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PAEDIATRIC NEW HIV INFECTIONS IN MALAWI: A BOX-JENKINS ARIMA APPROACH

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ABSTRACT:

Using annual time series data on the number of children (ages 0 – 14) newly infected with HIV in Malawi from 1990 – 2018, the study predicts the annual number of children who will be newly infected with HIV over the period 2019 – 2030. The paper applies the Box-Jenkins ARIMA methodology. The diagnostic ADF tests show that, S, the series under consideration is an I (2) variable. Based on the AIC, the paper presents the ARIMA (2, 2, 0) model as the optimal model. The diagnostic tests further show that the presented model is stable and its residuals are not serially correlated and are also normally distributed. The results of the study indicate that the number of new HIV infections in children in Malawi will continue to go down over the out-of-sample period. Our model implies that by 2021, Malawi could materialize a society free of pediatric HIV. In this regard, the country could be a good example, especially for neighboring countries; of how pediatric HIV can be prevented and controlled.

INTRODUCTION:

HIV/AIDS has become a major worldwide epidemic. Malawi has been severely affected by the HIV/AIDS epidemic. AIDS was first identified in Malawi in May 1985 (Government of Malawi, 2003). Malawi's HIV prevalence is one of the highest in the world, with 9.2% of the adult population (aged 15-49) living with HIV. In 2018, an estimated 1 million Malawians were living with HIV and 13000 Malawians died from AIDS-related illnesses. Over the last decade, impressive efforts to reduce the HIV epidemic have been made at both national and local levels. In 2018, 90% of people living with HIV in Malawi were aware of their status, of whom 87% were on treatment. Of these, 89% were virally suppressed, meaning the country is very close to reaching the 90-90-90 targets. This equates to 78% of all people living with HIV in Malawi on antiretroviral treatment (ART) and 69% of all people living with HIV virally suppressed. New infections have dramatically declined from 66000 new infections in 2005 to 38000 in 2018. An impressive Prevention of Mother-To-Child Transmission (PMTCT) programme in Malawi has also driven down new infections among children (ages 0-14). In 2018, there were 3500 new pediatric HIV infections, compared with 15000 in 2010 (UNAIDS, 2019). Thanks to a successful PMTCT programme, transmission rates from mother-to-child are now significantly reduced to as low as 8.8% at 12 months after birth (Avert, 2020). The main goal of this study is to predict the number of children newly infected with HIV in Malawi over the period 2019 – 2030. This paper will go a long way in examining the possibility of ending the HIV scourge in Malawi.

METHODODOLOGY:

3.1 The Box – Jenkins (1970) Methodology

The first step towards model selection is to difference the series in order to achieve stationarity. Once this process is over, the researcher will then examine the correlogram

in order to decide on the appropriate orders of the AR and MA components. It is important to highlight the fact that this procedure (of choosing the AR and MA components) is biased towards the use of personal judgement because there are no clear – cut rules on how to decide on the appropriate AR and MA components. Therefore, experience plays a pivotal role in this regard. The next step is the estimation of the tentative model, after which diagnostic testing shall follow. Diagnostic checking is usually done by generating the set of residuals and testing whether they satisfy the characteristics of a white noise process. If not, there would be need for model re – specification and repetition of the same process; this time from the second stage. The process may go on and on until an appropriate model is identified (Nyoni, 2018c). This approach will be used to analyze, S, the series under consideration.

3.2 The Applied Box – Jenkins ARIMA Model Specification

If the sequence $\Delta^d S_t$ satisfies an ARMA (p, q) process; then the sequence of S_t also satisfies the ARIMA (p, d, q) process such that:

$$\Delta^d S_t = \sum_{i=1}^{p} \beta_i \Delta^d L^i S_t + \sum_{i=1}^{q} \alpha_i L^i \mu_t + \mu_t \dots\dots\dots\dots\dots\dots\dots [1]$$

where Δ is the difference operator, vector $\beta \in \mathbb{R}^p$ and $\alpha \in \mathbb{R}^q$.

3.3 Data Collection

This study is based on annual observations (that is, from 1990 – 2018) on the number of children newly infected with HIV (ages 0 – 14) [denoted as S] in Malawi. Out-of-sample forecasts will cover the period 2019 – 2030. All the data was collected from the World Bank online database.

