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Projected Impact of International HIV Funding Withdrawal on HIV Transmission, Care Continuum Disruption, and AIDS-Related Mortality in Nigeria: A Dynamic Mathematical Modelling Study

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Abstract

Background: *Nigeria remains affected by HIV and highly dependent on donor-funded programmes. Reductions in international HIV financing may threaten HIV testing, treatment, viral suppression, and epidemic control. This study assessed the epidemiological impact of funding withdrawal on HIV transmission, care-continuum performance, and AIDS-related mortality in Nigeria.*

Methods: *A deterministic compartmental dynamic HIV transmission model was developed and calibrated using Nigeria-specific epidemiological and HIV care-continuum indicators obtained from UNAIDS, WHO, NACA, PEPFAR, and CDC reports. The model incorporated HIV transmission, diagnosis, antiretroviral therapy (ART) initiation, viral suppression, treatment interruption, and AIDS-related mortality. Five funding-retention scenarios were simulated over a 10-year projection horizon (2026–2036): status quo (100% retained funding), mild withdrawal (80%), moderate withdrawal (60%), severe withdrawal (40%), and extreme withdrawal (20%). Probabilistic sensitivity analyses using 500 Monte Carlo simulations were performed to evaluate model uncertainty.*

Results: *Under the extreme withdrawal scenario, diagnosis coverage declined to approximately 70%, ART coverage fell below 50%, and viral suppression decreased to nearly one-third of people living with HIV by 2036. Severe and extreme withdrawal scenarios produced marked increases in HIV incidence and AIDS-related mortality, with more than 700,000 excess HIV infections and approximately 90,000 excess AIDS-related deaths projected over the study period. The*

epidemiological burden increased disproportionately when retained funding fell below 60%. Abrupt funding withdrawal produced worse outcomes than gradual phased withdrawal. Sensitivity analyses identified HIV transmission rates, viral suppression, and AIDS-related mortality rates as key drivers of model outcomes.

Conclusion: *Substantial reductions in external HIV financing could reverse recent gains in HIV epidemic control in Nigeria, resulting in worsening HIV care-continuum performance, increasing HIV transmission, and rising AIDS-related mortality. Sustained HIV financing and carefully managed transition strategies are essential to preserve long-term epidemic control.*

Keywords: HIV/AIDS, Dynamic transmission modelling, HIV funding withdrawal, HIV care continuum, Nigeria, AIDS-related mortality

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Introduction

Nigeria continues to carry one of the largest HIV burdens globally, with approximately 1.9 million people living with HIV (PLHIV). Despite substantial progress in antiretroviral therapy (ART) scale-up and HIV service delivery over the past decade, the sustainability of the national HIV response remains heavily dependent on external donor financing, particularly support from the United States President's Emergency Plan for AIDS Relief (PEPFAR) and the Global Fund [1]. Global HIV financing has entered a period of increasing uncertainty. Recent reductions and disruptions in international development assistance, including pauses and proposed cuts to HIV-related foreign aid programmes, have raised concerns regarding the resilience of HIV treatment and prevention systems in low- and middle-income countries [2]. Mathematical modelling studies have projected that substantial reductions in international HIV financing could reverse decades of epidemiological progress, potentially leading to millions of additional HIV infections and AIDS-related deaths globally by 2030 [2]. The HIV care continuum, commonly conceptualised through the UNAIDS 95-95-95 targets, remains central to epidemic control strategies. These targets aim for 95% of PLHIV to know their HIV status, 95% of diagnosed individuals to receive ART, and 95% of those on ART to achieve viral suppression. Viral suppression is particularly critical because it substantially reduces onward HIV transmission and HIV-related mortality [3]. Nigeria has made notable progress toward these goals, with recent national reports indicating substantial improvements in diagnosis coverage, treatment uptake, and viral suppression [4]. However, sustaining these gains requires uninterrupted investments in HIV testing, ART delivery, retention-in-care services, laboratory monitoring, community outreach, and prevention programmes.

The Nigerian HIV programme remains particularly vulnerable to funding shocks because many critical HIV services, including testing infrastructure, treatment procurement, viral load monitoring, surveillance systems, and community-based interventions have historically relied on external financing mechanisms [1]. Emerging evidence from several sub-Saharan African countries has shown that disruptions in donor-supported HIV programmes can rapidly reduce HIV testing, ART initiation, prevention activities, and community outreach services, thereby increasing the risk of epidemic resurgence [3]. Nevertheless, there remains limited country-specific quantitative evidence regarding the potential epidemiological consequences of large-scale HIV funding withdrawal in Nigeria. Dynamic transmission models provide an important framework for evaluating long-term HIV epidemic trajectories under changing policy and financing conditions. Unlike static approaches, dynamic compartmental models explicitly capture temporal interactions between HIV transmission, disease progression, diagnosis, treatment uptake, viral

suppression, and mortality, thereby enabling estimation of both direct and indirect population-level effects of service disruption. Recent modelling studies have increasingly been used to evaluate HIV intervention sustainability, epidemic rebound risks, and financing transition scenarios in resource-constrained settings [2]. However, there remains a paucity of country-specific quantification of how progressive reductions in external HIV funding could affect the HIV care continuum and long-term epidemic trajectory in Nigeria using calibrated dynamic transmission models linked to real-world care cascade data.

In this study, we developed a deterministic dynamic HIV transmission model calibrated to Nigeria-specific epidemiological and HIV care-continuum indicators obtained from national and international data sources. We modelled varying levels of external HIV funding withdrawal and estimated their projected effects on HIV diagnosis coverage, ART uptake, viral suppression, HIV incidence, and AIDS-related mortality over a ten-year horizon. We further evaluated excess HIV infections and deaths attributable to funding shocks under multiple policy scenarios. By quantifying the potential epidemiological consequences of donor funding disruptions, this study aims to provide evidence to support sustainable HIV financing strategies and strengthen long-term epidemic control planning in Nigeria.

Methods

Study design and overview

This study employed a deterministic compartmental dynamic transmission modelling approach to quantify the epidemiological and HIV care-continuum consequences of external HIV funding withdrawal in Nigeria. The model incorporated HIV transmission dynamics, disease progression, HIV diagnosis, antiretroviral therapy (ART) initiation, viral suppression, retention in care, and AIDS-related mortality. Model projections were generated under varying levels of external HIV funding withdrawal over a 10-year projection horizon (2026 - 2036).

Study setting

The analysis focused on Nigeria, one of the countries with the largest HIV burden globally. Nigeria has an estimated population exceeding 220 million people and approximately 1.9 - 2.0 million people living with HIV (PLHIV) (UNAIDS, 2024). The national HIV programme relies substantially on external donor financing, particularly support from the United States President's Emergency Plan for AIDS Relief (PEPFAR) and the Global Fund (CDC, 2024; NACA, 2024).

Data sources

Model calibration targets and epidemiological parameters were obtained from publicly accessible secondary data sources. National HIV epidemiological indicators, including estimates of PLHIV, HIV incidence, AIDS-related mortality, diagnosis coverage, ART coverage, and viral suppression, were extracted from the Joint United Nations Programme on HIV/AIDS (UNAIDS) AIDSinfo database and national HIV programme reports from the National Agency for the Control of AIDS (NACA) [1,3,5,6]. Additional programme-level information related to HIV testing, treatment coverage, and service delivery was obtained from publicly available reports from the World Health Organization (WHO), PEPFAR, and CDC [7,8]. The primary calibration targets included: total number of PLHIV in Nigeria; HIV diagnosis coverage among PLHIV; ART coverage among PLHIV; Viral suppression among individuals receiving ART; Annual new HIV infections; and Annual AIDS-related deaths. All data used in this study were derived from publicly available aggregated secondary sources and therefore did not require ethical approval or informed consent.

Model structure

A deterministic compartmental dynamic transmission model was developed using a system of ordinary differential equations (ODEs), consistent with established HIV transmission modelling approaches previously applied in infectious disease epidemiology and HIV policy evaluation [9,10]. The population was stratified into mutually exclusive HIV disease and care-continuum compartments representing HIV acquisition, diagnosis, treatment status, viral suppression, and AIDS-related disease progression.

The model compartments included:

Susceptible individuals (S);

HIV-infected but undiagnosed individuals (I_u);

Diagnosed individuals not receiving ART (I_d);

Individuals receiving ART without viral suppression (T_u);

Virally suppressed individuals receiving ART (T_s);

Individuals with advanced HIV/AIDS (A);

Cumulative HIV infections; and

Cumulative AIDS-related deaths.

The model structure captured HIV transmission through a force-of-infection framework, with differential infectiousness assigned to each HIV disease state. Infectiousness was assumed to be highest among undiagnosed individuals and substantially reduced among virally suppressed individuals, consistent with evidence demonstrating markedly reduced HIV transmission among individuals achieving sustained viral suppression [9,10]. The force of infection was modelled as follows, based on standard compartmental infectious disease transmission formulations used in HIV epidemic modelling literature [11,12]

$$\lambda = \beta \times \frac{(I_u + \kappa_d I_d + \kappa_{tu} T_u + \kappa_{ts} T_s)}{N}$$ were

λ represents the force of infection;

β represents the HIV transmission coefficient;

κ_d, κ_{tu}, and κ_{ts} represent relative infectiousness modifiers for diagnosed untreated, treated unsuppressed, and virally suppressed individuals, respectively; and

N represents the total population.

Transitions between model compartments were governed by rates of HIV diagnosis, ART initiation, viral suppression, loss of viral suppression, treatment dropout, disease progression, and HIV-related mortality.

