Predicting TB Incidence in Zimbabwe: Artificial Neural Networks Reveals TB Program Success?

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Abstract - **Zimbabwe's HIV/TB program is one of the success stories to tell in the SADC region. The government with the support of its partners has implemented robust measures in order to prevent and control TB. The period 2000-2018 has been characterized by a significant decline in TB incidence as most health facilities in the country are offering HIV/TB program services. In this study the artificial neural network technique has been applied. The employed annual data covers the period 2000-2018 and the out-of-sample period ranges over the period 2019-2023. The residuals and forecast evaluation criteria (Error, MSE and MAE) of the applied model indicate that the model is stable in forecasting TB incidence in Zimbabwe. The results of the study indicate that TB incidence is likely to continue on a downward trajectory over the period 2019-2023. In order to contribute meaningfully to the national control strategy of a TB-free Zimbabwe, the government among other things; should intensify TB surveillance and control programs.**

Keywords: ANN, Forecasting, TB incidence.

I. INTRODUCTION

Since the advent of the HIV era, mycobacterium Tuberculosis (MTB) has become one of the leading causes of pneumonia in the Sub Saharan African region (Sgaragli & Frosini, 2016). In 2010, the entire world had about 8.8 million incident cases of tuberculosis (TB), 1.45 million people died from the disease and 24% of those who died were co-infected with HIV(WHO, 2011). The incidence of TB in Zimbabwe in 2014 was 242 per 100 000 population and in the same year 8000 deaths were as a result of TB alone. The TB incidence in Zimbabwe is being fueled by the HIV epidemic as in other SADC countries. In 2015 about 70% of notified TB cases were co-infected with HIV (Zimbabwe National TB control programme, 2016). Zimbabwe made its commitment to end TB and adopted the END TB strategy with its targets to reduce TB incidence by 90% and TB mortality by 95% by 2035 in comparison with the situation in 2015. TB bacilli have a potential to infect any organ in the body but primarily affects the lungs. Examples of other body organs or tissues that are usually affected are the meninges, abdominal organs, pericardium and bones. The bacterial infection tends to attack individuals with a weak immune system such as HIV infected people, under 5 children and the elderly people (WHO,2018) .The clinical symptoms of pulmonary TB include a productive cough for more than 2 weeks, fever, night sweats ,shortness of breath and weight loss (Sharma et al, 2016).The disease is transmitted via droplet infection after sneezing or coughing (Zheng et al, 2015).The diagnosis of the disease involves taking a relevant thorough history ,physical examination and carrying out appropriate confirmatory tests .After taking a history and physical examination the clinician has to collect sputum samples for lab investigation .Currently in Zimbabwe the sputum samples are sent for Gene -Expert analysis where the machine will detect the presence of MTB and also check whether the bacilli are resistant to rifampicin or not. Sputum smear microscopy is done as follow up of TB treatment. Additional samples which can be sent for confirmation are pleural fluid, cerebrospinal fluid and abdominal fluid samples. In certain circumstances patients can present with enlarged lymph nodes in the neck, axilla and supraclavicular regions. In such situations a properly trained clinician has to take a tissue biopsy and send it for histology. Sputum negative MTB poses a lot of diagnostic challenges in the clinical set up hence radiological tests are done in order to help detect the disease. The commonest radiological investigation which is readily available in the country is the chest x-ray. The radiological features which one should look for include cavitary lesions, pleural effusion and milliary infiltrates.

In Zimbabwe the TB program is run by the AIDS and TB unit under the Ministry Health and Child Care. TB services are offered for free at all levels of the health care delivery system and integrated into the primary health care system to strengthen efficient case finding and case holding (Zimbabwe National TB programme, 2016). Each district has a TB focal person who reports to the District Medical officer (DMO). The DMO in turn will report to the Provincial Medical officer (PMD). The PMD provides TB program oversight in the Province and is assisted by the Provincial TB/HIV/Leprosy officers and the provincial TB and leprosy coordinators. Collaboration of TB/HIV activities is carried out at all levels. The program is funded by the government