3.4 Diagnostic Tests & Model Evaluation

3.4.1 Stationarity Tests: Graphical Analysis

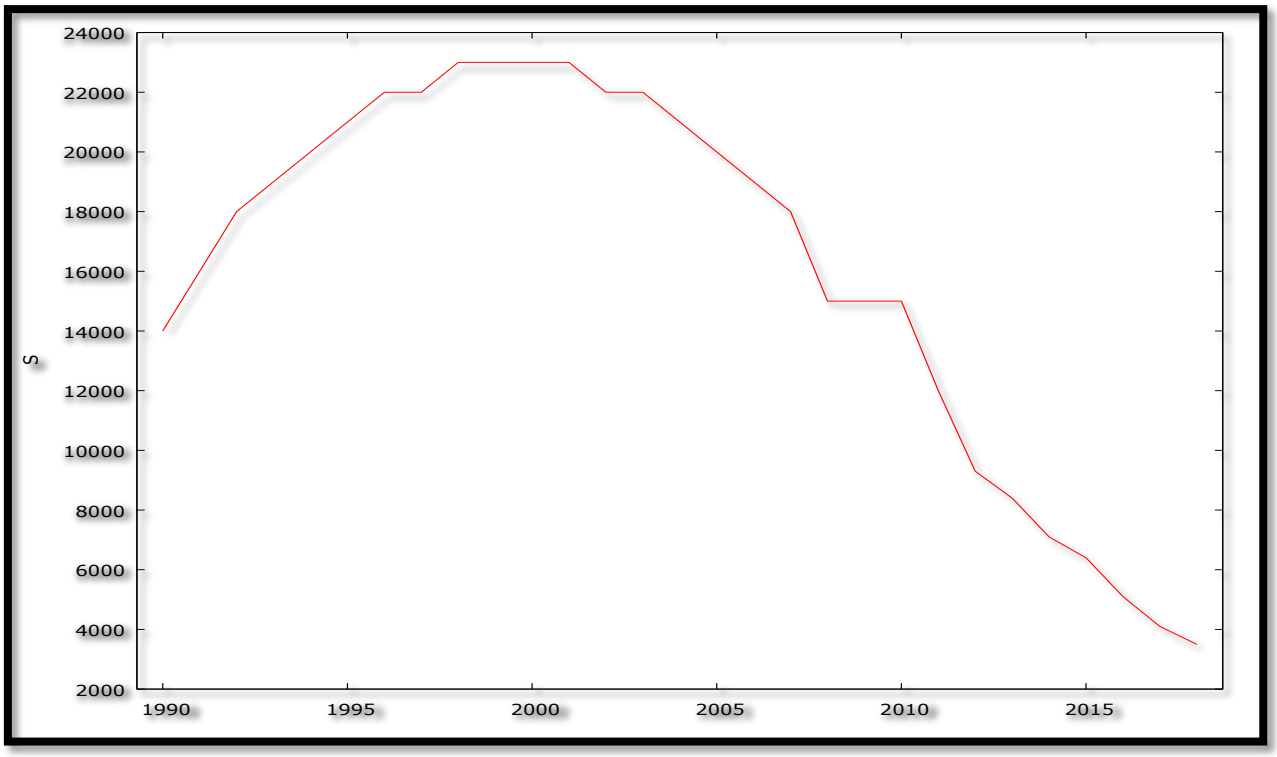

Figure 1

3.4.2 The Correlogram in Levels

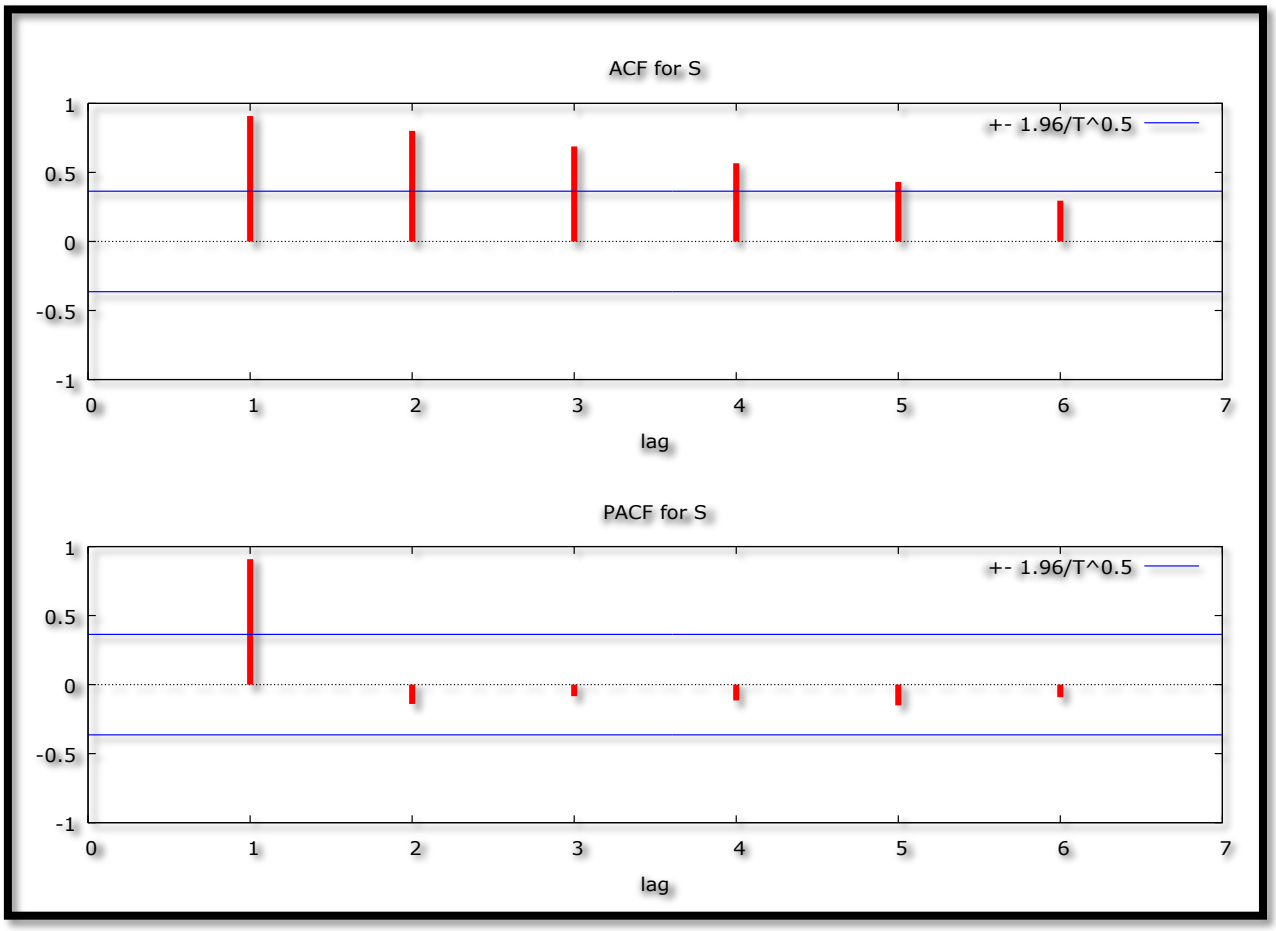

Figure 2: Correlogram in Levels

3.4.3 The ADF Test in Levels

Table 1: with intercept

Variable	ADF Statistic	Probability	Critical Values		Conclusion
S	1.424399	0.9986	-3.689194	@1%	Non-stationary
			-2.971853	@5%	Non-stationary
			-2.625121	@10%	Non-stationary

Table 1 shows that S is not stationary in levels. Figure 1 and 2 seem to indicate something else: that S is not I(0). In fact, figure has a clear trend, that initially goes upwards from 1990 to around 2001, after which N follows a downwards trend until 2018. Such a series cannot be stationary in levels. Figure seems to be consistent with figure 1 as most lags, especially of the ACF, are outside the confidence bands. Based on this, we proceed to test examine stationarity in first differences.

