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ARIMA MODELING OF NEONATAL MORTALITY IN CHITUNGWIZA CENTRAL HOSPITAL

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ABSTRACT

This study uses monthly time series data on neonatal death cases at CCH from January 2013 to December 2018; to predict neonatal death cases over the period January 2019 to December 2020. Unit root tests have shown that the series under consideration is I (0). The paper applied the Box-Jenkins SARIMA models. The residual correlogram of the chosen optimal model is stable and acceptable for forecasting neonatal death cases at CCH. The model predicts a slow but steady decrease in neonatal deaths over the out-of-sample period. In order to enhance the prevention of neonatal deaths at CCH, the study offers a 4-fold policy recommendation.

1. INTRODUCTION

The term "neonatal deaths (mortality)" refer to the number of neonates dying before reaching 28 days of age (Usman *et al.* 2019). Neonatal mortality is highest in the first 24 hours of life and accounts for 65% of infant mortality (Nouri *et al.* 2013). The first 2 days after birth account for over 50% neonatal deaths, while the first week of life accounts for over 75% of all neonatal deaths (Carlo & Travers, 2016). Death of a neonate has always been a devastating experience, especially for the mother and of concern in clinical practice (Feresu *et al.* 2005). Globally, 3 million babies die in the first seven days of life (Zupan & Aahman, 2005). In fact, 2.6 million children died in the first month of life in 2016 – nearly 7000 newborn deaths every day – most of which occurred in the first week, with about 1 million dying on the first day and close to 1 million dying within the next 6 days (UNICEF, 2017). Neonatal deaths are most frequently due to birth asphyxia, prematurity, sepsis as well as congenital malformation (Carlo & Travers, 2016). Thus, neonatal deaths are an indicator of healthcare systems in each country (Babaei *et al.* 2018) because they reflect the health of children and development of the economy and culture of a country or region (Chengye, 2012). However, neonatal deaths can "largely" be prevented (Tachiwenyika *et al.* 2011). In order to enhance the prevention of neonatal mortality, modeling and forecasting neonatal deaths is not unimportant, especially in developing countries such as Zimbabwe where neonatal mortality is still a serious problem. Therefore, this paper, hinged on 3-fold study objectives outlined below, will go a long way in uncovering the distribution and dynamics of neonatal mortality in Chitungwiza urban district and hence shed more light on policy formulation in order to tackle the neonatal mortality not only in Chitungwiza but also in the country at large.

Objectives of the Study

i. To investigate the months during which neonatal mortality cases mostly occur at Chitungwiza Central Hospital.
ii. To forecast neonatal mortality cases for the out-of sample period.
iii. To examine the pattern of neonatal mortality cases for the out-of-sample period.

Relevance of the Study

Neonatal mortality is still a significant public health problem worldwide and accounts for more than 60% of newborn deaths before their first birthday (UNICEF, 2008). Of the world's 7.7 million deaths in those aged younger than 5 years, 3.1 million are neonatal deaths (Rajaratnam *et al.* 2010). Approximately 99% of these neonatal deaths occur in low and middle – income countries, mostly in sub-Saharan Africa (Lawn *et al.* 2005) including Zimbabwe which continues to bear a heavy burden of neonatal mortality (Ministry of Health and Child Care, 2007). Annual neonatal mortality rate in Zimbabwe is approximately 24 per 1000 live births (Ministry of Health and Child Care, 2017) and this is unacceptably high. This study seeks to examine and forecast neonatal death cases at Chitungwiza Central Hospital (CCH), which is one of Zimbabwe's quaternary level hospitals. In order to deal with burden of neonatal mortality in Zimbabwe, there is need for reliable forecasts that will act as a guiding tool for policy makers in the health sector; hence, the need for this study. In this paper we focus on CCH only and attempt to come up with area specific (Chitungwiza dormitory) policy conclusions.

