

Rwanda's Art Program Success Story: Insights from the Artificial Neural Networks

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Abstract - Rwanda is one of the nations in Africa which has significantly improved access to antiretroviral therapy (ART) for people living with HIV. Modeling ART coverage in this country will help to assess the impact of the efforts made by government to improve access to ART and to control the HIV epidemic. In this research article, the ANN approach was applied to analyze ART coverage in Rwanda. 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 ART coverage in Rwanda. The results of the study indicate that ART coverage will be very high around 90%. The government is encouraged to continue on this commendable path. The authorities should continue strengthening TB/HIV collaboration and strengthen tracking of loss to follow up ART clients to improve adherence and clinical outcomes.

Keywords: ANN, ART coverage, Forecasting.

I. INTRODUCTION

Rwanda is a good example of a success story in the control of the HIV epidemic in Africa. However the epidemic continues to cause suffering and deaths among the population. The estimated number of new HIV infections in 2019 was 4409 and the estimated number of AIDS related deaths in the same year was 2939 (UNAIDS, 2019). The national HIV prevalence has been stable at 3% (RPHIA, 2019; NISR, 2015). The country has high concentration of HIV among female sexworkers (FSW) and 46% of key groups is living with HIV (Rwanda, 2016). HIV incidence among FSW is 3.5 per 100 person years compared with the general population which has an incidence rate of 0.27 per 100 person years (Braunstein et al, 2011; Nsanzimana, 2017). According to RPHIA 2019 the prevalence of HIV among adults in Rwanda was 3.0 %, annual incidence of HIV among adults was 0.08% and the prevalence of viral load suppression among all HIV positive adults was 76% . 83, 8% of HIV positive adults were aware of their HIV positive status, among the HIV positive adults 97.5% were on antiretroviral treatment (ART) and among adults on ART 90.1% achieved viral load suppression (VLS). According to the National strategic plan for HIV in Rwanda, the government has made significant strides in the HIV response. ART coverage has continued on an upward trend to reach levels, associated with global targets. The country has also witnessed improvements in the quality of ART services, high enrollments and retention rates. The country has succeeded in combating HIV/AIDS because of the strong commitment demonstrated by the political leadership and government partners to lessen the burden of the disease among the population (Rwanda strategic plan, 2018). ART services are offered for free at all levels of the health delivery system. The main goal is to detect and treat HIV cases early and to achieve viral load suppression.

Modeling techniques have been previously applied by researchers to predict the future trends of infectious diseases. Autoregressive Integrated Moving Average (ARIMA) and machine learning techniques are the widely used time series forecasting methods. ARIMA models were proposed by Box and Jenkins in the 1970s. ARIMA (p,d,q) is the basic representation of ARIMA models, where p and q represent the non-seasonal autoregressive and moving average parts and 'd' representing the non-seasonal differencing order. ARIMA model building involves a 3stage iterative process which is characterized by model identification, parameter estimation and diagnostic checking. Once the optimal parsimonious model is identified forecasting is then carried out (Nyoni & Nyoni, 2019a & b; Kaushiki & Sahi, 2018). The commonest machine learning algorithm in time series forecasting is the artificial neural network (multilayer perceptron). The model is made up of 3 layers : input, hidden and output layers. The layers are connected by connection weights. The nodes in each layer are known as processing elements. These processing elements can be active or passive. The active nodes contain activation functions which facilitate processing of information or signals (Fojnica et al, 2016; Zhan, 2013; Kaushiki & Sahi, 2018). The widely used activation functions include sigmoid, hyperbolic tangent, radial basis function and the Gaussian process activation functions. In this study we applied the ANN (9, 12, 1) model with the more

efficient hyperbolic tangent function. The findings from this study are expected to be used as an early surveillance tool in the control of the HIV epidemic in Rwanda.

II. LITERATURE REVIEW

Moyo et al (2017) examined changes and equity in ART use in Kenya and South Africa. The study analyzed national population based household surveys conducted in Kenya and South Africa between 2007 and 2012 for factors associated with lack of ART use among people living with HIV aged 15-64 years. The findings from the study revealed that ART use among PLHIV increased from 29.3% to 42.5% from 2007 to 2012 in Kenya and 17.4% to 30.3% from 2008 to 2012 in South Africa. Areas needing improvement include rural Kenyans, students in South Africa and among young people and drug users in both countries. Young et al (2017) investigated HIV associated mortality in the era of ART scale up in Nairobi, Kenya. HIV seropositivity in cadavers measured at the two largest mortuaries in Nairobi was used to estimate HIV prevalence in adult deaths. Model based estimates of the HIV infected and uninfected population for Nairobi were used to calculate a standardized mortality ratio and population attributable fraction for mortality among the infected versus uninfected population. Monte Carlo simulation was used to assess sensitivity to epidemiological assumptions. The study results revealed that 73.6% of adult people living with HIV receive antiretroviral drugs in Nairobi. Their risk of death is four fold greater than the uninfected while 16.1% of all adult deaths in the country can be attributable to HIV infection. Nsanzimana et al (2020) developed a Markov model to estimate the effects of targeted strategies to female sexworkers (FSWs) on the prevalence and incidence in Rwanda from 2017 to 2027. The model consisted of six states; HIV-, HIV+ undiagnosed /diagnosed with/without ART and death. Three populations were considered FSWs, sex clients and the general population for the period 2017-2027. The HIV epidemic among each of these populations was estimated using Rwanda’s demographic, sexual risk behavior and HIV associated morbidity and mortality data. The study concluded that continued efforts toward improving condom and ART use will be critical for Rwanda to continue their epidemic control.

