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Beyond Economic Determinism: Epidemic Scale, Gender Disparities, and Population-Level Health System Outcomes in the Global Human Immunodeficiency Virus Response (2024)

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Abstract

Background

Despite major global investments in HIV program, HIV remains a leading cause of mortality globally, with approximately 39 million people living with HIV and over 630,000 HIV-related deaths reported in 2024. Substantial cross-national variation in HIV-related mortality persists. While national wealth is a recognized determinant of survival, less is known about how epidemic scale, population-level health system functioning, and gender disparities jointly shape mortality outcomes in the contemporary treatment era.

Objective

This study examined the extent to which national wealth, epidemic scale, and population-level health system outcomes are associated with HIV-related mortality across countries, and assessed gender-specific disparities in HIV mortality and infection, including discordance between infection burden and mortality outcomes.

Methods

A cross-national ecological analysis of 105 countries with established HIV epidemics using 2024 data from the Joint United Nations Programme on HIV/AIDS (UNAIDS) and the World Bank was conducted. HIV mortality-to-prevalence ratios were analyzed in relation to GDP per capita, epidemic scale (people living with HIV), and world region using multivariable log-linear regression models with heteroskedasticity-robust (HC3) standard errors. Model-based standardized residuals were examined to identify countries with higher- or lower-than-expected mortality. Gender-disaggregated analyses assessed regional heterogeneity and discordance between HIV infection and mortality by sex.

Results

HIV mortality-to-prevalence ratios varied widely across countries (median 1.37%; range 0.10–7.62%). Higher GDP per capita was independently associated with lower HIV mortality ($\beta = -0.19$, $p = 0.008$), while larger epidemic scale was also associated with reduced mortality intensity ($\beta = -0.13$, $p = 0.001$). The multivariable model explained 44.5% of cross-country variation. Residual analyses identified both positive deviance and marked underperformance across regions and income levels. Globally, mean HIV mortality did not differ significantly between men and women; however, pronounced regional heterogeneity was observed. A male disadvantage paradox, higher male mortality despite lower infection burden was evident in several countries and was strongly associated with lower national wealth ($\rho = -0.70$, $p < 0.001$).

Conclusions

HIV mortality in 2024 reflects not only economic resources but also differences in epidemic scale, population-level health system outcomes, and gender-related inequities. Addressing persistent mortality gaps will require public health strategies that prioritize equity, system adaptation, and gender-responsive HIV responses beyond reliance on national wealth alone.

Introduction

Although there has been significant progress globally in HIV prevention, testing, and treatment over the last twenty years, HIV/AIDS is still one of the leading causes of death world-wide. By 2024 it was estimated that approximately 630,000 deaths were caused by HIV related illnesses; however, since 2010 there has been a notable decline in mortality rates due to increased access to antiretroviral therapy and continued public health initiatives (1). The inequality in HIV related deaths is also apparent in the geographic distribution of these deaths, as low- and middle-income countries in Sub-Saharan Africa bear a disproportionately high percentage of the global burden (1). It should be noted that this inequality is based on more than just financial resources; rather, it is influenced by the structural and contextual barriers that affect access to HIV care, treatment availability and the sustainability of HIV responses at a national level (1).

In addition to the geographic and country specific inequalities seen in HIV/AIDS deaths, there continue to be persistent gender-based inequalities in the global response to HIV/AIDS. Men have consistently demonstrated lower HIV testing, treatment initiation, and HIV treatment retention in comparison to women, which contributes to the observed difference in HIV-related outcomes based on gender (2, 3). Although gender-based inequalities in HIV-related outcomes have been identified, these inequalities are rarely studied in combination with other national level characteristics such as epidemic scale and gender-based barriers. This lack of equity in the global response to HIV/AIDS suggests that analysis beyond aggregate wealth measures is necessary to identify how the interaction between epidemic scale and gender-based barriers interact to influence HIV mortality across countries.

Mortality declines since the early 2000s have contributed to global gains in life expectancy. However, despite this global progress there remains significant disparity in mortality rates among countries with similar levels of economic development. As a result, it is clear that wealth alone cannot be used as a sole indicator to measure differences in mortality (1, 4). The emphasis on Gross Domestic Product (GDP) per capita has often overshadowed other population level influences such as the scale of epidemics, cumulative responses to those epidemics, and continued socioeconomic inequality as contributing factors to differing mortality rates across countries (4, 5). Additionally, few studies have examined how sex specific inequities throughout the HIV care continuum contribute to varying mortality rates across geographic regions (6).