2. LITERATURE REVIEW

Sarpong (2013) examined maternal mortality ratio (MMR) at the Okomfo Anokye Teaching Hospital in Kumasi, Ghana, from the year 2000 to 2010. The study explored the feasibility for application of ARIMA models in modeling and forecasting MMR. The results indicated that the hospital's MMR was relatively stable although it had a very alarming average quarterly MMR of 967.7 per 100000 live births which is about twice the national ratio of 58.41; the study concluded that the ARIMA (1, 0, 2) model was optimal for forecasting quarterly MMR at Okomfo Anokye Teaching Hospital. In Zimbabwe, Mlambo *et al.* (2013) examined the main causes of maternal mortality through carrying out key informant interviews based on convenient sampling. The study was done at Mpilo Hospital in Bulawayo. Their results show that hemorrhage was the leading cause of maternal deaths, amongst other causes such as abortion, hypertension and sepsis. In another Zimbabwean study, Nyoni (2019) modeled and forecasted maternal deaths in Zimbabwe using annual time series data covering the period 1990 – 2015. The author applied the Box-Jenkins ARIMA models and basically found out that in the next decade (2016-2025), maternal deaths will increase. In yet another recent Zimbabwean paper, Chaibva *et al.* (2019) analyzed stillbirths and neonatal deaths in Mutare district: the study conducted a retrospective review of 346 patient records, of women who delivered at Sakubva Hospital and those reffered for Mutare district facilities to Mutare Provincial Hospital, between January and June 2014 and then used descriptive statistics to explore the contributors to stillbirths and neonatal deaths in Mutare. Their results indicate that of the 346 women, 15.6% (i.e. 54) experienced an adverse pregnancy outcome (stillbirth or neonatal death). Their results also show that contributing factors to adverse pregnancy outcomes included birthweight, gestational age, delivery complications and delivery methods. Ezeh *et al.* (2014) studied the determinants of neonatal mortality in Nigeria using the Cox Regression model. Their results indicated that a higher birth order of newborns with a short birth interval of less or equal to 2 years and newborns with a higher birth order with a longer birth interval of greater than 2 years were significantly associated with neonatal mortality.

In a recent study in India, Mishra *et al.* (2019) forecasted Infant Mortality Rates (IMR) using ARIMA models. The forecast of the sample period (1971-2016) showed accuracy by the selected ARIMA (2, 1, 1) model. The post sample forecast with the ARIMA (2, 1, 1) model showed a decreasing trend of IMR (2017-2025). The forecast IMR for 2025 was 15/1000 live births. In another recent paper, Khan *et al.* (2019) modeled and forecasted IMR of Asian countries using the log-log regression and ARIMA models. Their empirical analysis showed that there was a negative correlation between IMR and GDP (PPP). Secondary data of IMR and GDP (PPP) from 1980 to 2015 was examined and forecast was done from 2016 to 2025: the AR (1) model was found for all countries except Japan and Nepal for which the ARIMA (1, 1, 1) model was found suitable. In yet another recent study, which was done in Africa; relatively closer to Zimbabwe, Usman *et al.* (2019) investigated the incidence of the rate of neonatal mortality in Nigeria using ARIMA models. Their trend plot of the incidence indicated that there was a steady decrease in the incidence rate over the years. The ARIMA (1, 1, 1) model was found to be the best fit model. The time series analysis also showed the neonatal mortality rate has reduced by 17.8% from 51.7% in the year 1990 to 33.9% in the year 2017.

While our study is completely new in the case of Zimbabwe, it is very closely related to Usman *et al.* (2019). Our study focuses on a specific teaching hospital, that is; Chitungwiza Central Hospital (CCH), unlike Usman *et al.* (2019) who focused on Nigeria as a country. Hence, our study's contribution is unique in the sense that it will generate results specifically meant for CCH instead of generalizing country specific results over individual hospital units. After all, our results can also be applied in similar teaching or central hospitals in Zimbabwe, especially the Parirenyatwa Group of Hospitals, the Sally Mugabe (formally Harare) Central Hospital as well as the Mpilo and the United Bulawayo Hospitals. Furthermore, this study can be replicated for these hospitals in order to get specific results for the particular hospitals.