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 Rwanda 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 annual ART coverages (referred to as R series in this study) in all age groups in Rwanda. The 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 World Bank online database

IV. FINDINGS OF THE STUDY

DESCRIPTIVE STATISTICS

Table 1: Descriptive statistics

Mean	Median	Minimum	Maximum
36.421	35.000	0.00000	87.000
Std. Dev.	C.V.	Skewness	Ex. kurtosis
31.008	0.85137	0.23919	-1.3336
5% Perc.	95% Perc.	IQ range	Missing obs.
undefined	87.000	61.000	0

ANN MODEL SUMMARY FOR ART COVERAGE IN RWANDA

Table 2: ANN model summary

Variable	R
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	0.028900
MSE	1.951129
MAE	1.210630

Residual Analysis for the ANN model

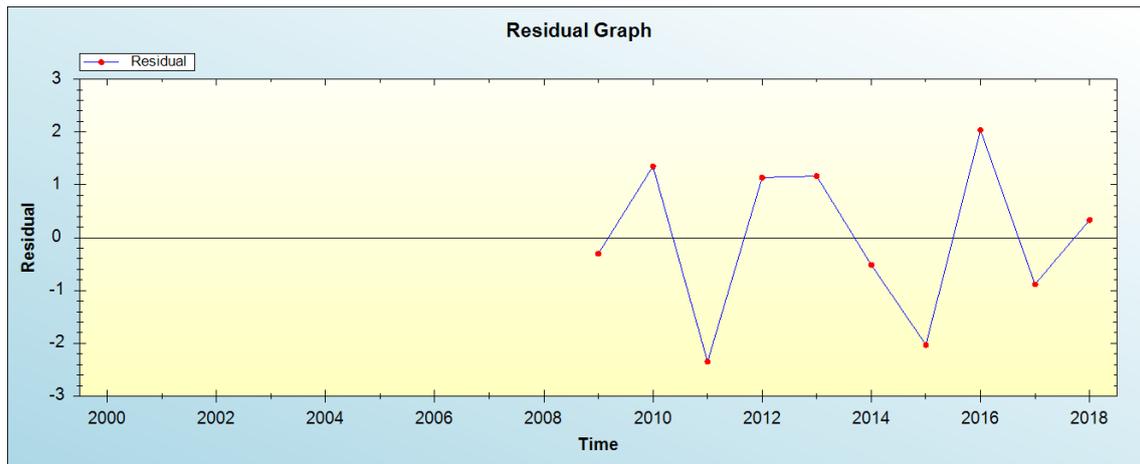


Figure 1: Residual analysis

In-sample Forecast for R

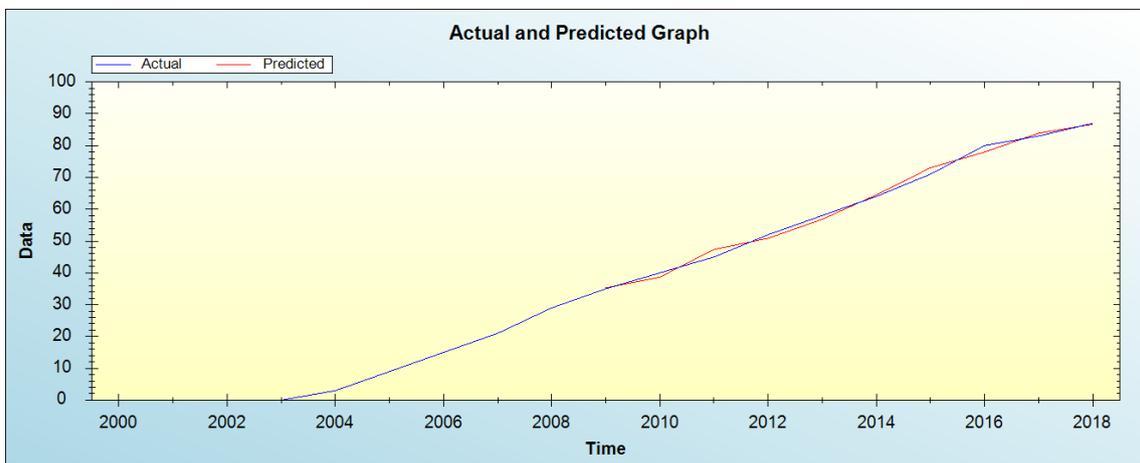


Figure 2: In-sample forecast for the R series

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

Out-of-Sample Forecast for R: Actual and Forecasted Graph

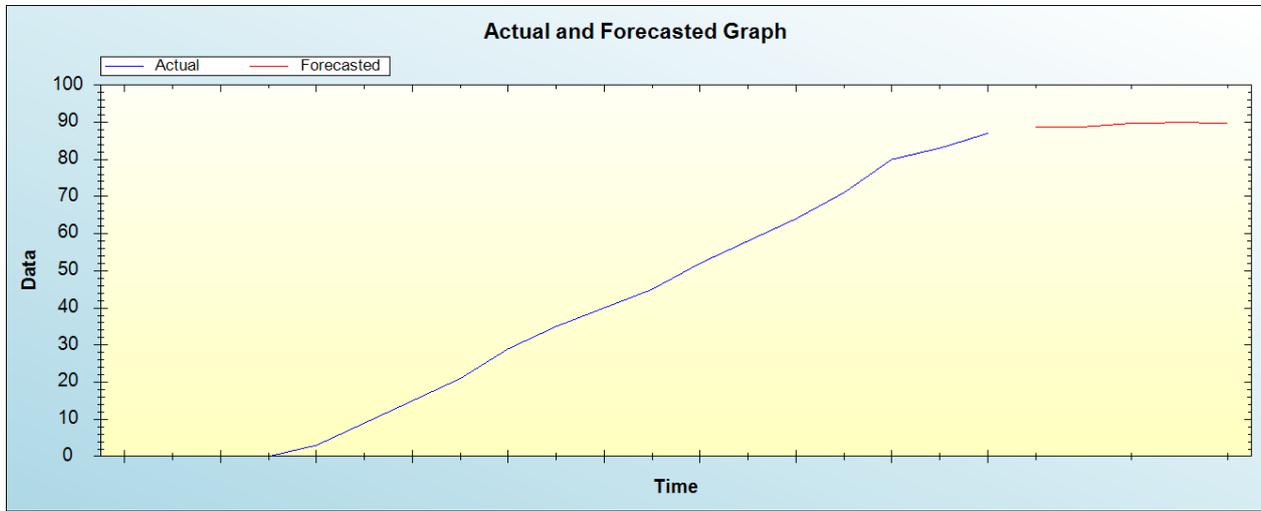


Figure 3: Out-of-sample forecast for R: actual and forecasted graph

Out-of-Sample Forecast for R: Forecasts only

Table 3: Tabulated out-of-sample forecasts

Year	Forecasted ART coverage
2019	88.6401
2020	88.7509
2021	89.7216
2022	89.9216
2023	89.7591

Over the study period the minimum and maximum ART coverage was 0 and 87 % respectively with an average of 36.421. The country commenced its National ART program in 2004 hence zero reporting of ART coverage was noted for the period 2000-2003. The data used