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PREDICTION OF HIV PREVALENCE AMONG INDIVIDUALS AGED 15-49 YEARS IN RWANDA USING HOLT'S LINEAR METHOD

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Abstract:
This study uses annual time series data of HIV prevalence among individuals aged 15-49 years for Rwanda from 1990 to 2020 to predict future trends of HIV prevalence over the period 2021 to 2030. The study utilizes Holt's linear exponential smoothing model. The optimal values of smoothing constants α and β are 0.9 and 0.1 respectively based on minimum MSE. The results of the study indicate that annual HIV prevalence among individuals aged 15-49 years will continue to decline over the out of sample period. Therefore, we encourage authorities to address main drivers of HIV transmission among this age group. There is need to improve HIV case detection and prevention among high risk groups

Keywords: *Exponential smoothing, Forecasting, HIV prevalence*

BACKGROUND

HIV remains a public health concern globally, causing negative health, social and economic consequences among all age groups in low-middle income countries (Kawuki *et al.* 2022; Negesse *et al.* 2021). According to UNAIDS data, around 38 million people were living with HIV (PLWH) worldwide in 2022. Africa reported the highest prevalence of HIV with an estimated average of 3.9% of its population living with HIV (Mbabazi *et al.* 2022; Operto, 2020). Young women and teenage girls account for 25% of new infections in Sub-Saharan Africa (SSA) (UNAIDS, 2020). Eastern and Southern African women face the highest burden of HIV contributing to three in five new infections, while young women aged 15 to 24 years are almost three times more likely than their male peers to acquire HIV infection (UNAIDS, 2020; Niragire *et al.* 2021). According to UNICEF, approximately more than 700 adolescents acquire HIV daily and over 360,000 are expected to die of HIV/AIDS related illnesses between 2018 and 2030. Adolescent HIV/AIDS-related mortality in Africa remains significant and AIDS is among the leading causes of death among African adolescents with SSA having the highest AIDS related mortality burden (Badru *et al.* 2017; UNICEF, 2015; WHO, 2014). Rwanda reported an HIV prevalence of 3.0% in 2019 among people aged 15–49 years and had a higher proportion of HIV in women (3.6%) than in men (2.2%) (Niragire *et al.* 2015). HIV prevalence in Rwanda is still low compared to other East African countries, however HIV risk factors continue to pose a huge threat to the upsurge of new HIV infections (Broderick *et al.* 2021; Niragire *et al.* 2021). Factors which predict HIV infection include sexual behaviors such as concurrent sexual partners, an earlier sex debut (< 19 years), and non-condom use. Furthermore, women with a history of sexually transmitted infections (STIs) living in woman headed households were more susceptible to HIV infection (Negesse *et al.* 2021). Limited comprehensive knowledge of HIV has been reported as one of the major factors associated with high prevalence of HIV among adolescents and young women (AGYW) (Frimpong *et al.* 2021; Siziya *et al.* 2008). Having adequate comprehensive HIV knowledge has been found to enhance adolescents' and young women's ability to negotiate for safer sex hence helping to reduce the risk of contracting HIV (Frimpong *et al.* 2021; De Coninck *et al.* 2014).

The objective of this paper is to model and forecast HIV prevalence among individuals aged 15-49 years for Rwanda using Holt's linear exponential smoothing technique. The findings of this research are anticipated to guide policy, planning and allocation of resources towards targeted HIV prevention, treatment and support programs in Rwanda with the aim of curbing new HIV infections and reducing HIV/AIDS related morbidity and mortality

