Modeling Maternal Mortality Rates in South Sudan

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Abstract—The maternal mortality rate (MMR) and the maternal deaths (MDs) in South Sudan are one of the highest in the world. The paper explores and compares the trends in HIV/AIDS and Non-HIV/AIDS related MMR. The results indicated that there is a declining trend in MMR. However, the decline in HIV/AIDS MMR is much slower than the decline in Non-HIV/AIDS MMR. The paper also aims for the first time to explore and compare the application of Log Linear and Poisson regression models to estimate MDs in South Sudan. Accuracy criteria such as coefficient of determination, Mean error are used to compare the predicting error of these models. The results show that Log Linear can model the MMR much better than Poisson.

Keywords- maternal mortality, trend analysis, Log Regression, Poisson Regression, $R^2$.

I. INTRODUCTION

South Sudan attained its independence from Sudan in 2011. Although endowed with rich oil reserves, the country capped its oil wells recently due to disputes with Sudan. Thus, a major source of funds for its development has been blocked. Simultaneously, internal conflicts deter international investors from undertaking or supporting long term developmental projects in the country. One important sector affected by these problems is its health care sector, which essentially relates to human well-being and development. Maternal mortality rate (MMR) has been defined as the number of maternal deaths per 100,000 live births. This is the most commonly used measure for maternal mortality rate [1].

According to the data by World Health Organization (WHO) [1], although maternal mortality rate (MMR) in S. Sudan decreased from 1,000 per 100,000 live births to 730 per 100,000 live births during 2005 to 2013, it is still the highest in the world. The problem becomes more serious when considering the high fertility rate, weak health care system and high incidence of Human Immune Deficiency virus (HIV/AIDS) in the country.

Downie [2] gave the figure as 2,050 per 100,000 live births. Combined with high fertility rates, the probability of an average South Sudanese woman dying during one of her pregnancies is one in seven. South Sudan also has a significant female population with HIV/AIDS [4].

According to Calvert [5], HIV-infected pregnant women have eight times the risk of mortality than HIV-uninfected pregnant women. Based on this, about 25% of total MMR was attributable to HIV in Sub-Saharan. In Malawi and Zimbabwe, MMR increased by 1.5 and 2.5 times respectively along with a 10-fold increase of HIV incidence [6]. The authors point out that obstetric risk increases when quality of delivery of health services deteriorates. Even if safe motherhood programs exist, HIV-related illnesses may increase due to crowding in health facilities thereby affecting quality of health services. While this may be a factor of concern for South Sudan, also, there may be little change in the utilization of ante-natal care by pregnant women. Mugo, Dibley, & Ago [7] observed from South Sudan survey data for 2010 that only about 40% of the pregnant women used antenatal services and the frequency was less than the recommended four visits. Only about 18% of the pregnant women visited four or more times. Such a low level of antenatal services utilization is sure to affect efforts to reduce MMR. The need for research and evaluation to create evidence on HIV-related MMR in Sub-Saharan Africa was highlighted by Kendall, et al. [8]. Clinical management of pregnant and post-partum HIV affected women, effect of expanded antiretroviral therapy on maternal mortality and morbidity, integrated service delivery models and interventions to enable women with a social environment of continuous care are suggested as the areas for this study. In the case of South Sudan the results of this study show that the country lacks in all these respects The findings of Li, et al. [9] also higher MMR with HIV$^+$ and recommended initiation of antiretroviral therapy as early as possible during pregnancy.

Most of the above authors point out to the fact that HIV$^+$ is not the direct cause of MMR except in cases like sepsis. However, the association of higher MMR with HIV is a matter of concern. As there is no direct relationship, healthy women need not be prevented from becoming pregnant if they desire so. Rise of healthy deliveries will result in decrease of MMR. The importance of attending to socio-economic factors to reduce MMR was highlighted an Indian work by Rai & Tulchinsky [10].

