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Utilizing Holt's double exponential smoothing model to explain the epidemiology of HIV in Botswana

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Abstract
This study uses annual time series data of HIV prevalence among individuals aged 15-49 years for Botswana from 1990 to 2020 to predict future trends of HIV prevalence over the period 2021 to 2030. The study utilizes Holt's linear method (HLM). 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 but still remain high. Therefore, policymakers must scale up HIV case detection, increase ART coverage among people living with HIV and improve coverage of HIV prevention interventions particularly among key populations.

Keyword (s): - *Exponential smoothing, Forecasting, HIV prevalence*

Background

According to the country progress report 2020, Botswana reported an HIV seroprevalence of 20.68% and is often among the highest in the Eastern and southern African region. The number of new HIV infections gradually declined since 2010 from 14000 to 9500. Approximately 33% of new HIV infections were reported among young people 15-24 years, with 70% of the infections among young people being among young girls. In 2019 more than 95% of people living with HIV knew their status. Knowledge of HIV status was revealed to be 88% among men, 70% young people 15 - 24 years with young men at 54% and young women at 78%. Adult ART Coverage stood at 84%, males at 70% and females at 93%. Viral load suppression among people living with HIV stood at 79% and 96% among those on ART. The Fifth Botswana AIDS Impact Survey (BAIS V) was used to measure national progress toward UNAIDS 95-95-95 targets (percent of persons living with HIV (PLHIV) aware of their status, on treatment, and virally suppressed. The survey indicated that National HIV prevalence among adults 15–64 years was 20.8%. The survey also confirmed achievement of UNAIDS 95-95-95 goals, both overall and among women Men had achieved the second and third 95 targets and surpassed 90% for the first 95 target (Mine *et al.* 2022). The purpose of this paper is to mode and forecast HIV prevalence among individuals aged 15-49 years for Botswana using Holt's double exponential smoothing technique. The study findings are envisaged to detect likely future changes in HIV prevalence among the 15-49 year age group. This will guide policy, planning and allocation of resources towards targeted HIV prevention and treatment programs particularly key populations.

Literature Review

Author(s)	Objective (s)	Methodology	Key Finding(s)
Karugaba et al.(2023)	-To explore the challenges and coping strategies of YALPH in order to inform health policies and programming in Botswana	-In-depth interviews were conducted with 45 YALPH (ages 18–27 years) who were enrolled on antiretroviral therapy at the Botswana-Baylor Children's Clinical Centre of	-the majority of YALPH had suppressed HIV viral load and perceived themselves to be in good physical health and functioning -challenges faced included occasional

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		Excellence (Botswana-Baylor Clinic -The data was analyzed using content analysis.	or longstanding poor antiretroviral therapy adherence, disabilities and impairments, poor school performance and attainment, unemployment, financial stressors, fear of stigma, disclosure worries and concerns, and limited social support.
Mine et al. (2022)	To measure national progress toward UNAIDS 95-95-95 targets (percent of persons living with HIV (PLHIV) aware of their status, on treatment, and virally suppressed). Botswana	- BAIS V used a two-stage cluster design to obtain a nationally representative sample of adults 15–64 years. - During March–August 2021, survey teams consented 14,763 participants in their households, administered questionnaires, and tested blood specimens for HIV Viral load and presence of antiretrovirals (ARVs) in the blood were measured. Viral load suppression (VLS) was defined as HIV RNA <1,000 copies per milliliter	-National HIV prevalence among adults 15–64 years was 20.8% (men: 15.2%; women: 26.2%), and 0.8% among children 0–14 years - National annual incidence of HIV was estimated to be 0.2% - VLS among all PLHIV was 91.8% (men: 88.1%; women: 94.0%) - Among adults 15–64 years living with HIV, prevalence of VLS ranged from 85.3% in Gaborone to 100.0% in Selibe Phikwe -Among PLHIV, 95.1% (men: 93.0%; women: 96.4%) were aware of their status, 98.0% (men: 97.2%; women: 98.4%) of those aware were on ART, and 97.9% (men: 96.6%; women: 98.6%) of those on ART achieved VLS
Olashore et al.(2023)	To determine the pattern of PDs in ALWHIV in	A cross-sectional survey of 622 ALWHIV (399 CIA	Depression and anxiety disorders were the most

