson Regression Equation, $R^2 = 92.68$

Non-HIV/AIDs without Hyperten_1 = $\exp(Y')$

$Y' = 5.567487-0.0161776834$ Haemorrhaging + 0.066157056 Unsafe Abortion  (4.9).

Table 4.17: shows actual and estimated values of MMR based on equation (4.9). Based on randomly selected MMR actual values, by using Bernoulli distribution with probability of 0.67, moreover, it represents MMR estimated errors
4.5.4.2 Errors analysis for the reduced Poisson model based on two significant physiological causes (haemorrhaging and unsafe abortion) as shown in Tables 4.17 and 4.18

Table 4.17: MMR predicted values vs. actual values for the reduced Poisson model (4.9) and the mean errors.

<table>
<thead>
<tr>
<th>(Y-Y’)</th>
<th>MMR Actual values (Y)</th>
<th>MMR Estimated values (Y’)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-67.93</td>
<td>1635</td>
<td>1702.93</td>
</tr>
<tr>
<td>-48.91</td>
<td>1518</td>
<td>1566.91</td>
</tr>
<tr>
<td>-70.77</td>
<td>1576</td>
<td>1646.77</td>
</tr>
<tr>
<td>-27.47</td>
<td>1607</td>
<td>1634.47</td>
</tr>
<tr>
<td>-83.91</td>
<td>1551</td>
<td>1634.91</td>
</tr>
<tr>
<td>-56.67</td>
<td>1552</td>
<td>1608.67</td>
</tr>
<tr>
<td>-410.04</td>
<td>1916</td>
<td>2326.04</td>
</tr>
<tr>
<td>139.18</td>
<td>1341</td>
<td>1201.82</td>
</tr>
<tr>
<td>173.74</td>
<td>1179</td>
<td>1005.26</td>
</tr>
<tr>
<td>98.61</td>
<td>1407</td>
<td>1308.39</td>
</tr>
<tr>
<td>169.92</td>
<td>1107</td>
<td>937.08</td>
</tr>
</tbody>
</table>

Mean Error = -16.75

Figure 4.24: Actual and estimated values of one-third of MMR based on the yearly data of independent variables (IV) of haemorrhaging and unsafe abortion, using reduced Poisson regression model given in Eq. (4.9).

Profile limits for MMR, haemorrhaging and unsafe abortion
The optimisation procedures to attain optimal min (haemorrhaging) and min (unsafe abortion) values for a given (MMR) level is outlined in the algorithm presented in Figure 4.25 below based on Equation (4.9).

\[ (Y^*) = 5.567487 - 0.0161776834 \times (\text{Haemorrhaging}) + 0.066157056 \times (\text{Unsafe Abortion}) \]  

(4.9).

4.6 Algorithm to develop profile limits for two significant physiological causes

The above prediction model is used to develop profile limits for MMR in terms of Haemorrhaging and Unsafe Abortion.

In this research, MATLAB, Minitab, R, and Excel Solver are used to obtain optimal values of haemorrhaging and unsafe abortion. Furthermore, to generate the lower and upper profile control limits for (MMR), the proposed predictive models presented in Equation (4.9) and the target minimum and maximum levels of MMR proposed by the UN agencies; MMR = 21 and MMR = 42 due to physiological causes, have been used. It was recommended that these limits should be achieved by 2030. The current MMR in South Sudan is around 206 deaths per 100,000 live births.

The following steps were taken to generate the lower and upper profile limits for yearly target values of Haemorrhaging and Unsafe Abortion to reduce MMR to the target minimum and maximum levels recommended by UN agencies.

Step 1: To achieve MMR = 42 (the maximum recommended by the UN agencies due to two significant physiological causes of haemorrhaging and unsafe abortion) from the current value of 78 by 2030, the government should reduce MMR by (approximately) 2.4 deaths per year. Therefore, the optimisation programme was deployed to obtain optimal sets of haemorrhaging and unsafe abortion for a given MMR with the starting value of 78. The MMR was then reduced by 2.4, year-on-year. The results in terms of numerical values are presented in Table 4.19. The profile limits are presented in Figures 4.24–4.24b. It should be observed that the constraint on haemorrhaging is that, it should be less than the existing minimum (haemorrhaging = 62), as our aim is to reduce haemorrhaging year-on-year. While the constraints on unsafe abortion should be smaller than the existing current minimum value of 16, its value should be further reduced. The results presented in the first three columns of Table 4.19 show that to reduce MMR from 78 to 42 by the year 2030, the government should reduce haemorrhaging from the current value of 62 to 33.38 while the value of unsafe abortion should
be reduced from the current value of 16 to 8.62. The five-year break-up values are highlighted in Table 4.19. Thus, for the year 2020, South Sudan should aim to reduce MMR caused by two significant physiological factors (haemorrhaging and unsafe abortion) from the current value of 78 to 66 by simultaneously reducing haemorrhaging from 62 to 52.46 and reducing unsafe abortion from 16 to 13.54. By 2025 the country should aim for MMR to be reduced from the present value of 78 to 54 by simultaneously reducing haemorrhaging from 62 to 42.92 and reducing unsafe abortion from 16 to 11.08. By the year 2030, the government and stakeholders should aim to have reduced MMR from the current value of 78 to 42 by reducing haemorrhaging from 62 to 33.38 and unsafe abortion from 16 to 8.62.

Step 2: To attain MMR = 78 (the minimum recommended by the UN agencies due to physiological causes) from the current value of 21 by 2030, step one was followed except that the target value was changed from 42 to 21 and the reduction in MMR was 3.8 per year. The optimisation results, in terms of numerical values, are presented in Table 4.19. The last three columns of Table 5.19 show that to achieve an MMR of 21 by the year 2030, the authorities in South Sudan should reduce unsafe abortion from 16 to 4.31, while reducing haemorrhaging from the current value of 62 to 16.69. The target statistics for 2020 would be MMR = 59 with haemorrhaging reduced to 46.90 and unsafe abortion reduced to 12.10. By 2025, the government and partners should aim to reduce MMR from the present value of 78 to 40, by simultaneously reducing haemorrhaging from 62 to 31.79 and unsafe abortion from 16 to 8.21. Therefore, developing health policies that target MMR, the haemorrhaging and unsafe abortion profile limits outlined in Table 4.19 would ensure the successful accomplishment of the UN target maternal mortality rate proposal.

The results also indicate that to achieve the UN recommended MMR levels of 21 at the minimum and 42 at the maximum by 2030, due to the two significant physiological causes, the government should simultaneously reduce unsafe abortion from the current value of 16 to 8.62 and 4.31, reduce haemorrhaging from the current value of 62 to 33.38 and 16.69. These findings confirm that reducing haemorrhaging and reducing unsafe abortion can result in reducing MMR.
Algorithmic to optimise MMR based on Haemorrhaging and Unsafe Abortion

Assign the current values as initial values for (haemorrhage) and (unsafe abortion). Set (MMR) recommended by UN as target (MMR). Enter required reductions for (haemorrhage) and (unsafe abortion) as haemorrhage reduction and unsafe abortion reduction.

Calculate (MMR), using equation (4.9)

If (MMR) = (Target UN MMR)

Stop and record min (haemo.), min (unsafe abortion) and min (MMR)

If (MMR) < (Target UN MMR)

New (haemo.) = (haemo.) + (haemo. Red.) / (2)

New (unsafe abortion) = (unsafe abortion) + (unsafe abortion red.) / (2)

(Haemorrhage) = New (haemo.)

If (MMR) > (Target UN MMR)

(Haemorrhage) = initial (haemo) - (haemo red.)

(Unsafe abortion) = initial (unsafe abortion) - (unsafe abortion red.)

Figure 4.25: Calculation of optimal min (haemorrhaging) and min (unsafe abortion) values for a given MMR level.
Table 4.18: Summary for the optimal values of haemorrhaging and unsafe abortion for a given MMR level

<table>
<thead>
<tr>
<th>Year</th>
<th>MMR targeting (42)</th>
<th>Haemorrhaging to meet 42</th>
<th>Unsafe Abortion to 42</th>
<th>MMR targeting (21)</th>
<th>Haemorrhaging to meet 21</th>
<th>Unsafe Abortion to 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>78</td>
<td>62</td>
<td>16</td>
<td>78</td>
<td>62</td>
<td>16</td>
</tr>
<tr>
<td>2016</td>
<td>75.6</td>
<td>60.09</td>
<td>15.51</td>
<td>74.2</td>
<td>58.98</td>
<td>15.22</td>
</tr>
<tr>
<td>2017</td>
<td>73.2</td>
<td>58.18</td>
<td>15.02</td>
<td>70.4</td>
<td>55.96</td>
<td>14.44</td>
</tr>
<tr>
<td>2018</td>
<td>70.8</td>
<td>56.28</td>
<td>14.52</td>
<td>66.6</td>
<td>52.94</td>
<td>13.66</td>
</tr>
<tr>
<td>2019</td>
<td>68.4</td>
<td>54.37</td>
<td>14.03</td>
<td>62.8</td>
<td>49.92</td>
<td>12.88</td>
</tr>
<tr>
<td>2020</td>
<td>66</td>
<td>52.46</td>
<td>13.54</td>
<td>59</td>
<td>46.90</td>
<td>12.10</td>
</tr>
<tr>
<td>2021</td>
<td>63.6</td>
<td>50.55</td>
<td>13.05</td>
<td>55.2</td>
<td>43.88</td>
<td>11.32</td>
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<tr>
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<td>12.55</td>
<td>51.4</td>
<td>40.86</td>
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<td>2023</td>
<td>58.8</td>
<td>46.74</td>
<td>12.06</td>
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<td>43.8</td>
<td>34.82</td>
<td>8.98</td>
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<tr>
<td>2025</td>
<td>54</td>
<td>42.92</td>
<td>11.08</td>
<td>40</td>
<td>31.79</td>
<td>8.21</td>
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<tr>
<td>2026</td>
<td>51.6</td>
<td>41.02</td>
<td>10.58</td>
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<td>28.77</td>
<td>7.43</td>
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<tr>
<td>2027</td>
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<td>10.09</td>
<td>32.4</td>
<td>25.75</td>
<td>6.65</td>
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<tr>
<td>2028</td>
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<td>28.6</td>
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<tr>
<td>2029</td>
<td>44.4</td>
<td>35.29</td>
<td>9.11</td>
<td>24.8</td>
<td>19.71</td>
<td>5.09</td>
</tr>
<tr>
<td>2030</td>
<td>42</td>
<td>33.38</td>
<td>8.62</td>
<td>21</td>
<td>16.69</td>
<td>4.31</td>
</tr>
</tbody>
</table>

The target MMR based on physiological causes for 2030 is 42 in the first three columns and 21 in the last three columns.

Figure 4.26: The boxplot presents the minimum values of MMR, minimum values of haemorrhaging, and minimum values of unsafe abortion, based on the UN target for MMR = 21 and 42, by 2030.
Figure 4.27: The lower and upper profile limits for MMR, haemorrhaging and unsafe abortion. The MMR is reduced by approximately 2.4 and 4.6 per year, respectively, to achieve the UN recommended target by 2030.

Figure 4.27a: Profile limits for the numerical values of MMR, haemorrhaging and unsafe abortion. The target MMR for 2030 is 42.
Figure 4.27b: Profile limits for the numerical values of MMR, haemorrhaging, and unsafe abortion. The target MMR for 2030 is 21.

4.7 Conclusions

South Sudan is amongst the countries with the highest maternal mortality rate. Factors contributing to the high maternal mortality rate are socio-economic, macro-economic, and physiological factors. The chapter investigated socio-economic factors and physiological causes of MMR based on international and national literature. Thirty years of South Sudan data was used to identify the most significant socio-economic factors and physiological causes of maternal mortality.

Studies on predictors of logarithmic multi-regression models provided distinct evidence that increasing skilled attendants at birth (SAB) and reducing the general fertility rate (GFR), while leaving the gross domestic product (GDP) constant at 1,772, can reduce the MMR in South Sudan by the year 2030 to the limits proposed by the UN agencies (WHO, USAID, UNICEF and the World Bank, 2015) and beyond.

Statistical analysis indicates that increasing SAB by 1.22% per year would reduce MMR by 1.4%. [95% CI (0.4%–5%)], while reducing GFR by 1.22% per year would reduce MMR by 1.8% [95% CI (0.5%–6.26)], when the GDP is held constant

Comparing the findings of this study to other similar studies suggests that reducing GFR is more effective and achievable than increasing SAB, when aiming to reduce MMR.
For the first time, optimisation has been deployed to develop the yearly profile limits for MMR, SAB, and GFR to achieve recommended lower and upper levels of MMR by 2030.

The optimal profile limits provide a quantitative guideline for the government and partners in terms of yearly SAB and GFR targets to reduce MMR to the level recommended by the UN.

Furthermore, analysis shows that haemorrhaging; microbial infections, preeclampsia, cardiovascular disease, liver disease, sepsis, and gastro-intestinal hepatic diseases are the most common physiological factors of MMR. Amongst these, deaths related to haemorrhaging, sepsis, and eclampsia are more common.

