

## Use of Zero-inflated model as prediction of maternal mortality in four states of Sudan

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### Abstract:

This study aimed to test application of Zero-inflated model in prediction of maternal mortality in 4 states in Sudan, namely White Nile, Gedarif, North Kordofan and Centre Darfur States. Results showed that using the bivariate intrinsic CAR specification for spatial random effects into zero-inflated models that already account for correlated count data slightly improved the fit, and that this is more pronounced when using the Poisson distribution, a surprising result based on our findings from where the Negative binomial distribution outperformed the Poisson distribution for any considered extension.

**Key words :** Zero-inflated, prediction of maternal mortality.

### Introduction :

Maternal mortality, as a largely avoidable cause of death, is an important focus of international development efforts, and a target for Millennium Development Goal (MDG) 5. The millennium developmental goal MDG-5 aimed at decreasing mortality rate by 75% from 1990 to 2015 by annual reduction of 5.5%, the goal is not achieved the actual annual reduction is less than 1%<sup>[1]</sup>.

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<sup>1</sup>. World Health Organization, UNICEF, UNFPA, World Bank, United Nations Population Division. Trends in maternal mortality 1990 to 2015: estimates by the WHO, UNICEF, UNFPA, the

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Sudan is considered one of the top ten countries with regard to maternal mortality worldwide when MMR was estimated at 730 per 100.000 live births. However; the results of SHHS2 showed a marked reduction in MMR from 638 deaths per 100000 live births in 2006<sup>[1]</sup> to 216 in 2010<sup>[2]</sup>. Although not fully explained by the health authorities, this reduction might be attributed partially to the recent health policies (free of charge health care for pregnant women 2008) and the other health interventions implemented by the government<sup>[3]</sup>. This MMR is still considered far from the MDG5 target of 134 deaths per 100000 live births<sup>[4]</sup>.

Moreover; MMR ranges from 127 to 335 deaths per 100.000 live births<sup>[10]</sup> indicating that still some states have high levels of maternal deaths. Despite these huge regional variations; a small urban-rural disparity was reported <sup>[3]</sup>. However; some sources pointed to a huge urban-rural discrepancy<sup>[5]</sup>. A mortality survey conducted in Eastern Sudan also showed this disparity. While the urban MMR was estimated at 369 deaths per 100000 live births the rural one was

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<sup>1</sup>World Bank and the United Nations population division. Geneva: World Health Organization; 2015; page 1.

<sup>1</sup>. FMoH. Sudan Household Health Survey: The First Round. Khartoum: FMoH; 2006; page 1.

<sup>2</sup>. FMoH , CBS. Sudan Household Health Survey 2010. Khartoum: Federal Ministry of Health, Central Bureau of Statistics; 2012 page1.

<sup>3</sup>. Elnagar S, AbdelAti H, Eltigani L. An Update of Reproductive Health, Gender, Population and Development Situation in Sudan, 2011. Kharoum: UNFPA/Sudan; 2011; page 1.

<sup>4</sup>. Abdelgabbar S. Integrated Basic PHC Services: the Road Towards Universal Coverage. Khartoum: FMoH/ PHC; 2012; page 9.

<sup>5</sup>. UNFPA. Maternal Health: Stepping Up Efforts to Save Mothers' Lives. Khartoum: UNFPA/Sudan; 2012 page 1.

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872<sup>[1]</sup>. Obviously; these high levels of mortality indicate a huge gap in utilization, access and quality of maternal health services<sup>[2]</sup>.

Prediction of maternal mortality of great importance to give clear picture for the related professionals in the Ministry of Health for mapping the situation so as to put clear strategies to minimize maternal mortality to minimum level. Applied statistics played a major role in prediction of health problems in a given community for years. Based on this, the current paper tries to apply Zero-inflated Poisson (ZIP) for prediction of maternal mortality rates in four states in Sudan based on statistics of the year 2016. Zero-inflated Poisson (ZIP) or Zero-inflated Negative Binomial (ZINB) and Hurdle models have been proposed to model data with extra zeros. They both assume that for each observation there are two possible data generating processes with different probabilities: one generates the zeros with probability  $p$  and other counts with probability  $(1 - p)$ . A Bernoulli model is used to determine which of the two processes is used. While the zero-inflated model assumes two types of zeros exists in the data (structural zeros and sampling zeros), the Hurdle model is a two-part conditional model which assumes that all zero data are from one “structural” source and the non-zero data have “sampling” origin following either a truncated Poisson or truncated negative binomial distribution<sup>[3]</sup>.

