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FORECASTING HIV PREVALENCE AMONG INDIVIDUALS AGED 15-49 YEARS IN SOUTH AFRICA 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 South Africa 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 0.6 respectively based on minimum MSE. The results of the study indicate that annual HIV prevalence among individuals aged 15-49 years will slightly decline over the out of sample period but still remain high. Therefore, we encourage authorities to scale up HIV testing, increase ART coverage and strengthen HIV prevention among this age group.

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

Background

The government of South Africa continues to battle the dual epidemic of HIV and TB among other public health challenges. According to UNAIDS, approximately there are more than 7.5 million PLHIV and has one of the largest HIV epidemics in the world. Robust surveillance mechanisms are being used to monitor the HIV epidemic in the country (Simbayi *et al.* 2019; Shisana *et al.* 2014; Shisana *et al.* 2009; Shisana *et al.* 2005; Shisana *et al.* 2002). Every 3–5 years surveys are conducted to track the HIV epidemic, its impact, and its dynamics in the country (Zuma *et al.* 2016; Rehle *et al.* 2015). The fourth survey in 2012 reported an increase in HIV prevalence from 10.6% to 12.2% over the period 2008-2012 (Zuma *et al.* 2016). In order to address this undesirable trend, the government rapidly scaled up ART coverage, which has led to improvements in HIV outcomes (Kim *et al.* 2021; Johnson *et al.* 2017). UNAIDS reported that in 2018, the annual number of new HIV infections declined to 240 000 people, which represented 0.49% of the uninfected population, compared with 0.64% in 2015. South Africa has achieved a 90% of PLHIV diagnosed, 68% of those diagnosed on ART and 88% of those on ART virally suppressed in 2018 (UNAIDS, 2019; CESAR, 2018). Despite remarkable progress, HIV prevalence in the country remains persistently high with 18.9% of adults aged 15 and older infected with the virus, and more than 200 000 new infections occurring every year (Cuadros *et al.* 2018; Palk & Blower, 2018).The majority of HIV spread in the Republic of South Africa is through heterosexual transmission (SANAC, 2017). The HIV epidemic is concentrated among key populations such as commercial sex workers and their clients and men who have sex with other men (UNAIDS, 2017). Predictors of HIV transmission include include having multiple sexual partners, inconsistent condom use, socio-economic power imbalances,

harmful gender norms, sexual violence, alcohol and substance use (Conroy *et al.* 2017; Madiba *et al.* 2017; Zungu *et al.* 2016). Sexual relationships between young women and older men have been driving the high prevalence of HIV in the country, particularly amongst those aged 15–24 years (De Oliveira *et al.* 2017; Evans *et al.* 2017). The government implemented interventions to address drivers of HIV transmission and to reduce morbidity and mortality amongst people living with HIV. These interventions included behavioral change strategies such as consistent and correct use of condom use, being faithful to one faithful sexual partner and promoting HIV testing among communities. Furthermore, the government adopted voluntary male circumcision as an HIV prevention strategy which has been to reduce the risk of female-to-male HIV acquisition by 60% (Bailey *et al.* 2007; Gray *et al.* 2007; Auvert *et al.* 2005). In addition, as part of the combined HIV prevention strategy, the Republic of South Africa is also implementing Pre-exposure prophylaxis for individuals who are at high risk of acquiring HIV and post exposure prophylaxis for healthcare workers who become exposed to the HIV virus via needle stick injures or after contact with infectious body fluids.

The objective of this paper is to model and forecast HIV prevalence among the 15-49 year age group using Holt's linear Method. The results of this study are expected to guide planning and allocation of resources towards HIV programs for young adults in the country.