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LITERATURE REVIEW

Author(s)	Objective (s)	Methodology	Key finding (s)
Niyompano et al. (2024)	To determine the prevalence of never being tested for HIV and its associated factors among sexually active individuals aged 15–56 who participated in the Rwanda AIDS Indicators and HIV Incidence Survey (RAIHIS).	-cross-sectional study -Applied Bivariate and multivariate logistic regression models	The prevalence of non-testing for HIV was 17.37%. Being aged 15–30 years (aOR 2.57, 95%CI 1.49–4.43, p < 0.001) and male (aOR 2.44, 95%CI 1.77–3.36, p < 0.001) was associated with an increase in the odds of never testing for HIV
Kawuki et al. (2023)	To determine the prevalence of the risk factors for the acquisition of HIV among sexually active women in Rwanda.	- Secondary data from the 2020 Rwanda Demographic Health Survey, comprising 10,684 sexually active women, was used -Multivariable logistic regression was conducted to determine the associated risk factors using the SPSS (version 25).	More than a quarter of sexually active women in Rwanda had exposure to at least one risk factor for HIV acquisition.
Kawuki et al. (2023)	To assess the prevalence of comprehensive knowledge about HIV/AIDS and associated factors among adolescent girls in Rwanda	-used secondary data from the Rwanda Demographic and Health Survey (RDHS) 2020 comprising 3258 adolescent girls (aged 15 to 19 years). -Conducted multivariable logistic regression to explore the associated factors, using SPSS (version 25).	Adolescent girls with secondary education (AOR = 1.40, 95% CI: 1.13–3.20), health insurance (AOR = 1.39, 95% CI: 1.12–1.73), a mobile phone (AOR = 1.26, 95% CI: 1.04–1.52), exposure to television (AOR = 1.23, 95% CI: 1.05–1.44), and a history of an HIV test (AOR = 1.26, 95% CI: 1.07–1.49) had higher odds of comprehensive HIV knowledge, compared to their respective counterparts
Nsanzimana et al. (2022)	To measure national HIV Incidence and prevalence. District-level Estimates were modeled to inform resources allocation	The 2018–2019 Rwanda Population–based HIV Impact Assessment (RPHIA) was conducted	HIV Prevalence among adults in Rwanda Is 3.0%; HIV Incidence is low at 0.08%. District-level Modeling has identified disproportionately affected urban

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			hotspots: areas to focus resources.
Biraguma et al. (2018)	To determine the association between physical and mental health-related dimensions of quality of life (QOL) with behavioral and biological risk factors, after controlling socio-demographic and HIV-related factors in adults living with HIV in Rwanda.	-Cross-sectional study -using the WHO STEPwise approach and Kinyarwanda version of the MOS-HIV Health Survey, risk factors for NCDs and HRQOL were analyzed for 794 PLWH, both HIV+ on ART and ART-naïve. Multiple regression analysis was used to examine the relationship between CMD risk factors and physical health and mental health summary scores.	Behavioral and biological risk factors for NCDs were significantly associated with a lower HRQOL.
Nsanzimana et al. (2017)	to characterize HIV incidence across Rwanda	prospective HIV incidence survey for the period of 2013−14	The incidence of HIV in Rwanda was higher than that previously estimated from models, with outbreaks seeming to contribute to the ongoing epidemic
Nsanzimana et al. (2015)	to assess the effect of increased access to antiretroviral therapy on life expectancy among HIV-positive patients in two distinct periods of lower and higher antiretroviral therapy coverage (1997–2007 and 2008–11).	retrospective observational cohort study	Life expectancy at 20 years of age in the period of 1997–2007 was 20·4 additional years (95% CI 19·5–21·3); for the period of 2008–11, life expectancy had increased to 25·6 additional years (95% CI 24·8–26·4).

METHODOLOGY

This study utilizes an exponential smoothing technique to model and forecast future trends of HIV prevalence among individuals aged 15-49 years in Rwanda. In exponential smoothing forecasts are generated from the smoothed original series with the most recent historical values having more influence than those in the more distant past as more recent values are allocated more weights than those in the distant past. This study uses the Holt's linear method (Double exponential smoothing) because it is an appropriate technique for modeling linear data.

Holt's linear method is specified as follows:

Model equation

$A_t = \mu_t + \rho_t \mathbf{t} + \varepsilon_t$

Smoothing equation

$S_t = \alpha A_t + (1-\alpha)(S_{t-1} + b_{t-1})$

$0 < \alpha < 1$

Trend estimation equation

$b_t = \beta (S_t - S_{t-1}) + (1-\beta) b_{t-1}$

$0 < \beta < 1$

Forecasting equation

$f_{t+h} = S_t + h b_t$

A_t is the actual value of HIV prevalence at time t

ε_t is the time varying **error term**

μ_t is the time varying mean (**level**) term

ρ_t is the time varying **slope term**

t is the trend component of the time series

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S_t is the exponentially smoothed value of HIV prevalence at time t
α is the exponential smoothing constant for the data
β is the smoothing constant for trend
f_{t+h} is the h step ahead forecast
b_t is the trend estimate (slope of the trend) at time t
b_{t-1} is the trend estimate at time t-1

Data Issues

This study is based on annual HIV prevalence among individuals aged 15-49 years in Rwanda for the period 1990 – 2020. The out-of-sample forecast covers the period 2021 – 2030. All the data employed in this research paper was gathered from the World Bank online database.