Poisson regression was used to develop a prediction model to estimate maternal mortality based on the top five significant physiological causes. The results show that these causes contributed 97.43% to the variations in MMR. Judging by their corresponding variance inflation factor (VIF) and p-value, we can conclude that all five causes are statistically significant. However, based on the literature recommendations, we have developed the reduced Poisson regression models based on haemorrhaging only and the two significant physiological causes of haemorrhaging and unsafe abortion that can be controlled by the Government and other stakeholders by regulating and enlightening people of South Sudan about the negative side of unsafe abortion. To reduce the impact of the sample size on the reliability of the developed reduced Poisson models, we repeated the random sample selection 30 times using Bernoulli distribution with a probability of 0.67 to select two thirds of the data to build the models, and one third to assess efficacy. The results show that haemorrhaging alone is responsible for 90.27% of variation in MMR in South Sudan. The results of error analysis show that the proposed reduced model can predict MMR for a given level of haemorrhaging with a mean error of -34.5517 and standard error of mean 0.0151. The proposed reduced model is based on the average coefficient of 30 models. Moreover, the outcomes of the analysis show that the two significant causes of haemorrhaging and unsafe abortion are responsible for 92.68% of the variation in MMR and their outcome error analysis demonstrates that the proposed reduced Poisson regression model can predict MMR for a given level of haemorrhaging and unsafe abortion with a mean error of 16.76616 and a standard error of
mean 0.022677. The reduced Poisson model is also based on the average coefficient of 30 models as shown in Table 4.16

For the first time, this chapter has deployed optimisation procedures to develop yearly lower and upper profile limits for MMR, targeting the UN’s recommended lower and upper MMR levels by 2030. The MMR profile limits have been accompanied in by the profile limits for optimal yearly values of SAB and GFR levels. Further, the MMR profile limits have been also developed and accompanied by the profile limits for optimal values of haemorrhaging and unsafe abortion.

To reduce MMR, the following actions are recommended. Haemorrhaging and unsafe abortion are potentially life threatening and need to be managed effectively and in a timely manner to prevent adverse outcomes. The effective management of haemorrhaging and unsafe abortion can reduce MMR by a substantial amount. However, this requires policies and interventions at a number of levels. The hospital infrastructure should provide the necessary items and equipment to manage haemorrhaging. These include the availability of blood for transfusion, supply of oxytocin hormones, surgical items, and items to help prevent bleeding. Hospital staff, including midwives, nurses, doctors, and TBAs should have the necessary expertise and training to effectively deal with haemorrhaging. The measures will require a significant investment by the government, UN agencies, and other stakeholders. The investment is required to build more upgraded medical facilities, update the training of medical personnel, and improve roads, transport, and communication. In addition, the investment should provide home delivery services for pregnant women who live in rural areas or poorer communities.

This conclusion outlines the important of increasing SAB and reducing GFR to achieve the UN targeted level by 2030. Further, information on how to achieve an increase in SAB and reduction in GFR, haemorrhaging and unsafe abortion are provided in Chapter 6 under Recommended Policies.

The outcomes of this study can effectively aid authorities to make informed evidence-based intervention decisions on resource allocation to reduce the MMR. The findings of this study
will also provide useful guidelines for healthcare development programmes to prioritise and effectively distribute their limited health resources to areas of urgent need.

These findings are pivotal as they provide some guidance to policy makers and other stakeholders on resource allocation in South Sudan’s public health to target specific socio-economic factors (SAB, GFR, and GDP) and physiological causes (haemorrhaging, sepsis, unsafe abortion, and indirect causes) with the aim of minimising MMR.

4.8 The portion of results of this chapter has been published in the following papers:

A) Journal papers:


B) Conferred IEEE Conference papers


5  POLICIES RECOMMENDED FOR REDUCING MMR IN SOUTH SUDAN

5.1 Introduction
This chapter outlines steps taken by the South Sudan government and international agencies to reduce MMR in the past few years. The chapter explores recommended and implemented policies, the impact of implemented policies in other countries, and South Sudan in reducing MMR.

Finally, the chapter outlines recommendations to the government and other stakeholders in the country to effectively reduce MMR.

5.2 Policies suggested to reduce MMR in South Sudan
It is suggested that the policies and strategies listed below will achieve a reduction MMR (MoH; NBS; WHO, 2011/2012).

1) Increased availability and accessibility of antenatal services;

2) Utilisation of skilled health personnel during pregnancy, childbirth, and postnatal periods at all levels of the health system;

3) Provision of emergency obstetric services at a reasonable distance from villages;
4) Increased budget allocations and government spending for reproductive health (maternal health) programmes;

5) Provision of reproductive health/family planning services, including uninterrupted supplies, and making trained providers available;

6) Increase the training of midwifery and nursing personnel at the grass roots, as the key to reducing maternal mortality;

7) Investment in infrastructure development, including roads and transport, midwifery, and nursing schools;

8) Enhanced investment in social development, including women’s empowerment, education, and gender equality; and

9) The negotiation of a political peace agreement between all political stakeholders and civil societies in the country; furthermore, the conduct of political dialogue and reconciliation between various ethnic groups across the country, to restore the breakdown in social relationships, caused by civil war.

5.3 Results of the recommended policies

1) South Sudan obtained the support of UNICEF, WHO, other UN agencies and many other foreign countries to expand healthcare facilities for pregnant women and paediatric care to newborns. These facilities were equipped with qualified personnel, medicines, operating theatres, labour rooms, delivery rooms, and wards. Furthermore, they had antenatal and postnatal care units. They have established intensive health-training institutes in 2010. This included the Juba College of Nursing and Midwifery, the Kajo Keji Health Training Institute, and specialised hospitals (see Tables 5.1, 5.2, 5.5 and Figures 5.2 and 5.3.); and

2) The government and aid agencies have started to implement policies and strategies (1, 2, 4–7) by increasing resource allocation for hospitals, primary healthcare units (PHCU), and primary healthcare centres (PHCC).
Table 5.1: Projected infrastructural investments in PHCU, PHCC and hospitals

The number in () represents the target numbers.

<table>
<thead>
<tr>
<th>Type</th>
<th>Renovation, Reconstruction</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHCU</td>
<td>Major renovation: 6-7 per state per year</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>70</td>
<td>70</td>
<td>320</td>
</tr>
<tr>
<td></td>
<td>Minor renovation: 4-5 per state per year (316</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>total for PHCUs and PHCCs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction Staff Houses</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>PHCC (204)</td>
<td>Minor renovation: 2 per State per year</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Minor renovation: 2-3 per State per year</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>31</td>
<td>116</td>
</tr>
<tr>
<td></td>
<td>Construction Staff Houses</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>Construction</td>
<td>Construction (in nine states needed 438. The</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>total of 200 to be constructed in 5 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>remaining to be planned)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>County Hospital (27)</td>
<td>Replacement/Repairs of all County Hospitals</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>over 10 years period: three per year at least</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State Hospital (7)</td>
<td>Repairs/Replacement all State Hospitals over 10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>years (priority as from 2015)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teaching Hospitals</td>
<td>Repairs – Three Teaching Hospitals over 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>(3)</td>
<td>years: Rebuilding of Malakal priority</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Malakal</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Juba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wau</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specialised Hospitals</td>
<td>• Dr John Garang Memorial Hospital</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Maternal and Neonatal Centre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Juba Diagnostic Health Care Centre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Maternal Centre and Children Hospital in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Malakal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Women’s Hospital in Rebuke</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Military’s Hospital, Maternal Department</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in Juba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


3) Table 5.1 shows that within the limitations of its resources and financial capacities, South Sudan is gradually investing higher amounts on infrastructure and healthcare delivery accessible to the maximum population in each locality.

4) The Juba facility trains nurses and midwives at diploma level and the quality of training has improved over the years. Team spirit and attitude towards care is also progressing. The insistence on cultural practice is decreasing (e.g. polygamy, childbirth, and home delivery). Resources and knowledge are available, but they need to be fully and effectively deployed.
Lacks of trained and poorly trained personnel are two major problems in maternal healthcare. Table 5.2 shows the implemented policies required to increase the number of health professional students and graduates and achieve the policy.

Table 5.2: Human resource gap for health centre numbers

<table>
<thead>
<tr>
<th>Priority Human Resources for Health</th>
<th>2012 Existing Baseline</th>
<th>2016 (Ministry of Health recommended staffing)</th>
<th>Number staff actual recruited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultant/Specialist/Registers</td>
<td>18</td>
<td>96</td>
<td>78</td>
</tr>
<tr>
<td>Medical Officers</td>
<td>86</td>
<td>472</td>
<td>386</td>
</tr>
<tr>
<td>Registered Nurse</td>
<td>83</td>
<td>1,024</td>
<td>941</td>
</tr>
<tr>
<td>Enrolled Nurse</td>
<td>1110</td>
<td>4,984</td>
<td>3,874</td>
</tr>
<tr>
<td>Registered Midwife</td>
<td>19</td>
<td>512</td>
<td>493</td>
</tr>
<tr>
<td>Enrolled Midwife</td>
<td>132</td>
<td>3,656</td>
<td>3,524</td>
</tr>
<tr>
<td>Clinical Officers</td>
<td>224</td>
<td>1,490</td>
<td>1,266</td>
</tr>
<tr>
<td>Laboratory Technologist</td>
<td>38</td>
<td>230</td>
<td>192</td>
</tr>
<tr>
<td>Laboratory Technician</td>
<td>75</td>
<td>690</td>
<td>615</td>
</tr>
<tr>
<td>Pharmacist</td>
<td>18</td>
<td>137</td>
<td>115</td>
</tr>
<tr>
<td>Pharmacy Technician</td>
<td>32</td>
<td>822</td>
<td>790</td>
</tr>
<tr>
<td>Nutritionist</td>
<td>35</td>
<td>144</td>
<td>109</td>
</tr>
<tr>
<td>Dentist</td>
<td>20</td>
<td>81</td>
<td>61</td>
</tr>
<tr>
<td>Dental Technician</td>
<td>14</td>
<td>162</td>
<td>148</td>
</tr>
<tr>
<td>Medical Imaging Technician</td>
<td>14</td>
<td>81</td>
<td>67</td>
</tr>
<tr>
<td>Radiologist</td>
<td>0</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Physiotherapist</td>
<td>0</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Disease Surveillance Officer</td>
<td>35</td>
<td>160</td>
<td>125</td>
</tr>
<tr>
<td>Monitoring and Evaluation Officer</td>
<td>35</td>
<td>318</td>
<td>283</td>
</tr>
<tr>
<td>Public Health Officer</td>
<td>37</td>
<td>1,845</td>
<td>1,770</td>
</tr>
<tr>
<td>Psychiatrist</td>
<td>0</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Psychiatric Technician</td>
<td>0</td>
<td>112</td>
<td>112</td>
</tr>
<tr>
<td>Statisticians</td>
<td>0</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,025</strong></td>
<td><strong>17,138</strong></td>
<td><strong>15,071</strong></td>
</tr>
</tbody>
</table>


Table 5.2 shows an acceptable shortfall in resources for 2016. Recruitment was 15,071 in 2016, 2,067 fewer than projected. These numbers are a robust estimation.
Table 5.3: The proposed health sector development plan (HSDP) 2012–2016’s yearly Budget in South Sudanese pounds (SSPs).

<table>
<thead>
<tr>
<th>Year</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operational Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Care</td>
<td>184,545,792</td>
<td>245,916,863</td>
<td>260,672,363</td>
<td>283,579,182</td>
<td>354,313,809</td>
<td>1,329,028,009</td>
</tr>
<tr>
<td>Secondary Care</td>
<td>168,784,316</td>
<td>220,893,078</td>
<td>285,308,009</td>
<td>367,320,762</td>
<td>474,498,399</td>
<td>1,516,804,565</td>
</tr>
<tr>
<td>Teaching and Specialist Hospitals</td>
<td>67,736,488</td>
<td>75,198,180</td>
<td>85,148,760</td>
<td>98,658,541</td>
<td>117,257,668</td>
<td>443,999,547</td>
</tr>
<tr>
<td>Management and Training</td>
<td>34,167,941</td>
<td>36,512,315</td>
<td>38,856,689</td>
<td>41,201,063</td>
<td>43,545,437</td>
<td>194,283,444</td>
</tr>
<tr>
<td>Total Operational Costs</td>
<td>455,234,536</td>
<td>578,520,436</td>
<td>669,985,822</td>
<td>790,759,457</td>
<td>989,615,314</td>
<td>3,484,115,565</td>
</tr>
<tr>
<td></td>
<td>Capital Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary Care</td>
<td>41,188,084</td>
<td>109,550,808</td>
<td>109,550,808</td>
<td>109,550,808</td>
<td>109,550,808</td>
<td>479,391,316</td>
</tr>
<tr>
<td>Teaching and Specialist Hospitals</td>
<td>28,712,750</td>
<td>52,032,750</td>
<td>52,032,750</td>
<td>52,032,750</td>
<td>52,032,750</td>
<td>236,843,750</td>
</tr>
<tr>
<td>Management and Training</td>
<td>17,774,583</td>
<td>17,774,583</td>
<td>17,774,583</td>
<td>13,669,583</td>
<td>13,669,583</td>
<td>80,662,917</td>
</tr>
<tr>
<td>Total Capital Cost</td>
<td>119,019,269</td>
<td>342,466,779</td>
<td>342,466,779</td>
<td>225,420,534</td>
<td>206,596,993</td>
<td>1,235,970,353</td>
</tr>
<tr>
<td>Leadership Government and Finance</td>
<td>6,830,529</td>
<td>8,679,819</td>
<td>10,051,800</td>
<td>11,863,406</td>
<td>14,846,245</td>
<td>52,271,798</td>
</tr>
<tr>
<td>Human Resources</td>
<td>29,728,590</td>
<td>38,827,189</td>
<td>47,284,846</td>
<td>51,190,333</td>
<td>54,314,828</td>
<td>221,345,787</td>
</tr>
<tr>
<td>Health Infrastructure</td>
<td>2,798,958</td>
<td>260,696</td>
<td>260,697</td>
<td>260,698</td>
<td>260,699</td>
<td>3,841,749</td>
</tr>
<tr>
<td>Pharmaceuticals and medical supplies</td>
<td>8,233,609</td>
<td>11,412,348</td>
<td>14,208,415</td>
<td>18,329,330</td>
<td>25,228,161</td>
<td>77,411,864</td>
</tr>
<tr>
<td>Procurement</td>
<td>597,107</td>
<td>1,714,346</td>
<td>1,714,347</td>
<td>1,129,117</td>
<td>1,035,000</td>
<td>6,189,917</td>
</tr>
<tr>
<td>Monitoring and Evaluation Systems</td>
<td>6,268,731</td>
<td>6,268,732</td>
<td>6,268,733</td>
<td>6,268,734</td>
<td>6,268,735</td>
<td>31,343,665</td>
</tr>
<tr>
<td>Total Governance and Management Cost</td>
<td>54,457,525</td>
<td>67,163,130</td>
<td>79,788,839</td>
<td>89,041,618</td>
<td>101,953,669</td>
<td>392,404,781</td>
</tr>
<tr>
<td>TOTAL</td>
<td>628,711,330</td>
<td>988,150,345</td>
<td>1,092,241,440</td>
<td>1,105,221,609</td>
<td>1,298,165,976</td>
<td>5,112,490,699</td>
</tr>
<tr>
<td>Cost per Capita</td>
<td>$24</td>
<td>$37</td>
<td>$41</td>
<td>$42</td>
<td>$50</td>
<td></td>
</tr>
</tbody>
</table>

Source: Government of South Sudan’s Report about their Health Sector Development Plan 2012–2016

Table 5.3 shows the proposed health development plan (HSDP) for the 2012–2016 budget increased from SSP 54,457,525 in 2012 to SSP 101,953,669 in 2016, which was 87% (e.g. SSP in South Sudanese Pounds).