Baseline population initialization

The model was initialized using Nigeria-specific HIV care-continuum estimates. Initial compartment sizes were derived directly from national estimates of PLHIV, diagnosis coverage, ART coverage, viral suppression, and AIDS-related mortality. The initial number of individuals with advanced HIV/AIDS was estimated using annual AIDS-related deaths divided by the assumed AIDS mortality rate. Numbers of virally suppressed and treated unsuppressed individuals were estimated from ART coverage and viral suppression indicators. Remaining PLHIV were allocated into diagnosed untreated and undiagnosed compartments. The susceptible population was estimated as the total Nigerian population minus the estimated number of PLHIV.

Funding withdrawal scenarios

External HIV funding withdrawal was modelled as proportional reductions in HIV programme performance parameters affecting:

HIV testing and diagnosis;

ART initiation;

Viral suppression;

Retention in care; and

Treatment continuity.

Five funding scenarios were evaluated:

Status quo (100% funding retained);

Mild withdrawal (80% funding retained);

Moderate withdrawal (60% funding retained);

Severe withdrawal (40% funding retained); and

Extreme withdrawal (20% funding retained).

Under each scenario, reductions in funding proportionally reduced HIV diagnosis, ART initiation, and viral suppression rates, while increasing treatment dropout and loss of suppression. Additional analyses compared abrupt funding withdrawal with gradual phased withdrawal over time.

Model calibration

The HIV transmission coefficient was calibrated to reproduce observed annual HIV incidence in Nigeria using a deterministic calibration approach. Calibration involved solving for the transmission parameter required to reproduce observed annual HIV incidence under baseline care-continuum conditions. This approach is consistent with previously described infectious disease

model calibration frameworks for HIV transmission modelling [10,13].

Model validity was further assessed by comparing baseline model outputs against observed national estimates for:

Total PLHIV;

Diagnosis coverage;

ART coverage;

Viral suppression;

Annual HIV incidence; and

Annual AIDS-related mortality.

Absolute and relative calibration errors were calculated.

Scenario simulations

All scenario analyses were simulated over a 10-year period from 2026 to 2036 using the lsoda ordinary differential equation solver implemented in the deSolve package in R. Primary epidemiological outcomes included HIV diagnosis coverage, ART coverage, and Viral suppression. In addition annual HIV incidence, annual AIDS-related deaths, cumulative HIV infections, and cumulative AIDS-related deaths were included in the outcome. We also used the following as secondary policy outcomes: excess HIV infections attributable to funding withdrawal, excess AIDS-related deaths attributable to funding withdrawal, and time to loss of HIV care-continuum thresholds.

Probabilistic sensitivity analysis

Probabilistic sensitivity analysis (PSA) was conducted to evaluate parameter uncertainty and model robustness. Key epidemiological and programme parameters were sampled from log-normal distributions across 500 Monte Carlo simulations, consistent with recommended approaches for uncertainty quantification in epidemiological and health policy models [14,14]. Parameters varied during PSA included: HIV transmission coefficient, HIV diagnosis rate, ART initiation rate, viral suppression rate, treatment dropout rate, loss of viral suppression; and AIDS-related mortality rate. For each scenario, median estimates and 95% uncertainty intervals (UI) were calculated for cumulative HIV infections, cumulative AIDS-related deaths, excess infections, and excess deaths. For each scenario, median estimates and 95% uncertainty intervals (UI) were calculated for cumulative HIV infections, cumulative AIDS-related deaths, excess infections, and excess deaths.

One-way sensitivity analysis and tornado analysis

One-way sensitivity analyses were conducted to identify model parameters with the greatest influence on cumulative AIDS-related deaths. Key parameters were independently varied by ±20% while holding all other parameters constant. Results were summarized using tornado plots to evaluate the relative contribution of individual parameters to model uncertainty.

Heatmap analysis

Two-dimensional heatmap analyses were conducted to evaluate the interaction between HIV funding retention and treatment dropout pressure. Funding retention levels and treatment dropout multipliers were jointly varied to estimate excess AIDS-related deaths across combinations of programme disruption severity.

Statistical analysis and software

All analyses were conducted using R statistical software (version 4.5.2). Dynamic transmission modelling was implemented using the deSolve package. Data management and visualization were performed using tidyverse, ggplot2, and patchwork packages. Model outputs, simulation tables, sensitivity analyses, and publication-quality figures were automatically exported through a fully reproducible analysis pipeline.

Reproducibility and transparency

The complete analytical workflow, including data processing, model initialization, calibration, scenario simulation, sensitivity analysis, and figure generation, was implemented within a single reproducible R-based pipeline. All parameter assumptions, transition equations, and scenario definitions were explicitly documented to facilitate reproducibility and external validation.

Ethical considerations

This study used aggregated secondary data obtained from publicly accessible sources and did not involve identifiable human participants. Ethical approval and informed consent were therefore not required.

Results

Projected effects of funding withdrawal on HIV care-continuum indicators

The calibrated dynamic transmission model successfully reproduced key national HIV epidemiological and care-continuum indicators for Nigeria under baseline conditions. Simulated baseline estimates for total people living with HIV (PLHIV), diagnosis coverage, ART coverage, viral suppression, annual HIV incidence, and AIDS-related mortality closely aligned with observed national estimates, supporting the internal validity of the model and its suitability for scenario projection analyses.

Under the status quo scenario, the model projected continued improvement across all HIV care-continuum indicators between 2026 and 2036. Diagnosis coverage increased progressively from approximately 90% at baseline to more than 95% by the end of the projection period, while ART coverage and viral suppression also improved steadily over time. In contrast, progressive external funding withdrawal was associated with substantial deterioration in HIV service performance. The magnitude of decline increased with the severity of funding reduction. Under the mild withdrawal scenario (20% funding reduction), diagnosis coverage, ART coverage, and viral suppression remained relatively stable, although improvements observed under the status quo were attenuated. However, moderate-to-severe withdrawal scenarios produced marked declines across all care-continuum indicators. The most pronounced deterioration was observed under the extreme withdrawal scenario (80% funding reduction). By 2036, diagnosis coverage declined to approximately 70%, ART coverage declined to below 50%, and viral suppression fell to nearly one-third of PLHIV. Intermediate withdrawal scenarios demonstrated graded declines, suggesting a dose-response relationship between funding retention and continuity of HIV care services. Among the continuum indicators, viral suppression appeared most sensitive to funding withdrawal, followed by ART coverage, whereas diagnosis coverage demonstrated comparatively greater resilience during early years of programme disruption. Results were presented in figure 1