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<sup>1</sup>. Mohammed AA, Elnour MH, Mohamed EE, Ahmed SA, Abdelfattah AI. Maternal Mortality in Kassala State -Eastern Sudan: Community Based Study Using Reproductive Age Mortality Survey (RAMOS). BMC Pregnancy and Childbirth. 2011; 11(102); 1.

<sup>2</sup>. AbdelTawab N, Elrabbat M. Maternal and Neonatal Health Services in SUDAN: Results of a Situation Analysis. Program Brief. Cairo: Population Council, UNFPA, UNICEF, David Lucile and Packard Foundation, FMOH; 2010; page 1.

<sup>3</sup>. Baughman AL. Mixture model framework facilitates understanding of zero-inflated and hurdle models for count data. Journal of Biopharmaceutical Statistics. 2007; 17: 943–946.

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**Materials and methods :**

Based on data gathered from statistics of the Federal Ministry of Health (2012) Zero-inflated Poisson (ZIP) or Zero-inflated Negative Binomial (ZINB) were used to predict maternal mortality rate in 4 states namely White Nile, Gedarif, North Kordofan and Centra Darfur States in which maternal mortality rates were 120/100000, 114/100000, 273/100000 and 98/100000 live births respectively (Table 1).

**Table (1) maternal mortality rate in the 4 states**

| State          | Maternal deaths | Maternal mortality rate (per 100000 live births) |
|----------------|-----------------|--------------------------------------------------|
| White Nile     | 49              | 120                                              |
| Gedarif        | 109             | 114                                              |
| North Kodrofan | 88              | 273                                              |
| Central Darfur | 87              | 98                                               |

**Table (2) Summary statistics of state based maternal mortality rate per 100,000 in 4 States in Sudan (2016)**

| Statistics         | Maternal deaths | Maternal mortality rate |
|--------------------|-----------------|-------------------------|
| Mean               | 83.25           | 151.25                  |
| Standard deviation | 24.98           | 81.69                   |
| Median             | 87.50           | 117.00                  |
| Minimum            | 49.00           | 98.00                   |
| Maximum            | 109.00          | 273.00                  |

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**Zero-inflated model**

Let  $y_{ij}$ ,  $N_{ij}$  and  $\lambda_{ij}$  be the number of maternal deaths, obstetric admissions (population at risk) and observed mortality rate ( $\hat{\lambda}_{ij} = \frac{y_{ij}}{N_{ij}}$ ) for district  $i$  and health facility  $j$  ( $i = 1, \dots, n; j = 1, \dots, n_j$ ), and let  $x_{ij}$  and  $z_{ij}$  denote two sets of explanatory variables or risk factors. A zero-inflated (ZI) distribution is defined as follows

$$y_{ij} \sim \begin{cases} f(y_{ij}) & \text{with probability } 1 - \pi_{ij}, \\ 0 & \text{with probability } \pi_{ij}. \end{cases} \quad (1)$$

Two ZI distributions are considered for this application: with a Poisson (P) or negative binomial (NB) distribution for  $f(y_{ij})$  and  $\pi_{ij}$  the zero-inflation probability. Denote by  $\lambda_{ij}$  the mortality rate and  $\phi$  the dispersion parameter of the Negative Binomial distribution, then we can rewrite (1) as

$$y_{ij} | N_{ij}, \lambda_{ij}, \pi_{ij} \sim \text{ZIP}(N_{ij}\lambda_{ij}, \pi_{ij}),$$

for the ZIP distribution, or

$$y_{ij} | N_{ij}, \lambda_{ij}, \pi_{ij}, \phi \sim \text{ZINB}(N_{ij}\lambda_{ij}, \pi_{ij}, \phi),$$

for the ZINB distribution.