The continued internal and external conflicts have destructed even the hospitals operation tasks [3]. Lack of humanitarian emergencies mostly in difficult-to-access areas, poor infrastructure, poor illiterate low-skilled population, low agricultural production, weak health care systems and shortage of technically capable medical staff are all factors and the causes of the largely unmet health care demands. High rates of both communicable and non-communicable diseases are reported even if there is no reliable health statistics data. Poor literacy levels act as barrier to improving health awareness to the tradition-bound population.

Lack of access to health care facilities is a major factor due to lack of roads and transport system [3]. South Sudan has
about 1,147 health care facilities that function to serve around nine million populations. Out of the facilities, only 37 are hospitals. As more than 50% of the population needs to walk three miles or more to the nearest primary health care unit, it not surprising that outpatient visit rate is only 20% per year. Ill-equipped buildings with poor hygiene are the common feature of these primary health care units. Chronic shortage of health care professional staff at all levels is demonstrated by 1.5 doctors and two nurses per 100,000 people. Health departments of the state and central governments are managed by poorly qualified personnel.

All the above factors affect the total health care system and in particular high maternal mortality rate problem.

One of the aims of this paper is to explore and compare the trend in the HIV+/AIDS, non-HIV+/AIDS MDs, and total maternal mortality rates between January 1986 and October 2015 through the data collected from one of the major health care referral center in South Sudan (Juba Teaching Hospital[JTH], Juba, South Sudan). Juba Teaching Hospital is a 580-bed facility located in Juba City and is the biggest referral hospital in the whole country. The hospital is directly funded by the central government through the National Ministry of Health (NMoH), and supported by Risk Management Foundation (RMF), United Nation (UN) agencies and others (World Bank, United States Agency for International Development (USAID), and World Health Organization (WHO)). The results show that in general MMR is declining. However, the HIV+/AIDS MMR is declining at a much slower rate compared to the Non-HIV+/AIDS MMR.

Since the causes of death for HIV+/AIDS and non-HIV+/AIDS Maternal Deaths (TMDs) are different, the authors have decided to separate the HIV+/AIDS and Non-HIV+/AIDS total maternal mortality data for further statistical analysis. In the following sections we only report the analysis of the Non-HIV+/AIDS Maternal Deaths data.

This study for the first time aims to examine and investigate suitability of the Multi-log regression and Multi-Poisson regression models for estimating and detecting changes over time in rates of Non-HIV+/AIDS maternal deaths in South Sudan. Based on the recommendation in the literatures listed above, the independent variables included in the analysis are Skilled Attendant at Birth (SAB), General Fertility Rate (GFR), Gross Domestic Product (GDP). Accuracy criteria such as coefficient of determination, Mean error and standard error of mean are used to compare the predicting error of these models. The results show that Log Linear Regression can model the Maternal Mortality Death much better than Poisson Regression.

A reliable model to estimate the maternal deaths would assist the authorities to make an inform decision on resource allocation and lacking resources.

Methods

Time series plot and trend analysis are often used to observe patterns and structures in data over time. In this paper we have used Statistical package R to carry out trend analysis and model fitting to HIV+/AIDS, non-HIV+/AIDS, and total maternal mortality rates. Regression modelling is a useful technique to model the strength and direction of relationship between one or more independent variables and a dependent variable. In this paper, multi-log regression and multi-Poisson regression have been utilized to gain insights into the predictors of non-HIV+/AIDS Maternal Mortality Rate (MMR) (i.e. The independent variables that deployed into the model include Skilled Attendant at Birth (SAB), General Fertility Rate (GFR), Gross Domestic Product (GDP). The data used for this analysis are the aggregated data at the yearly level (1986 to 2015). (Source: Juba Teaching Hospital[JTH], S. Sudan).