	Botswana; to compare and explore the differences in the pattern and their associated factors between congenitally infected adolescents (CIAs) and behaviorally infected adolescents (BIAs).	and 223 BIA) with the Mini International Neuropsychiatric Interview-Kid Screen.	prevalent PDs in ALWHIV, who differed in psychiatric presentations, the BIAs being more likely to present with internalizing disorders, while the CIAs had more externalizing disorders
Bhebhe et al. (2022)	To evaluate factors associated with undiagnosed HIV infection using HIV-1 phylo-genetic, behavioural, and demographic data.	Applied logistic regression	Those with undiagnosed infections are likely to be young men and women who do not use condoms consistently. Among women, several factors were predictive: being married, educated, and testing frequently increased risk. Men at risk were more difficult to delineate. A sizeable proportion of undiagnosed infections were recent based on a genetic diversity-based classifier
Ussery et al. (2022)	To report rates and characteristics of incident HIV infections.	Applied Cox proportional hazards regression model	Despite an overall reduction in HIV incidence and approaching the UNAIDS 95-95-95 targets, high HIV incidence was observed in adolescent girls and young women
Ramogola-Masire et al. (2019)	To describe key periods in the history of the national public health response to the human immunodeficiency virus (HIV) epidemic	Descriptive study	-There are high rates of HIV in Botswana

in Botswana		

Methodology

This study utilizes Holt's double exponential smoothing technique to model and forecast future trends of HIV prevalence among individuals aged 15-49 years in Botswana. 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

$$A_t = \mu_t + \rho_t \mathbf{t} + \varepsilon_t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots[1]$$

Smoothing equation

$$S_t = \alpha A_t + (1\text{-}\alpha)(S_{t-1} + b_{t-1})\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots[2]$$

$0 < \alpha < 1$

Trend estimation equation

$$b_t = \beta(S_t - S_{t-1}) + (1\text{-}\beta)b_{t-1}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots[3]$$

$0 < \beta < 1$

Forecasting equation

$$f_{t+h} = S_t + hb_t\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..[4]$$

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**

$\mathbf{t}$ is the trend component of the time series

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

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Data Issues

This study is based on annual HIV prevalence among individuals aged 15-49 years in Botswana 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)	1.427104
Sum Square Error (SSE)	222.671782
Mean Square Error (MSE)	7.182961
Mean Percentage Error (MPE)	-4.242699
Mean Absolute Percentage Error (MAPE)	13.031066