3.4.4 The Correlogram (at First Differences)

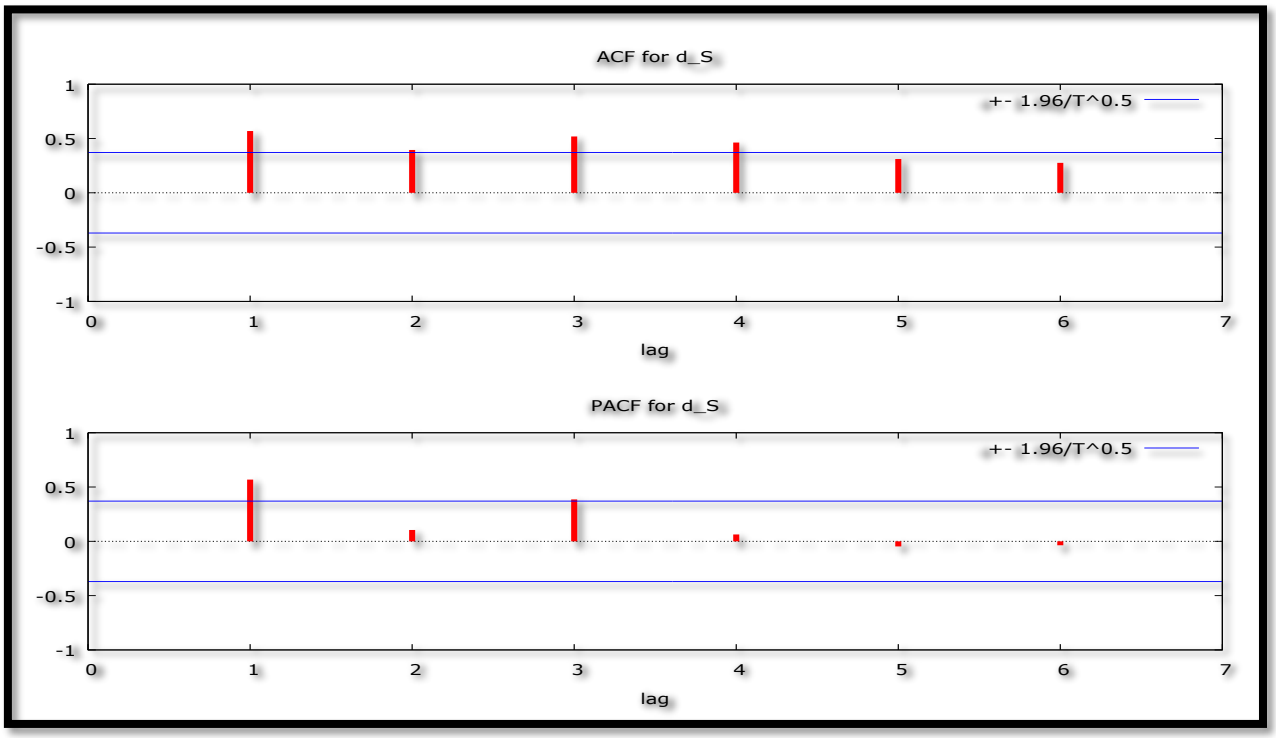

Figure 3: Correlogram (at First Differences)

3.4.5 The ADF Test (at First Differences)

Table 2: with intercept

Variable	ADF Statistic	Probability	Critical Values		Conclusion
ΔS	-2.906940	0.0577	-3.699871	@1%	Non-stationary
			-2.976263	@5%	Non-stationary
			-2.627420	@10%	Stationary

Figure 3 still suggests that S is not an I (1) variable while table 2 shows that S is now stationary but at 10% level of significance. Due to this inconsistency, we proceed to test for stationary after second differences.