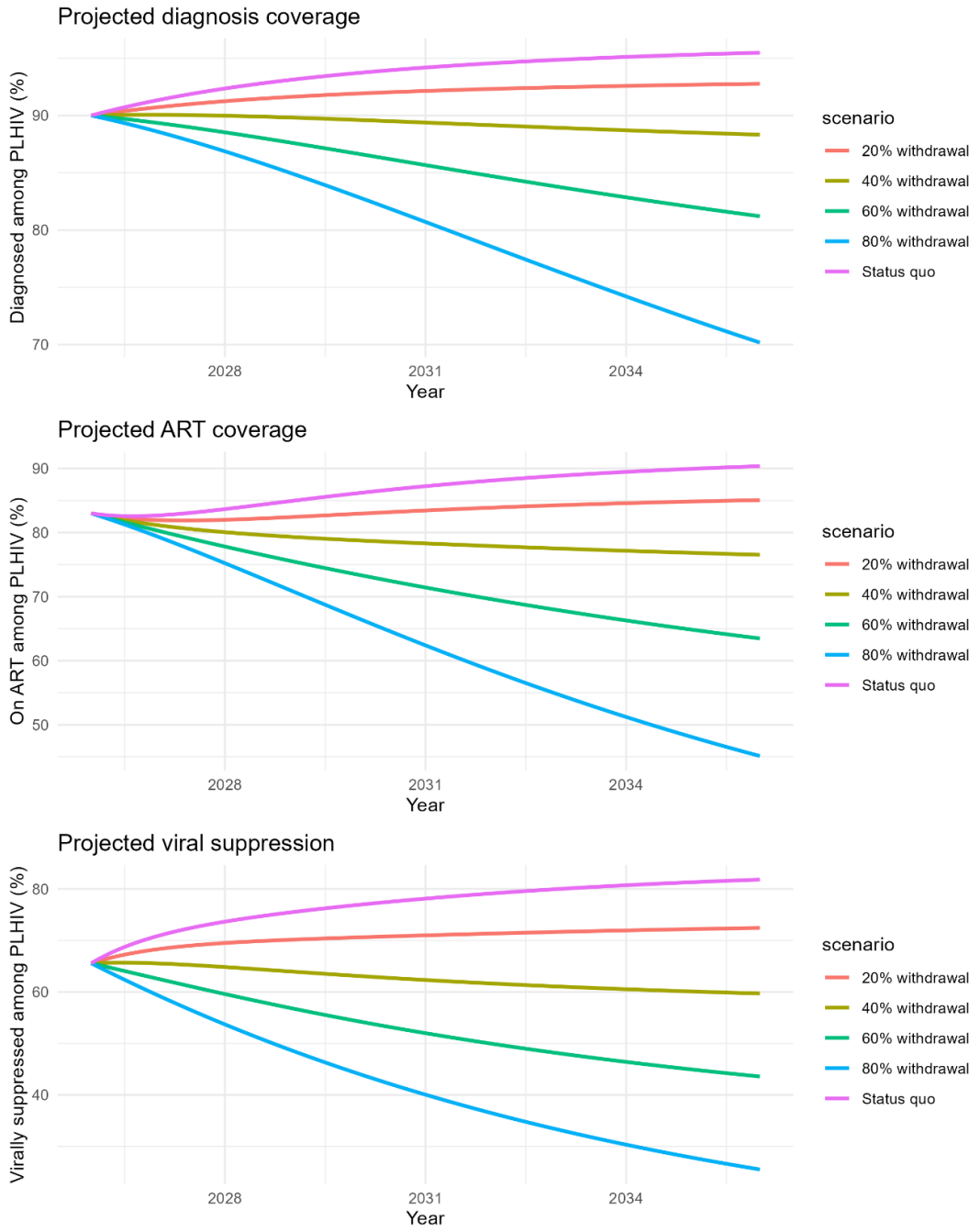

Figure 1. Projected Diagnosis, ART and Viral Suppression Coverage

Projected HIV incidence under funding withdrawal scenarios

Figure 2 presents the projected annual HIV incidence rate of. Under the status quo scenario, annual HIV incidence gradually declined throughout the projection period, reflecting continued improvements in HIV diagnosis, treatment coverage, and viral suppression. In contrast, all funding withdrawal scenarios resulted in progressive increases in annual HIV incidence, with larger increases observed under more severe funding reductions. The increase in HIV incidence became particularly pronounced under severe and extreme withdrawal scenarios. Under the extreme withdrawal scenario, annual new HIV infections increased substantially over time and exceeded four times the projected status quo incidence by the end of the projection period. Moderate withdrawal scenarios produced slower but sustained

increases in HIV transmission, indicating progressive epidemic rebound following reductions in programme performance.

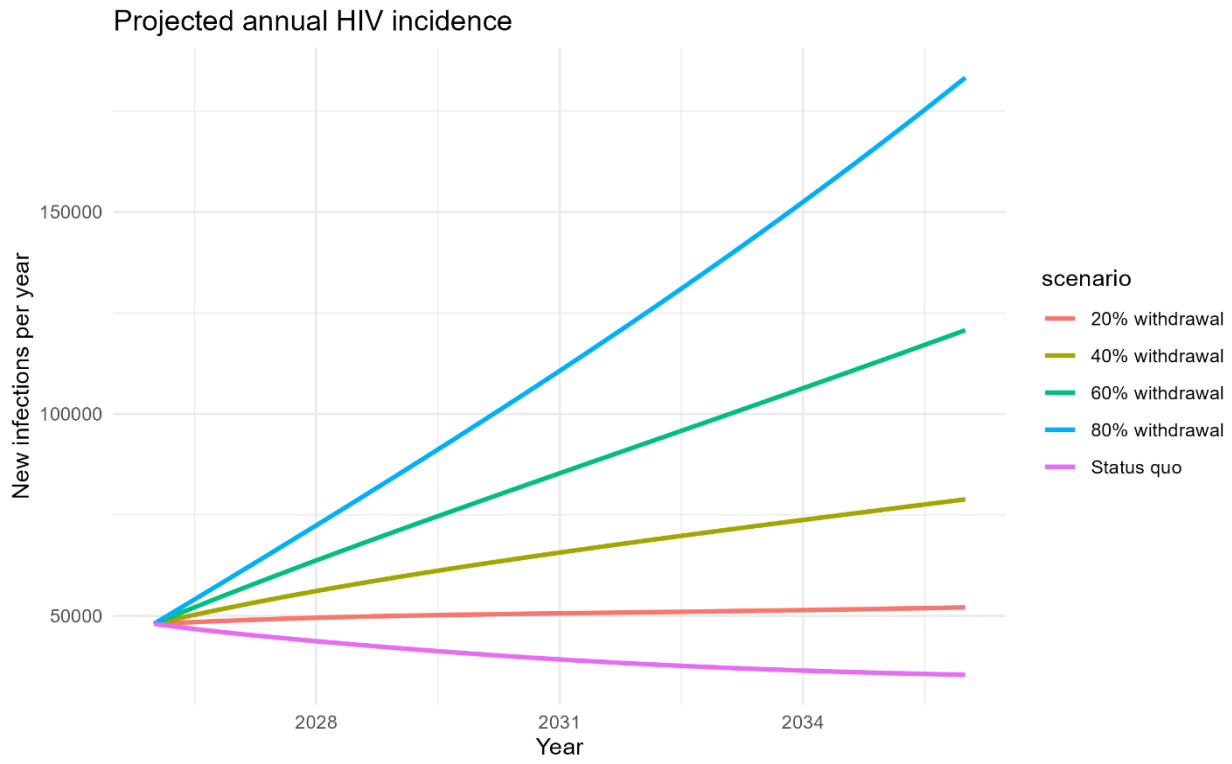

Figure 2. Projected Annual HIV Incidence

Projected AIDS-related mortality

As shown in figure 3, projected annual AIDS-related deaths declined steadily under the status quo scenario throughout the simulation period. Mild funding withdrawal attenuated these gains but still maintained a gradual reduction in mortality over time. However, moderate-to-severe withdrawal scenarios substantially altered mortality trajectories. Under severe and extreme withdrawal scenarios, AIDS-related mortality initially declined during the early years of projection but subsequently plateaued and rebounded as treatment interruptions, reduced viral suppression, and increasing HIV transmission accumulated over time. The extreme withdrawal scenario produced the largest mortality burden, with annual AIDS-related deaths increasing markedly during later projection years relative to all other scenarios.

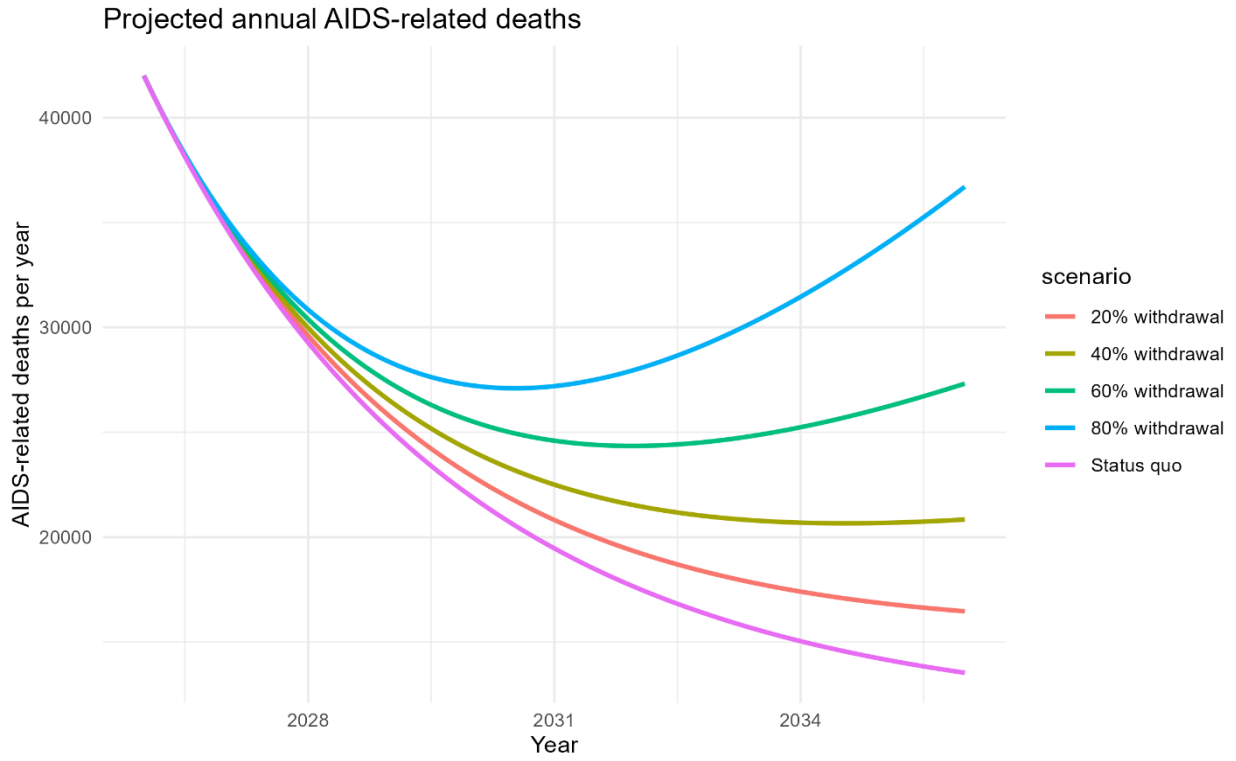

Figure 3. Projected annual AIDS-related deaths

Excess HIV infections and AIDS-related deaths attributable to funding withdrawal

Compared with the status quo scenario, all funding withdrawal scenarios generated substantial cumulative excess HIV infections and AIDS-related deaths between 2026 and 2036. The cumulative burden increased progressively with worsening funding reduction. Severe and extreme withdrawal scenarios produced the largest excess burden, with the extreme withdrawal scenario generating more than 700,000 excess HIV infections and approximately 90,000 excess AIDS-related deaths over the 10-year projection period. The relationship between retained funding and excess epidemiological burden appeared strongly nonlinear, with disproportionately larger increases in infections and deaths observed once retained funding fell below approximately 60% (figure 4 and 5).

