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Relying on Holt's linear exponential smoothing model forecasts to inform the national HIV policy in Eswatini

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Abstract
This study uses annual time series data of HIV prevalence among individuals aged 15-49 years for Eswatini 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 0.4 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 major drivers of HIV transmission among young adults with more focus being given to HIV prevention interventions.

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

Background

HIV remains a public health issue of concern especially in low-middle income countries. As revealed by UNAIDS, 38 million people were living with HIV (PLHIV) in 2019, and 1.7 million became newly infected. However substantial progress has been made in the reduction of new HIV infections. The global uptake of highly effective antiretroviral drugs (ART) more than tripled from 7.7 million in 2010 to 25.4 million in 2019, with a coinciding 39% reduction in HIV-related deaths. The global HIV response strategy consists of HIV testing services, highly effective antiretroviral medications, combined HIV prevention services and demand generation of ART services to increase uptake. This global HIV response has brought excellent results such that many countries are hoping to eliminate new HIV infections soon (UNAIDS, 2014; Cohen *et al.* 2011; Bailey *et al.* 2007; Gray et al. 2007; Auvert *et al.* 2005). The Kingdom of Eswatini has an estimated population of close to 1.1 million inhabitants. The country reported the highest national HIV seroprevalence in the region (UNAIDS, 2021, CSO, 2017). According to the Swaziland and HIV Estimates and Projections Report 2015, Eswatini reported 13, 910 new HIV infections, 263,040 people living with HIV (PLHIV), and 5890 HIV/AIDS related mortality. The main drivers of HIV transmission include low prevalence of male circumcision; multiple, long-term concurrent sexual relationships, early sexual debut and intergenerational sex, low condom use, especially in long-term sexual partnerships, lack of family and community support, and multiple structural factors (Jameson *et al.* 2015; UNICEF, 2011). The three main structural factors that influence HIV incidence include income inequality, gender inequality, transactional sex and education (Fielding-Miller *et al.* 2016; Jameson *et al.* 2015; CSO, 2011; PRSA, 2007). Income inequality has been shown to be significant contributor to sexual risk in women in Eswatini (Hajizadeh *et al.* 2014). The poor economic prospects for young women contribute to the increasing prevalence of intergenerational and transactional sex, particularly as young women develop desires and needs consistent with modern expectations of lifestyle (Gorgens *et al.* 2020). In 2011, the Swaziland HIV Incidence Measurement Survey (SHIMS) reported
seroincidence stood at 2.38% among adult ages 18 to 49 years (Justman *et al.* 2017; Bicego *et al.* 2013). The objective of this paper is to model and forecast HIV seroprevalence among the 15-49 year age group using Holt's linear exponential smoothing model. The study findings are expected to guide policy formulation, planning and allocation of resources towards HIV prevention, treatment and care programs among young adults.

Literature review

Author(s)	Objective (s)	Methodology	Main finding(s)
Jung et al. (2022)	To identify the prevalence of HIV	Data were obtained from Swaziland HIV	A low rate of HIV testing was identified

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	testing and associated factors among young adolescents aged 10 to 14 years in Eswatini, a country with the highest HIV prevalence in the world.	Incidence Measurement Survey between 2016 and 2017 (SHIMS 2), an internationally supported national survey aimed at combating HIV/AIDS	among young adolescents in Eswatini compared to the intended global goal of HIV testing coverage
Chipanta et al. (2021)	To measure social protection (SP) coverage among the general population and women and men living with HIV (WLHIV, MLHV), female and male sex workers (FSW, MSW), men who have sex with men (MSM), adolescent girls young women (AGYW), and orphans vulnerable children (OVC).	Utilized Population-Based HIV Impact Assessments data from Eswatini, Malawi, Tanzania and Zambia and then generated survey-weighted proportions for each population group receiving any SP benefits, along with 95% confidence intervals (CI) using jackknife variance estimation.	The proportion reported receiving SP benefits among the general population ranged from 7.7% (95% CI: 6.7%–8.8%) in Zambia to 39.6% (95% CI: 36.8%– 42.5%) in Eswatini. SP benefits by WLHIV, MLHIV, AGYW, OVC, SW and MSM – were lower than the 2017-19 global average of 45%.
Mutai et al. (2021)	To identify HIV predictors as well as predicting persons at high risk of the infection.	Applied machine learning approaches for building models using population-based HIV Impact Assessment (PHIA) data for 41,939 male and 45,105 female respondents with 30 and 40 variables respectively from four countries in sub-Saharan countries.	Application of XGBoost algorithm appeared to significantly improve identification of HIV positivity over the other five algorithms by f1 scoring mean of 90% and 92% for males and females respectively.
Dlamini et al. (2021)	To establish the association between hypertension and other possible confounding factors on viral load and CD4-cell counts in hypertensive and non-hypertensive HIV/AIDS patients receiving antiretroviral therapy (ART) at a large	Retrospective longitudinal review of the medical records of 560 ART patients divided into non-hypertension and hypertension groups (n = 325 and n = 235) from July 27 to September 8, 2018.	Results show a significant association between hypertension and CD4 cell counts but not viral load. In ART patients with and without hypertension, the factors associated with prognostic markers were different.