II-a Multi-Log Linear Regression model

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

\[ Y = f(X_1, X_2, \ldots, X_p, \beta) + \epsilon \]

Where \( Y \) is the response variable and \( X_1, \ldots, X_p \) are \( p \) predictors, \( f \) is the function which links the predictors to the response, that its general form is a linear combination of predictors, and \( \epsilon \) is error representing the discrepancy in the approximation (Montgomery et al., 2012). Using the yearly data from 1986-2015 for South Sudan, we have developed the following log linear regression model to describe the changes in Total Non-HIV+/AIDS Maternal Deaths (TMDs) Rate in terms independent variables (IVs), SAB, GFR and GDP. Statistical package Minitab 17 and R are used to fit the best model.

The following Log Linear regression model was the outcome of the analysis based on 2/3 of the data:

**Multi-Log Regression Equation**

\[ R^2 = 77.11\% \]

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

We have modified the data provided by (WHO, UNICEF, UBFPA, the World Bank, and United Nations Population Division Maternal Mortality Estimation Inter-Agency Group in 1986-2015) to obtain a yearly value (rather than 5 years value) for independent variables (IVs) of SAB, GFR and GDP. The models are built based on randomly selected 2/3 of the data to overcome the decrease trend of the TMDs over the years. The remaining 1/3 will be used to assess the efficacy of the proposed models.

II-b Poisson Regression model

The Poisson regression model expresses the natural logarithm of the outcome or incident over a particular period of time 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 log linear model with explanatory \( Y \) is written as

\[ \log (Y) = \beta + \beta X \]

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

\[ \log (Y) = \beta + \beta X \]
Where, the row vector $\beta$ represents the coefficient factors and column vector $X$ represents the independent variables (IVs). The following Poisson regression model was the outcome of the analysis based on 2/3 of the data:

**Multi-Poisson Regression Equation:** $R^2 = 79.75\%$

$Y = 4.227 \cdot 0.3819 \text{SAB} + 0.03237 \text{GFR} + 0.002902 \text{GDP}$, \ldots, \ldots, (2)

### III. STATISTICAL ANALYSIS

The statistical analysis in this paper includes trend analysis, time series modeling, multi-log linear regression and multi-Poisson regression.

#### III-a Time series analysis

Time series plot and summary statistics including means and standard deviations and box plots have been produced for yearly level of HIV+/AIDS, non-HIV+/AIDS and total MMR from 1986 to 2015 and are presented in Table 1 and Figures 1-2.

A linear trend model was fit to each individual time series of HIV+/AIDS MMR, non-HIV+/AIDS MMR, and the total MMR. The models are presented in Figures 3-5. The slopes of the models were compared to the slope of the total maternal mortality rate model. The fitted models are presented in Table 2.

The results in Table 1 show that the mean HIV+/AIDS MMR for the period of 1986 to 2015 was almost one-third of the total MMR. The balance of the MMR was attributed to Non-HIV+/AIDS related causes.

**Table 1:** Presents Summary Statics for HIV+/AIDS, non-HIV+/AIDS and total maternal mortality rate.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV+/AIDS MMR</td>
<td>1014.61</td>
<td>579.21</td>
</tr>
<tr>
<td>Non-HIV+/AIDS MMR</td>
<td>2344.32</td>
<td>1466.39</td>
</tr>
<tr>
<td>Total MMR</td>
<td>3358.94</td>
<td>1674.88</td>
</tr>
</tbody>
</table>

**Figure 1:** Box plots for yearly HIV+/AIDS, non-HIV+/AIDS and total MMR over the period of 1986-2015.

The three time series are shown in the figure below.

**Figure 2:** Trend Comparisons for yearly HIV+/AIDS, non-HIV+/AIDS and total maternal mortality over the period of 1986-2015.