Findings of the study

Exponential smoothing Model Summary

Table 1: ES model summary

Variable	A
Included Observations	31
Smoothing constants	
Alpha (α) for data	0.900
Beta (β) for trend	0.100
Forecast performance measures	
Mean Absolute Error (MAE)	0.207329
Sum Square Error (SSE)	4.485410
Mean Square Error (MSE)	0.144691
Mean Percentage Error (MPE)	-1.119141
Mean Absolute Percentage Error (MAPE)	6.930046

Residual Analysis for the Applied Model

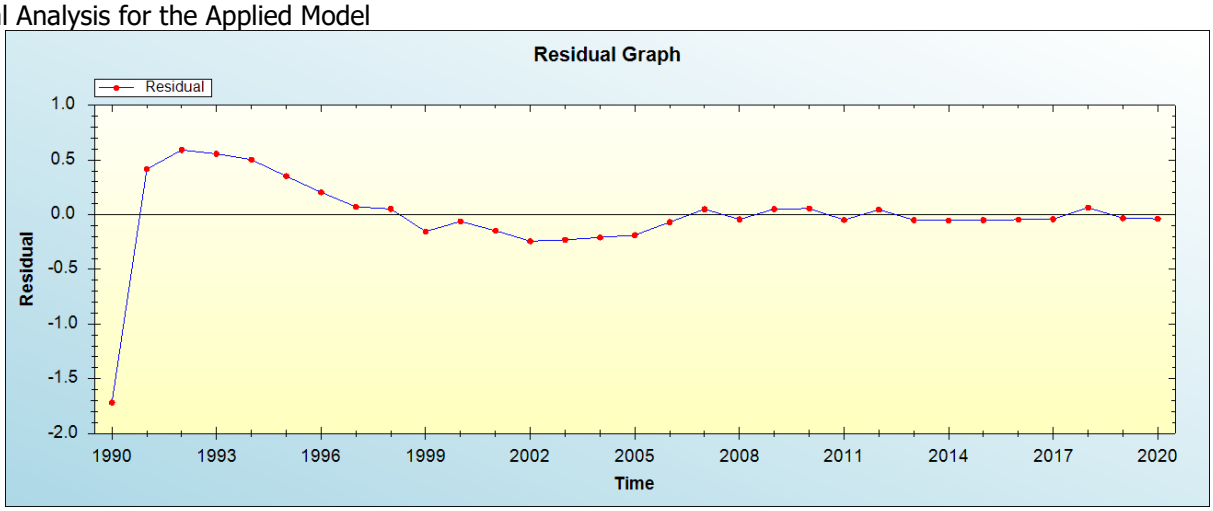

Figure 1: Residual analysis

In-sample Forecast for A

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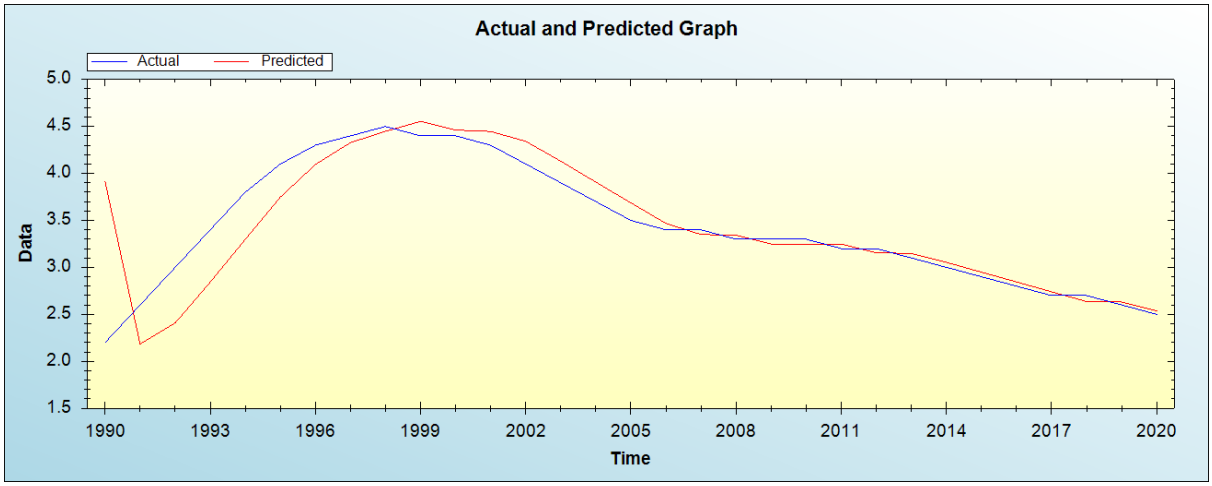
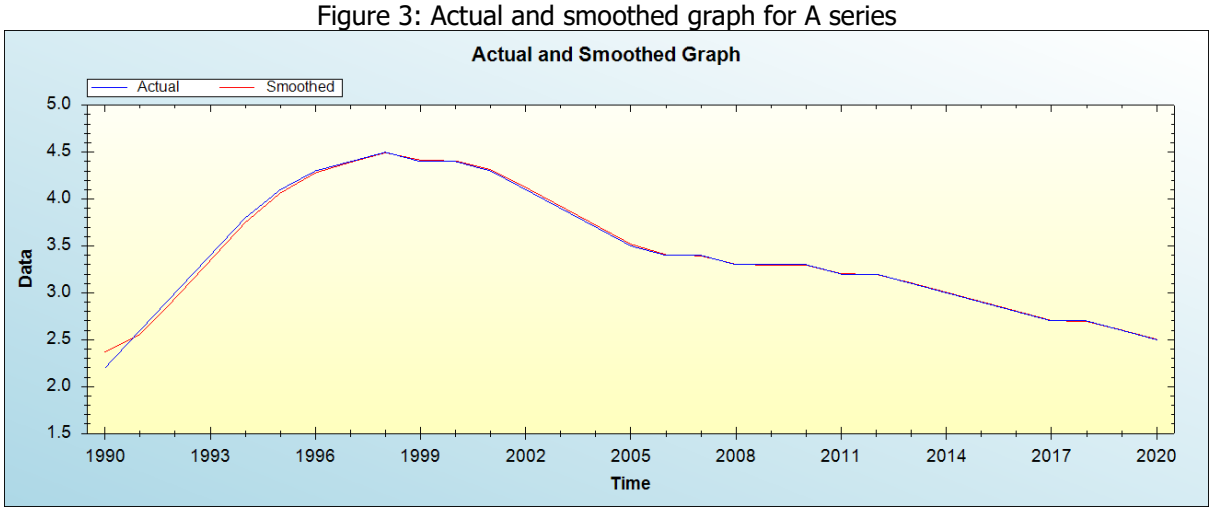