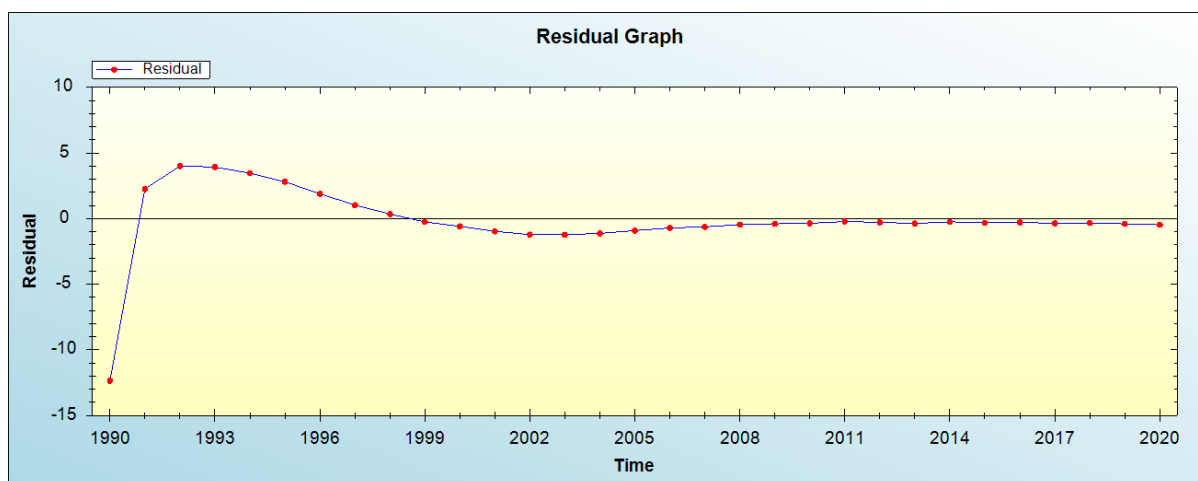Residual Analysis for the Applied Model

Figure 1: Residual analysis

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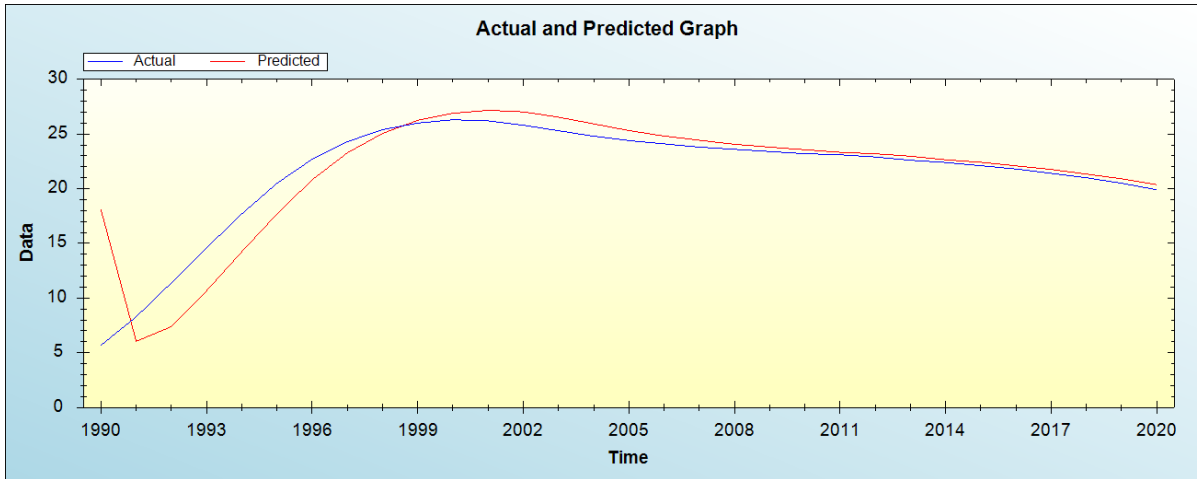
In-sample Forecast for A