3. METHODOLOGY

A time series is a sequence of observations taken sequentially in time (Box *et al*, 2015). Our choice of using a time series model is justified because data used for this study was recorded chronologically. The

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analytical approach to this study is hinged on the Box-Jenkins Seasonal Autoregressive Integrated Moving Average (SARIMA) model. The SARIMA model is apparently a combination of non-seasonal and seasonal components, and can be specified as SARIMA $(p,d,q)x(P,D,Q)_s$, where p, d and q are orders of the non-seasonal autoregressive (AR), non-seasonal differencing and non-seasonal moving average (MA) parts of the model. P, D and Q are orders of the seasonal AR, seasonal differencing and seasonal MA parts of the model and s is the length of the seasonal period. The AR process captures previously observed values up to a specified maximum lag, plus a disturbance term. The process of differencing is called "integration" and apparently captures the stabilization of the data by removing seasonality or trend, while the MA process accounts for disturbance terms. The basic algebraic specification of the SARIMA model applied in this study is consistent with Brockwell & Davis (1991) and is as given below:

$$\varphi(B^s)\emptyset(B)\Delta^d\Delta_s^D X_t = \theta_0 + \gamma(B^s)\theta(B)\alpha_t \quad [1]$$

The non-seasonal factors are given as:

$$\left.\begin{aligned} AR&: \emptyset(B) = 1 - \emptyset_1 B - \cdots - \emptyset_p B^p \\ MA&: \theta(B) = 1 + \theta_1 B + \cdots + \theta_q B^q \end{aligned}\right\} \quad [2]$$

The seasonal factors are given as:

$$\left.\begin{aligned} Seasonal\ AR&: \varphi(B^s) = 1 - \varphi_1 B^s - \cdots - \varphi_P B^{Ps} \\ Seasonal\ MA&: \gamma(B^s) = 1 + \gamma_1 B^s + \cdots + \gamma_Q B^{Qs} \end{aligned}\right\} \quad [3]$$

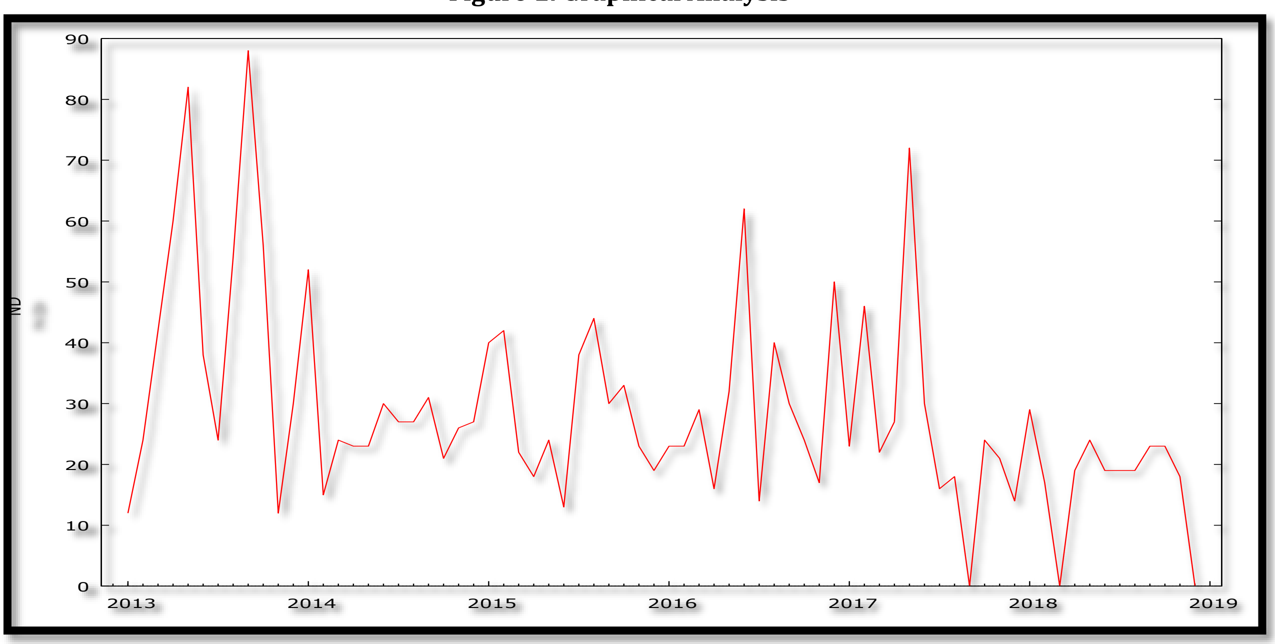
Where X_t is the data series (that is ND), α_t is the disturbance term, B is the backshift operator, $\emptyset$ is the coefficient of the non-seasonal AR, θ is the coefficient of the non-seasonal MA, φ is the coefficient of the seasonal AR, γ is the coefficient of the seasonal MA, Δ^d is the difference operator, with d order of differencing and Δ_s^D is the seasonal difference operator, with D seasonal order of differencing and s length of the seasonal period. In this paper, a SARIMA $(p,d,q)(P,D,Q)_{12}$ model was constructed using monthly neonatal mortality case data from January 2013 to December 2018.