in this study is positively skewed with an excess kurtosis of -1.3336 meaning that the data is not normally distributed. The residual graph and model evaluation statistics indicate that the applied ANN model is stable and suitable for forecasting ART coverage in Rwanda. The neural network model simulates the observed data very well as shown in figure 2. The model predicts that ART coverage in Rwanda will be high around 90% throughout the period 2019-2023. This means the country has a successful ART program.

V. CONCLUSION & RECOMMENDATIONS

Rwanda is one of the countries in Africa which has a successful ART program. Over the period 2000-2018 the country has witnessed an upward trend in ART coverage. The model projections indicate that the country is likely to achieve the global HIV goal of 90-90-90 target. The country is a good example of how a successful ART program should be implemented. The nation has done well in improving access to antiretroviral therapy to people living with HIV. We encourage the authorities in Rwanda to continue on this commendable path. The health authorities are encouraged to continue strengthening TB/HIV collaboration and strengthening the system of tracking loss to follow up ART clients to improve ART adherence and clinical outcomes.

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Citation of this Article:

Dr. Smartson. P. NYONI, Thabani NYONI, “Rwanda’s Art Program Success Story: Insights from the Artificial Neural Networks” Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 5, Issue 3, pp 217-221, March 2021. Article DOI <https://doi.org/10.47001/IRJIET/2021.503036>