5) Many international organisations have provided support with better reproductive health and family planning programmes and medicines at no/affordable costs. For example, women’s health care centres have subsidised contraceptive medicine and other contraceptive devices, and medication related to pregnancy healthcare. Table 5.4 shows
increased investment in the operating costs of government health centres, to accomplish policy and strategy numbers 1–6.

Table 5.4: Investment summary in South Sudanese pounds (SSPs) Million

<table>
<thead>
<tr>
<th>Cost Summary SDG million</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Cost</td>
<td>579</td>
<td>670</td>
<td>791</td>
<td>990</td>
<td>3,484</td>
</tr>
<tr>
<td>Health System Strengthening</td>
<td>67</td>
<td>80</td>
<td>89</td>
<td>102</td>
<td>392</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>342</td>
<td>342</td>
<td>225</td>
<td>207</td>
<td>1,236</td>
</tr>
<tr>
<td>Gross Cost</td>
<td>988</td>
<td>1,092</td>
<td>1,105</td>
<td>1,298</td>
<td>5,112</td>
</tr>
<tr>
<td>Cost per capita in US dollars</td>
<td>$40</td>
<td>$43</td>
<td>$42</td>
<td>$48</td>
<td></td>
</tr>
</tbody>
</table>

Sources of Finance SDG million

<table>
<thead>
<tr>
<th>Sources of Finance</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOSS: 2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>216</td>
</tr>
<tr>
<td>DP health commitments</td>
<td>197</td>
<td></td>
<td></td>
<td></td>
<td>543</td>
</tr>
<tr>
<td>Financing Gap</td>
<td>791</td>
<td>1,092</td>
<td>1,105</td>
<td>1,298</td>
<td>4,353</td>
</tr>
<tr>
<td>Total sources required</td>
<td>988</td>
<td>1,092</td>
<td>1,105</td>
<td>1,298</td>
<td>5,112</td>
</tr>
</tbody>
</table>

Source: government of South Sudan’s Report about their Health Sector Development Plan 2012–2015.

Table 5.4 shows that the cost summary (in SSP) has increased by 31% from SSP 988 million in 2012 to SSP 1,298 million in 2015.

6) Local midwives are being trained in scientific obstetric care. Nelson et al. (2011) reports on methods used for improving maternal, newborn, and child healthcare in South Sudan by the Division of Global Health and Human Rights (Department of Emergency Medicine, Massachusetts General Hospital, Boston, USA) in partnership with the MoH. The aim is to improve the limited capacity of frontline health workers. The training package consists of a participatory training course, and pictorial checklists as guidelines for prevention, care, and re-useable medical equipment and commodities. The programme was started in 2010 using a ‘train the trainer’ model. There were five-day and eight-day curricula. During the year of the publication of this report, 72 local trainers and 632 frontline health workers had been trained covering seven out of the former 10 states of South Sudan. Encouraging results have been obtained in the initial monitoring and
evaluation. Thus, there is evidence that committed programmes with adequate funds and resources can provide quick results in training many health workers for skilled birth attendance and increasing health worker capacities. These reflect government policies (numbers 2–7).

However, the pace of the impact of the implemented policies and strategies has been slow due to cultural practices of polygamy and child brides, socio-economic division, and a current civil war.

According to the constitution, the South Sudanese Ministry of Health has a highly decentralised administration system (see Figure 5.1), to reach the grass roots population.

Stages of Health Administration of the MoH Structure in South Sudan:

![Diagram](image)

Figure 5.1: The decentralised management structure of the Ministry of Health, South Sudan.

The responsibilities at each level have been well-defined with numerical targets; however, they are short of resources to get close to achieving these targets. More than 50% of the population are below the poverty line (2009 estimate), which means that most healthcare components are unaffordable. Literacy rates of below 27% and female literacy rates of less than half this figure
render literature-heavy healthcare awareness programmes ineffective (CIA, The World Fact
book: South Sudan, 2017). In its latest report, the UNDP (2018) provided figures, which stated
that at least 80% of people were living on less than US$ 1 per day and 75% of them had no
access to health facilities. These figures show that a lack of resources and poverty are
worsening, which could be due to continuing internal conflicts. However, there has been a
significant downward trend in MMR per 100,000 live births in South Sudan during the period
Division, 8 November 2017), as seen in Table 5.6 and Figure 5.3.

According to Emergency Obstetric and Neonatal Care (EMONC), late referrals, and zig-
zagging and multiple referrals were associated with high MMR in South Sudan. In their study
Elmusharaf et al. (2017) collected data using the Critical Incident Technique (CIT) and
interviews during the period 2010–2012. Based on interviews with 20 women and 15 men in
South Sudan, Mugo et al. (2018) observed that the quality of antenatal care services was poor
due to lack of essential medicine, supplies, and tools, which led to mothers’ dissatisfaction with
the services. In addition, the sudden onset of labour and lack of safety and security were
important reasons for home delivery. Lack of transport, due to non-availability of vehicles and
poor roads, high costs related to long distances from healthcare facilities restricted or delayed
the arrival of women to healthcare facilities. Therefore, the government has attempted to
overcome these challenges by providing health skilled personnel, health facilities, medicine
supplies and tools, vehicles for transport, and essential needed maternal health care services,
evidenced in Table 5.6.

5.3.1 Impact of recommended policies to reduce MMR
The following section highlights the impact of recommended policies aiming to reduce MMR,
and future recommendations.
5.3.2 Increasing skilled attendants at births (SAB) and decreasing GFR to reduce MMR

The Real Medicine Foundation (RMF) at the Juba College of Nursing and Midwifery (JCONAM), South Sudan has a yearly target of between 40 and 60 students’ intake for its Registered Nursing and Midwifery Diploma course (Vitale, 2017).

The numbers of students in the strategic plan and designed programme during the reporting period are tabulated in Table 5.5 together with MMR per year.

Graduate students have been, and will be, positioned in central hospitals; state and county hospitals, and primary healthcare centres to reduce the gap between the high demands for skilled services and the small number of available service providers. The South Sudan population is growing at an estimated annual rate of 4.08%, reaching over 13 million in 2017 (National Bureau of Statistics NBS). The Juba College of Nursing and Midwifery educates students from all 32 states and serves as the first college of its kind, operated by South Sudan. The college aims to improve the quality of, and access to, professional healthcare services by teaching necessary skills through a three-year diploma programme in nursing and midwifery. These qualifications in South Sudan are accredited by the Ministry of Higher Education and Technology and Juba University. The college contributes to reducing the MMR and child mortality rate by providing the medically skilled people needed in South Sudan.

The college accommodates students from Kajo Keji Health Training Institute due to the relocation of students and teaching staff to Juba, because of the insecurity in the area since 2016.
Table 5.5: Graduated nursing and midwifery students from Juba College of Nursing and Midwifery, and trends of MMR in South Sudan between 2010 and 2017

<table>
<thead>
<tr>
<th>Year</th>
<th>Graduated nursing</th>
<th>Graduated midwifery</th>
<th>Total</th>
<th>MMR trends in S. Sudan</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>876</td>
</tr>
<tr>
<td>2012</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>857</td>
</tr>
<tr>
<td>2013</td>
<td>15</td>
<td>15</td>
<td>30</td>
<td>841</td>
</tr>
<tr>
<td>2014</td>
<td>23</td>
<td>22</td>
<td>45</td>
<td>823</td>
</tr>
<tr>
<td>2015</td>
<td>23</td>
<td>15</td>
<td>38</td>
<td>789</td>
</tr>
<tr>
<td>2016</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>730</td>
</tr>
<tr>
<td>2017</td>
<td>30</td>
<td>23</td>
<td>53</td>
<td>730</td>
</tr>
<tr>
<td>Total</td>
<td>91</td>
<td>75</td>
<td>166</td>
<td></td>
</tr>
</tbody>
</table>

Note: There were no graduated students in 2016, because of fighting between the government and SPLA In Opposition (IO) forces in Juba City at J1’s Palace, on 8 July 2016.

As the accessibility to SAB is provided, a better GFR is now occurring. Further, investment in infrastructure, health facilities, and health supplies has contributed to a reduction in MMR and GFR (See Tables 5.5 and 5.6 and Figures 5.2 and 5.3).

Figure 5.2: Graduated nursing and midwifery and trends of MMR 2010–2017

In 2017, the college intake was 45 nursing and 40 midwifery students. Due to the country’s need for qualified medical staff, the MoH and leadership from JCONAM decided to increase the annual intake from 60 to at least 80 students.

Figure 5.2 shows that the increase in trained personnel has created a significant downward trend in MMR per 100,000 live births in South Sudan from 1990 to 2017 (WHO, UNICEF, UNFPA, the World Bank and the United Nations Population Division, 8 November 2017).
Trends of MMR per 100,000 live births 1990–2017, together with SAB, GFR and GDP are listed in Table 5.6

Table 5.6: Trends of the MMR, SAB, GFR, and GDP in South Sudan from 1990 to 2017.

<table>
<thead>
<tr>
<th>Year</th>
<th>MMR</th>
<th>SAB</th>
<th>GFR</th>
<th>GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1730</td>
<td>10</td>
<td>201</td>
<td>2312</td>
</tr>
<tr>
<td>1991</td>
<td>1700</td>
<td>12</td>
<td>212</td>
<td>2474</td>
</tr>
<tr>
<td>1992</td>
<td>1670</td>
<td>12</td>
<td>212</td>
<td>2474</td>
</tr>
<tr>
<td>1993</td>
<td>1630</td>
<td>12</td>
<td>212</td>
<td>2474</td>
</tr>
<tr>
<td>1994</td>
<td>1580</td>
<td>12</td>
<td>212</td>
<td>2474</td>
</tr>
<tr>
<td>1995</td>
<td>1530</td>
<td>12</td>
<td>212</td>
<td>2474</td>
</tr>
<tr>
<td>1996</td>
<td>1470</td>
<td>14</td>
<td>190</td>
<td>2852</td>
</tr>
<tr>
<td>1997</td>
<td>1410</td>
<td>14</td>
<td>190</td>
<td>2852</td>
</tr>
<tr>
<td>1998</td>
<td>1370</td>
<td>14</td>
<td>190</td>
<td>2852</td>
</tr>
<tr>
<td>1999</td>
<td>1340</td>
<td>14</td>
<td>190</td>
<td>2852</td>
</tr>
<tr>
<td>2000</td>
<td>1310</td>
<td>14</td>
<td>190</td>
<td>2852</td>
</tr>
<tr>
<td>2001</td>
<td>1270</td>
<td>17</td>
<td>178</td>
<td>3439</td>
</tr>
<tr>
<td>2002</td>
<td>1230</td>
<td>17</td>
<td>178</td>
<td>3439</td>
</tr>
<tr>
<td>2003</td>
<td>1190</td>
<td>17</td>
<td>178</td>
<td>3439</td>
</tr>
<tr>
<td>2004</td>
<td>1150</td>
<td>17</td>
<td>178</td>
<td>3439</td>
</tr>
<tr>
<td>2005</td>
<td>1090</td>
<td>17</td>
<td>178</td>
<td>3439</td>
</tr>
<tr>
<td>2006</td>
<td>1030</td>
<td>20</td>
<td>165</td>
<td>3513</td>
</tr>
<tr>
<td>2007</td>
<td>971</td>
<td>20</td>
<td>165</td>
<td>3513</td>
</tr>
<tr>
<td>2008</td>
<td>928</td>
<td>20</td>
<td>165</td>
<td>3513</td>
</tr>
<tr>
<td>2009</td>
<td>886</td>
<td>20</td>
<td>165</td>
<td>3513</td>
</tr>
<tr>
<td>2010</td>
<td>876</td>
<td>20</td>
<td>165</td>
<td>3513</td>
</tr>
<tr>
<td>2011</td>
<td>869</td>
<td>24</td>
<td>152</td>
<td>2368</td>
</tr>
<tr>
<td>2012</td>
<td>857</td>
<td>24</td>
<td>152</td>
<td>2368</td>
</tr>
<tr>
<td>2013</td>
<td>841</td>
<td>24</td>
<td>152</td>
<td>2368</td>
</tr>
<tr>
<td>2014</td>
<td>823</td>
<td>24</td>
<td>152</td>
<td>2368</td>
</tr>
<tr>
<td>2015</td>
<td>789</td>
<td>24</td>
<td>152</td>
<td>2368</td>
</tr>
<tr>
<td>2016</td>
<td>730</td>
<td>27</td>
<td>140</td>
<td>1457</td>
</tr>
<tr>
<td>2017</td>
<td>730</td>
<td>27</td>
<td>140</td>
<td>1457</td>
</tr>
</tbody>
</table>
Figure 5.3: Time-series plot of MMR, SAB, GFR, and GDP from 1990 to 2017.
Furthermore, Figure 5.3 shows a small increase in SAB, more decrease in GFR and a significant decrease in GDP. Also, an increase in SAB and improvement in accessibility to trained personnel has reduced the physiological causes of MMR as presented in Table 5.7.