Data Issues

This study is based on neonatal deaths (neonatal mortality cases) at Chitungwiza Central Hospital, over the period January 2013 to December 2018. The out-of-sample forecast covers the period January 2019 to December 2021. All the data employed in this paper was obtained from DHIS2 system for Chitungwiza urban district.

Diagnostic Tests and Model Evaluation
Stationarity Tests: Graphical Analysis

Figure 1: Graphical Analysis



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Unit Root Tests

Table 1: Unit root tests

	Augmented-Dickey-Fuller (ADF) Test	
	Test Statistic	
Variable	Constant	Constant + Trend
ND_t	-5.844090***	-6.919769***
*NB: ***, ** and * imply rejection of null hypothesis at 1%, 5% and 10% levels of significance, respectively.*		

Figure 1 above shows the time trend of the series under consideration. A formal test for stationarity is shown in table 1, where the ADF test was applied. Table 1 above, indicate that the series under consideration is stationary, hence I (0).

Model Evaluation (without a constant)

Table 2: Model evaluation

Model	AIC	ME	RMSE	MAE
SARIMA (0,0,3)(2,0,0)$_{12}$	**640.8452**	6.3356	19.798	15.187
SARIMA (0,0,1)(1,0,0)$_{12}$	649.1065	9.1476	21.989	16.855
SARIMA (0,0,2)(2,0,0)$_{12}$	642.9915	6.4182	20.522	16.057
SARIMA (0,0,0)(1,0,0)$_{12}$	660.3542	8.239	26.672	18.934
SARIMA (0,0,0)(2,0,0)$_{12}$	655.6835	5.9364	26.106	18.61
SARIMA (0,0,0)(3,0,0)$_{12}$	653.9450	4.6713	25.781	18.241
SARIMA (0,0,1)(0,0,0)$_{12}$	665.4913	17.168	23.883	19.044
SARIMA (0,0,2)(0,0,0)$_{12}$	656.0779	13.535	22.023	17.59
SARIMA (0,0,3)(0,0,0)$_{12}$	648.9796	11.234	20.681	16.348
SARIMA (0,0,3)(3,0,0)$_{12}$	641.2870	5.6021	19.673	14.886

Table 2 shows that the best model, based on the AIC, is the SARIMA (0,0,3)(2,0,0)$_{12}$.