with assistance from partners like USAID, PEPFAR, THE UNION and CHALLENGE TB. The main goal of the program is to detect and treat TB early to minimize community spread of the epidemic especially sputum positive cases. Screening of patients at all levels of care using the TB screening tool is being done. Suspected cases are sent for confirmatory tests. All positive cases are notified and immediately commenced on anti-TB treatment under the Directly Observed Treatment Short course (DOTS) strategy. It is crucial that patients adhere to treatment to prevent the emergence of drug resistant TB and improve clinical outcomes (Sgaragli & Frosini, 2016). Furthermore, the government is seized with making sure that TB prevention is prioritized especially in children who are TB contacts and for HIV positive patients on antiretroviral treatment. Isoniazid prophylaxis is given to all patients with no contraindications. Globally there are many empirical studies on TB. However, there are few such studies in Zimbabwe. Forecasting the incidence of TB in the country will help the government of Zimbabwe to understand the evolution of the epidemic and this will trigger an appropriate response to the disease. Therefore, in this piece of work the researchers applied ANN (9,12,1), the multilayer perceptron (MLP) to forecast TB incidence using annual data covering the period 2000-2018 and the forecast period is 2019-2023.Further more the results of the study will assist the health authorities to assess the impact of TB preventive and control measures implemented by government and enable it to strengthen certain policies in order to curb the spread of TB in the community.

II. LITERATURE REVIEW

There are few empirical papers on TB that have been done in Zimbabwe. Lenka et al (2012) analyzed the association of BMI category change with TB treatment mortality in HIV positive smear negative and extrapulmonary TB patients in Myanmar and Zimbabwe. A retrospective cohort study of adult HIV-positive new TB patients in Médecins Sans Frontiers (MSF) treatment programs in Myanmar and Zimbabwe was conducted using Cox proportional hazards regression to estimate the association between BMI category change and mortality. A cohort of 1090 TB patients (605 smear-negative and 485 extrapulmonary) was followed during TB treatment with mortality rate of 28.9 per 100 person-years. In multivariable analyses, remaining severely underweight or moving to a lower BMI category increased mortality (adjusted hazard ratio 4.05, 95% confidence interval 2.77–5.91, p,0.001) compared with remaining in the same or moving to a higher BMI category. The researchers concluded that there is a strong association between BMI category change during the first month of TB treatment and mortality. BMI category change could be used to identify individuals most at risk of mortality during TB treatment among smear-negative and extrapulmonary patients. Nyoni & Nyoni (2019a) forecasted TB notifications at Zengeza clinic in Chitungwiza using monthly time series data covering the period January 2013- December 2018.The SARIMA $(2,0,2)$ $(1,0,1)_{12}$ model predicted that TB notifications would decline over the out of sample period January 2019-December 2030. Nyoni & Nyoni (2019b) forecasted TB notifications at Silobela District hospital using a univariate monthly time series data covering the period January 2014 to December 2018. The applied SARIMA $(1,0,1)(1,0,1)_{12}$ model predicted that TB notifications would decline over the out of sample period covering January 2019 -December 2021.

III. METHOD

The Artificial Neural Network (ANN), which we intend to apply; is a data processing system consisting of a large number of simple and highly interconnected processing elements resembling a biological neural system. It has the capability of learning from an experimental or real data set to describe the nonlinear and interaction effects with great accuracy. ANN-based curve fitting technique is one of the extensively applied artificial intelligence methods that are used for forecasting and prediction purpose. It consists of basically three layers i.e., input layer, hidden layer, and output layer, the present work includes the number of years as input layer and the annual TB incidence in Zimbabwe as output data for the network. In this paper, our ANN is based on the hyperbolic tangent function.

Data Issues

This study is based on TB incidences per 100 000 people (referred to as Z series in this study) in Zimbabwe. The annual data covers the period 2000-2018 while the out-of-sample forecast covers the period 2019-2023. All the data employed in this research paper was gathered from the World Bank online database.

IV. FINDINGS OF THE STUDY

Descriptive Statistics

Table 1: Descriptive statistics

Mean	Median	Minimum	Maximum
437.84	450.00	210.00	617.00
Std. Dev.	C.V.	Skewness	Ex. Kurtosis
155.28	0.35465	-0.19057	-1.5209
5% Perc.	95% Perc.	IQ range	Missing obs.
Undefined	617.00	327.00	0

Table 1 indicates that TB incidence in Zimbabwe is still very high, with an annual average incidence of approximately 438 per 100 000 people over the period 2000 – 2018.