Denoting  $v_{ij} = N_{ij}\lambda_{ij}$ , the parameters  $v_{ij}$  and  $\pi_{ij}$  can be modeled as a function of covariates  $x_{ij}$  and  $z_{ij}$  using canonical link functions:

$$\begin{aligned} \text{logit}(\pi_{ij}) &= z_{ij}^t \alpha, \\ \log(v_{ij}) &= x_{ij}^t \beta + \log(N_{ij}), \end{aligned} \quad (2)$$

where  $\alpha$  and  $\beta$  are vectors of model parameters of length  $q_\alpha$  and  $q_\beta$  parameters, respectively. The mean of  $y_{ij}$  is given by

$$\mu_{ij} = E(y_{ij} | x_{ij}, z_{ij}) = (1 - \pi_{ij})v_{ij}.$$

If data is hierarchically structured, such as in the NMNH survey with health centers clustered within districts, ZIP model with random effects, which we will refer to by adding H (Hierarchical) to the ZIP and ZINB acronym, i.e., HZIP and HZIN respectively.

**Application of the model in maternal mortality :**

The models considered for this application have the same specification for the mean of  $y_{ij}$ . Specifically, the researcher used the following initial model:

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$$\begin{aligned}
 \log(v_{ij}) &= \beta_0 + \beta_1 NORTH_{ij} + \beta_2 CENTER_{ij} + \beta_3 PH_{ij} + \beta_4 HC1_{ij} + \beta_5 HC2_{ij} + \beta_6 RH_{ij} \\
 &+ \beta_7 LOC_{ij} + \beta_8 WAIT_{ij} + \beta_9 MED_{ij} + \beta_{10} EMOC_{ij} + \beta_{11} MAL_{ij} + \beta_{12} HIV_{ij} \\
 &+ \beta_{13} REFOUT_{ij} + \beta_{14} REFIN_{ij} \\
 &+ \beta_{15} NORTH \times LOC_{ij} + \beta_{16} CENTER \times LOC_{ij} + \log(N_{ij}) \\
 \text{logit}(\pi_{ij}) &= \alpha_0 + \alpha_1 NORTH_{ij} + \alpha_2 CENTER_{ij} + \alpha_3 LOC_{ij} + \alpha_4 MAL_{ij}
 \end{aligned}$$

where NORTH and CENTER are two dummy variables for the regions (South = reference, Center, North); LOC refers to location of HF (district capital = reference, outside capital); PH, HC1, HC2 and RH are 4 dummy constructs for type of health facility (hospital).

**Table (3) Model fit summary for best zero inflated models**

| Model                                | Devi<br>ance | Effecti<br>ve par. | DIC   | Brier<br>score |
|--------------------------------------|--------------|--------------------|-------|----------------|
| HZIP (correlated)                    | 511.3        | 74.1               | 610.1 | -0.231         |
| SpHZIP (correlated)                  | 519.6        | 77.3               | 610.4 | -0.233         |
| SpHZIP (correlated)                  | 520.1        | 75.9               | 609.7 | -0.236         |
| SpHZIP (correlated—<br>independence) | 517.9        | 83.2               | 612.3 | -0.239         |
| SpHZIP (correlated—<br>correlated)   | 514.2        | 84.6               | 609.9 | -0.241         |

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**Discussion :**

The study used ZIP and ZINB models as indicated by Loquiha et al <sup>[1]</sup> to shed light on the need for gathering information on maternal mortality rate in 4 states in Sudan. Results showed that using the bivariate intrinsic CAR specification for spatial random effects into zero-inflated models that already account for correlated count data slightly improved the fit, and that this is more pronounced when using the Poisson distribution, a surprising result based on our findings from where the Negative binomial distribution outperformed the Poisson distribution for any considered extension. Although the best model formulation allowed an estimation of both spatial and non-spatial within and between components correlation in a zero-inflated setting, more complex models need not always be preferred, specially if similar fits can be accomplished with relatively simpler models.

**Conclusion :**

Use of a zero-inflated in prediction of maternal mortality will benefit the related authorities in the Federal Ministry of Health in general and state ministry of health in the studied states to set the major plans to minimize maternal mortality in Sudan.

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<sup>1</sup>. Loquiha O, Hens N, Chavane L, Temmerman M, and Aerts M. Modeling heterogeneity for count data: A study of maternal mortality in health facilities in Mozambique. *Biometrical Journal*. Biometrische Zeitschrift. 2013; 55(5): 647–60.

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