Analysis of the Residuals of the SARIMA (0, 0, 3)(2, 0, 0)$_{12}$ Model

Residual Correlogram of the SARIMA (0, 0, 3)(2, 0, 0)$_{12}$ Model

Figure 2: Residual correlogram

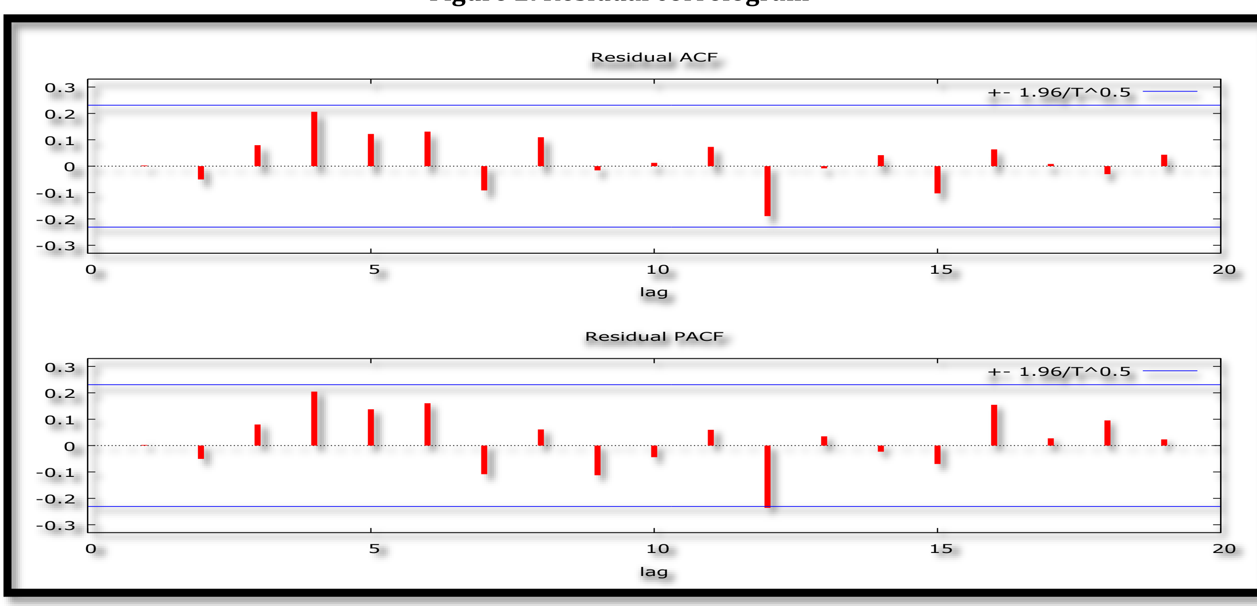

Figure 2 above, indicates that the selected optimal model is not suffering from autocorrelation and hence stable. Therefore, the model is suitable for forecasting neonatal deaths at CCH.

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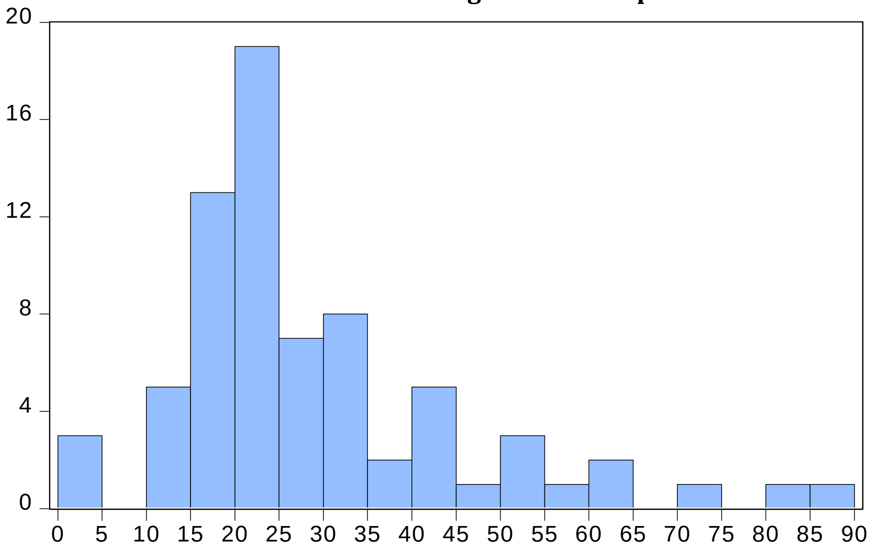
4. FINDINGS OF THE STUDY