The purpose of this research was to address these gaps through a study to determine if the scale of an epidemic and sex specific inequity in mortality rates related to HIV infection can be attributed to factors beyond wealth of a nation in 2024. Through the use of a cross-national ecological public health framework, we analyzed country level data from UNAIDS and the World Bank to determine if differences in mortality rates exist even when adjusting for GDP per capita, size of the epidemic, and region. Specifically, we sought to: (i) determine the relationship between national wealth and HIV related mortality in the post pandemic context; (ii) investigate sex specific inequity in mortality and determine regional patterns of male disadvantage; and (iii) characterize cross-national variation in mortality relative to epidemic burden, identifying countries with lower- or higher-than-expected mortality outcomes. We accomplished this by employing multiple variable log linear regression analysis, gender-stratified analyses, and residual-based approaches to provide an integrated population-based evaluation of structural factors influencing HIV mortality across countries.

Methodology

Study design

A cross-sectional comparative ecological design was used with countries being the unit of analysis to determine how much the degree of wealth in a country, the size of the HIV epidemic, and gender disparities in a country relate to HIV mortality rates beyond the use of economic factors. This design provides an applicable framework for comparing the functioning of systems and evaluating the differences in health-related outcomes between different nations.

Data sources

A secondary, publicly accessible data from two established, international organizations was used to generate our estimates of HIV related indicators. UNAIDS provided us with data regarding the number of individuals who live with HIV (PLHIV) and the number of adult deaths due to AIDS, by sex. National economic data from the World Bank were used to represent national wealth (2024), using Gross Domestic Product (GDP) per Capita (current U.S. Dollars).

Study population and inclusion criteria

The original database used in this study had data on HIV estimates for over 170 countries. To help ensure the data we were to analyze were both reliable and biologically valid, we pre-determined and applied a set of eligibility and exclusion criteria. Eligible countries were those for whom complete data existed on HIV mortality, HIV Prevalence (PLHIV) and GDP per Capita. Excluded from this study were countries with less than 1000 Adults Living with HIV to minimize the effects of stochastic variability associated with small epidemic sizes. Countries with a biologically implausible ratio of mortality to prevalence greater than 20% were also excluded since it is unlikely that such high mortality rates could occur given the widespread availability of Antiretroviral Therapy (ART) for PLHIV in 2024; these ratios are likely due to errors in the reporting or denominators of either HIV Mortality or Prevalence. Our sample of

105 countries represented all six WHO Regions and provided analytical stability and epidemiologic relevance.

Ethical considerations

The data collected from this study were all secondary, publicly accessible, and compiled at the national level without any personal identifiable information. Therefore, there were no requirements for ethical review or informed consent under Institutional and International Guidelines.

Variables and measures

- **HIV-related mortality**: The mortality-to-prevalence ratio was used as a way to operationalize HIV-related mortality. The mortality-to-prevalence ratio is defined as the number of AIDS-related deaths divided by the number of individuals with HIV in a particular country and year. Since this ratio will vary based upon the size of the epidemic within a country, it serves as an annual proxy for mortality intensity allowing comparisons to be made across different countries with varying levels of epidemic intensity. Although the mortality-to-prevalence ratio is not a true case fatality rate, it has been commonly used in comparative studies when longitudinal individual level data are not available. Due to the lack of standardized survival data at the global level, the mortality-to-prevalence ratio can serve as a practical population-based indicator to compare mortality rates across different locations. To correct for right skewness and to facilitate interpretation in regression models, the mortality-to-prevalence ratio was log transformed.
- **National wealth**: National wealth was measured by GDP per capita in current US dollars as reported by the World Bank. Prior to analysis, GDP per capita was log transformed to address non-linear relationships between wealth and health outcomes and to enable the interpretation of regression coefficients as elasticities
- **Epidemic scale**: Epidemic scale was defined as the total number of adults living with HIV (PLHIV) in each country. This variable was included as a proxy for programmatic maturity and health system experience in HIV service delivery. Epidemic scale was log-transformed to reduce skewness and minimize the influence of extreme values.