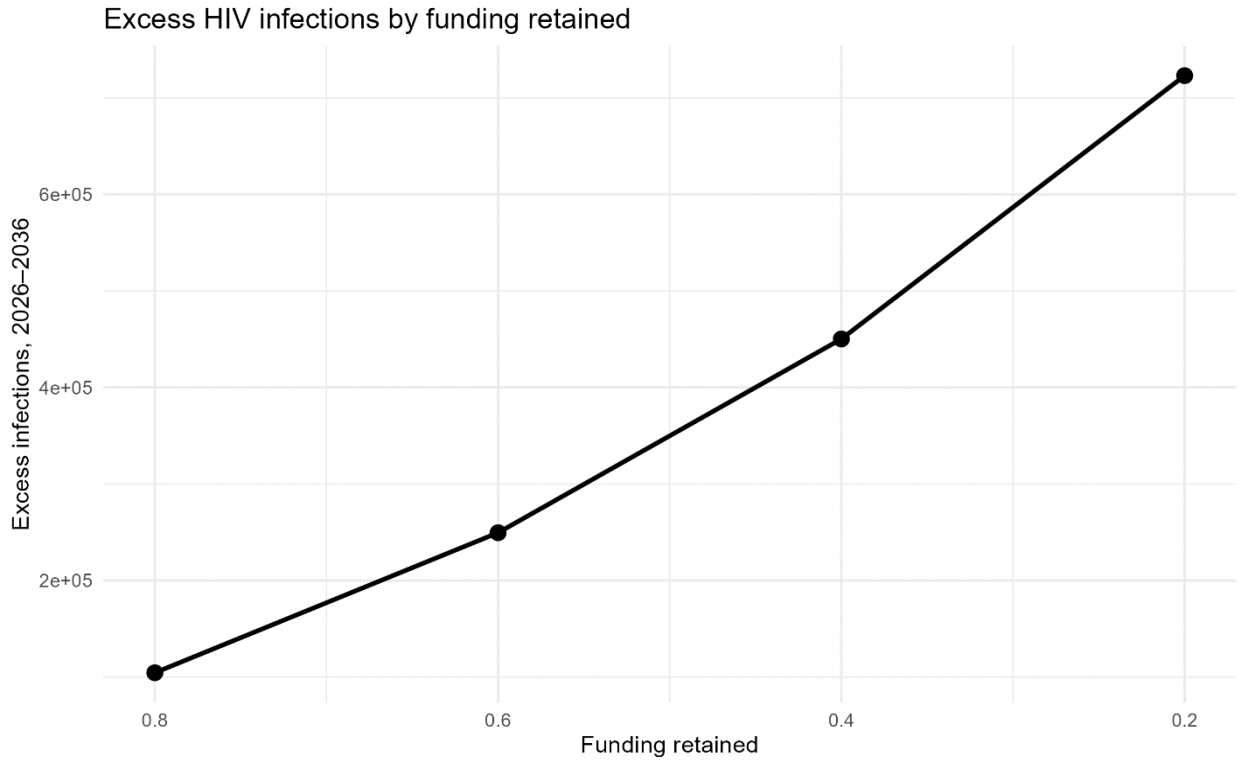

Figure 4. Excess HIV infections by funding retained

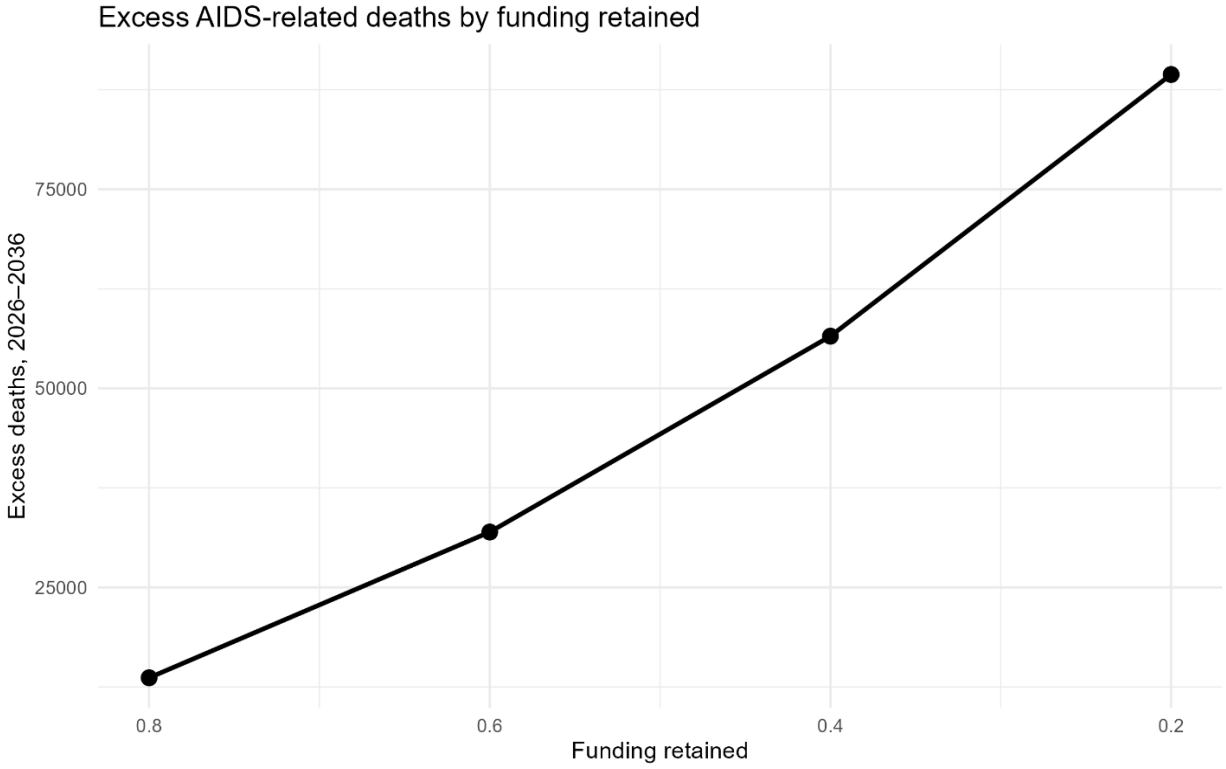

Figure 5. Excess HIV death by funding retained

Cumulative epidemiological burden under funding withdrawal scenarios

The cumulative epidemiological burden increased progressively across worsening funding withdrawal scenarios throughout the projection period. Under the status quo scenario, cumulative HIV infections and AIDS-related deaths increased gradually over time, reflecting ongoing HIV transmission and mortality despite continued programme improvements. However, all funding withdrawal scenarios produced substantially greater cumulative burden relative to the status quo trajectory. The divergence between scenarios became increasingly pronounced after approximately 2029, particularly under severe and extreme withdrawal conditions. By 2036, the extreme withdrawal scenario generated the largest cumulative burden, with cumulative HIV infections exceeding one million cases and cumulative AIDS-related deaths surpassing 300,000 deaths. In contrast, cumulative infections and deaths remained substantially lower under continued funding retention. The nonlinear widening between the status quo and withdrawal scenarios suggests that reductions in HIV programme performance accumulate over time, resulting in progressively amplified epidemic rebound and mortality burden during later years of programme disruption (figure 6 & 7).