Descriptive Statistics

Figure 3: Descriptive statistics



Series: ND
Sample 2013M01 2018M12
Observations 72

Mean	28.84722
Median	24.00000
Maximum	88.00000
Minimum	0.000000
Std. Dev.	16.78670
Skewness	1.392751
Kurtosis	5.425198
Jarque-Bera	40.92182
Probability	0.000000

Over the study period, the average number of neonatal deaths at CCH is approximately 28 per month. The minimum number of neonatal death cases is zero and this was experienced during the months of September 2017, as well as March and December 2018. The maximum number of neonatal death cases over the study period is 88 per month and this is unacceptably high. This was experienced in the month of September 2013. Such large numbers of neonatal deaths indicate that there is need for serious action on the part of policy formulation and implementation. The series under consideration is positively skewed and not normally distributed as shown by the skewness and kurtosis statistics. The Jarque-Bera statistic, with a highly statistically significant probability, at 1% level of significance; also confirms that the series under consideration is not normally distributed.

Results Presentation

Table 3: Main Results of the SARIMA (0, 0, 3)(2, 0, 0)$_{12}$ Model

$$\varphi(B^s)ND = \theta_0 + \theta(B)\alpha_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [4]$$

Equation [4] can be expressed as follows:

$$(1 - \varphi_1 B^{12} - \varphi_2 B^{12})ND = \theta_0 + (1 + \theta_1 B + \theta_2 B^2 + \theta_3 B^3)\alpha_t \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

Variable	Coefficient	Standard Error	z	p-value
φ_1	0.338821	0.109435	3.096	0.0020***
φ_2	0.286037	0.130898	2.185	0.0289**
θ_1	0.533557	0.110862	4.813	0.000149***
θ_2	0.244745	0.120591	2.030	0.0424**
θ_3	0.225426	0.115152	1.958	0.0503*

NB: ***, ** and * imply statistical significance at 1%, 5% and 10% levels of significance

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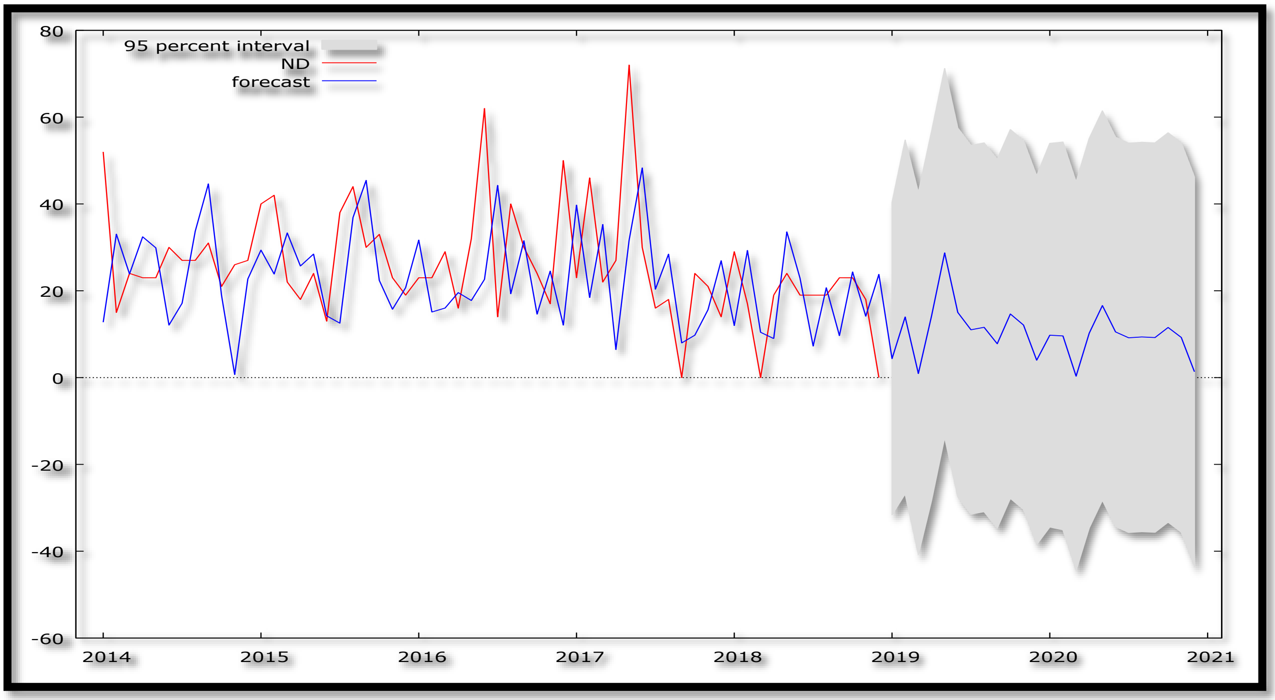
Forecast Graph
Figure 4: Forecast Graph