3.4.6 The Correlogram (at Second Differences)

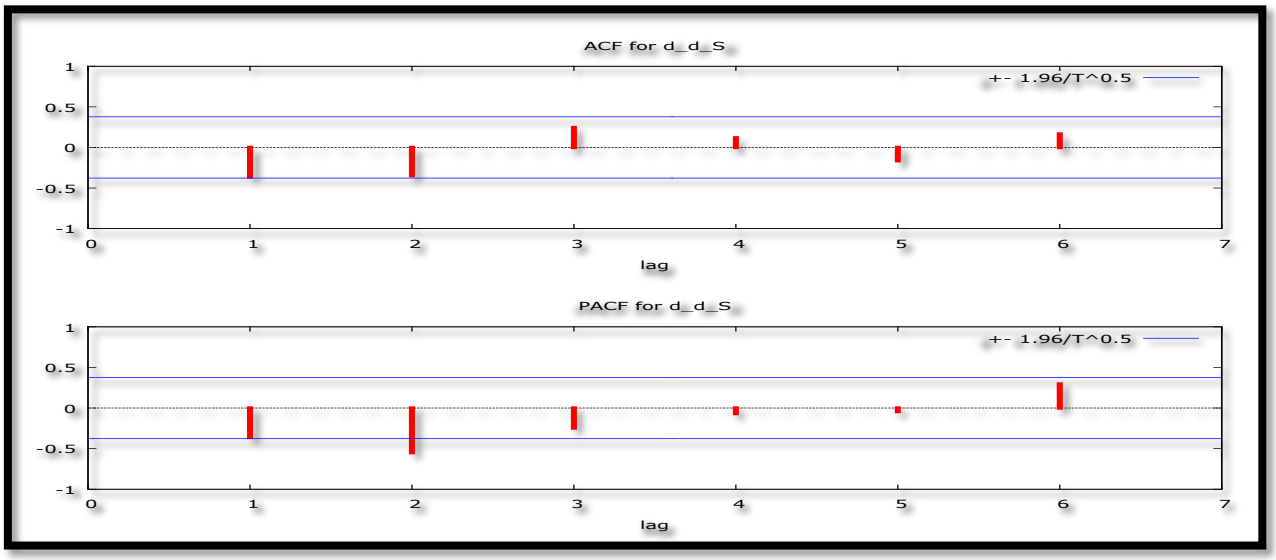

Figure 4: Correlogram (at Second Differences)

3.4.7 The ADF Test (at Second Differences)

Table 3: with intercept

Variable	ADF Statistic	Probability	Critical Values		Conclusion
$\Delta^2 S$	-7.364492	0.0000	-3.724070	@1%	Stationary
			-2.986225	@5%	Stationary
			-2.632604	@10%	Stationary

Figure 4 and table 3 show that S is an I (2) variable.

3.4.8 Evaluation of ARIMA models (with a constant)

Table 4: Evaluation of ARIMA Models (with a constant)

Model	AIC	U	ME	RMSE	MAPE
ARIMA (1, 2, 1)	452.0241	0.81339	-39.69	891.27	6.7056
ARIMA (2, 2, 0)	**449.8438**	0.7185	-14.704	857.1	6.0956
ARIMA (0, 2, 1)	450.0265	0.81329	-40.399	891.34	6.6963
ARIMA (0, 2, 2)	452.0027	0.8143	-33.946	890.4	6.7775
ARIMA (2, 2, 2)	451.0339	0.76934	-14.257	807.46	6.1438
ARIMA (3, 2, 0)	449.9418	0.74622	-21.62	825.4	5.6985
ARIMA (3, 2, 1)	451.6272	0.76188	-26.342	819.96	5.9773
ARIMA (1, 2, 2)	453.2040	0.79633	-48.606	877.99	6.4635

A model with a lower AIC value is better than the one with a higher AIC value (Nyoni, 2018b) Similarly, the U statistic can be used to find a better model in the sense that it must lie between 0 and 1, of which the closer it is to 0, the better the forecast method (Nyoni, 2018a). In this research paper, only the AIC is used to select the optimal model. Thus the ARIMA (2, 2, 0) model is finally chosen.