Literature Review

Author (s)	Objective (s)	Methodology	Main finding (s)
Johnson et al. (2022)	To quantify the extent to which incidence declines are attributable to different HIV programs	Calibrated a mathematical model of the South African HIV epidemic to age- and sex-specific data from antenatal surveys, household surveys, and death registration, using a Bayesian approach.	HIV incidence in South Africa has declined substantially since 2000, with ART and condom promotion contributing most significantly to this decline.
Zuma et al. (2022)	To present key findings from the fifth HIV prevalence, incidence, and behavior survey conducted in 2017 following policy, programme, and epidemic change since the prior survey was conducted in 2012.	A cross-sectional population based household survey collected behavioral and biomedical data on all members of the eligible households.	Although condom use at last sex act remains unchanged, there continue to be some challenges with the lack of significant behavior change as people, especially youth, continue to engage in risky behavior and delay treatment initiation
Local Burden of Disease HIV Collaborators (2021)	To assess HIV incidence and HIV mortality for all second-level administrative units across sub-Saharan Africa.	-used a model-based geostatistical framework to estimate HIV prevalence at the second administrative level in 44 countries in sub-Saharan Africa for 2000–18 and sought data on the number of individuals on antiretroviral therapy (ART) by second-level administrative unit	estimates suggested that most second-level administrative units in sub-Saharan Africa are falling short of the targeted 75% reduction in new cases and deaths by 2020

Kim et al. (2021)	To generate high-resolution HIV prevalence maps and identified people living with HIV (PLHIV) in underserved areas to provide essential information for the optimal allocation of HIV- related	The data come from the South Africa Demographic and Health Survey conducted in 2016 and spatial variables from other published literature	The study showed extensive spatial variation of HIV prevalence and significant numbers of PLHIV in underserved areas in South Africa
Orel et al. (2020)	To predict the HIV status of individuals based on socio-behavioral characteristics	Trained four machine-learning algorithms and selected the best based on the f1 score.	XGBoost performed best in predicting HIV with a mean f1 of 76·8% [95% confidence interval 76·0%-77·6%] for males and 78·8% [78·2%-79·4%] for females. - the researchers were able to identify PLHIV and those at high risk of infection who may be offered pre-exposure prophylaxis and/or voluntary medical male circumcision

Methodology

This study utilizes an exponential smoothing technique to model and forecast future trends of HIV prevalence among individuals aged 15-49 years in South Africa. 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

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

$0<\propto<1$

Trend estimation equation

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

$0<\beta<1$

Forecasting equation

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

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

S_t is the exponentially smoothed value of HIV prevalence at time t

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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 South Africa 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	0.600
Forecast performance measures	
Mean Absolute Error (MAE)	0.330793
Sum Square Error (SSE)	12.122054
Mean Square Error (MSE)	0.391034
Mean Percentage Error (MPE)	-8.902040
Mean Absolute Percentage Error (MAPE)	22.729091