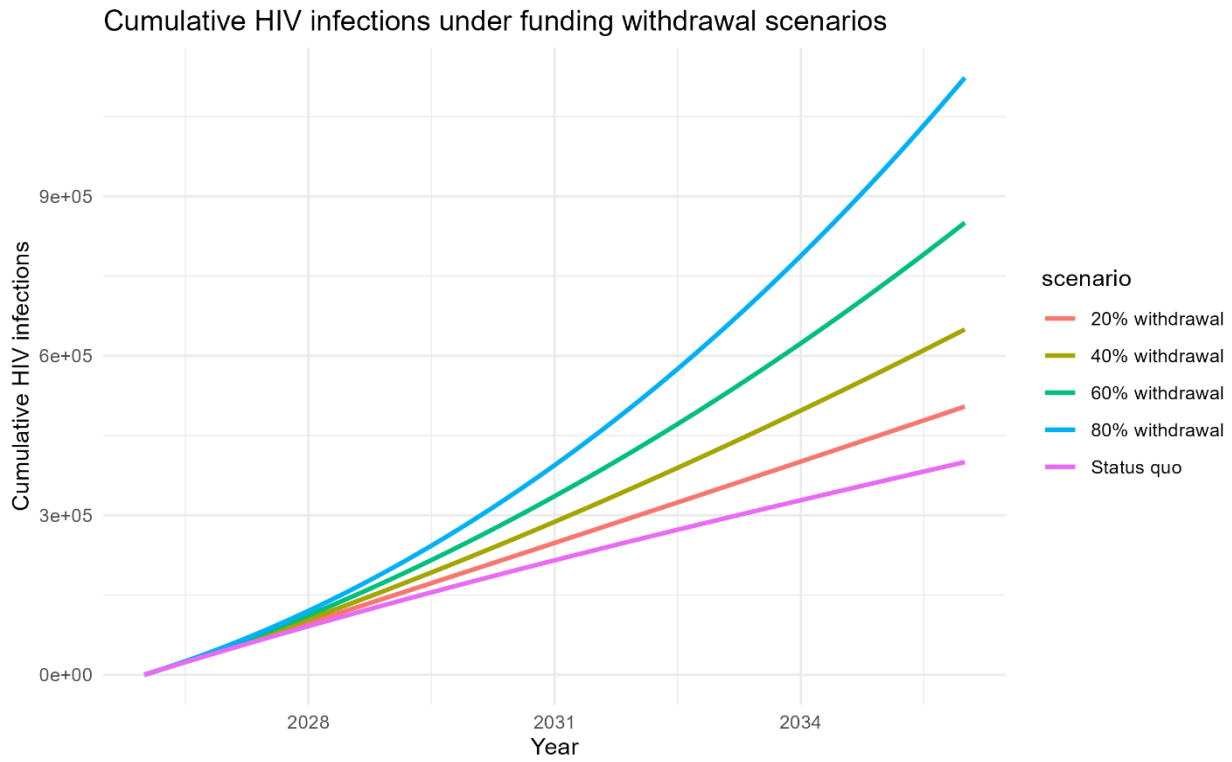

Figure 6. Cumulative HIV Infection

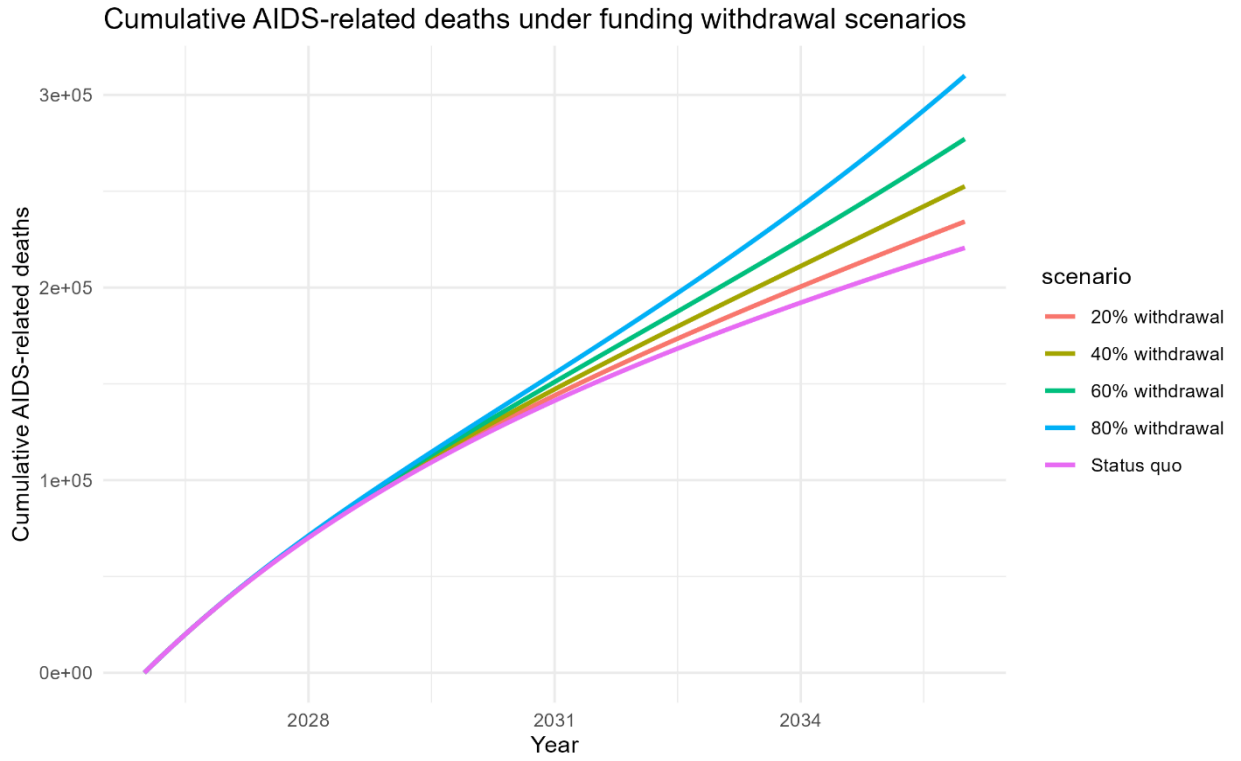

Figure 7. Cumulative AIDS-related deaths under funding withdrawal scenarios

Time to deterioration of HIV care-continuum thresholds

Additional analyses demonstrated progressive loss of HIV care-continuum performance thresholds under worsening funding withdrawal scenarios. Under severe and extreme withdrawal conditions, the model projected early declines below internationally recognised HIV programme targets, including diagnosis coverage, ART coverage, and viral suppression thresholds. The extreme withdrawal scenario resulted in the most rapid deterioration, with diagnosis coverage declining below 90% early during the projection period and viral suppression showing the earliest and steepest reductions. In contrast, the mild withdrawal scenario maintained most care-continuum indicators near baseline levels throughout the projection horizon, although gains observed under the status quo scenario were substantially attenuated (figure 8).

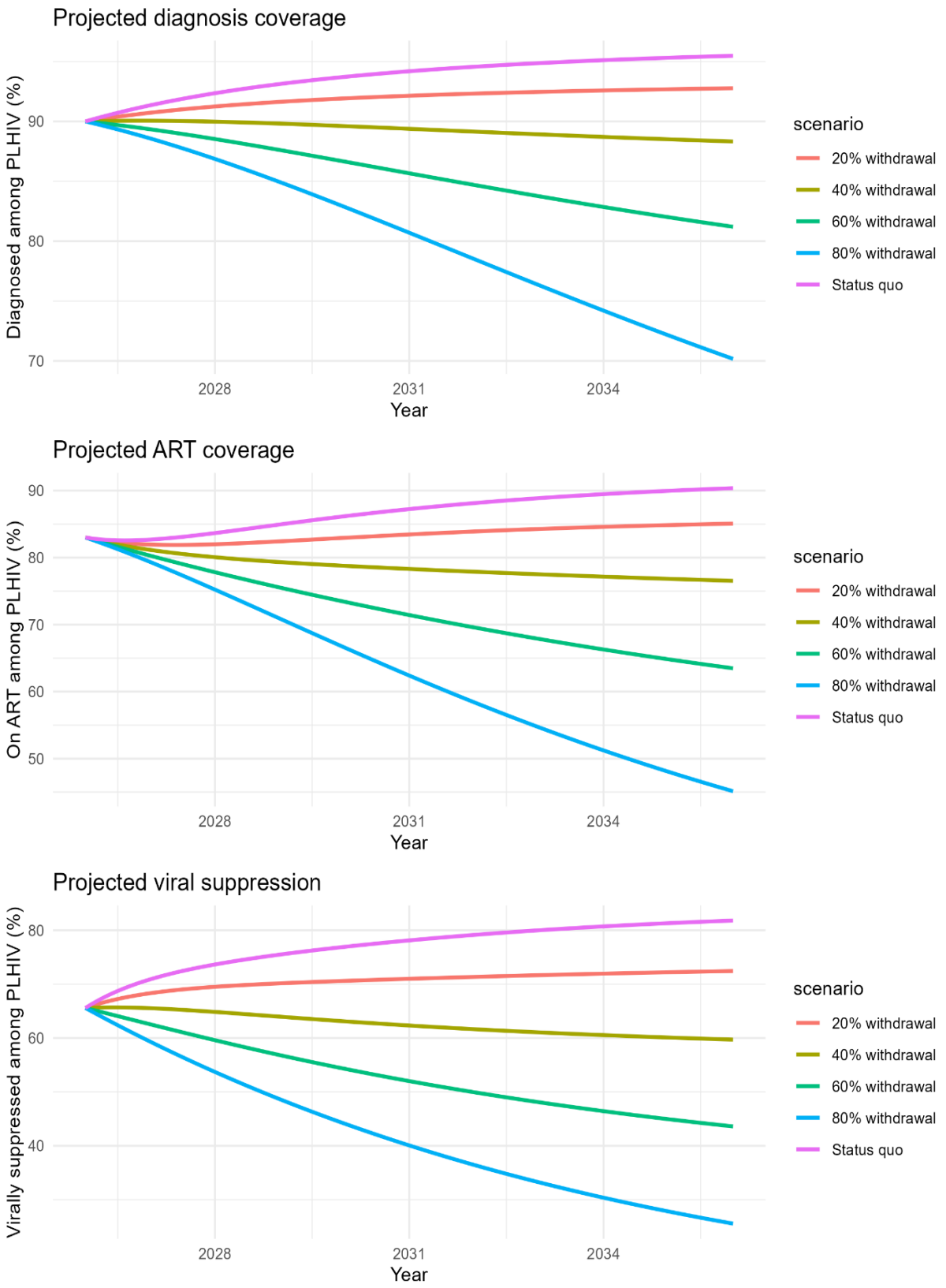

Figure 8. Time to deterioration of HIV care-continuum thresholds

Model uncertainty and probabilistic sensitivity analysis

Probabilistic sensitivity analyses demonstrated that the projected increase in HIV infections and AIDS-related deaths remained consistent across parameter uncertainty ranges (Figures 9 & 10). Median excess infections and excess deaths increased progressively as retained funding declined, with the largest burdens observed under severe and extreme withdrawal scenarios. Although uncertainty intervals widened under lower retained funding conditions, the direction of effect remained stable across simulations, indicating robust model behaviour despite uncertainty in epidemiological and programme parameters. The uncertainty intervals were widest under the extreme withdrawal scenario, reflecting increasing instability and variability in epidemic trajectories under severe programme disruption. Notably, even under lower-bound uncertainty estimates, severe funding reductions were consistently associated with substantial excess HIV infections and AIDS-related mortality relative to the status quo scenario.