Gender-specific indicators

Separate gender-specific mortality ratios were calculated for men and women using sex disaggregated UNAIDS estimates. A gender mortality gap was defined as the ratio of male to female mortality-to-prevalence ratios, with values greater than one representing greater mortality among men relative to women. Gender-specific analyses were conducted to identify regional patterns of male disadvantage in HIV mortality.

Antiretroviral therapy (ART) coverage was not included as a covariate in the multivariable models due to substantial missingness across countries and high collinearity with GDP per capita, which could compromise model stability and interpretability.

Statistical analysis

- Descriptive statistics were used to summarize country characteristics overall and by world region, including national wealth, epidemic burden, and HIV-related mortality indicators. Continuous variables were summarized using means, medians, and interquartile ranges, as appropriate.
- Bivariate associations between national wealth (GDP per capita) and HIV-related mortality were assessed using Spearman's rank correlation coefficient due to non-normal distributions.
- Multivariable log-linear regression models were then fitted to estimate the independent association between HIV-related mortality and national wealth, epidemic scale (people living with HIV), and world region. All continuous predictors were log-transformed to improve model fit and facilitate interpretation of coefficients as elasticities. Model assumptions were assessed through visual inspection of residual distributions and standard diagnostic plots.
- Model residuals from the multivariable regression were analyzed to identify countries with mortality outcomes that deviated substantially from model-based expectations. Standardized residuals were used to characterize relative over- and under-performance, providing an additional, model-informed perspective on health system performance beyond crude mortality levels. Countries with consistently negative residuals indicating lower-than-expected mortality relative to epidemic burden and economic context were interpreted as demonstrating positive deviance.
- To examine gender-specific disparities in HIV mortality, gender-stratified mortality-to-prevalence ratios were calculated for men and women. Paired statistical comparisons were conducted to assess differences between male and female mortality at the country level, and regional heterogeneity was examined using stratified analyses.
- Geospatial visualizations were used to explore the geographic distribution of epidemic burden, HIV-related mortality, gender disparities, and health system performance categories. Country-level maps were generated to support descriptive interpretation of regional clustering and global patterns. These visual analyses were intended to complement statistical findings rather than to perform formal spatial inference.

All analyses were conducted using reproducible statistical workflows implemented in Python within Jupyter Notebook environments. The full analytical code and processed datasets are available in a publicly accessible GitHub repository. As this study relies on aggregated country-level indicators, inferences regarding health system performance should be interpreted as population-level proxies rather than direct assessments of service delivery. Statistical significance was assessed at a two-sided alpha level of 0.05.

Results

Descriptive statistics

The study population consisted of 105 countries with established HIV epidemics and are located in every WHO (World Health Organization) Region. Africa had the highest percentage (43.8%) of countries represented in this sample, followed by Asia, the Americas, Europe, and Oceania. The median HIV Mortality-to-Prevalence Ratio was 1.37%with values ranging from 0.10% to 7.62%, indicating more than a 70-fold variation in mortality intensity across countries. Countries also exhibited wide variations in wealth as measured by Gross Domestic Product (GDP) per capita ranging from $219 to $112,895. There is large variation in the number of persons living with HIV within countries, with some countries reporting less than 2,000 persons and other countries reporting over 7.7 million persons infected. There was little difference in the mean Mortality-to-Prevalence Ratios for men and women at the global level (Table 1).

Table 1
Characteristics of the study sample (N = 105 countries)

Variable	Mean (SD)	Median	Min–Max
GDP per capita (USD)	12,274 (20,584)	4,413	219–112,895
HIV mortality-to-prevalence ratio (%)	1.63 (1.15)	1.37	0.10–7.62
Female mortality ratio (%)	1.97 (1.66)	1.41	0.12–8.62
Male mortality ratio (%)	1.88 (1.29)	1.67	0.06–6.63
People living with HIV	280,642 (839,546)	50,000	1,900–7,700,000
Region	**Countries, n (%)**		
Africa	46 (43.8%)		
Asia	21 (20.0%)		
Americas	18 (17.1%)		
Europe	17 (16.2%)		
Oceania	3 (2.9%)		

Association between national wealth and HIV-related mortality

Figure 1 illustrates the bivariate association between GDP per capita and HIV-related mortality using a log scale. There was a strong inverse relationship as higher wealth at the country level is generally related to lower HIV mortality-to-prevalence ratios. The use of Spearman's rank correlation analysis showed there was a moderate to strong negative association between GDP per capita and HIV-related mortality ($\rho \approx -0.53$, $p < 0.001$).