Figure 2: In-sample forecast for the A series

Actual and Smoothed graph for A series

Figure 3: Actual and smoothed graph for A series



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

Figure 4: Out-of-sample forecast for A: actual and forecasted graph

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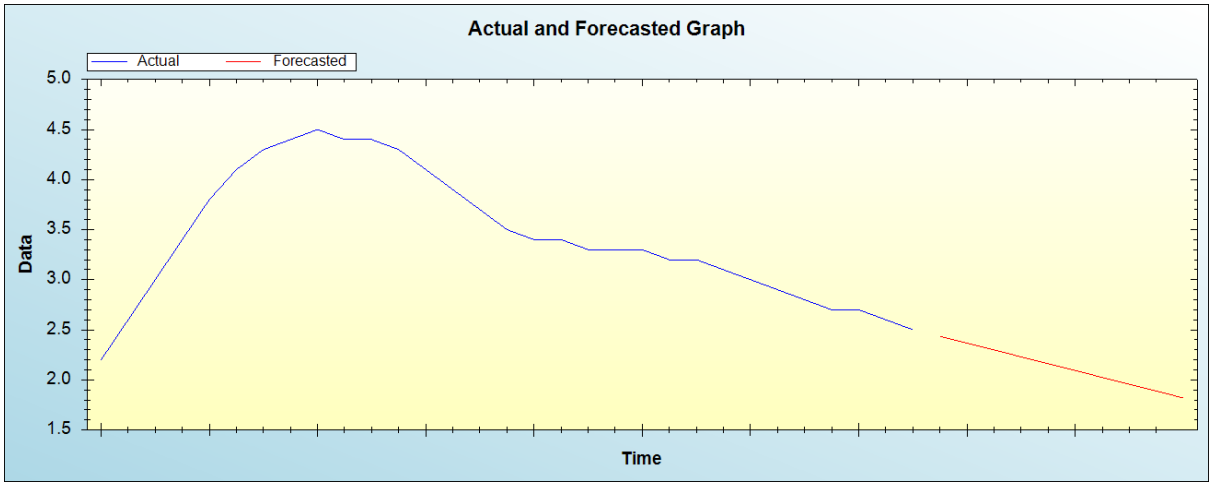

Out-of-Sample Forecast for A: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted HIV prevalence
2021	2.4353
2022	2.3669
2023	2.2984
2024	2.2300
2025	2.1615
2026	2.0930
2027	2.0246
2028	1.9561
2029	1.8877
2030	1.8192

The main results of the study are shown in table 1. It is clear that the model is stable as confirmed by evaluation criterion as well as the residual plot of the model shown in figure 1. It is projected that annual HIV prevalence among individuals aged 15-49 years will continue to decline over the out of sample period.

Policy implication and conclusion

Our model projections indicate that annual HIV prevalence among individuals aged 15-49 years will continue to decline over the out of sample period. Therefore, this research calls for the authorities to address main drivers of HIV transmission among this age group. There is need to improve HIV case detection and prevention among high risk groups.

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