3.5 Residual & Stability Tests

3.5.1 Correlogram of the Residuals of the ARIMA (2, 2, 0) Model

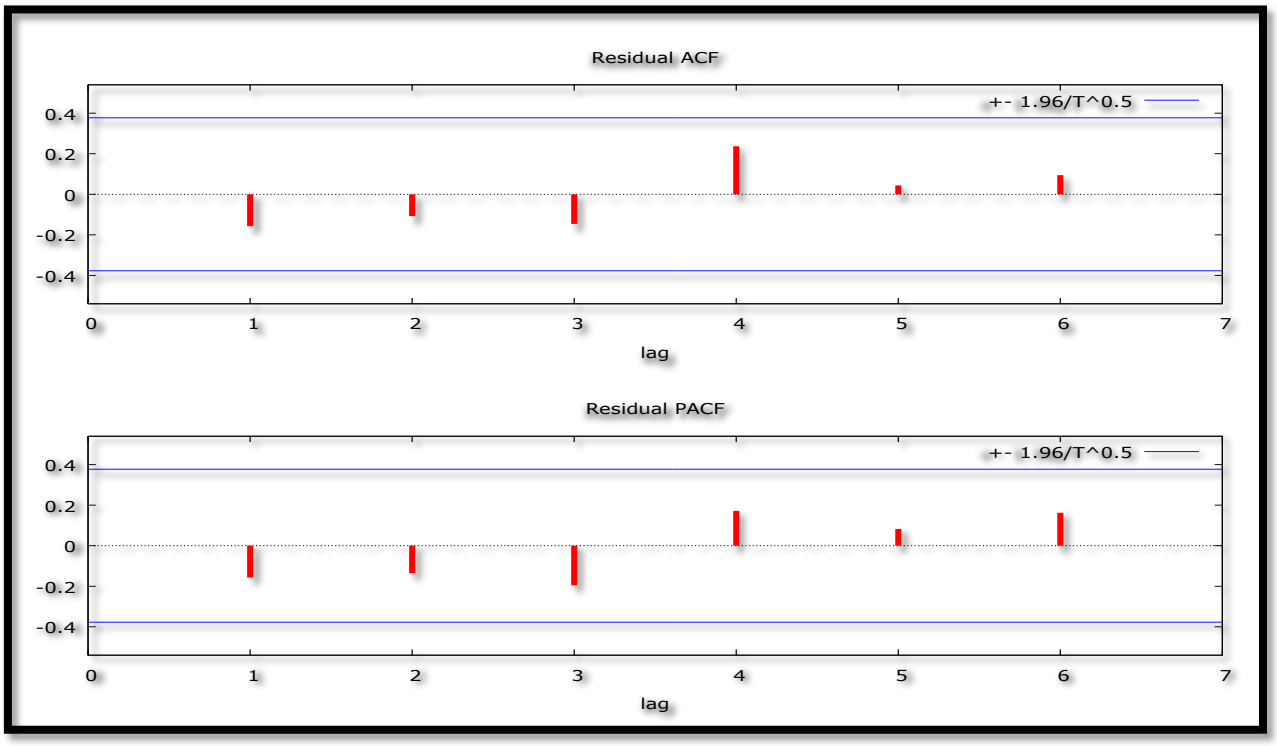

Figure 5: Correlogram of the Residuals

Figure 5 indicates that the estimated best model is adequate since ACF and PACF lags are quite short and within the bands.

3.5.2 Stability Test of the ARIMA (2, 2, 0) Model

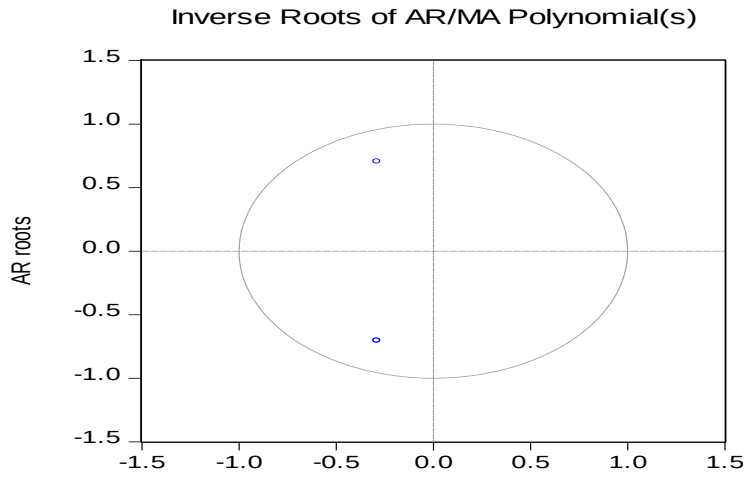

Figure 6: Inverse Roots

Considering that all the AR roots lie inside the unit circle, it implies that the estimated ARIMA process is (covariance) stationary; thus confirming that the ARIMA (2, 2, 0) model is really stable and suitable for forecasting annual number of new HIV infections in Malawi.