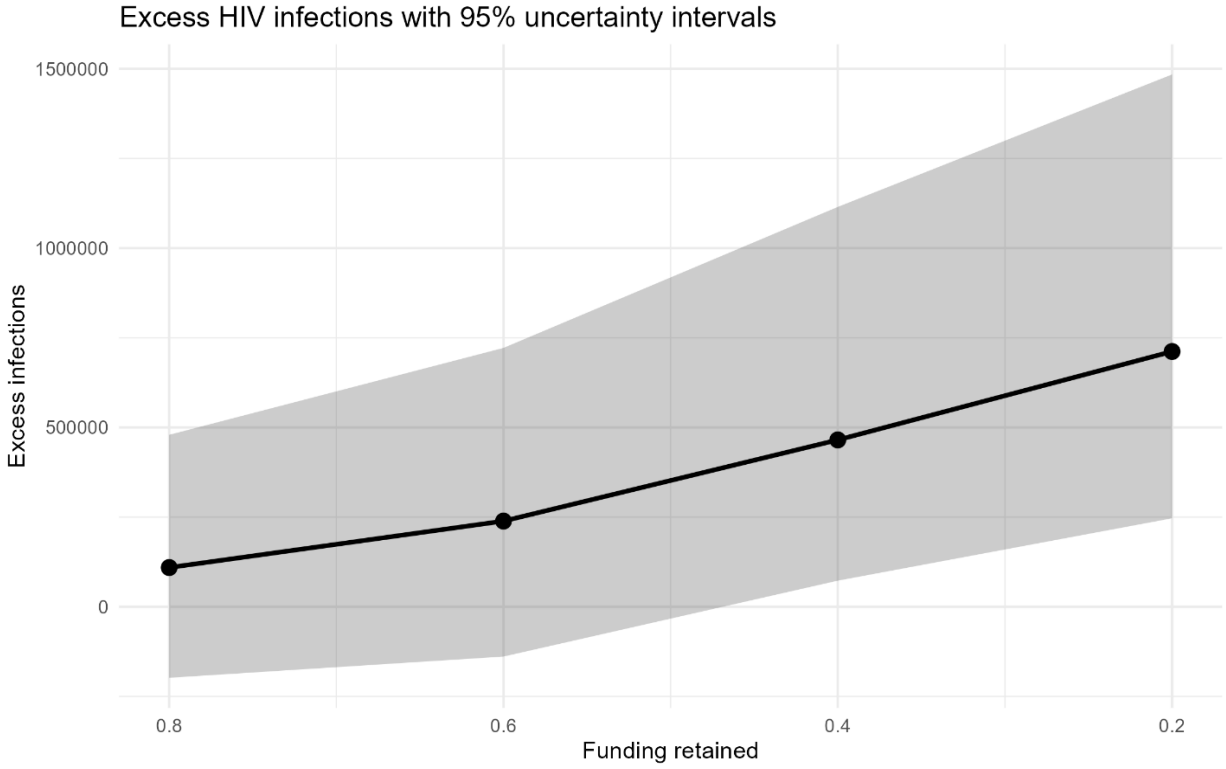

Figure 9. Excess HIV infections with 95% uncertainty intervals

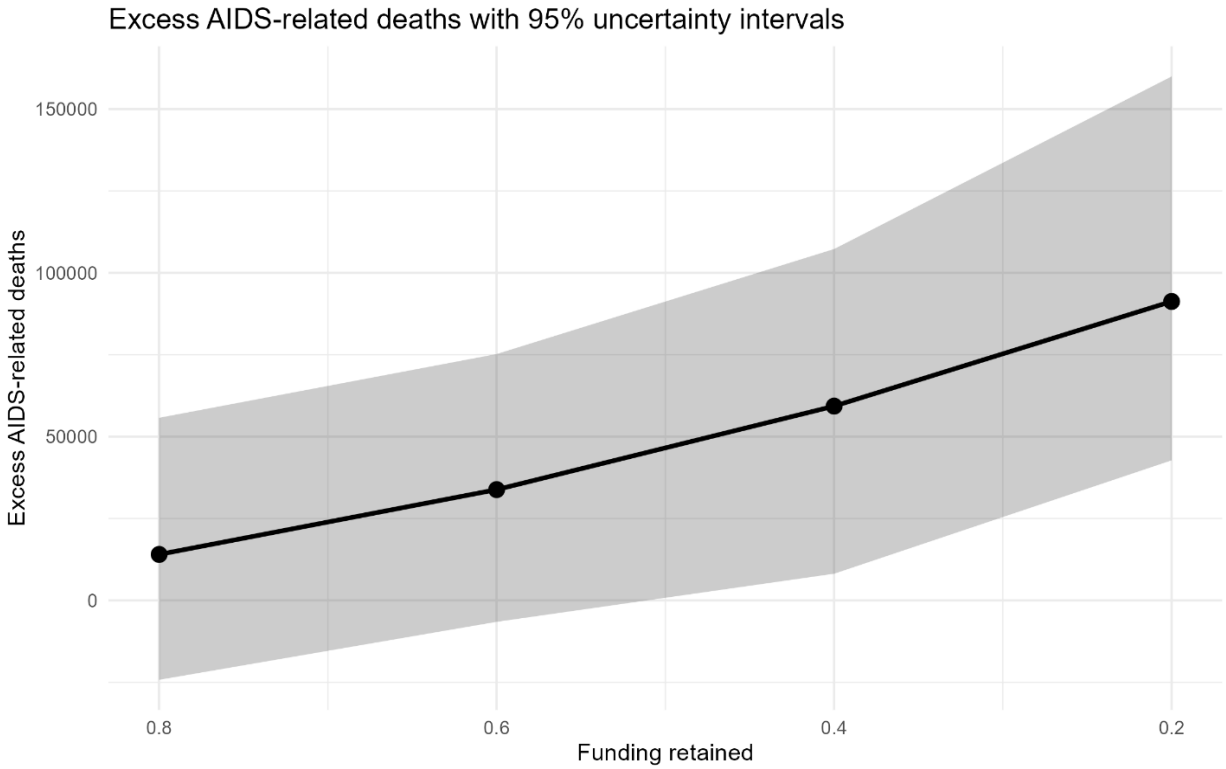

Figure 10. Excess AIDS-related deaths with 95% uncertainty intervals

Drivers of projected AIDS-related mortality

One-way sensitivity and tornado analyses identified AIDS-related mortality rates and HIV transmission rates as the dominant drivers of cumulative AIDS-related deaths within the model. Viral suppression rates and HIV diagnosis rates also contributed substantially to model uncertainty, whereas treatment dropout and ART initiation rates had comparatively smaller effects. These findings suggest that maintenance of viral suppression and prevention of HIV transmission are critical determinants of long-term epidemic outcomes during periods of programme instability. The results additionally highlight the importance of sustaining treatment continuity and advanced HIV care services to minimize mortality during funding transitions (figure 11).

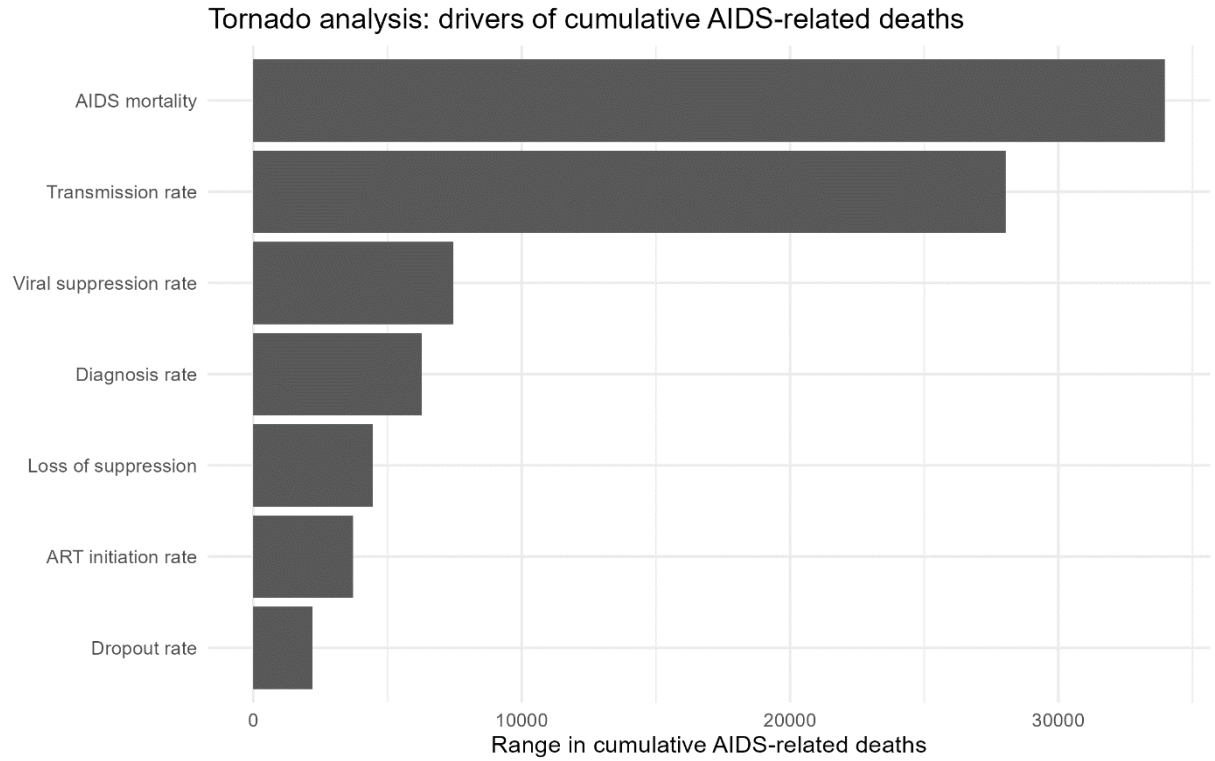

Figure 11. Driver of cumulative AIDS-related deaths

Interaction between funding retention and treatment dropout

The heatmap analyses presented in figure 12 demonstrated a strong interaction between retained funding and treatment dropout pressure on excess AIDS-related mortality. Lower retained funding levels were consistently associated with increasing excess deaths across all dropout conditions. However, the mortality burden intensified further as treatment dropout pressure increased. The combination of severe funding reduction and elevated treatment interruption produced the greatest projected mortality burden, suggesting that disruptions in treatment continuity may substantially amplify the epidemiological consequences of donor funding withdrawal. Overall, the heatmap analysis identified retention-in-care as a major system vulnerability during HIV programme destabilization.