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	hospital in Eswatini over a 4-year period		
Nkambule et al. (2021)	To measure HIV prevalence, incidence (recent infection based on limiting antigen 1.5 optical density units and HIV RNA 1000 copies/mL), viral load suppression (HIV RNA<1000 copies/mL among all seropositive adults) and unsuppressed viremia (HIV RNA 1000 copies/ mL among all, regardless of HIV status) and assessed for temporal changes	trend analysis of the log ratio of proportions, using a Z statistic distribution	National HIV incidence in Eswatini decreased by nearly half and viral load suppression doubled over a five-year period. Unsuppressed viremia in the total population decreased 58%.
Gorgens et al. (2020)	To report on both key elements of study design/ protocol and baseline results from an impact evaluation of an intervention incentivizing (i) initiation, enrolment, attendance or completion of some form of education, and (ii) lower risk sexual behavior	Two factorial design in which participants are enrolled in either the incentive for education arm (‘education treatment arm’ providing a conditional cash incentive) or the control arm (‘education control arm’). In each of these arms, 50% of participants were randomized to also be eligible for selection – three times a year – to participate in a conditional raffle conditional on testing negative for curable STIs (syphilis and Trichomonas vaginalis).	An educational cash incentive and raffle incentive impact evaluation that addresses adolescent girls and young women who are in-education and out-of-education has the potential to reduce HIV risk in adolescent girls and young women in Eswatini.
Kitchen et al. (2020)	To elicit the facilitators and inhibitors to HIV testing uptake in Eswatini.	Conducted 26 in-depth interviews with stakeholders from policy, implementation, donor, local advocacy	Essential facilitators included good governance via institutional and national budgetary commitments, which

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		and academic sectors to elicit the facilitators and inhibitors to HIV testing uptake in Eswatini.	often led to swift adoption of globally recommended programs and standards. The integration of HIV testing into all points of care fostered a sense that testing was part of routine care, which reduced stigma. Challenges, however, centred on social norms that disadvantage certain groups with high ongoing HIV risk (such as key populations, adolescent girls and young women), a heavy reliance on external donor funding, and stigma that had subsided but nevertheless persisted
Belle & Gamedze (2019)	To investigate the behavioral factors that contributed to the transmission of HIV and AIDS among female youth of Mbabane in Swaziland and to suggest measures that could encourage positive female youth behavior change in order to mitigate the spread and impacts of the pandemic. T	qualitative research approach	The findings indicated that though the majority of the respondents had knowledge of HIV and AIDS, positive behavior change remained a challenge. Most respondents (88%) had one sexual partner with 38% reporting condom use during their last sexual encounter. HIV/AIDS awareness was widespread. However, there were still characteristics of resistance to behavior change, because there was evidence of underestimation of HIV risk through engagement in behavior, which

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			contributed to HIV infection and spread.

Methodology

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

$E_t=\mu_t + \rho_t \mathbf{t} + \varepsilon_t$……...……[1]

Smoothing equation

$S_t= \alpha E_t$ + (1-α) $(S_{t-1} + b_{t-1})$……..…[2]

$0<\alpha<1$

Trend estimation equation

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

$0<\beta<1$

Forecasting equation

$f_{t+h}= S_t$ + hb_t……..……[4]

E_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
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 Eswatini 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	E
Included Observations	31
Smoothing constants	
Alpha (α) for data	0.900
Beta (β) for trend	0.400
Forecast performance measures	
Mean Absolute Error (MAE)	0.931365

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Sum Square Error (SSE)	95.923324
Mean Square Error (MSE)	3.094301
Mean Percentage Error (MPE)	-15.215741
Mean Absolute Percentage Error (MAPE)	32.798473