The trend of MMR due to physiological causes from 1986 to 2017, together with the physiological cause (haemorrhaging) is shown in Table 5.7 and Figure 5.4. The full table is presented in Appendix (D)
Table 5.7: Physiological causes (haemorrhaging) impact on maternal mortality rate (MMR) 2015–2030;

<table>
<thead>
<tr>
<th>Year</th>
<th>MMR Target 140</th>
<th>MMR Target 70</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MMR Per 100,000 Live Births (Upper Limit=140)</td>
<td>Haemorrhaging</td>
</tr>
<tr>
<td>2015</td>
<td>206</td>
<td>47</td>
</tr>
<tr>
<td>2016</td>
<td>195</td>
<td>47</td>
</tr>
<tr>
<td>2017</td>
<td>184</td>
<td>46</td>
</tr>
<tr>
<td>2018</td>
<td>173</td>
<td>46</td>
</tr>
<tr>
<td>2019</td>
<td>162</td>
<td>45</td>
</tr>
<tr>
<td>2020</td>
<td>151</td>
<td>45</td>
</tr>
<tr>
<td>2021</td>
<td>140</td>
<td>45</td>
</tr>
<tr>
<td>2022</td>
<td>130</td>
<td>44</td>
</tr>
<tr>
<td>2023</td>
<td>119</td>
<td>44</td>
</tr>
<tr>
<td>2024</td>
<td>108</td>
<td>43</td>
</tr>
<tr>
<td>2025</td>
<td>97</td>
<td>43</td>
</tr>
<tr>
<td>2026</td>
<td>86</td>
<td>43</td>
</tr>
<tr>
<td>2027</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>2028</td>
<td>64</td>
<td>42</td>
</tr>
<tr>
<td>2029</td>
<td>53</td>
<td>41</td>
</tr>
<tr>
<td>2030</td>
<td>42</td>
<td>41</td>
</tr>
</tbody>
</table>
Figure 5.4: Plot of maternal mortality rate (MMR) and significant physiological cause (haemorrhaging), based on the UN targets 70 and 140 by 2030.

Table 5.7 shows a reduction in MMR from 216 in 2012 to 195 in 2016 simultaneously and a reduction in haemorrhaging from 54 in 2012 to about 45 in 2016, when the UN targets MMR = 140 by 2030. Moreover, a reduction in MMR from 216 in 2012 to approximately 194 in 2016 concurrently with reduction of deaths due to haemorrhaging causes from 54 in 2012 to about 47 deaths in 2016 when the UN targets MMR = 70 by 2030.

Figure 5.5: An area plot presents minimum values of MMR and minimum values of haemorrhaging based on the UN targets 70 and 140 by 2030.
Figure 5.6: Histogram presents minimum values of MMR and minimum values of haemorrhaging based on the UN targets for MMR = 70 and 140 by 2030.

5.4 Policies recommended in other developed and developing countries and their impact on MMR reduction

A set of pre-conditions helped developed countries to significantly reduce maternal mortality. The highly influencing favourable factors were: early awareness of the magnitude and seriousness of the problem before it became too complicated to be rectified within a reasonable time, realisation that most maternal deaths are avoidable, and the mobilisation of professionals and the community. The timing and speed of these factors determined the country’s variations. Professionalism in care delivery was marked specifically by the willingness of decision makers to take responsibility, providing the most modern obstetrical care and making it available to the population, and the encouragement of midwifery care and defining clearly the accountability of professionals for addressing maternal health in an effective way. The Swedish model for the reduction of maternal mortality is comprised of three components:

1. An active policy of training midwives, selected for their social profile;
2. Capacity to introduce modernisation as ‘health missionaries’; and
3. A close follow-up of compliance with hygiene and technical prescriptions.
Later, the Netherlands, Norway, and Denmark adopted this model. In the case of England and Wales, although the Swedish model was accepted, the indecision of the government and funding problems delayed the achievement of reduction in maternal mortality. Accessible technologies and reliable hospital care reduced maternal mortality rates further to current levels of 20 or less in Western Europe and the USA. The combined effects of factors from 2013 to 2017, as seen in Table 5.5, such as the earliest availability of and reaction to information, creation of professional and public awareness and responses, a policy on midwifery development supported by doctors, and a strategy to implement adapted versions of the Swedish model played a more important role than technology in this respect.

Even in poor countries, the difference between Sri Lanka (75 to 30 during 1990–2015), Malaysia (79 to 40 during 1990–2015), and Thailand (40 to 20 during 1990–2015) shows the importance of access to early information, professionalism, and quality care. Accessibility includes physical, financial, cultural, and psychosocial dimensions. The accountability of health professionals is very important, including what happened both inside and outside hospitals with respect to the quality of care. Stress on avoidable maternal deaths focuses on what is possible to achieve and the successful strategies to attain it. Table 5.8 presents indicators of health status in Southern Sudan compared with an average region in the Middle East and North Africa countries.

Table 5.8: Indicators of health status in Southern Sudan compared with average of the region Middle East and North Africa (MENA):

<table>
<thead>
<tr>
<th>Indicator</th>
<th>South Sudan</th>
<th>Regional level averages</th>
<th>Indicator Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal Mortality Rate (MMR)</td>
<td>2,054</td>
<td>210</td>
<td>Deaths per 100,000 live births</td>
</tr>
<tr>
<td>Infant Mortality Rate</td>
<td>102</td>
<td>33</td>
<td>Deaths per 1,000 live births</td>
</tr>
<tr>
<td>Under Five Mortality Rate</td>
<td>135</td>
<td>43</td>
<td>Deaths per 1,000 live births</td>
</tr>
<tr>
<td>Total Fertility Rate (TFR: GFR)</td>
<td>6.7</td>
<td>2.9</td>
<td>Births per woman</td>
</tr>
<tr>
<td>First Antenatal visit</td>
<td>48%</td>
<td>78%</td>
<td>Visiting during pregnancy</td>
</tr>
<tr>
<td>Institutional deliveries</td>
<td>13.6</td>
<td>65</td>
<td>Deliveries attended at HFIs</td>
</tr>
<tr>
<td>Skilled Birth Attendance (SBA: SAB)</td>
<td>10% (Now 20%)</td>
<td>76%</td>
<td>All deliveries attended by skilled HRH</td>
</tr>
<tr>
<td>Contraceptives Prevalence Rate (CPR)</td>
<td>&lt;3%</td>
<td>56%</td>
<td>Use of contraceptives among CBA women</td>
</tr>
<tr>
<td>DTP3 coverage (routine)</td>
<td>72 (routine)</td>
<td>89</td>
<td>% of children vaccinated</td>
</tr>
</tbody>
</table>

Stunting
Access to health care (%) 0.2(<25%) NA Visit per person/year

Source: SSHHS, 2006 and World Children’s Status report UNICEF 2008. Institutional deliveries conducted at HFIs also by non-professional staff.

5.4.1 Policies on physiological causes
A shift in the cause of maternal mortality from the traditional haemorrhaging during delivery or eclampsia to diabetes, obesity, cardiovascular disease, and heart failure indicates the need for a different approach as in the case of the USA, which was reported by the Institute of Health Metrics and Evaluation (IHME, 2017). Immediate action on this issue has already progressed well. The USA achieved a slower reduction of maternal mortality than Sweden, and other European countries, due to late information, lack of public pressure, persistent down-rating of midwifery by obstetricians, and insistence on institutional delivery over home delivery without providing basic access and care facilities (IHMF, 2017). The USA achieved better results only when these barriers were removed. In India, the access factor determined the relative vulnerability of high MMR in rural and urban areas of its richer and poorer states. An approximate 4.7% decline in annual MMRs was achieved by an annual increase in skilled birth attendance by 3.5% (IHMF, 2017). The direct causes of most maternal deaths were related to obstetrics. Two-thirds of women died seeking some form of healthcare, mostly during a critical medical condition (IHMF, 2017).

In Kenya, although skilled attendance increased steadily, its effect on reducing MMR was significant only when it reached 50% (Makuei et al., 2016). The reduced delivery rate reflecting increased socio-economic status (per capita GDP on PPP as proxy) will reduce MMR risk automatically. Sudan achieved a much better reduction of MMR with a lower level of skilled attendance, but much faster increase of GDP reflecting better access and affordability (Makuei et al., 2016). Uganda recorded similar MMR reduction, but with a strategy similar to Kenya. Overall, there is a need for effective intrapartum-care strategies irrespective of the country context. Projects designed vertically for safe motherhood in a few countries with funding assistance from UK and USA was not successful in some countries due to insufficient support from the national government (Makuei et al., 2016). Limiting the child-bearing age to
an age beyond which MMR risk increased greatly and not having more than two children, were used in some countries. The education and empowerment of women to elevate their socio-economic status and economic dependency of the nation were important factors. In countries where MMR was due to ante-partum haemorrhaging and not obstructed labour, skilled attendants did not have a significant impact. Near-misses due to delays needed to be controlled in almost all country contexts.
In summary, recommended policies, strategies and their impact on reducing the MMR in South Sudan requires three steps of recommended policies, implemented and achieved policies, and the impact to date as follows:

5.4.2 Summary chart of recommended policies and strategies for reducing MMR in South Sudan is as in the following steps:

1. **Recommended Policies**

   - **Addressing infrastructure**
     - ANC Access: Antenatal care services
   - **Addressing physiological causes**
     - Reducing MMR due to direct causes (e.g. haemorrhaging, sepsis, prolonged, Unsafe Abortion, Hypertension) from 106 in 2012 to 104.8 in 2016
     - Reducing MMR due to indirect causes (e.g. malaria, Anaemia, HIV/AIDS, heart diseases, hepatitis's) from 63 in 2012 to 61.74 in 2016
     - Increasing skilled health professional
     - Reducing GFR

2. **Implemented and achieved policies**

   - Using Tables 5.1-5.5, the Government has been addressing improvement on infrastructure and ANC access
   - Increasing number of PHCC from 80 in 2012 to 416 in 2016 and PHCU increased from 140 in 2012 to 720 in 2016, and specialist hospitals increased from one (1) in 2012 to seven (7) in 2016, as it's clear in Table 5.1
   - It is clear in Tables 5.1-5.5 and Figures 5.2-5.4
   - Reducing direct and indirect causes of MMR by increasing many PHCC, PHCU and skilled health workers as in Tables 5.1-5.5, and Figures 5.2-5.4
   - Improving road, communication network, hygiene, health facilities, supplies… etc.

Figure 5.7: Shows recommended policies and strategies on reducing the MMR in South Sudan

Figure 5.7a: Implemented and achieved policies
Impact to date:

Reducing MMR from 857 in 2012 to 730 in 2016, which is 15% during the five years period. This is clear in Table 5.6 and Figure 5.3

Addressing infrastructure by increasing spending:

From SSP 628,711,330 in 2012 to SSP 1,298,165,976 in 2016 as it’s in Tables 5.3 and 5.4

ANC access:

Total budget increased from SSP 629 million in 2011 to SSP 1,298 million in 2015, covering the following shortcoming

ANC services:

Increasing health care facilities from 124 in 2012 to 1362 in 2016, increasing PHCC from 80 in 2012 to 416 in 2016, PHCU from 140 in 2012 to 720 in 2016, and specialist hospitals from one (1) in 2012 to seven (7) in 2016

Health skilled professional:

Increasing from 2,025 in 2012 to 15,071 in 2016, as in Table 5.2 and 5.5

Reducing physiological causes such as haemorrhage (See Table 5.7), it was decreased from 54 in 2012 to 47 in 2016, when MMR target is 140 by 2030, and decreased from 54 in 2012 to 46.59 in 2016, when MMR target is 70 by 2030

Increasing SAB and reducing GFR:

Increasing SAB from 24 in 2012 to 27 in 2016, which was 13% and reducing GFR from 152 in 2012 to 140 in 2016, that was 8%, (See Tables 5.6 and Figure 5.3).

Figure 5.7b: Shows the impact of implemented policies on reducing MMR in South Sudan
5.5 Recommendations to the Government and stakeholders

1) Based on the results of this study, Skilled Attendance at Birth (SAB) needs to be increased consistently to reduce MMR in the short term as well as long term. A substantial increase of SAB by importing medical skills staff from other countries until enough locally trained skills are available may be a possible, immediate step. Funding from international organisations may be possible on a specific term basis. The training of many local women on skilled attendance at birth, ante-natal care, post-natal care and paediatric care need to be done by offering scholarships to encourage maximum enrolment. Facilities in existing medical institutions need to be expanded to manage increased intake onto these courses. More institutions for training in nursing, especially related to ante-natal care and post-natal care of mothers and children need to be established in both governmental and private sectors. Incentives of various kinds may be provided for attracting foreign and private investments in this field. The aim is to achieve adequate numbers of local skilled assistants at birth as quickly as possible, so that dependence on foreign skills can be gradually reduced. This will also be culturally more suitable, more training and enlightenment of traditional birth attendants (TBA). Continuing in-service training for medical staff is crucial. The developed profile limits can be used to determine the target number.

2) Accessibility and affordability are two elements related to efficient implementation of programmes aimed to reduce MMR. Accessibility can be improved only by building infrastructure of effective roads, transport-network system, provide communication in local languages, and healthcare facilities in various community localities to minimise travelling. Mobile clinics can reach the required placed; telemedicine and rural volunteers with smartphones can alert a nearby healthcare facility when childbirth is due in the locality. To achieve this, fast internet technology needs to be established by encouraging private providers.