Residual Analysis for the Applied Model

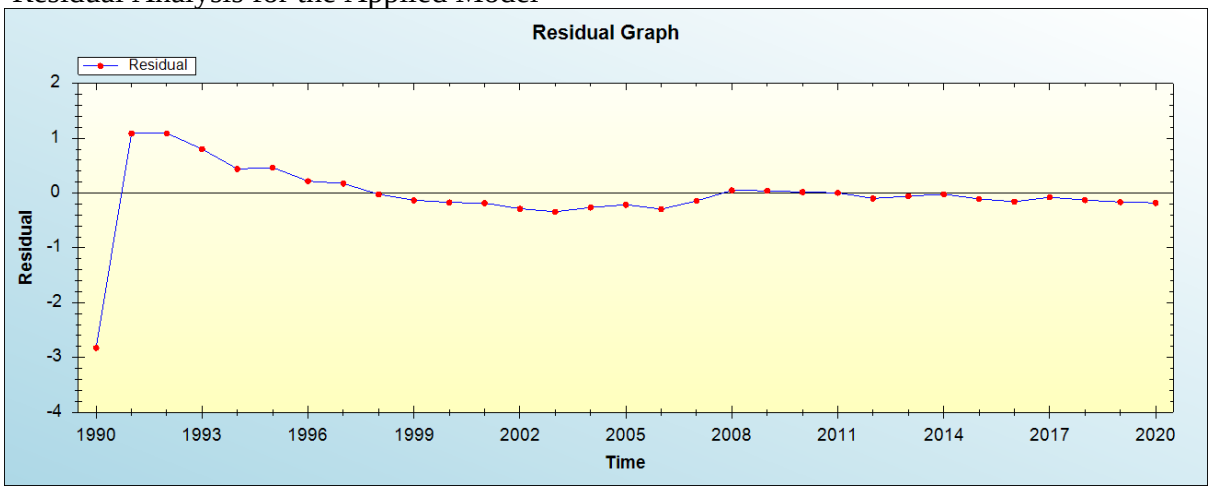

Figure 1: Residual analysis

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In-sample Forecast for A

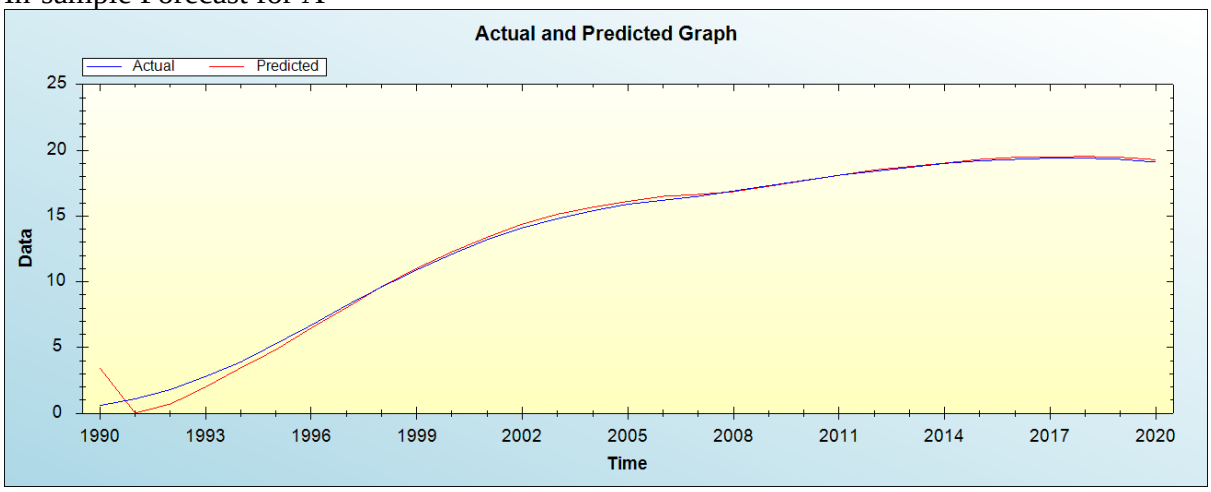

Figure 2: In-sample forecast for the A series

Actual and Smoothed graph for A series

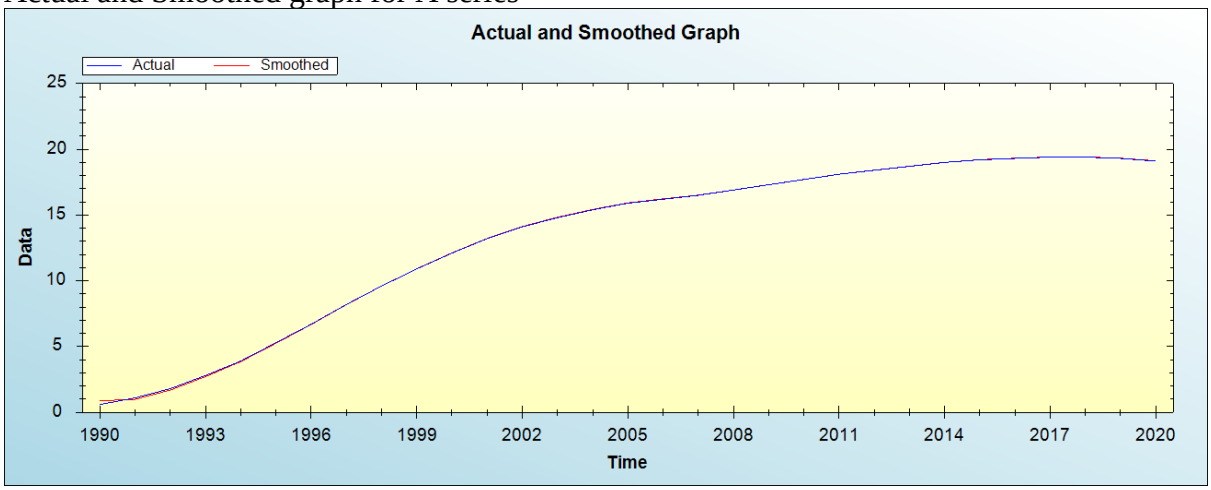

Figure 3: Actual and smoothed graph for A series

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

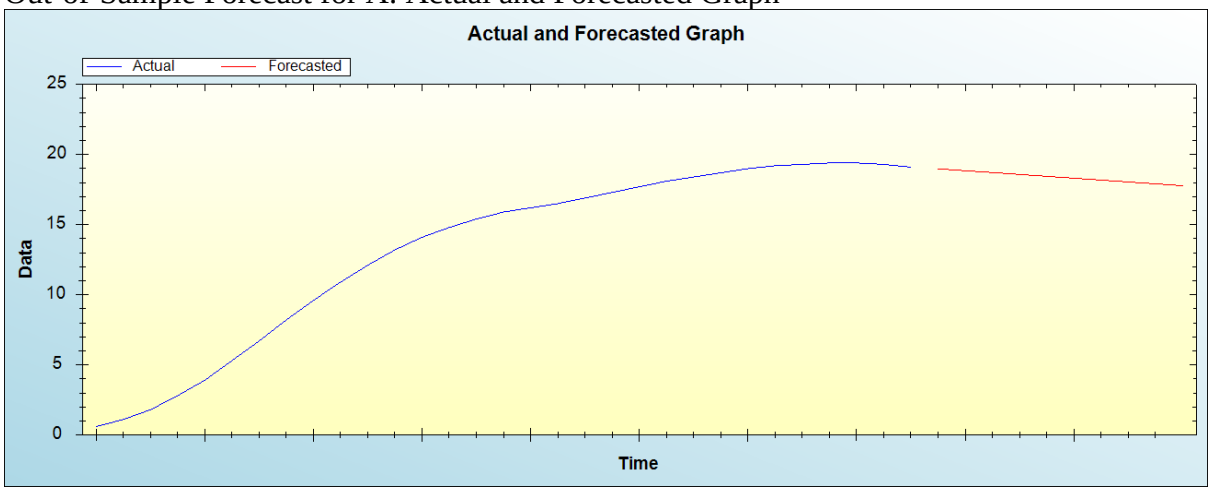

Figure 4: Out-of-sample forecast for A: actual and forecasted graph

Out-of-Sample Forecast for A: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted HIV prevalence
2021	18.9838
2022	18.8498
2023	18.7157
2024	18.5816
2025	18.4476
2026	18.3135
2027	18.1794
2028	18.0454
2029	17.9113
2030	17.7772

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 slightly decline over the out of sample period but still remain high.

Policy implication and conclusion

Our research paper established that annual HIV prevalence among individuals aged 15-49 years will slightly decline over the out of sample period but still remain high. Therefore, this paper highlights the importance of scaling up HIV testing, increasing ART coverage and strengthening HIV prevention among this age group. There is need to pay particular attention to high risk groups in order to effectively control HIV spread in the community.

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