Residual Analysis for the Applied Model

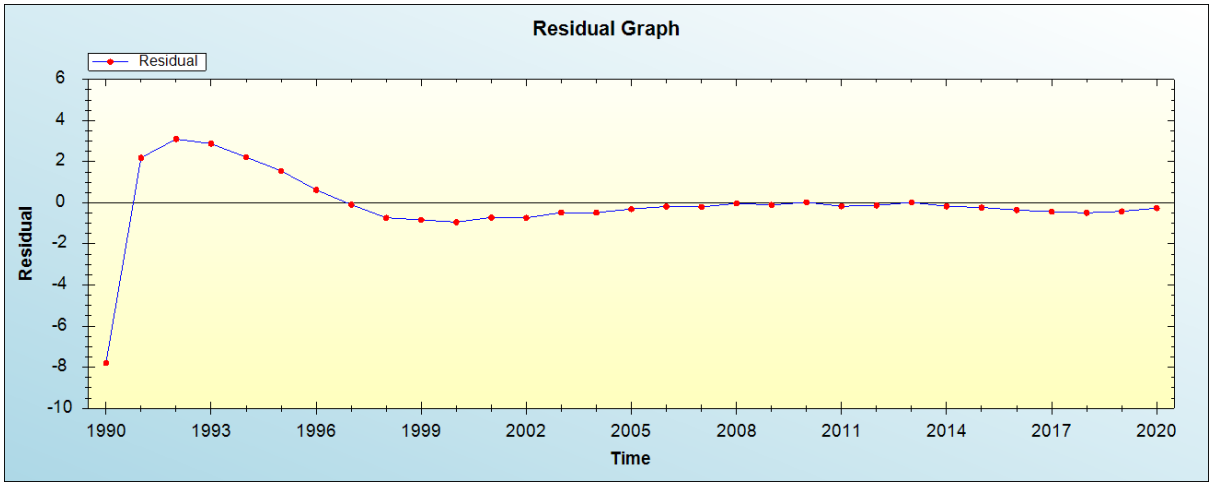

Figure 1: Residual analysis

In-sample Forecast for E

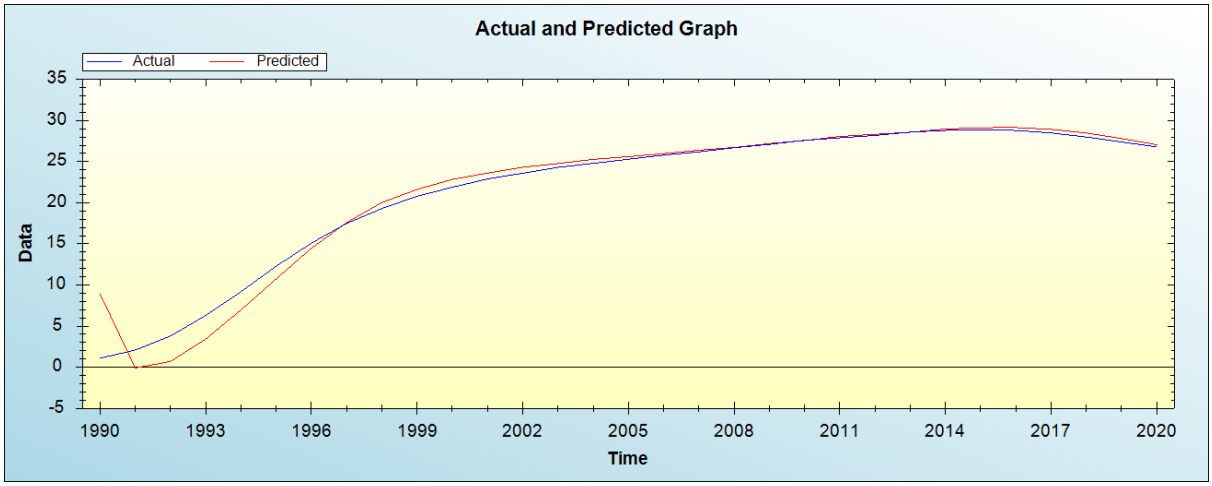

Figure 2: In-sample forecast for the E series

Actual and Smoothed graph for E series

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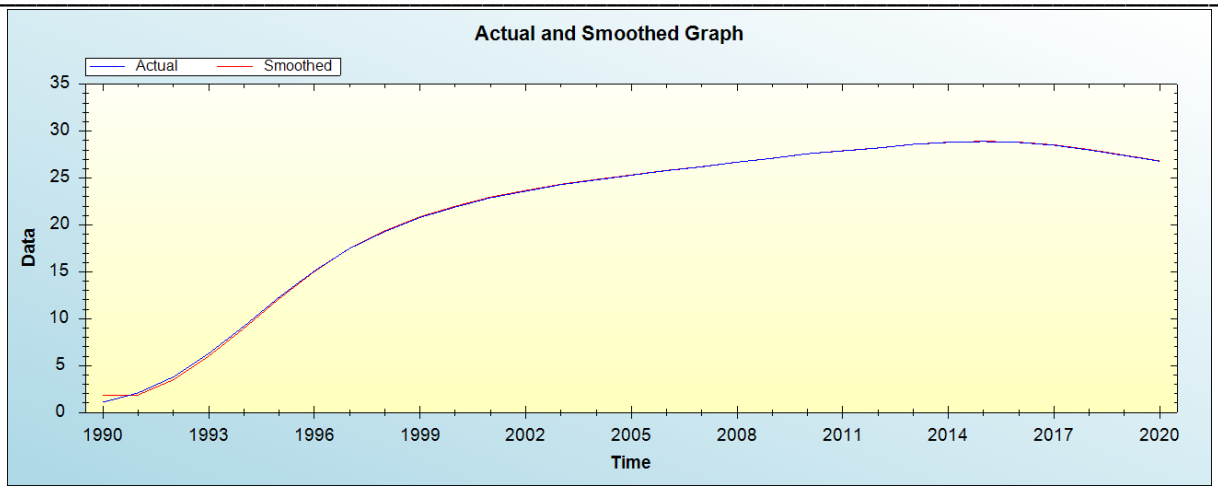

Figure 3: Actual and smoothed graph for E series

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

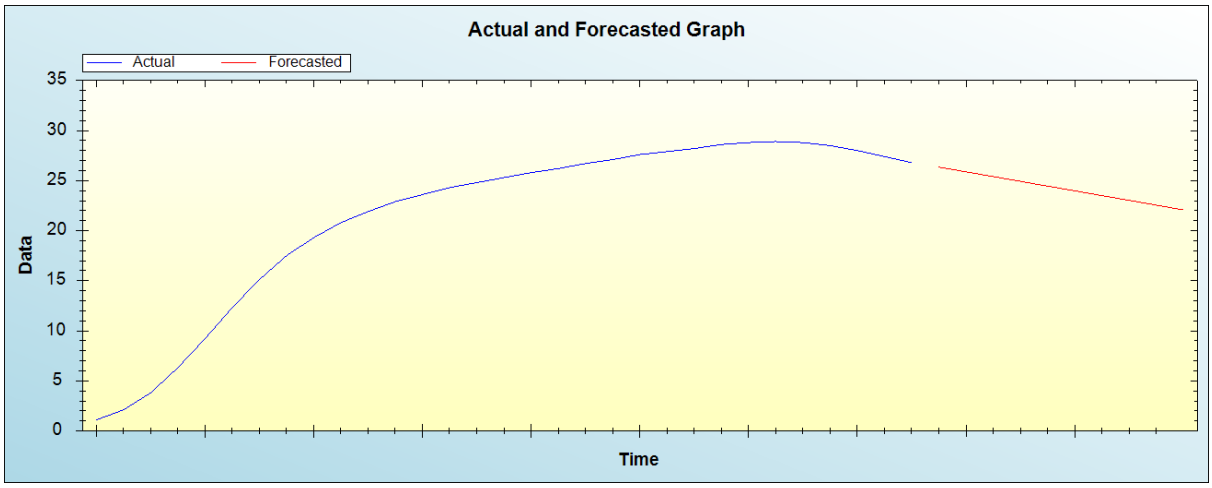

Figure 4: Out-of-sample forecast for E: actual and forecasted graph

Out-of-Sample Forecast for E: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted HIV prevalence
2021	26.3509
2022	25.8757
2023	25.4005
2024	24.9254
2025	24.4502
2026	23.9750
2027	23.4999
2028	23.0247
2029	22.5496

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2030	22.0744

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 decline over the out of sample period.

Policy implication and conclusion

Eswatini Kingdom is one of the SADC countries which continues to face a serious challenge of high HIV prevalence. This study establishes that the annual HIV prevalence among individuals aged 15-49 years will decline in the out of sample period but still remain high. Therefore, health authorities must address major drivers of HIV transmission among young adults with more focus being given to HIV prevention interventions.

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