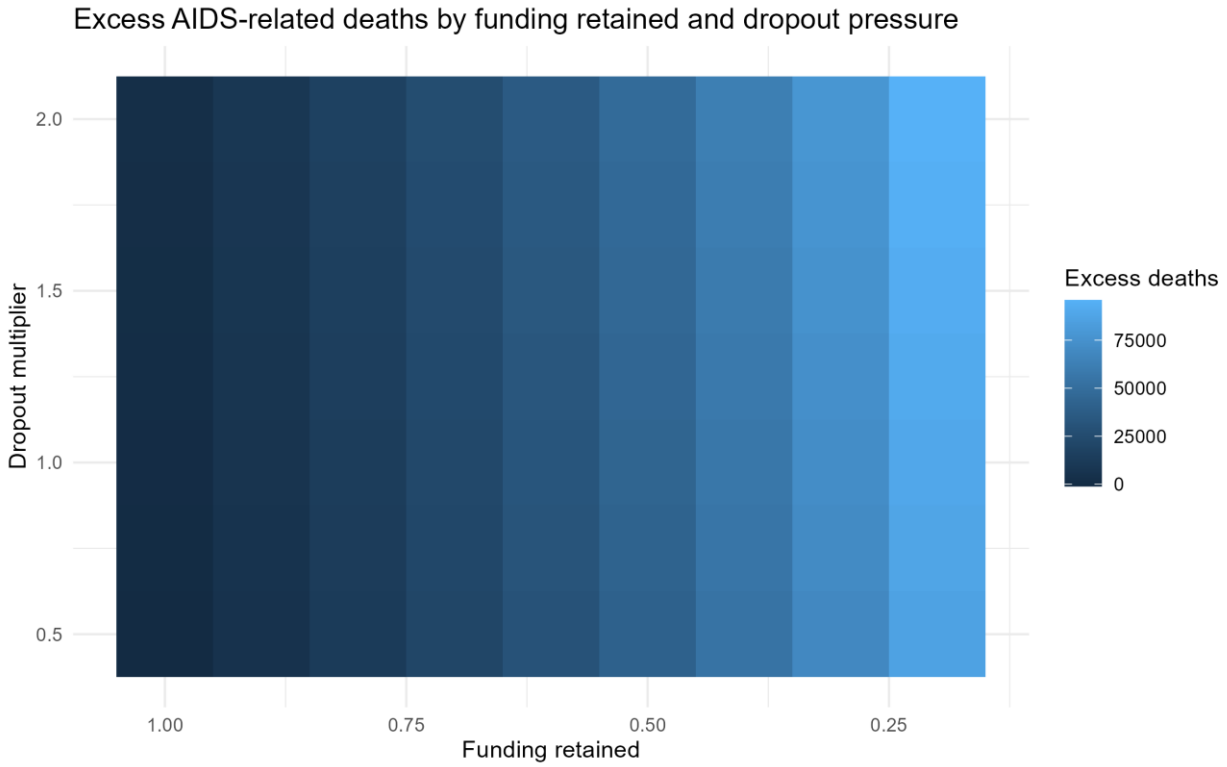

Figure 12. Heatmap of Excess AIDS-related death by funding retained and dropout pressure.

Abrupt versus gradual funding withdrawal

Figure 13 captured the comparative analyses of abrupt versus gradual funding withdrawal. The chart showed that abrupt funding withdrawal consistently produced greater cumulative AIDS-related mortality than gradual phased withdrawal across all funding-retention scenarios. Although both withdrawal patterns resulted in worsening mortality relative to the status quo scenario, gradual reductions attenuated the rate of mortality accumulation over time. The differences between abrupt and gradual withdrawal became increasingly evident during later projection years, particularly under severe and extreme funding reductions. These findings suggest that phased financing transitions may partially mitigate the adverse epidemiological effects associated with sudden programme disruption. Collectively, the advanced analyses reinforce the central finding that sustained HIV programme financing is critical for maintaining HIV epidemic control in Nigeria and preventing substantial excess HIV infections and AIDS-related deaths following donor funding shocks.

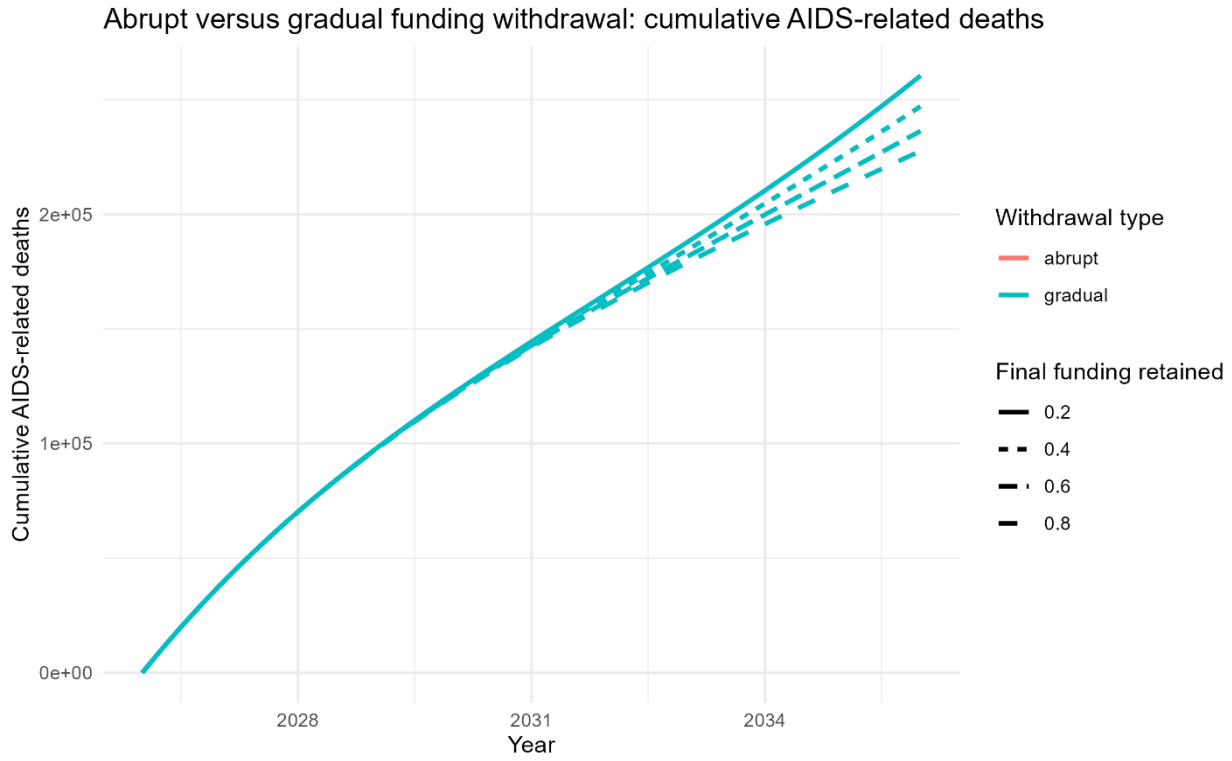

Figure 13. Abrupt and Gradual deaths

Discussion

In this study, we developed and calibrated a dynamic HIV transmission model to quantify the epidemiological and HIV care-continuum consequences of external funding withdrawal in Nigeria. The findings demonstrate that reductions in donor-supported HIV financing could substantially disrupt HIV diagnosis, treatment coverage, and viral suppression, resulting in progressive increases in HIV incidence and AIDS-related mortality. The projected burden increased disproportionately under severe funding withdrawal scenarios, suggesting that the Nigerian HIV response may be highly vulnerable to sustained financing shocks. Under the status quo scenario, the model projected continued improvements in diagnosis coverage, ART coverage, viral suppression, and declining HIV incidence and AIDS-related mortality over the next decade. However, these gains were rapidly reversed under progressive funding withdrawal scenarios. Viral suppression and ART coverage were particularly sensitive to reductions in programme financing, while HIV incidence increased substantially as treatment coverage and viral suppression deteriorated. These findings are biologically and epidemiologically plausible because reduced viral suppression increases onward HIV transmission and contributes to long-term epidemic rebound.

The projected deterioration in HIV outcomes aligns with emerging modelling evidence demonstrating the potential consequences of disruptions in PEPFAR-supported HIV programmes across sub-Saharan Africa. Recent mathematical modelling studies have estimated that reductions in international HIV financing could lead to millions of excess HIV infections and AIDS-related deaths globally, particularly in countries with high dependence on external HIV funding [15].

Our findings are also consistent with recent reports from UNAIDS and WHO warning that HIV programme disruptions associated with donor funding instability could reverse decades of progress in HIV epidemic control [16]. In particular, WHO has highlighted that interruptions in HIV service delivery, supply chains, and health workforce support may substantially increase barriers to HIV testing and treatment continuity in low- and middle-income countries [17]. Nigeria may be especially vulnerable to these disruptions because of its large HIV burden and continued dependence on donor-supported HIV services. Although domestic HIV

financing has increased over time, a substantial proportion of HIV commodities, laboratory systems, treatment programmes, and technical support mechanisms remain externally funded. Abrupt reductions in donor financing could therefore destabilize multiple interconnected components of the HIV care continuum simultaneously, including testing services, ART initiation, retention in care, viral load monitoring, and treatment adherence support.