Out of Sample Forecasts
Table 4: Out-of-sample forecasts (January 2019 – December 2020)

Year: Month	Predicted Neonatal Deaths	Standard Error	95% Confidence Interval
2019:01	4.35905	18.3518	(-31.6098, 40.3280)
2019:02	13.9670	20.8007	(-26.8015, 54.7356)
2019:03	0.932352	21.2801	(-40.7758, 42.6405)
2019:04	14.1606	21.6785	(-28.3284, 56.6496)
2019:05	28.7264	21.6785	(-13.7626, 71.2154)
2019:06	15.0187	21.6785	(-27.4703, 57.5077)
2019:07	11.0142	21.6785	(-31.4748, 53.5032)
2019:08	11.5863	21.6785	(-30.9027, 54.0753)
2019:09	7.79289	21.6785	(-34.6961, 50.2819)
2019:10	14.6578	21.6785	(-27.8312, 57.1468)
2019:11	12.1056	21.6785	(-30.3834, 54.5946)
2019:12	4.00452	21.6785	(-38.4845, 46.4935)
2020:01	9.77202	22.5526	(-34.4302, 53.9743)
2020:02	9.59496	22.7953	(-35.0830, 54.2729)
2020:03	0.315901	22.8460	(-44.4615, 45.0933)
2020:04	10.2326	22.8890	(-34.6290, 55.0943)
2020:05	16.5980	22.8890	(-28.2636, 61.4596)
2020:06	10.5234	22.8890	(-34.3383, 55.3850)
2020:07	9.16655	22.8890	(-35.6951, 54.0282)
2020:08	9.36038	22.8890	(-35.5012, 54.2220)
2020:09	9.21925	22.8890	(-35.6424, 54.0809)
2020:10	11.5452	22.8890	(-33.3164, 56.4069)
2020:11	9.25029	22.8890	(-35.6113, 54.1119)
2020:12	1.35682	22.8890	(-43.5048, 46.2184)

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Graphical Presentation of the Predicted Monthly Neonatal Mortality Cases at Chitungwiza Central Hospital