3) Emergency transport by providing ambulances for pregnant woman and for waiting at houses for delivery in each healthcare centre, especially in rural areas.

4) Regulating the married age to be 15–49 years, and preventing unsafe abortion in the country.

5) Affordability can be increased by improving socio-economic standards of people for which the rate of increase in GDP need to be sufficiently high to reflect in per capita GDP. The pace of economic development needs to be increased by attracting foreign
direct investments in core sectors to increase and sustainably use the rich natural resources of the country and build capacities.

6) Affordability is also related to the empowerment of women by educating and making them independent earners. Encouraging a set quota for females into these programmes would be a step in the right direction. As mentioned above, if the maximum number of young women can be attracted to study nursing and midwifery, it solves many problems related to maternal healthcare, newborn healthcare, and motherhood healthcare services.

7) Methods to electronically collect reliable data related to all aspects of MMR and across the country on a regular basis need to be devised and implemented. The developed database can facilitate this.

8) Encouraging and providing funding for research about maternal health care, motherhood and childbirth by higher-education institutions.

9) Professional development for medical staff and capacity building in public healthcare services are vital.

10) Regular and systematic collection of reliable data needs to be ensured with suitable institutional mechanisms, systems, and policies. Accountability at all levels can be insisted only if data are available by establishing a civil registration system and identity card for every citizen in the country.

11) Overall, the Medical Code of Conduct and restricted medical practice regulations based on honesty and truthful accountability and political commitment by all stakeholders for the improvement of maternal healthcare services in South Sudan.
5.6 Chapter summary

Policies discussed in sections 1–6 are designed to improve MMR. It shows that the government and policy makers have taken positive steps, particularly in increasing SAB and reducing GFR. In terms of physiological causes, they have also taken positive steps by increasing primary healthcare units (PHCU), primary healthcare centres (PHCC), and specialised hospitals, increasing SAB, improving roads, infrastructure, communication networks, education for women, and increasing the quota of females in all government institutions. As a result, there has been a significant downward trend in MMR in South Sudan, especially during the period 2013–2017, (see Tables 5.5–5.7 and Figures 5.2–5.4).

However, statistics show that more should be done for roads, transport and communication-networks, education for girls, and the empowerment of women. Marrying age regulations for girls should be 15–49, and health facilities and supplies should be provided across the country.
6 DISCUSSION

6.1 Introduction
South Sudan is in urgent need of mitigation measures to reduce the current MMR of 730 maternal deaths per 100,000 live births annually to as low a rate as possible within the shortest possible time. However, a lack of data on the actual mortality rate and mathematical models for estimations and projections towards the future are the two biggest bottlenecks hindering any concrete steps. There is no method to evaluate the likely impact of an intervention strategy to reduce the rate. To serve these three objectives, this study used secondary data on actual death rates from the Juba Teaching Hospital, the sole authentic source in the country for the period of 1986–2015. Different models were tested. The WHO log regression and Poisson regression equations, using Gross National Product (GDP), Skilled Assistance at Birth (SAB) and General Fertility Rate (GFR) as variables predicting MMR, were found to be the most suitable, when tested for efficacy over a range of years. Further, Poisson regression was used to develop the model based on physiological causes of direct causes, e.g. haemorrhaging, sepsis (infections), prolonged (obstructed) labour, unsafe abortion, and indirect causes, e.g. anaemia, malaria, HIV/AIDS, and heart disease, as independent variables.

The results obtained in the previous chapter are explained and interpreted in this chapter. Part of the explanations and interpretations are given in the Results chapter. Literature support for those conclusions will be examined.
6.2 Overall result
The results demonstrate that providing skilled birth assistance can decrease the maternal mortality ratio. Although reduction of GDP also reduced MMR, the economic growth of the country cannot be stopped by reducing the GDP. GFR is an inherent demographic factor. Increasing GFR will increase MMR. Regression equations show to what level MMR can be reduced by increasing SAB and reducing GFR to a predetermined level. Since GFR cannot be changed quickly, reducing a long-term strategy is crucial. What happens in each year when such a strategy is used over a pre-determined long period was estimated using trend analysis equations.

Optimisation methods were used to determine the strategies required to reduce MMR to predetermined levels. Strategies to manipulate SAB and GFR for yearly targets of reduction of MMR to desired levels were estimated. The Millennium UN Goal is to achieve an MMR of 70 (minimum) and 140 (maximum), by 2030. To achieve 140 by 2030, the current SAB value of 19 needs to be increased to 50 and GFR should decrease from its current value of 175 to 97. So, to reduce MMR to 70 by 2030, GFR should decrease from the current value 175 to 75 and SAB should increase from the current value 19 to 76 by 2030.

One limitation of the estimation could be that GDP was assumed to remain constant. This assumption was based on the barriers that exist currently for economic progress.

6.3 Literature support for overall results
The need for a model to estimate MMR due to the absence of reliable data was explained by AbouZahr and Wardlaw (2001) and by Hill et al. (2007). Even if data are available, inherent weaknesses render them unusable. The data weaknesses of different types are generally found in the case of developing and poor countries. The main reasons are the absence of vital civil registration system and lack of resources to establish adequate institutional mechanisms and to meet the cost of data collection and processing.

De Brouwer et al. (1998, 2001) studied how western countries achieved low MMR. There was early awareness of the magnitude and seriousness of the problem. It was realised from studies
that most maternal deaths are avoidable. For this purpose, both professionals and the community were mobilised. The timing and speed of these factors determined the countries’ variations. Professionalism in care delivery was done in a professional manner with willingness of decision makers to take responsibility. The most modern obstetrical care was provided and was accessible to the entire population. In some countries, midwifery care was discouraged. The accountability of professionals was clearly defined for addressing maternal health in an effective way. However, the Swedish model, adapted by Norway, the Netherlands and Denmark, consisted of the selection of good midwives and training them for modern care practices, rather than discouraging midwifery altogether. Hygiene and technical specifications were prescribed and their compliance was monitored closely.

However, applying these strategies in South Sudan to reduce the current MMR of over 700 to 140 or 70 by 2030 appears difficult for the following reasons:

1) South Sudan only became independent in 2011. Many national developmental factors have priority over MMR reduction. Frequent internal conflicts pose a major barrier for development;

2) The economy is not sound due to oil pricing problems with Sudan. Although South Sudan is rich in oil resources, being a landlocked country, it must depend on Sudan for its oil export;

3) Public awareness of the problem is limited. There had not been any attempt in this direction by South Sudan;

4) There are very few healthcare professionals who can provide effective leadership for the reduction of MMR. Poor infrastructure limits access to quality healthcare for most pregnant mothers;

5) Only traditional midwives are available in villages. Training them professionally is a long process due to a lack of resources. Although some international agencies are assisting in this respect, it is still inadequate; and

6) No standards or technical specifications exist for obstetric care.
The importance of early information and action to professionalise with accountability, and access to quality care, was demonstrated by the differences in MMR reduction achieved in 2015 by Sri Lanka (30), Malaysia (40), and Thailand (20), as highlighted in the Literature Review (LR) chapter.

Possible further problems are: administrative delays, procedural delays, and clinical mismanagement. Thus, there are many ‘ifs’ and ‘buts’ in the entire care-seeking process, affecting MMR.

It is possible to avoid 16%–33% of all maternal deaths by primary or secondary prevention of the four well-known complications of obstructed labour, eclampsia, puerperal sepsis, and obstetric haemorrhaging, through SAB. The results of the present study show a significant contribution of SAB in reducing MMR in South Sudan.

In the case of South Sudan, healthcare expenditure as a percentage of GDP increased from 0.922% in 2013 to 1.137 in 2014. The global average was 5.917% in 2013 and 5.959% in 2014. Thus, although increasing, South Sudan spends a very low portion of its funds for healthcare. This demonstrates the need to improve healthcare expenditure and for it to be awarded a higher priority by South Sudan government.

A more detailed analysis of MMR with HIV/AIDs, MMR without HIV/AIDs, and total MMR was described in the Results chapter. Non-HIV/AIDs MMR accounted for about two-thirds of the total MMR. The fact that the remaining one-third of MMR was related to HIV/AIDs and the slower rate of its decline compared to the total and non-HIV/AIDs MMR, demonstrates the need for specific strategies to reduce HIV/AIDs, which should also reduce MMR.

The findings of this study show that the percentage decline from 1986–2008 to 2009–2015 was 60.2% in the case of non-HIV/AIDs MMR, compared to only 28.3% in the case of HIV/AIDs MMR. This result demonstrates the difficulty of reducing MMR if HIV/AIDs complications are present. In the analysis by Khan et al. (2006), for Africa, among global continents, HIV/AIDs were associated with maternal mortality to the extent of 6.2%. However, interventions such as antiretroviral therapy (ART) may not be useful, as per the findings of a
Botswana study reported by Zash et al. (2017) The study revealed that even when there was high rate of use of ART during pregnancy and postpartum, Botswanan women with HIV were five times more likely to die than those who were non-HIV in the 24 months postpartum. On the other hand, in South Africa, the recent reduction in HIV-related MMR (although still high) was traced to increased availability of ART from the data compiled and analysed by Mnyani et al. (2017). In South Africa, 4,823 women (aged 15–49 years) tested positive for HIV, among them, 156 were pregnant (4.7%) in 2008. In 2012, there were 8,253 HIV-detected women with 240 (4.5%) of them pregnant (Eaton, et al., 2014).

### 6.4 Regression models for non-HIV+/AIDs maternal deaths (MDs): healthcare-related predictors

Based on the results outlined in the previous chapter, the Log-linear regression model predicted MMR better than Poisson regression models.

$$
\ln(\text{Non-HIV/AIDS}) = -20.8 - 8.30 \ln(\text{SAB}) + 8.10 \ln(\text{GFR}) + 5.12 \ln(\text{GDP}) \tag{6.1}
$$

Interestingly, the slopes of SAB and GFR were similar and much higher than that of GDP, indicating greater effect for SAB and GFR in reducing MMR. The models were derived using two-thirds randomly selected data, and their predictability was tested using the remaining one-third of the data. For the entire period 1986–2015, the mean non-HIV/AIDs MMR was 28.27, SAB 15.98%, and GFR 179.9 per 1,000 women of reproductive age and per capita GDP 1,256 USD.

The poor economic condition of South Sudan may not permit increasing SAB, reducing GDP and GFR simultaneously. Therefore, prioritisation over a period, sequential focusing on these factors one-by-one over a period, may be a more practical approach.

### 6.5 Impact of independent variables (SAB, GFR) on MMR

If resources are available, SAB can be increased to provide safe delivery. Presently, against a global average of 78.13% of total births attended by skilled staff, for South Sudan, 19% were attended by skilled staff. In comparison, it was 51% in 2015 for Afghanistan, 100% for
Australia in 1991, 77% in 1988 for Botswana, 87% in 1988 itself for Sri Lanka and countries such as South Africa, Sri Lanka, Malaysia, and Kenya achieving 100% already in different years (World Bank Group, 2017). Thus, South Sudan must go a long way to obtain significant MMR reduction through the increase of SAB.

### 6.6 Optimal linear profile limits for MMR and their impacts on resources allocation and policy making

The optimisation results show that, to achieve reduction of MMR from the current (2015) value of 730 to 140 by 2030, annual MMR must be reduced by 39 each year. During this period, the SAB needs to be increased from the current 19 to 50 and GFR should be decreased from the current 175 to 97. The overall target can be broken up into annual and five-yearly targets for convenience.

To achieve a more ambitious UN target of MMR = 70 by 2030, higher levels of efforts are required. Ln (MMR) should decrease by 0.156, Ln (SAB) should increase by 0.09, and Ln (GFR) should decrease by 0.05 to 0.06. GDP was held constant, assuming the economic development of the country to be at steady state. Profile limits for minimum and maximum values for the three variables were graphed and presented in the results. Similar results were also presented for a compromise target of MMR 105 by 2030. As is evident, the slopes of the profiles were steeper for the target of 70 compared to 105 and 140.

Certainly, the utilisation of a profile limit to determine the extent of changes required in the factors to achieve a pre-determined target of MMR is a new approach in this field of study. Profile limits and optimisation techniques have been used in diverse fields. Kalejahi et al. (2014) used multivariate curve resolution with an alternating least square (MCR-ALS) technique to study simultaneous degradation of organic pollutants of dye industry by advanced oxidation process. As the reactions involved second-order kinetics, the overlapping spectra needed to be resolved to study the dye concentrations during the reaction. In an earlier similar work on chemical reaction, band boundaries were determined using the same method (MCR-ALS) by Garrido et al. (2005). Multivariate regression analysis was used for optimisation of
glucose control and reduction of glucose variability in diabetic pregnant women in the work of Dalfra et al. (2011). Thus, multivariate profiling and optimisation has been used in many types of work including some healthcare aspects, but rarely in the case of maternal mortality.

6.7 Prediction models for MMR based on physiological factors

The results of this study revealed that haemorrhaging (30% of total reviewed cases) and indirect causes (22%) are significant physiological factors related to non-HIV/AIDS (MMR) in South Sudan. Time-series analysis Figures 5.4-5.6 showed a decline trend in the five main causes of non-HIV/AIDS MMR. However, compared with the trend in non-HIV/AIDS MMR, the haemorrhaging is declining at a much slower rate followed by indirect causes, Sepsis (infection), Prolonged (Obstructed Labour) and unsafe abortion respectively. All variables were positively and significantly correlated with non-HIV/AIDS MMR and among themselves. Regression equations fitted all the physiological variables except hypertension (as it was related to haemorrhaging). Our analyses show that all physiological causes had an impact on MMR, as it clears in Figures 5.4-5.6. However, in this study we have only investigated the impact of haemorrhaging and unsafe abortion. This is because these two causes can be controlled by the government and other stakeholders by regulations and enlightenment about the negative side of unsafe abortion. Therefore, we used haemorrhaging and unsafe abortion as predictors in our models. Poisson regression was more efficient to predict MMR. Consequently, Poisson model was deployed to model MMR in terms of haemorrhaging and unsafe abortion and haemorrhaging only.