ANN MODEL SUMMARY FOR TB INCIDENCE (new cases per 100 000 population/year) IN ZIMBABWE

Table 2: ANN model summary

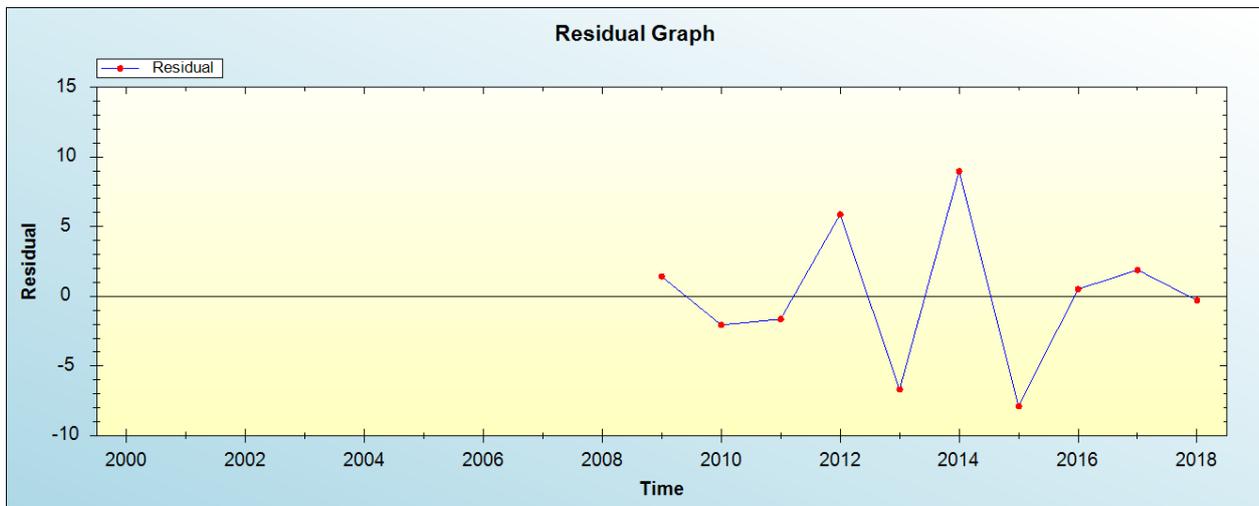| Variable	Z
Observations	10 (After Adjusting Endpoints)
Neural Network Architecture:	
Input Layer Neurons	9
Hidden Layer Neurons	12
Output Layer Neurons	1
Activation Function	Hyperbolic Tangent Function
Back Propagation Learning:	
Learning Rate	0.005
Momentum	0.05
Criteria:	
Error	
MSE	
MAE	

Residual Analysis for the ANN model

Figure 1: Residual analysis
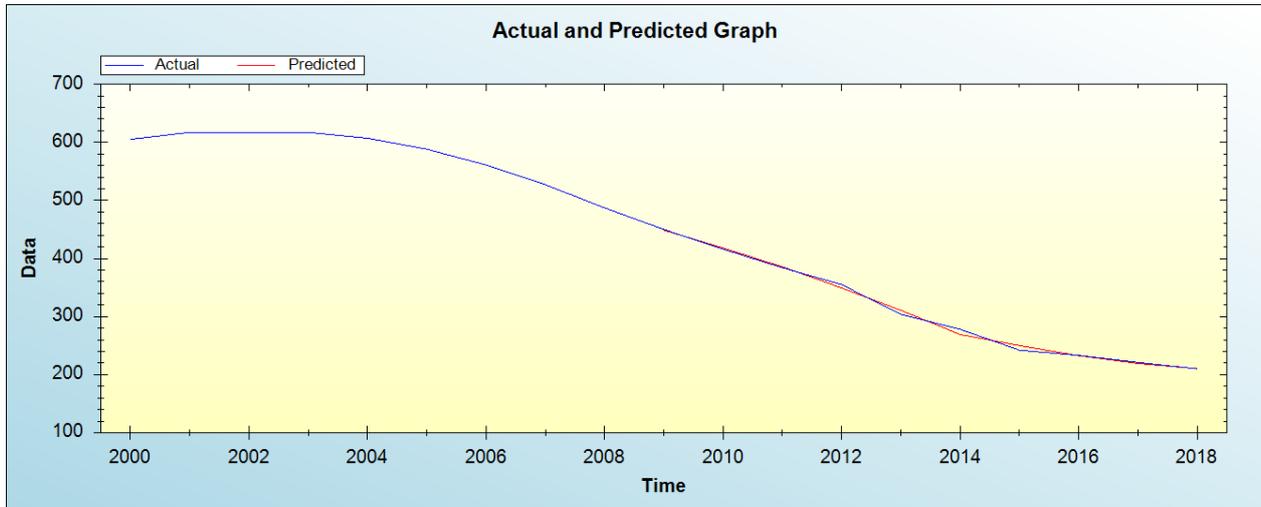
In-sample Forecast for Z

Figure 2: In-sample forecast for the Z series

Figure 2 shows the in-sample forecast for Z series.