**Table 2:** Time series models fitted to yearly HIV+/AIDS, non-HIV+/AIDS and total maternal mortality rate.

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

**Figure 3:** Trend analysis for yearly HIV+/AIDS maternal mortality rate over the period of 1986-2015.

**Figure 4:** Trend analysis for yearly non-HIV+/AIDS maternal mortality rate over the period of 1986-2015.
Figures 3-5 show that the HIV+/AIDS MMR linear trend model has a slope of 1,337, the Non-HIV+/AIDS MMR linear trend model has a slope of 4,585, and the Total MMR linear trend model has a slope of 5,992. These results indicate that the difference between the slopes of the Non-HIV+/AIDS MMR and the Total MMR series (1,407) is much less than the difference between the slopes of the HIV+/AIDS MMR and the Total MMR series (4,655). 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.

The summary statistics for the three time series by the year groupings are shown in the table .3 with the comparison graph in Figure 6.

<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>1087.00</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>

The results in the table .3 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 3, 4. However the numerical and graphical comparisons given in table .3 and Figure 6 show a significant decrease in mortality rate in the period of 2009-2015. Since the causes of death for HIV+/AIDS and Non-Maternal Deaths (TMDs) are different the authors have decided to model them separately. Due to the limitation constrain, here we only outline the regression analysis of the Non-HIV+/AIDS Maternal Deaths (TMDs).

III-b Regression Models for non-HIV+/AIDS Maternal Deaths (TMDs)

As mentioned earlier, to establish Log Linear and Poisson Regression models, we used randomly selected two third of the Yearly Data to build the models. The models are then used to predict the remaining ten (10) years’ data for Total Non-HIV+/AIDS Maternal Death (TMDs). The analysis was carried out using Microsoft Excel, R and Minitab version .17 statistical soft wares.

The results of the prediction errors are presented in the table 4, and Figures 7-8. Table 4 indicates that the mean error percentage and the SE Mean for the Log linear regression is much smaller than Poisson regression. Therefore we can conclude that Log linear regression outperforms Poisson regression in predicting the mortality data for South Sudan.

The results of error analyses form the following regression models:

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

\[ \log(\text{Non-HIV+/AIDS}) = -20.8 - 8.30 \log(\text{SAB}) + 8.10 \log(\text{GFR}) + 5.12 \log(\text{GDP}) \]  \[ \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (1) \]

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

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

\[ Y' = 4.227 - 0.3819 \text{SAB} + 0.03237 \text{GFR} + 0.002902 \text{GDP}, \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (2) \]
Table 4: Presents errors analysis based on two third 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 7: Presents actual and estimated values of one third of Non-HIV+/AIDs MDs based on the independent variables SAB, GFR and GDP, using log linear regression.

Figure 8: Presents actual and estimated values of one third of Non-HIV+/AIDs MDs based on independent variables SAB, GFR and GDP, using Poisson regression.

IV. DISCUSSION

The overall maternal mortality rate has been declining in South Sudan. However, the MMR in South Sudan is still one of the highest in the world ([1], [4]). Breaking down the MMR in the form of HIV+/AIDS MDs based and Non-HIV+/AIDS MMR and analysis of the trend serve many purposes, including; providing a magnitude of the HIV+/AIDS MDs based MMR and providing insights into the trend in HIV+/AIDS MDs based and Non-HIV+/AIDS MMR. Such information is vital for the health policy makers in South Sudan and also for not-for-profit organizations like the United Nation organizations. The analysis will provide an effective decision making tool for formulating optimal strategies and resource allocation to address the issue of high MMR in South Sudan.

The result of the analysis have indicated that HIV+/AIDS MDs based MMR is a substantial contributor of the overall MMR in South Sudan with almost one-thirds of the maternal mortality deaths being attributed to HIV+/AIDS MDs related causes. A further cause of alarm is that the HIV+/AIDS related MMR is declining at a much slower rate compared to the overall MMR. This indicates that in the short to long term future, the MMR attributed to HIV+/AIDS related causes might become a major contributor to the overall MMR.