The work of Goodburn and Campbell (2001) on clinical causes of maternal deaths shows that haemorrhaging with 25% and indirect causes with 20% incidence levels were the top two physiological causes of maternal deaths, as was also found in this study. Resources for health, referrals, and community services required for effective implementation of the listed quality care were also presented by the author. In the case of South Sudan, it is not that these are totally absent, but they are significantly inadequate, at least partly constrained by funding deficits in the context of the poor economic condition of the country.
6.8 Development of the profile limits for the reduced Poisson regression

As physiological causes accounted for 206 MMR out of 730 in 2015, the optimised haemorrhaging values to achieve the UN maximum MMR of 42 and minimum value of 21 due to physiological causes (UN targets for 2030) are estimated. To reduce MMR due to physiological causes from 206 to 42, the maternal deaths due to haemorrhaging needs to be reduced from current 47 to 10 by 2030. In their work, Haeri and Dildy (2012) observed that a major portion of postpartum haemorrhaging (PPH) is preventable. If the specific risk factor for the PPH in each patient is identified, appropriate interventions to prevent PPH using Oxytocin or prostaglandins, or another method, can be implemented to prevent maternal deaths due to haemorrhaging.

A staged protocol, based on the degree of blood loss and response of the patient to interventions, was found effective to increase maternal safety by reducing maternal haemorrhaging (Shields, et al., 2011). Such approach may be useful to South Sudan for efficient utilisation of its scarce resources available for this purpose.

Overall, it is possible to reduce haemorrhaging-related maternal deaths in South Sudan by identifying associated risk factors, high efficiency of interventions in healthcare facilities, and staging the protocols for efficient utilisation of scarce resources.

6.8.1 Administrative Tasks

1) The programmes recommended by the government and UN agencies to reduce MMR

In the literature review chapter, the NBS report (Sudan, 2012) was cited, which had summarised the suggestions of the South Sudan Government and international agencies. The report produced a list of challenges and strategies that needed to be addressed. These challenges and strategies were responsible for achieving a 20% reduction in MMR by 2015.

2) The suggestions implemented by the Government and its partners

All the suggestions have been implemented, but the current implementation levels of all these suggestions are variously and highly inadequate, inefficient, and ineffective due to political and funding problems. As the scope for self-funding is negligible due to current political and...
economic conditions of the country, external funding is necessary to finance the implementation of the recommendations.

3) The impact of implementation in terms of performance and effectiveness
Despite all the above problems, MMR in South Sudan has declined over the years from an estimated 1,730 in 1990 to about 730 in 2015, 57%. With an average decline of about 2.3% per year, if this declining trend continues, MMR would have reduced to 574 by 2030. However, the UN Millennium Development Goals stipulates the reduction of MMR to a maximum of 140 and a minimum of 70 by 2030. The distance from 574 to 140 is substantial. These data also demonstrate the inadequate implementation of MMR-reduction strategies.

4) Successful programmes in other countries of the region
In the literature review, examples of some developing countries that had achieved MMR levels comparable to developed countries were discussed. Factors that contributed to their success were also identified as follows: early identification of the problem, creating awareness, setting standards and implementing quality care, with, or without, training skilled assistants at birth and/or various birth control and family planning strategies, institutional mechanisms for regular collection of relevant data, context-specific researches for solutions, use of community health workers for promotion of healthy motherhood and delivery, and providing infrastructure for better access to quality healthcare, even for those in isolated rural areas. These policies were variously implemented in countries such as Sri Lanka, Indonesia, Thailand, and Malaysia for the reduction of MMR from 400 to 50 or below, taking progressively less time as they progressed from one stage to the next stage in reduction.

What further strategies are required for reducing MMR to the UN recommended levels of 140 and 70 by 2030?

Although non-HIV/AIDS MMR was higher in number and impact, the HIV/AIDS MMR was also quite significant. Considering this significant effect, the need for acceleration of current programmes to prevent HIV/AIDS is obvious.

The first two factors are: funding and political stability. If political stability is ensured, it can facilitate economic development, and, thus, at least partial funding from self-sources is
possible. Politically calm atmospheres and efforts on economic development will facilitate international support and funding for key activities. MMR should be one of the top priorities at this stage.

The results of this study show that although there are many factors related to MMR reduction, in the context of South Sudan, only SAB, GFR, and GDP appeared to be important, based on the ability of predictive models to provide reliable estimates of MMR. Increases of SAB, reductions in GFR, whilst helping GDP to remain constant were associated with the reduction of MMR.

Optimisation for SAB and GFR values to be achieved to reduce MMR to 140, 105 and 70 were identified in this work. Also, among physiological causes of MMR, haemorrhaging was found to be the most significant factor. The optimal level of haemorrhaging and unsafe abortion needed to achieve MMR (due to physiological causes) 140, 105, and 70 were also estimated.

6.9 Chapter summary

Thirty years of South Sudan data were used to identify the most significant and influential economic factors and physiological causes of maternal mortality. The analysis shows that the SAB, GFR, and GDP are significant economic factors, further, haemorrhaging, microbial infections, preeclampsia, cardiovascular diseases, liver disease, sepsis, and gastro-intestinal hepatic diseases are the most common physiological causes of MMR. Amongst these, deaths related to haemorrhaging, sepsis, and eclampsia are more common.

Multi-variant Log-linear and Poisson regression models were used to develop a prediction model to estimate maternal mortality based on the three most influential economic factors (SAB, GFR, and GDP), and the top five physiological causes (haemorrhaging, sepsis (infections) labour (prolonged), unsafe abortion, and indirect causes (anaemia, malaria, HIV/AIDS, heart disease). The results show that these causes contribute 97.43% to the variation in maternal mortality rate. Judging by their corresponding variance inflation factor (VIF) and p-value, the conclusion is that all five causes are statistically significant. However, based on the literature recommendations, we developed multivariate Log-linear regression
models and reduced Poisson regression models based on the SAB, GFR, and haemorrhaging, while keeping GDP constant at 1,772 and haemorrhaging only respectively. The results show that haemorrhaging alone is responsible for 90.27% of the variation in maternal mortality rate in South Sudan. The findings indicate that the proposed reduced model can predict MMR for a given level of haemorrhaging with a mean error of -34.5517 and standard error of mean 0.0151. Furthermore, there were two significant physiological causes of haemorrhaging and unsafe abortion. The outcomes show that haemorrhaging and unsafe abortion are responsible for 92.68% of variations in the MMR. These outcomes indicate that the reduced Poisson model can predict MMR for a given level of haemorrhaging and unsafe abortion with a mean error of 16.76616 and standard error of mean 0.022677. To reduce the impact of the sample size on the reliability of the developed reduced Poisson model, we repeated a random sample selection 30 times using Bernoulli distribution with a probability of 0.67 to select two-thirds of the data to build the models and one-third to assess the efficacy.

For the first time, the author deployed optimisation to develop the yearly optimal lower and upper profile limits for SAB, GFR, unsafe abortion, and haemorrhaging levels, and MMR (due to SAB, GFR, unsafe abortion and haemorrhaging) to achieve the UN recommended minimum and maximum levels by 2030. Furthermore, to reduce the MMR, the following actions are recommended. The SAB, GFR and haemorrhaging are potentially life-threatening and need to be managed effectively and in a timely manner to prevent adverse outcomes. The effective management of these factors and causes can reduce MMR by a substantial amount. However, this requires policies and interventions at many levels. Roads, communication, transport, women’s empowerment, education, family planning programmes, and hospital infrastructure should provide the necessary items and equipment to manage haemorrhaging and other causes, including availability of blood for transfusion, supply of oxytocin hormones, surgical items, and items that can help prevent bleeding. Hospital staff, including midwives, nurses, doctors and TBAs should have the necessary enlightenment, expertise, and training to effectively deal with haemorrhaging. The measures will require a significant investment by the South Sudan Government, UN agencies, and other stakeholders. The investment is required to build more
upgraded medical facilities, update the training of medical personnel, and improve road, transport, and communication. In addition, providing home delivery services for pregnant women who live in rural areas or poor setting communities. Moreover, the government should control unsafe abortion by regulating and enlightening people of South Sudan about the negative side of unsafe abortion.

The developed profile limits presented in this study can effectively aid policy makers in their resource allocation tasks aimed to reduce mortality rate caused by SAB, GFR, haemorrhaging, and unsafe abortion.
7 Conclusions and Recommendations

7.1 Conclusion

South Sudan is amongst countries with the highest maternal mortality rate (MMR) with 730 per 100,000 live births in 2015. Healthcare in conflict-affected countries such as South Sudan is affected by the fragility of institutions and systems, society, and economic development due to the volatility in economic, social, and political fronts. It is well documented that KPIs contributing to high MMR include socio-economic, macro-economic, and physiological factors. The aim of this study was to identify the most significant KPIs impacting MMR in South Sudan, then to measure the effect of changes in the KPIs as well as changes in health policies of the government regarding MMR over the study period. In this study, the maternal mortality rate due to socio-economic factors, physiological causes, and the government’s health policies have been analysed.

Time-series, multivariate regression models and multivariate profile monitoring algorithms were deployed to describe, monitor, and predict MMRs in South Sudan.

There was a serious lack of reliable data as there are no institutional mechanisms and systems with which to collect data on a regular basis. Therefore, actual data regarding South Sudan were collected from many authentic sources. The research used data collected from the Department of Statistics, the Juba Teaching Hospital (JTH), the Reproductive Health
Department, the Ministry of Health (MoH), the National Bureau of Statistics (NBS, 2015), the South Sudan National Baseline Household Survey (2009), South Sudan Household Health Survey (2008), Census of Population and Housing (NBS, 2008), and the reports of United Nations’ Organisations and their partners (WHO, UNAID, UNICEF, and UNDP). The data was collected during the period 17 August 1986 to 26 October 2015. The creation of a structure for an informative national data-recording system was the most significant step for this project. The author had consultation discussions with 30 experts and a review of literature to derive this database system. Retrospective and prospective data on maternal deaths, gross domestic product (GDP), skilled attendants at birth (SAB), general fertility rate (GFR), physiological causes such as haemorrhaging, sepsis, prolonged labour, unsafe abortion, anaemia, malaria, HIV/AIDS, and heart disease and project infrastructural plan and investments were used for analysis.

Correlation coefficients, time series modelling, multi-log regression, Poisson regression, optimisation and multivariate profile monitoring were deployed to summarise, forecast, and model MMR in South Sudan.

The study explored and compared the trends in HIV+/AIDS and non-HIV+/AIDS related to the MMR during the period 1986–2015. The results of this analysis indicate that there was a general declining trend in HIV+/AIDS, non-HIV+/AIDS, and total MMR during the period of study. However, the decline in HIV+/AIDS MMR is much slower compared to non-HIV+/AIDS MMR.

Trend analysis also shows that about two-thirds of the total MMR was accounted for by non–HIV+/AIDs MMR. Therefore, further research and evaluation are needed for improving clinical management of pregnant and postpartum pregnant women with HIV+/AIDS.

Multi-variate Log-linear and Poisson regression models were used to develop predictive models to estimate MMR based on the three most influential economic factors (SAB, GFR, and GDP), and the top five significant physiological causes, e.g. haemorrhaging, sepsis, prolonged labour, unsafe abortion, and indirect causes, including anaemia, malaria, HIV/AIDS, and heart disease.
Accuracy criteria such as coefficient of determination and mean error were used to compare the predicting error of these models. The results show that Log-regression can predict MMR in terms of socio-economic factors with mean error of 0.008.

Results also show that logarithmic multi-regression models provided distinct evidence that increasing Skilled Attendant at Birth (SAB) and decreasing General Fertility Rate (GFR) while leaving the Gross Domestic Product (GDP) constants at 1,772, during the period of study can reduce MMR in South Sudan by 2030 to the lower- and upper-target levels proposed by the 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%]) while decreasing GFR by 1.22% per year would reduce MMR by 1.8% (95% CI [0.5%–6.26]), when the GDP is held constant at given average of 1,772.

However, the comparison of the findings of this study, to other similar studies, suggests that reducing GFR is more effective and achievable than increasing SAB, when aiming to reduce MMR.

For the first time, optimisation has been deployed to develop the yearly optimal lower and upper profile limits for MMR, SAB, and GFR to achieve the UN-recommended lower and upper MMR levels by 2030. To achieve the maximum target value of MMR = 140 in 2030, South Sudan needs to reduce MMR by 39 per year from the current value of 730. This would only be achieved by simultaneously increasing SAB from the current value of 19 to 50 and reducing GFR from current value of 175 to 97. To achieve the lower UN MMR target of 70 by 2030, the SAB level must be increased to 76 and GFR level must be reduced to 75. Developed optimal profile limits provide a quantitative guideline for the government in terms of yearly SAB and GFR targets to reduce MMR to the level recommended by UN agencies.

The current efforts to increase intake to nursing and midwifery training courses may need further enhancements to meet SAB demands. However, the increase in students’ intake needs to be supported with matched training staff and other facilities.

A reduction in GFR requires the increased use of contraceptives, control of childbirth and early marriages, and family planning for adequately spaced births. These strategies are difficult to implement, especially among the illiterate and tradition-bound rural communities. So,
increasing literacy levels also becomes a part of the total programme. The study also investigated the physiological causes of MMR based on international and national comprehensive literature studies. Thirty years of South Sudan data were used to identify the most significant physiological causes of maternal mortality. The analysis shows that haemorrhaging; microbial infections, preeclampsia, cardiovascular diseases, liver diseases, sepsis, and gastro-intestinal hepatic diseases are the most common physiological causes of MMR. Amongst these, deaths related to haemorrhaging, sepsis, prolonged labour, unsafe abortion, and indirect causes are more common.