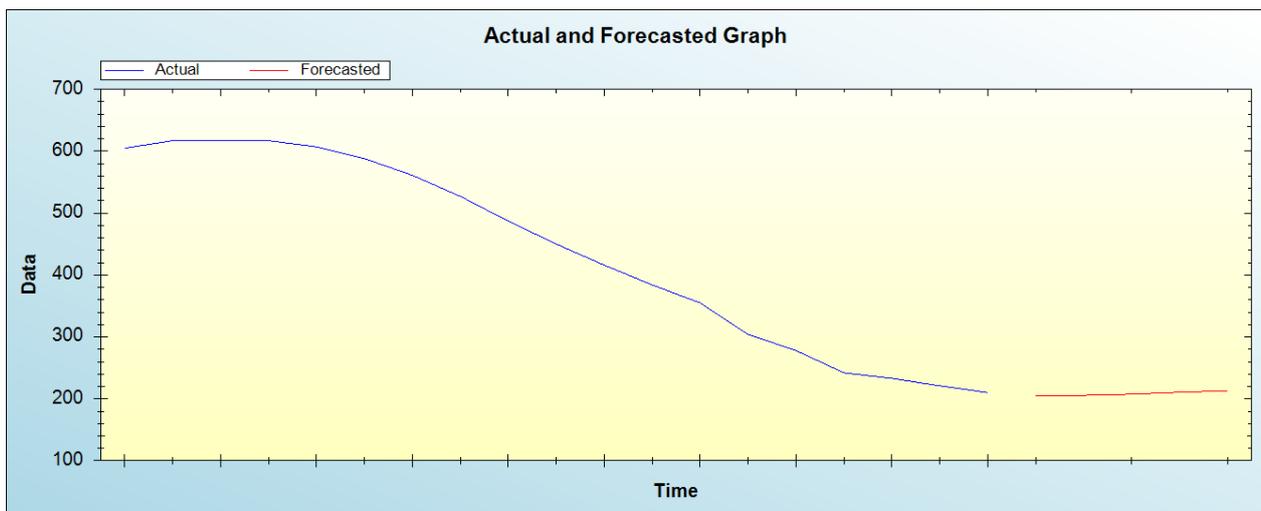*Out-of-Sample Forecast for Z: Actual and Forecasted Graph*

Figure 3: Out-of-sample forecast for Z: actual and forecasted graph

Out-of-Sample Forecast for Z: Forecasts only

Table 3: Tabulated out-of-sample forecasts

Year	Forecasts
2019	205.0060
2020	205.5080
2021	207.4709
2022	210.6648
2023	212.8586

Over the study period 2000-2018 the country has experienced a downward trajectory in the incidence of TB. The minimum and maximum TB incidence was 210 and 617 cases per 100 000 population/year with an average of 438 cases per 100 000/year. The applied data is negatively skewed with an excess kurtosis value of -1.5209 implying that it is not normally distributed. The residual graph and model evaluation criteria (Error, MSE, MAE) indicate that the model is stable and suitable for forecasting TB

incidence in Zimbabwe. Figure 2 shows that the applied ANN (9,12,1) accurately simulates the observed values for Zimbabwe. The model predicts that TB incidence in the country will remain high and projects a slight increase from 205 cases per 100 000 population in 2019 up to 213 cases per 100 000 population/year in 2023.

V. CONCLUSION & RECOMMENDATIONS

Zimbabwe's TB/HIV program is one of the best in the SADC region characterized by good program linkages to effectively detect and treat HIV and TB early. The government recommended the use of Isoniazid prophylaxis for HIV infected patients on antiretroviral therapy who do not have contraindications as a measure to prevent new TB infections. The ministry of Health also put in place administrative structures to ensure timely case detection and treatment, community awareness and reporting of all TB and HIV cases. The TB/HIV program is linked to sexual and reproductive health, HIV testing services, Voluntary Medical Male Circumcision (VMMC) and other clinical services in order to capture all clients who need HIV/TB program services. Despite having limited program funding the government has performed very well because TB incidence has been on a commendable downward trajectory from 2000-2018. The model predicted that TB incidence will remain high and the country will have a slight increase in the incidence of TB between 2019- 2023. In this piece of work the researchers recommend that the government of Zimbabwe should continue strengthening HIV/TB program linkages, training of healthcare workers on the emerging trends on TB /HIV, intensify TB surveillance and control programs.

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