3.5.3 Normality Test of the Residuals of the ARIMA (2, 2, 0) Model

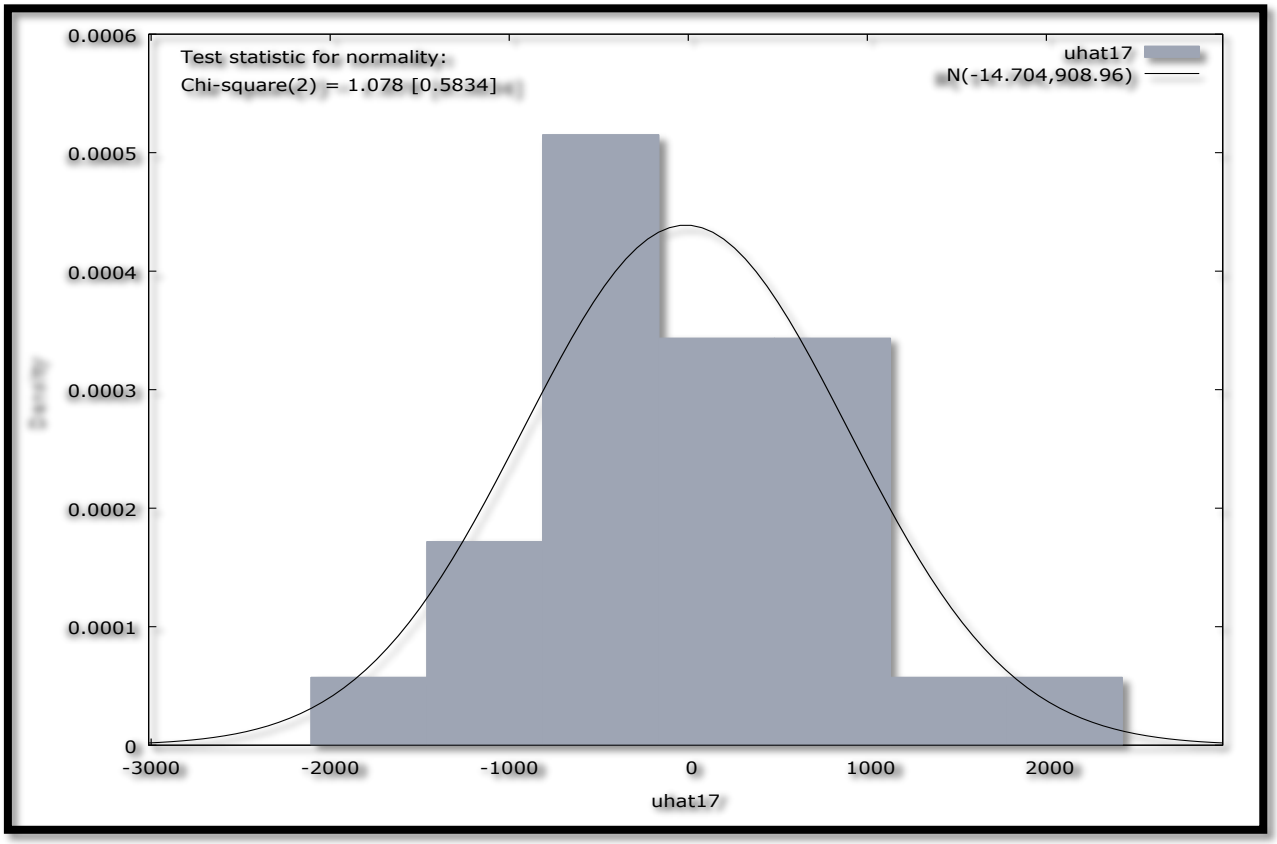

Figure 7: Normality Test

Considering that the probability value of the chi-square statistic is insignificant, we reject the null hypothesis and conclude that the residuals of the ARIMA (2, 2, 0) model are normally distributed.

4.0 FINDINGS OF THE STUDY:

4.1 Descriptive Statistics

Table 5: Descriptive Statistics

Description	Statistic
Mean	16100
Median	18000
Minimum	3500
Maximum	23000

Over the study period, the annual average number of new HIV infections in children in Malawi is 16100. The minimum number of new HIV infections in children in the country is 3500 and was just recently recorded in 2018; while the maximum is 23000 new infections, which was observed over the period 1998 – 2001.

4.2 Results Presentation

Table 6: Main Results

ARIMA (2, 2, 0) Model:

The chosen parsimonious model, the ARIMA (2, 2, 0) model can be expressed as follows:

$$\Delta^2 S_t = -103.238 - 0.558435\Delta^2 S_{t-1} - 0.539432\Delta^2 S_{t-2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

Variable	Coefficient	Standard Error	z	p-value
constant	-103.238	80.2735	-1.286	0.1984
β_1	-0.558435	0.160047	-3.489	0.0005***
β_2	-0.539432	0.160465	-3.362	0.0008***

Table 6 shows the main results of the ARIMA (2, 2, 0) model.