The numerical results indicate that the top five physiological causes contributed 97.43% to the variation in maternal mortality rate (due to physiological causes). The analysis of the predicting errors shows that Poisson regression can describe MMR in terms of physiological causes more accurately than the Log-regression model. Therefore, Poisson regression is used to assess the impact of physiological causes on MMR.

Their corresponding variance inflation factor (VIF) and p-value, indicate that all the top five causes are statistically significant in describing MMR. However, based on the literature’s recommendations, the study has also developed two reduced Poisson regression models to describe MMR in terms of haemorrhaging only, and haemorrhaging and unsafe abortion.

To reduce the impact of the sample size on the reliability of the developed reduced Poisson models, repeated random sample selection was used 30 times using Bernoulli distribution with 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 models were developed based on the average coefficients of the 30 models. The results indicate that the proposed reduced Poisson model with $R^2$ of 90.27% can describe MMR for a given level of haemorrhaging with a mean error of -34.5517 and standard error of mean 0.0151. Further, the physiological causes of haemorrhaging and unsafe abortion will contribute 92.68% to the variation in MMR. The outcomes indicate that the reduced Poisson model can describe MMR for a given level of haemorrhaging and unsafe abortion with a mean error of 16.76616 and standard error of mean 0.022677.
For the first time, the author has deployed optimisation to develop the yearly optimal lower and upper profile limits for haemorrhaging levels and MMR (due to physiological causes) to achieve the UN recommended minimum and maximum levels of 21 and 42 by 2030. The minimum and maximum limits for total MMR due to physiological causes are estimated based on the assumption that 30% of total MMR is due to physiological causes.

The MMR due to physiological causes in 2015 for South Sudan was 206 per 100,000, with 62 MMR due to haemorrhaging. The profile limits indicate that, to achieve (due to physiological causes) the MMR upper limit of 42 and 21 by 2030, death due to haemorrhaging should be reduced from the current value of 62 to minimum of 42 and minimum of 21.

The profile limits for MMR in terms of haemorrhaging and unsafe abortions indicate that, in 2015, the total number of deaths due to haemorrhaging and unsafe abortion was 78 of which 62 was due to haemorrhaging and 16 due to unsafe abortion. Therefore, to achieve the UN target levels of 42 and 21 by 2030, deaths due to haemorrhaging and unsafe abortion should simultaneously be reduced from the current value of 62 and 16 to (33 and 17) and (9 and 4) respectively.

The study also investigated the impact of government policies aimed to reduce MMR. The analysis shows that the government has taken positive step to reduce MMR by targeting KPIs. The lacks of trained and poorly trained personnel are still two major problems in maternal healthcare. As such, the government must implement policies to increase the number of health professional students and graduates.

The proposed health development plan (HSDP) for 2012–2016 had a budget increase of 87%. Healthcare costs increased by 31% from 2012 to 2015. This resulted in MMR (due to physiological causes) decreasing from 216 in 2012 to 202 in 2016, while death due to haemorrhaging was reduced from 54 in 2012 to 47 in 2016. Further, the MMR was reduced from 857 in 2012 to 730 in 2016 while SAB increased from 24 in 2012 to 27 in 2016 and GFR decreased from 152 in 2012 to 140 in 2016.
The increased budget was used to significantly improve healthcare facilities by increasing the number of primary healthcare units (PHCU), primary healthcare centres (PHCC), specialised hospitals, improving roads, infrastructure, communication-network, 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 during the period 2013–2017.

The training of nurses and midwives, a reduction in adversely affecting cultural practices, and the improvement of resources and knowledge are in progress. The need for the development of a reliable database has also been stressed.

The study indicates that a lack of appropriate levels of SAB, GFR, and mismanagement of haemorrhaging and unsafe abortion, are potentially life-threatening and need to be managed effectively and in a timely manner to prevent adverse outcomes. However, this requires policies and interventions at many levels such as, roads, communication-networks, transport, women-empowerment, education, and family planning programmes. The hospital infrastructure should provide the necessary items and equipment’s to manage haemorrhaging and other causes; these include the availability of blood for transfusion, supply of oxytocin hormones, surgical items, and items that can help prevent bleeding. In addition, the provision of home-delivery services and waiting houses for due pregnant women in each PHCC and PHCU, especially in rural areas or poor setting communities.

Limiting the child-bearing age to a certain age beyond which MMR risk increase highly and not having more than two children were used in some countries. Education and empowerment of women to elevate their socio-economic status and economic dependency of the nation were crucial factors.

Decentralisation should replace the current highly centralised healthcare management system.

The developed profile limits presented in this study can effectively aid policy makers in their resource allocation tasks aimed to reduce mortality rate caused by socio-economic factors and haemorrhaging causes.

In conclusion, the outcomes of this study can effectively aid the South Sudan Government to design and implement more efficient health policies and resource allocation to reduce maternal
deaths and mortality rate. The study adds new analysis and recommendations to South Sudan’s maternal deaths and MMR literature for public healthcare. Further, the findings of this research provide useful administrative and scientific guidelines for the expansion of healthcare service programmes and for the effective distribution of limited government resources, specifically in rural areas, including analysis of where further aid investments are likely to best impact on reducing the MMR.

Contributions of this research to reduce MMR in South Sudan are as follows:

(i) The initiation for the development of a highly-needed reliable electronic maternity database for South Sudan;

(ii) Identification of the most influential socio-economic factors and physiological causes for high maternal deaths in South Sudan;

(iii) The development of reliable and effective multivariate regression models, Poisson regression models, and time-series models to accurately estimate and forecast maternal mortality in terms of the influential socio-economic factors and physiological causes in South Sudan;

(iv) The development of multivariate profile monitoring algorithms to monitor and control the changes in the significant factors responsible for the MMR; and

(v) Assessment of the impact of policies designed to reduce MMR.

7.2 Recommendations

Based on the detailed statistical analysis carried out in this study, the author listed the following recommendations to achieve the minimum and maximum UN MMR targets by 2030:

- Skilled Attendants at Birth (SAB) needs to be increased consistently to reduce MMR in the short term as well as long term. Initially, as a short-term step, trained health workers may be imported from other countries until enough locally trained skills are available. For this, funding from international organisations may be possible on a specific term basis.
• Side-by-side training of many local women on skilled attendance at birth, ante-natal care, post-natal care, and paediatric care need to be carried out by offering scholarships to encourage maximum enrolment. Many of them could be sent to foreign countries as currently available facilities may not be adequate to reach the required numbers within the shortest time.

• Facilities in existing medical institutions need to be expanded to manage increased intake into these courses (midwifery and nursing). More institutions for training in nursing, especially related to ante-natal care and post-natal care of mother and child need to be established to reduce dependence on foreign skills gradually.

• Accessibility and affordability are two elements related to efficient implementation of programmes meant to reduce the MMR. Accessibility can be improved only by building infrastructure of good roads, a transport network system, providing communication in local languages, and healthcare facilities in various community localities to minimise travelling. Mobile clinics can reach the required places. Telemedicine and rural volunteers with smartphones could be useful to alert nearby healthcare facilities when childbirth is imminent in the locality. For this, fast internet technology needs to be established by encouraging private providers.

• Emergency transport can be ensured by providing ambulances for pregnant woman and a waiting house for delivering in each healthcare centre, especially in rural areas.

• Age for marriage should be regularised and limited to 15–49 years, preventing unsafe abortion in the country by providing regulations and the enlightenment of people of South Sudan.

• Affordability can be increased by improving socio-economic standards for people for whom the rate of increase in GDP needs to be sufficiently high to reflect in per capita GDP. The pace of economic development needs to be increased by attracting foreign direct investments in core sectors, to increase and sustainably use the rich natural resources of the country, build capacity.

• Affordability is also related to the empowerment of women by educating and making them independent earners. As mentioned above, if the maximum number of young women can be attracted to study nursing and midwifery courses, it will solve many problems.

• Encouraging and providing funds for research about maternal healthcare, motherhood, and childbirth by higher-education institutions are crucial.
• Professional development for medical staff and capacity building in public healthcare services are vital. This will improve the quality of care and accountability.

• A regular and systematic collection of reliable data needs to be ensured with suitable institutional mechanisms, systems, and policies. Accountability at all levels can be only be insisted upon if data are available.

7.3 Limitations

7.3.1 Factors impacting MMR
This research investigated the impact of SAB, GFR, and GDP on MMR in South Sudan. However, as highlighted in the introduction, factors impacting the MMR include socio-economic and macro-economic factors and physiological causes (WHO, 2015a, 2015b). Lack of access to healthcare facilities is also a major factor due to the lack of roads and transportation systems (Gorgeu, R., 2012; Mugo et al., 2015). More than 50% of the population must walk three miles or more to the nearest primary healthcare unit. All these factors affect the total healthcare system, and the high MMR problem. Kruk et al. (2010) investigated the impact of the community’s perceptions on the quality of care provided by the local health system on pregnant woman’s decisions to deliver in a clinic. They have suggested that improving the quality of care at first-level clinics may assist the efforts to increase facility delivery in sub-Saharan Africa (Downie, 2012).

This study also encountered limitations associated with the accuracy of the information recorded on the manual pregnancy register or inaccurate data transfer to the electronic database. However, monitoring and controlling the process of data collection and transfer was conducted to reduce potential errors.

7.4 Future research directions

The optimal profile limits for socio-economic and physiological factors are each developed by optimising two significant KPIs of MMR. Further research can be carried out to develop the profile limits based on more than two KPIs.

The proposed MMR modelling can be extended to assess the simultaneous impact of several microeconomic policies on MMR upon availability of further economic data.
Further research and evaluation are needed for improving clinical management of pregnant and postpartum women with HIV+/AIDs.

7.5 A portion of the results from this chapter has been published in the following papers:

A) Journal papers:

B) Referred Conference papers
8 References


Elmusharaf, K., Byrne, E., AbuAgla, A., AbdelRahim, A., Manandhar, M., Sondorp, E., et al. (2017). Patterns and determinants of pathways to reach comprehensive emergency obstetric and
neonatal care (CEmONC) in South Sudan: qualitative diagrammatic pathway analysis. *BMC pregnancy and childbirth*, 17(1), 278.


PEPFAR. (2017). Republic of South Sudan Country Operational Plan (COP) 2017 Strategic Direction Summary (SDS). PEPFAR.


9 APPENDICES

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A. ETHICS APPROVAL

9.1 Ethics Approval by Ministry of Health (MoH), South Sudan and accepted by College Human Ethics Advisory Network (CHEAN), RMIT University, Melbourne, Australia, and registered under number: ASEHAPP 97-16
To: Gabriel Moksei Deng  
RMIT University Melbourne Australia

RESEARCH APPROVAL LETTER

6th October, 2015

Dear Deng,

SUBJECT: PERFORMANCE EVALUATION OF THE PROCEDURES AimED TO REDUCE MORTALITY RATE IN SOUTH SUDAN

I am writing in response to the request of authorization for the study on “Performance Evaluation of the Procedures Aimed to Reduce Mortality Rate in South Sudan”. As part of your secondary data, after close review on the proposal, I am glad to inform you that the ethical committee at the Ministry of Health, Republic of South Sudan has approved the study. The ministry acknowledges the importance of the study to evaluate the performance and effectiveness of the health policy procedures to reduce Maternal Mortality rate in South Sudan.

Please, keep the Ministry of Health, Republic of South Sudan and the relevant State Ministries of Health and concerned authorities informed on the implementation progress. I look forward to the report and recommendations that will be generated from the study. Note that the study should not be published in any form without the notification of the Ministry of Health.