There are many causes of the general high prevalence of HIV+/AIDS in the country including low levels of education in large proportions of population. Frequent internal and external conflicts (e.g. wars) in the country are also contributors to the high prevalence of HIV+/AIDS in the country. Internal and external conflicts plagued S. Sudan from 1983 to 2005, and again from 2013 to the present. This has caused a mass population displacement from within the country and from outside the country. Moreover, many people from neighboring countries like Uganda, Kenya, Ethiopia and Sudan have moved into South Sudan. As the incidence of HIV+/AIDS in these countries are also high, therefore, it is safe to conclude that these people may have contributed to the high prevalence of HIV+/AIDS based MMR in South Sudan.

The need to improve and increase evidence for effective interventions for reducing mortality among pregnant women with HIV+/AIDS were stressed by Kendall, et al. [4]. However, to overcome this challenge we need better quality data on causes and factors of deaths among such women and enhanced and harmonized monitoring of the current health care programs. The authors have dedicated separate section of this project to this task and results will be reported in future papers. In the second part of the current research we have modeled the Non-HIV+/AIDs maternal deaths based on the Yearly Data of independent variables SAB, GFR and GDP, using log linear regression and Poisson regression. The accuracy of prediction is pivotal to ensure that the estimate and forecast correctly reflects the future data. In this study, we have used coefficient of determination $R^2$, mean error and standard error of the mean to evaluate and assess the efficacy of the proposed models. The results of the analysis presented in table 4 together with the coefficient of determination $R^2$ show that log linear regression model based on independent variables (IVs) SAB, GFR and GDP can explain 77.1% of the variation in maternal deaths with the mean prediction error of 0.008.

For the future strategy management and action planning of maternal mortality rate (MMR) reduction in South Sudan, more accurate forecast models will be developed. One way to increase the prediction accuracy is to incorporate more independent variables in the models.

V. CONCLUSION

The need and urgency for the proposed work arises from the globally highest maternal mortality rate (MMR) reported for South Sudan. Although some efforts were made through policies and programs of the government and assistance by
various international agencies, reported reduction in mortality rate is only modest.

This study aims to compare the trends in HIV+/AIDS MDs and Non-HIV+/AIDS related mortality rates in South Sudan. Whilst it is observed that the HIV+/AIDS MDs based MMR, Non-HIV+/AIDS MMR, and overall MMR are on a general decline, the decline in HIV+/AIDS based MMR is much slower compared to the overall MMR.

There is a possibility that in the near future the HIV+/AIDS based MMR will be a bigger contributor to the overall MMR compared to Non-HIV+/AIDS based MMR.

In recent years, there has been increasing interest in estimating and forecasting maternal deaths. Prior maternal death estimation can guide and assist the national and local governments to make informed maternal health care policies and medical resources allocation decisions especially in rural areas. Separating the Non-HIV+/AIDs maternal deaths from the total maternal deaths, this paper has developed two models based on independent variables (IVs) SAB, GFR and GDP to estimate the maternal deaths. The models are developed using real data from the biggest referral hospital in South Sudan. The estimated maternal deaths were then compared with the recorded ones to evaluate the efficacy of these models. The accuracy criteria such as mean error and standard error of mean SE mean were used to compare the forecast errors of the models.

The analysis of the prediction error shows that the proposed multi-log linear regression model is capable of predicting the maternal death with minimum mean error and is outperforming Multi-Poisson regression. The results also show that Skilled Attendant at Birth (SAB) is the most significant factor in decreasing the maternal death followed by based on independent variables; General Fertility Rate (GFR) and Gross Domestic Product (GDP).

The outcomes obtained from this study offer both challenges and opportunities for development of health care services as well as guide line for the resource allocation. Some of these may include improving the education levels and capacity building in medical fields in South Sudan.

Further research and evaluation are needed for improving clinical management of pregnant and postpartum pregnant women with HIV+/AIDS and other Non-HIV+/AIDS conditions.

The creation of a structure for an informative national data recording system is the most significant step in achieving the goal of this project. The authors had consultation discussions with 30 experts and review of literature to derive this conclusion.

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