Forecast Graph

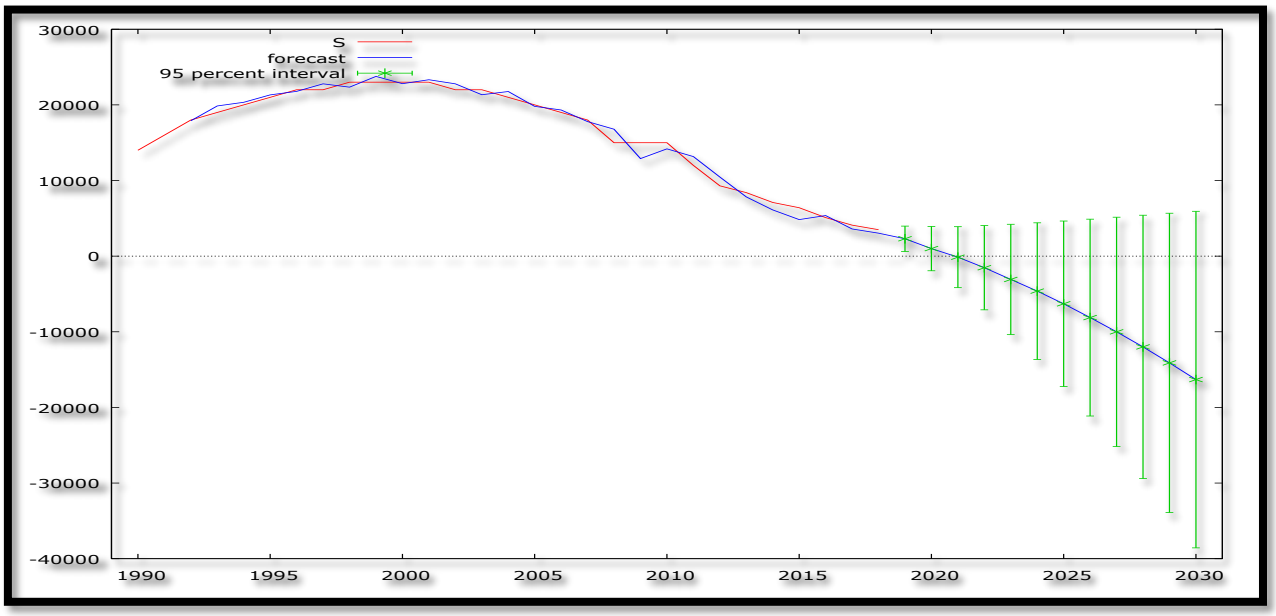

Figure 8: Forecast Graph – In & Out-of-Sample Forecasts

Figure 8 shows the in-and-out-of-sample forecasts of the S series. The out-of-sample forecasts cover the period 2019 – 2030.

Predicted S– Out-of-Sample Forecasts Only

Table 7: Predicted S

Year	Predicted S	Standard Error	95% Confidence Interval
2019	2298.22	852.357	(627.628, 3968.80)
2020	1000.14	1495.42	(-1930.83, 3931.11)
2021	-136.128	2056.10	(-4166.00, 3893.75)
2022	-1527.39	2839.65	(-7093.01, 4038.22)
2023	-3080.12	3722.43	(-10375.9, 4215.70)
2024	-4621.71	4606.50	(-13650.3, 4406.86)
2025	-6299.00	5582.13	(-17239.8, 4641.77)
2026	-8123.10	6639.28	(-21135.9, 4889.65)
2027	-10008.6	7732.21	(-25163.5, 5146.27)
2028	-11997.2	8882.37	(-29406.3, 5411.93)
2029	-14111.7	10094.9	(-33897.3, 5673.92)
2030	-16316.8	11351.5	(-38565.4, 5931.80)

Table 7 and figure 8 show the out-of-sample forecasts only. The number of new pediatric HIV infections in Malawi is expected to decline significantly, such that somewhere around 2021, the country could be free from pediatric HIV. This can happen, it is possible. The results of this study are consistent with Avert (2020) which argued that the PMTCT programme in Malawi has been successful.

5.0 CONCLUSION:

The paper shows that the ARIMA (2, 2, 0) model is not only stable but also the most suitable model to forecast the annual number of new HIV infections in children in Malawi over the period 2019 – 2030. The findings of the study ironically imply that the PMTCT programme in the country can be thought of as a success. Malawi can possibly win the war against pediatric HIV, very soon. We recommend the continued implementation of the PMTCT programme, with considerations for further expansion and coverage of the programme, especially in areas such as Lilongwe and Blantyre where the HIV epidemic is usually concentrated.

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