Best regards,

Dr. Richard Loku Lino
Director General of Policy, Planning, Budgeting and Research
Ministry of Health, Republic of South Sudan, Juba

CC: Under Secretary, MOH-RSS
CC: Director General, for Reproductive Health, MOH-RSS

Ministry of Health
Headquarters, Ministerial Complex, Juba, South Sudan - P.O.Box 88, Juba.
Tel: +211 (0) 177 800 281 / +211 (0) 177 800 278

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B. RECOMMENDED MATERNAL DEATHS CHARACTERISTICS (CAUSES AND FACTORS) AND MODELS

9.2 The recommended maternal deaths characteristics (causes and factors) and models which have been used in this research:

Table 9.1 presents the recommended maternal deaths characteristics (causes and factors) and models

<table>
<thead>
<tr>
<th>Cause/model</th>
<th>Factor/model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haemorrhaging/Hypertension</td>
<td>Skilled attended at births (SAB)</td>
</tr>
<tr>
<td>Sepsis (Infections)</td>
<td>General Fertility Rate (GFR)</td>
</tr>
<tr>
<td>Disorders</td>
<td>General Domestic Product (GDP)</td>
</tr>
<tr>
<td>Prolonged (Obstructed Labour)</td>
<td>HIV+/AIDs</td>
</tr>
<tr>
<td>Unsafe (Abortion)</td>
<td>Malaria</td>
</tr>
<tr>
<td>Indirect causes</td>
<td></td>
</tr>
</tbody>
</table>

The purpose of our work is to quantify relationships of changes in maternal mortality rates due to changes in independent variables as well as changes in health policies of the government over the study period in different regions of South Sudan. Hogan, et al, used a Poisson regression model with specified year and direct cause of death as covariate. This enables one to obtain different equations for different years and might reflect changes in health policies. The model is:

\[ \ln(\lambda) = \beta_1 \text{Year} + \beta_2 C_1 + \beta_3 C_2 + \beta_4 C_3 + \beta_5 C_4 \ldots \]

Where \( \lambda \) is mortality rate, \( \beta \) values are coefficients and \( C \) terms are causes of death. The regression model of WHO has two parts: a linear regression to predict maternal deaths due to direct and indirect causes except HIV+/AIDS when pregnancy was substantial aggravating factor. In the second part HIV+/AIDs-related maternal deaths out of total AIDS deaths which can be categorised as indirect maternal deaths is estimated. The model has only three predictor variables: gross domestic product (GDP), general fertility rate (GFR) and skilled attendant at birth (SAB). The model has the form:

\[ \log(\text{PM}) = a+b_1 \log(\text{GDP})+b_2 \log(\text{GFR})+b_3 \log(\text{SAB})+c+r+e \]

where, PM is the proportion of maternal deaths among Non-HIV+/AIDS women of 15-49 age group; na is Non-HIV+/AIDs women of 15-49 age group, GDP is gross domestic product per capita in constant terms, GFR is general fertility rate as live births per woman of 15-49 years, SAB is skilled assistance (e. attendance) at birth, c is country variable, \( r \) is the regional variable and \( e \) is the error variable. All variables for every \( i \) observation, for country \( c \) within region. However, we need to see whether these factors are adequate to predict South Sudan maternal deaths by collecting data on all variables possibly associated with maternal deaths as reported in the literature and carry out correlation and regression analysis. Combinations of major variables which explain most variations in maternal deaths need to be selected and used in the optimal model with the estimated regression coefficient. Predictive validity needs to be confirmed for the regression equation so developed using standard statistical procedures. Instead of five-year groups, our study will have annual estimates. If all of the steps mentioned above, conducted and give the best results, this will answer Qs 7, 8, 9 and 10. Thus, all the aims, objectives, and questions of this study are fulfilled by carrying out successfully this research methodology.
C. DESIGNED QUESTIONNAIRE’S TABLE FOR DATA COLLECTION FROM SOUTH SUDAN

Table 9.2 presents data collection questionnaire for MMR in South Sudan

<table>
<thead>
<tr>
<th>Patient code or No#</th>
<th>Year of death in day or month</th>
<th>Age</th>
<th>Was death due to materiality cause</th>
<th>Place (state or region)</th>
<th>Skilled attendance at birth (SAB)</th>
<th>Pregnancy # (GFR)</th>
<th>Causes of Death</th>
<th>Name of cause</th>
<th>Gestation weeks at time of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>* 1</td>
<td>(e.g. 10/05/2012)</td>
<td>(e.g. 24)</td>
<td>Yes/no</td>
<td>Juba</td>
<td>Yes/no</td>
<td># of kids</td>
<td>(e.g. C1, C2, C3, C4 etc.)</td>
<td>Infection or prolonged (…etc…)</td>
<td>(e.g. 38)</td>
</tr>
</tbody>
</table>

Maternal mortality Information from Juba Teaching Hospital, in 1986-2015, Juba, South Sudan

Column 1: Patient code or number (e.g. 1, 2, 3, etc.),

Column 2: Year of death in day/month (e.g. 15/May/2015),

Column 3: Age (e.g. 15, 18, and 24. Etc.), Column 4: Was death due to maternal cause (e.g. yes/no),

Column 5: Place (state/region, e.g. CES/Juba),

Column 6: Skilled attendance at birth (SAB) (e.g. yes/no),

Column 7: General fertility rate (GFR, number of children)

Column 8: Causes of death (e.g. we may have more than one major reason for the death and want to know all the reasons)

Column 9: Haemorrhaging, Infections… etc…..

Column 10: Gestation weeks at time of death.

The meaning of C1, C2, C3, C4… in column 7. In Wuhan province of China, maternal mortality rate reduced from 33.41 in 2001 to 10.63 in 2012. The four major causes of deaths were used, as follow: C1 = Obstetric haemorrhaging, C2 = pregnancy complications, C3 = amniotic fluid embolism, C4 = gestational hypertension.

Note: This is an example of how this spread sheet should be filled for maternal health data
D. DEVELOPED ELECTRONIC DATABASE FOR MMR INVESTIGATION IN SOUTH SUDAN

9.3 Developing and Selecting Prediction Models of Maternal Deaths (MDs)

The framework is as follows:

Table (Box) 9.3: Development of electronic database for maternal mortality rate (MMR) investigation in South Sudan

1. Identify of significant and influential predictors (factors) and causes for maternal mortality rate (MMR) in South Sudan, based on literature study for Non-HIV/AIDS maternal deaths (MDs)

2. Do analysis and model fitting to select the most influential and significant factors (predictors) of the MMR

3. Develop electronic questionnaires to record the significant predictors (factors)

4. Collect the hard copy data from authentic sources like: Juba Teaching Hospital (JTH), Ministry of Health (MoH), the National Bureau of Statistics (NBS) and UN agencies’ (e.g. WHO, USAID, UNICEF, the World Bank and the United Nations’ Population Division, … etc.)

5. Transfer the hard copied data into electronic questionnaire

6. Continue further research to identify the most common causes of death during, at and after delivery.

7. Do model fitting and statistical analysis to validate these causes

8. Improve the questionnaire to include (incorporate) these causes

9. The improvement of the electronic questionnaire will be continued through this research.

10. The electronic database completed based on past collected data would be offered to the S. Sudanese government and the UN agencies as a starting point for electronic recording database.
E. SOUTH SUDAN’S FACTS MAP (CIA, MAY 2018)

9.4 South Sudan’s Fast Facts:
South Sudan is a landlocked country located in east-central Africa, bordering Sudan in the North, Ethiopia in the East, Kenya, Uganda, and Democratic Republic of the Congo in the South and the Central African Republic in the West. On July 9, 2011, South Sudan attained its independence from Sudan. Thus, it is one of the youngest nations in the world.

South Sudan has rich biodiversity which includes lush savannahs, swamplands, and rainforests that are home to many species of wildlife. South Sudan’s population, with predominantly African cultures who tend to adhere to Christian or animist or Islam beliefs, was long at odds with Sudanese governments. South Sudan’s capital is Juba which is the largest city in the country. It has a population over 13 million people and an area slightly smaller than Texas and bigger than France.

Figure 9.1: South Sudan’s borders with six countries including Sudan, since 1956
Flag of South Sudan

![Flag of South Sudan](image)

Figure 9.2 (Source - CIA, 2016): The nation flag of South Sudan compasses of six colours (black, white, red, green, blue and gold)

South Sudan’s Flag has three equal horizontal bands with black at the top, then red and green; the red band is edged in white, a blue isosceles triangle based on the hoist side contains a five-pointed gold star, black represents the people of South Sudan (Sudan: means the land of black people in Arabic); red the bloodshed in the struggle for freedom; green the verdant land, and blue the waters of the Nile. The gold star presents the unity of the states making up South Sudan.

### A) About South Sudan

#### (i) Political and Conflict Timeline Facts

**January 1, 1956**: Sudan gains its independence after an agreement between the United Kingdom and Egypt.

**March 27, 1972**: The signing of the Addis Ababa Agreement ends 17 years of civil war between the northern Khartoum forces and southern Anyanya rebels. Part of the agreement includes the creation of the autonomous region of South Sudan, with Juba as its capital.

**1977**: Oil is discovered in south-western Sudan. Civil war during the 1980s and 1990s prevented much exploration or development of the oil deposits.

**May 1983**: Col. John Garang de Mabior forms the Sudan People's Liberation Army and the Sudan People's Liberation Army moment (SPLA/M) and leads his forces against the government, reigniting the civil war. The South is fighting against the government’s proposal to redivide the region and the imposition of Islamic law, oppression and marginalization; and militaristic rule.
January 9, 2005 - The Comprehensive Peace Agreement (CPA) is signed by representatives from the North and the South. Part of the agreement includes independence for southern Sudan within six years and that Islamic law would not apply there.

April 11-15, 2010 - Sudan holds multi-party elections for the first time in 24 years. Mr Salva Kiir is elected as a president of Southern Sudan with 93% of the vote.

January 9-15, 2011 – South Sudanese people vote in a referendum to secede or remain as a part of a unified Sudan. Sudanese nationals in the South, North, and in several foreign countries, including Australia, Canada, Egypt, Ethiopia, Kenya, Uganda, UK, DRC, South Africa and the United States cast votes.

February 7, 2011 - The Southern Sudan Referendum Commission announces that 98.83% of population have voted for separation from the North. US President Barack Obama declares Washington's intention to recognize South Sudan as an independent state in July, when the Comprehensive Peace Agreement is scheduled to end.

July 9, 2011 - South Sudan becomes an independent nation, with a population of over eight million people. Salva Kiir becomes the first president of the newly formed country.

July 14, 2011, South Sudan becomes the 193rd member nation of the United Nations.

July 29, 2011 - South Sudan is admitted to the African Union.

May 2012 – President Salva Kiir writes letters to more than 75 government officials and to eight foreign governments in an attempt to recover $4 billion lost to corruption. "If funds are returned, the government of the Republic of South Sudan will grant amnesty and keep your name confidential," writes the President in a letter sent to former and current "senior" officials.

July 2013 – President Kiir dismisses his entire Cabinet, including Vice President Riak Machar.

December 15, 2013 - Deadly clashes begin, which President Kiir later calls a failed coup attempt by soldiers loyal to Machar. Days later, the Ministry of Foreign Affairs says 500 died and 800 were wounded in the fighting.

August 26, 2015 - Under threat of UN sanctions, President Kiir signs a peace deal which rebel leader Machar signed the previous week.
February 11, 2016 – President Salva Kiir reinstates Dr Riak Machar, a political rival, as first vice president as part of a peace deal to end the two-year civil war. Machar is sworn in on April 26, 2016.

July 7-10, 2016 - Fighting breaks out with skirmishes between the Government’s Forces (the Sudan People's Liberation Army), loyal to the President, and soldiers (rebels) backing Dr Riak Machar. The disputes leave more than 150 dead across Juba.

July 11, 2016 - Following an overnight lull, fighting resumes through parts of Juba. Present Kiir demands an immediate end to the fighting between his soldiers and those loyal to the vice president, and Machar later calls on his troops to respect the ceasefire. However, the fighting does not stop.

July 23, 2016 - Kiir removes Machar as vice president for the second time and replaces him with Taban Deng Gai, who had previously served as Machar's chief negotiator, as well as South Sudan's mining minister.

September 4, 2016 - South Sudan's government agrees to the deployment of an additional 4,000 peacekeepers on behalf of the UN Security Council. There are already 12,000 UN peacekeepers in the country.

(ii) Geographical and Statistical Facts

- **Area:** 644,329 sq km, slightly smaller than Texas and bigger than France (643,801 sq. km)
- More than half (51%) of the population is below the age of eighteen.
- 72% of the population is below the age of thirty
- 83% of the population is in rural areas
- 27% of the adult population is literate
- 51% of the population live below the poverty line
- 78% of households depend on crop farming or animal husbandry as their primary source of livelihood
- 55% of the population has access to improved sources of drinking water
- Population: 13,026,129 (July 2017, EST.)
- Median age: 17.1 years
• Area: 644,329 sq km, slightly smaller than Texas and bigger than France (643,801 sq. km)
• More than half (51%) of the population is below the age of eighteen.
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• 83% of the population is in rural areas
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• 55% of the population has access to improved sources of drinking water
• Population: 13,026,129 (July 2017, est.)
• Median age: 17.1 years

![Age breakdown (2015)](image)

Figure 9.3 South Sudan: Age breakdown Encyclopedia Britannica, Inc. by (Nation Bureau of Statistics (NBS), 2015)

• Capital: Juba and the largest city in the country
• Ethnic Groups: There are 64 Ethnic Groups. Dinka 35.8%, Nuer 15.6%, Shilluk, Azande, Bari, Kakwa, Kuku, Murle, Mandari, Didinga, Ndogo, Bviri, Lndi, Anuak, Bongo, Lango, Dungotona, Acholi, etc. (2011 est.)
• Religion: Animist, Christian and Islam
• Unemployment: 18.5% (ages 15-24)
• The Boma National Park, situated close to the Ethiopian border is a vast expanse of wilderness that is home to wildlife including migratory herds of over a million Mongalla gazelle, white-eared kob, tiang and antelope.
Nimule, the small but breathtaking national park is home to the now-extinct white rhino. Today many hippo, the Ugandan kob, buffalo and elephants live here.

South Sudan’s vast plains and plateaus are drained by the Nile River and its tributaries. This river system runs from south to north across the entire length of the east-central part of the country. At the heart of the country is clay plain, the centre of which is occupied by an enormous swampy region known as Al-Sudd (the Sudd).

There are two contrasting upland areas. The Ironstone Plateau lies between the Nile-Congo watershed and the clay plain; its level country is marked with inselbergs (isolated hills rising abruptly from the plains). On the Uganda border there are massive ranges with peaks rising to more than 10,000 feet (3,000 metres). The Imatong Mountains contain Mount Kinyeti (elevation 10,456 feet [3,187 metres]), the highest point in South Sudan.

B) Other Facts:

(iii) The following are other facts about South Sudan:

- The country is poverty-stricken despite containing vast oil reserves.
- A demilitarized, jointly monitored Common Border Zone was established between Sudan and South Sudan to ease tensions regarding the oil-rich Abyei region.
- The country went through 50 long years of spasmodic civil wars. It was only in 2005 that North Sudan and South Sudan signed a cease fire and the fighting finally stopped.
- South Sudan is one of Africa’s most linguistically-diverse countries. It has several hundreds of language groups.
- NBA players, the 7’7”-tall Manute Bol who was the second tallest person in the world and the Chicago Bulls-player, Lual Deng both hailed from Southern Sudan.
- Today, though many ecologists’ head for South Sudan it offers practically zero tourist infrastructure, no paved roads and the communications infrastructure is almost non-existent.