One of the most important findings from this study was the nonlinear relationship between retained funding and epidemiological burden. Excess HIV infections and AIDS-related deaths increased disproportionately once retained funding declined below approximately 60%, suggesting the presence of programme fragility thresholds. This finding implies that HIV epidemic control may remain relatively resilient to mild reductions in financing but could rapidly deteriorate once programme disruptions exceed critical operational thresholds. Similar concerns regarding abrupt loss of epidemic control following programme destabilization have recently been raised in international modelling analyses of HIV funding cuts [15]. The study additionally demonstrated that abrupt funding withdrawal produced worse epidemiological outcomes than gradual phased withdrawal. Although both withdrawal approaches increased cumulative AIDS-related mortality, phased financing reductions attenuated the magnitude of epidemic rebound. This finding has important policy implications because it suggests that carefully planned financing transitions may partially mitigate the adverse consequences of donor withdrawal. Recent commentaries have similarly emphasised the need for structured sustainability transitions, domestic co-financing strategies, and gradual programme handovers to prevent severe service disruption in HIV-endemic countries [18].

The sensitivity analyses identified AIDS-related mortality rates and HIV transmission rates as the dominant drivers of cumulative AIDS-related deaths. Viral suppression and diagnosis rates also contributed substantially to projected uncertainty. These findings reinforce the importance of maintaining treatment continuity and viral suppression during periods of programme instability. The observed influence of viral suppression is consistent with established evidence demonstrating that effective ART substantially reduces HIV transmissibility and HIV-related mortality. Continued investment in retention-in-care programmes, viral load monitoring, and uninterrupted ART access may therefore be critical for minimising the impact of funding disruptions.

This study has several strengths. First, the model was calibrated to publicly available Nigeria-specific epidemiological and HIV care-continuum indicators obtained from UNAIDS, WHO, NACA, and PEPFAR-related sources. Second, the study evaluated multiple funding withdrawal scenarios, allowing assessment of graded programme disruption effects rather than binary programme collapse assumptions. Third, the analysis incorporated probabilistic sensitivity analysis, tornado analysis, and heatmap interaction analyses to evaluate parameter uncertainty and programme fragility. Finally, the modelling framework integrated both epidemiological outcomes and HIV care-continuum dynamics, enabling simultaneous evaluation of transmission and service-delivery consequences.

Limitations

However, this study has some limitations. First, the analysis used a deterministic compartmental modelling framework and therefore did not explicitly capture individual-level heterogeneity in HIV risk behaviour, spatial transmission dynamics, or subnational variation in health-system performance across Nigeria. Nevertheless, the model was designed primarily to evaluate population-level national policy scenarios rather than individual-level transmission pathways. Some of the epidemiological and programme parameters were derived from publicly available aggregate national estimates rather than longitudinal patient-level data. However, these estimates were obtained from widely used national and international HIV surveillance sources, including UNAIDS, WHO, NACA, and CDC/PEPFAR reports, and were further evaluated through calibration and probabilistic sensitivity analyses. Also, the model assumed proportional effects of funding withdrawal on HIV programme performance indicators, whereas real-world programme disruptions may vary across geographic regions and service-delivery domains. Nonetheless, multiple funding-retention scenarios, uncertainty analyses, and abrupt-versus-gradual withdrawal simulations were conducted to explore a broad range of plausible outcomes. In addition, the analysis did not explicitly model additional system-level disruptions such as laboratory supply interruptions, workforce migration, or macroeconomic instability, which may further influence long-term HIV outcomes.

Consequently, the projected estimates should be interpreted as policy-oriented scenario projections rather than precise forecasts of future epidemic trajectories. Further validation using longitudinal programme data and real-world post-disruption outcomes would strengthen confidence in the projected estimates.

Implications

The findings have important implications for HIV policy and programme sustainability in Nigeria and other donor-dependent settings. Sustained HIV epidemic control will likely require increased domestic financing, strengthened health-system resilience, and strategic transition planning to reduce vulnerability to external funding shocks. The findings additionally support calls for diversified HIV financing models, integration of HIV services into broader health systems, and strengthened local ownership of HIV programmes across sub-Saharan Africa [19].

Conclusion

Overall, this study suggests that substantial reductions in external HIV financing could reverse recent gains in HIV epidemic control in Nigeria, leading to worsening HIV care-continuum performance, increasing HIV incidence, and rising AIDS-related mortality. The projected burden was greatest under severe and abrupt withdrawal scenarios, highlighting the importance of sustained financing and carefully managed transition strategies for maintaining long-term HIV epidemic control.

References

1. CDC. HIV and TB Overview: Nigeria. Global HIV and TB. December 2, 2025. Accessed May 10, 2026. https://www.cdc.gov/global-hiv-tb/php/where-we-work/nigeria.html
2. Brink D ten, Martin-Hughes R, Bowring AL, et al. Impact of an international HIV funding crisis on HIV infections and mortality in low-income and middle-income countries: a modelling study. *The Lancet HIV*. 2025;12(5):e346-e354. doi:10.1016/S2352-3018(25)00074-8
3. UNAIDS U. People living with HIV who have suppressed viral loads | Indicator Registry. 2026. Accessed May 10, 2026. https://indicatorregistry.unaids.org/indicator/people-living-hiv-who-have-suppressed-viral-loads
4. UNAIDS. Nigeria | UNAIDS. 2026. Accessed May 10, 2026. https://www.unaids.org/en/regionscountries/countries/nigeria
5. NACA. 2024 ANNUAL HIV PROGRAM PERFORMANCE REVIEW - NACA Nigeria. 2024. Accessed May 10, 2026. https://naca.gov.ng/2024-annual-hiv-program-performance-review/
6. PHIS3. Nigeria National HIV Surveillance Report January 2024. Phis3project. 2024. Accessed May 10, 2026. https://www.phis3project.org.ng/phis3-resources/nigeria-national-hiv-surveillance-report-january-2024/
7. PEPFAR. The United States President's Emergency Plan for AIDS Relief - United States Department of State. United States Department of State. 2025. Accessed May 10, 2026. https://www.state.gov/pepfar/
8. WHO. HIV data and statistics. 2024. Accessed May 10, 2026. https://www.who.int/teams/global-hiv-hepatitis-and-stis-programmes/hiv/strategic-information/hiv-data-and-statistics
9. GARNETT GP, ANDERSON RM. Balancing sexual partnership in an age and activity stratified model of HIV transmission in heterosexual populations. *IMA Journal of Mathematics Applied in Medicine & Biology*. 1994;11(3):161-192. doi:10.1093/imammb/11.3.161
10. Knight J, Kaul R, Mishra S. Risk heterogeneity in compartmental HIV transmission models of ART as prevention in Sub-Saharan Africa: A scoping review. *Epidemics*. 2022;40:100608. doi:10.1016/j.epidem.2022.100608
11. J. Jaime Caro, Andrew H. Briggs, Uwe Siebert, Karen M. Kuntz. Modeling Good Research Practices-Overview: A Report of the ISPOR-SMDM Modeling Good Research Practices Task Force–1. 2012. Accessed May 10, 2026. https://journals.sagepub.com/doi/10.1177/0272989X12454577
12. Roy Anderson, Robert May. Infectious Diseases of Humans: Dynamics and Control | Oxford Academic. 1991. Accessed May 10, 2026. https://academic.oup.com/book/53038
13. Dankwa EA, Cavalli L, Balasubramanian R, et al. Calibration of transmission-dynamic infectious disease models: A scoping review and reporting framework. *PLOS Computational Biology*. 2025;21(11):e1013647. doi:10.1371/journal.pcbi.1013647

14. Briggs AH, Weinstein MC, Fenwick EAL, Karnon J, Sculpher MJ, Paltiel AD. Model Parameter Estimation and Uncertainty Analysis: A Report of the ISPOR-SMDM Modeling Good Research Practices Task Force Working Group–6. *Med Decis Making*. 2012;32(5):722-732. doi:10.1177/0272989X12458348

15. Hontelez JAC, Goymann H, Berhane Y, et al. The impact of the PEPFAR funding freeze on HIV deaths and infections: a mathematical modelling study of seven countries in sub-Saharan Africa. *eClinicalMedicine*. 2025;83. doi:10.1016/j.eclinm.2025.103233

16. United Nations. *UNAIDS GLOBAL AIDS UPDATE 2025: Aids, Crisis and the Power to Transform*. UNITED NATIONS; 2025. Accessed May 13, 2026. https://www.unaids.org/sites/default/files/2025-07/2025-global-aids-update-JC3153_en.pdf

17. WHO. Potential impact of funding cuts on the HIV response. 2025. Accessed May 13, 2026. https://www.who.int/news/item/26-03-2025-new-study-highlights-the-potential-impact-of-funding-cuts-on-the-hiv-response

18. Cluver L, Makangila G, Hillis S, et al. Protecting Africa's children from extreme risk: a runway of sustainability for PEPFAR programmes. *The Lancet*. 2025;405(10490):1700-1712. doi:10.1016/S0140-6736(25)00401-5

19. Kulohoma BW, Wesonga CA. HIV response financing challenges in Sub-Saharan Africa: barriers to achieving the 95-95-95 UNAIDS targets. *Front Public Health*. 2025;13:1658229. doi:10.3389/fpubh.2025.1658229