Figure 5: Graphical presentation of out-of-sample forecasts

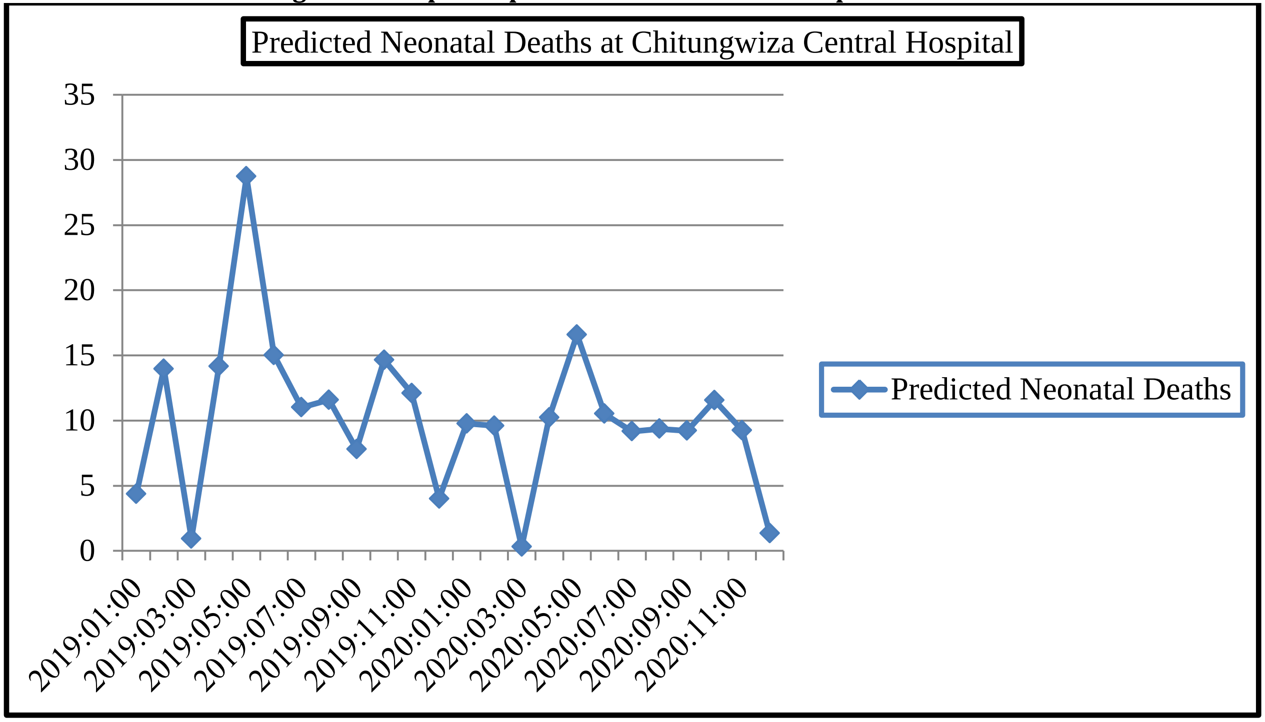

Table 3 shows the main results of the selected optimal model. Equations [4 & 5] are the mathematical representation of the optimal model. The striking feature of this model is that all of its parameters are statistically significant. Figure 4, table 4 and figure 5 show forecasts of the model. The selected optimal model generally predicts that there will be a decline in neonatal deaths at CCH for the out-of-sample period. This means that current policies and programmes designed to combat neonatal mortality Chitungwiza (and other parts of Zimbabwe) are on the winning side in the war against neonatal mortality in Zimbabwe. This precisely suggests that policies for pediatric management at CCH (and of course, in Zimbabwe at large) are effective and should be maintained.

5. CONCLUSION & RECOMMENDATIONS

In this study, the SARIMA $(0,0,3)(2,0,0)_{12}$ model has been successfully used to model neonatal death cases at CCH over the period Janauary 2013 to December 2018. The forecasts show a slow but steady decrease in neonatal deaths at CCH. It could be inferred that the fight against neonatal mortality is gradually being won in Zimbabwe. However, more attention should be paid to this fight to engender even a rapid decline than is currently witnessed. Further studies should explore the main causes of neonatal deaths in Chitungwiza urban district and other areas in Zimbabwe at large. The following recommendations are derived:

i. There is need for increased training programs in resuscitation and in essential newborn care in order to maintain low levels of and or eradicate neonatal deaths.
ii. The government of Zimbabwe should work towards improving access to healthcare, especially for expectant mothers in the CCH catchment area.
iii. The government of Zimbabwe should also work toward capacity building at CCH in order for the hospital to continue offering comprehensive neonatal care services.
iv. There is need for consistent home visits by community health workers, for neonatal care.

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