Figure 2: In-sample forecast for the A series

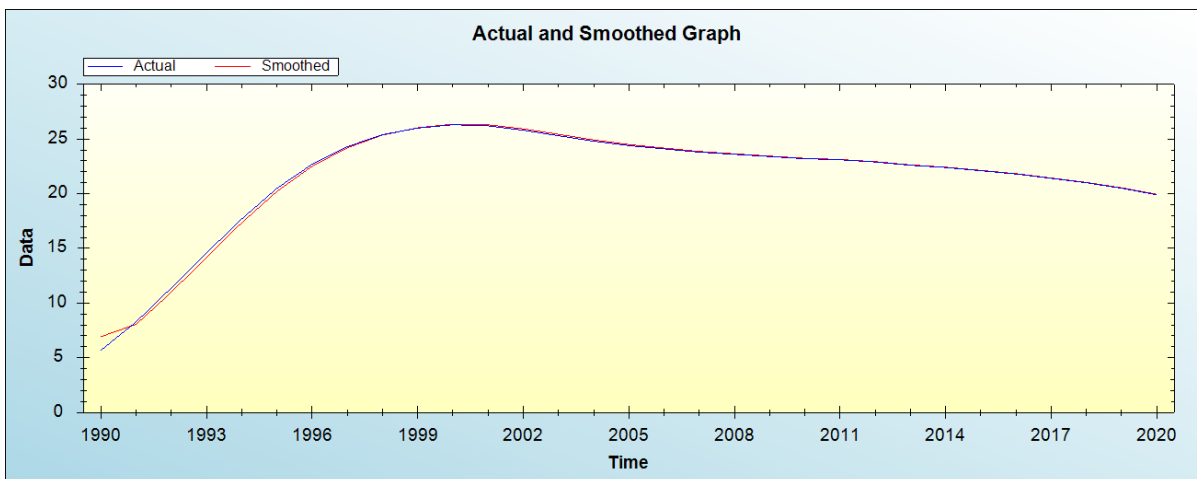Actual and Smoothed graph for A series

Figure 3: Actual and smoothed graph for A series

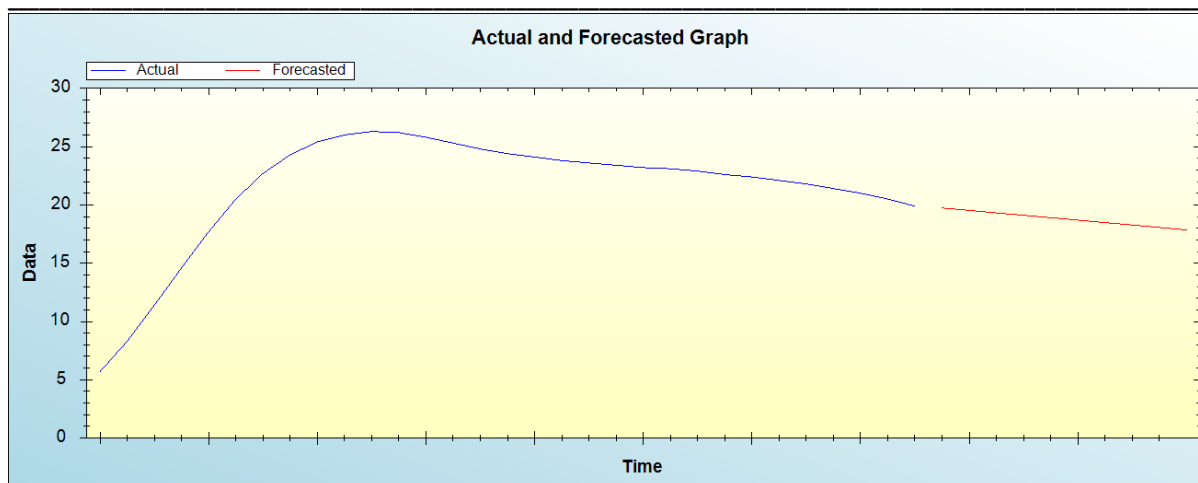Out-of-Sample Forecast for A: Actual and Forecasted Graph

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

Out-of-Sample Forecast for A: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted HIV prevalence
2021	19.7383
2022	19.5291
2023	19.3200
2024	19.1109
2025	18.9018
2026	18.6926
2027	18.4835
2028	18.2744
2029	18.0653
2030	17.8562

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 suggest that HIV prevalence among individuals 15-49 years will remain high in Botswana. Hence, policymakers must scale up HIV case detection, increase ART coverage among people living with HIV and improve coverage of HIV prevention interventions particularly among key populations.

References

[1] Global AIDS Monitoring 2020, Country progress report - Botswana pp.4
[2] Mine et al (2022). Botswana achieved the Joint United Nations Programme on HIV/AIDS (UNAIDS) 95-95-95 targets: Results from the Fifth Botswana AIDS Impact Survey (BAIS V), 2021

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