Figure 1. Association between GDP per capita and HIV mortality-to-prevalence ratio across 105 countries (log–log scale).

Although the general association was evident, a significant amount of scatter in the data was visible surrounding the regression trend line showing a visual evident that countries with the same levels of GDP per capita had significantly different mortality results; a number of low- and middle-income countries had achieved mortality rates that were as good or better than many of the wealthier countries. In contrast, several countries that had a larger GDP per capita than others had higher mortality rates than their economic peer groups. This indicates that although national wealth is still an important variable related to HIV mortality rates, the size of a country's GDP per capita is not sufficient to explain all of the variability of HIV mortality rates across countries, and therefore the need for multivariable analyses incorporating epidemic scale and system-level factors.

Multivariable regression analysis

Table 2 displays the results of multivariable log-linear regression models to assess if HIV-related mortality is related to national wealth, the size of the epidemic, and world region. When controlling for the size of the epidemic and region, the association between national wealth (GDP) and HIV-related mortality did not change direction, although it was reduced in magnitude as compared to the bivariate analysis. The size of the epidemic also independently predicted HIV-related mortality, such that larger epidemics had lower mortality-to-prevalence ratios after controlling for both GDP per capita and region. Regional variations continued to exist within the adjusted model indicating there are significant variations between world regions. The model diagnostic statistics indicated a good model fit; however, the residual analysis revealed a large degree of unexplained variability which led to further investigation of how each country deviated from model-predicted values.

Table 2
Multivariable log-linear regression of HIV mortality-to-prevalence ratio (N = 105 countries)

Variable	Coefficient (β)	Std. Error	95% CI	p-value
Intercept	3.49	0.73	2.04 to 4.94	**< 0.001**
Region (ref: Africa)				
Americas	−0.55	0.20	−0.95 to − 0.14	**0.009**
Asia	−0.15	0.17	−0.49 to 0.19	0.382
Europe	−0.91	0.27	−1.44 to − 0.38	**0.001**
Oceania	−0.10	0.37	−0.84 to 0.64	0.788
Log GDP per capita	−0.19	0.07	−0.33 to − 0.05	**0.008**
Log epidemic scale (PLHIV)	−0.13	0.04	−0.20 to − 0.06	**0.001**
Dependent variable: log(HIV mortality-to-prevalence ratio)				

R^2 = 0.445 | Adjusted R^2 = 0.411 | F-statistic = 10.33 ($p < 0.001$) | AIC = 190.8 | BIC = 209.4

Coefficients are from ordinary least squares (OLS) regression models with log-transformed continuous variables. Africa is the reference category for world region. Confidence intervals and p-values are based on heteroskedasticity-robust standard errors (HC3).

Model-based deviance in HIV mortality

Standardized residuals from the multivariable regression model identified a small subset of countries exhibiting extreme deviations from model-predicted HIV mortality (|standardized residual| ≥ 2) after adjustment for national wealth, epidemic scale, and region (Fig. 2; Table 3).

Two countries demonstrated lower-than-expected mortality, consistent with positive deviance: Germany (standardized residual = − 2.39) and Azerbaijan (− 2.07). In contrast, three countries exhibited higher-than-expected mortality, including Latvia (3.28), Indonesia (2.39), and Djibouti (2.17). These deviations were observed across multiple regions and income levels, indicating substantial heterogeneity in mortality outcomes beyond model-predicted expectations.

Figure 2. Countries with higher- and lower-than-expected HIV mortality after multivariable adjustment (2024).

Table 3
Countries exhibiting extreme deviations from model-predicted HIV mortality (|standardized residual| ≥ 2), 2024

Country	Region	GDP per capita (USD)	People living with HIV	Mortality-to-prevalence ratio (%)	Standardized residual
Positive deviance (lower-than-expected mortality)					
Germany	Europe	56,104	97,000	0.10	−2.39
Azerbaijan	Asia	7,284	9,800	0.51	−2.07
Underperformance (higher-than-expected mortality)					
Djibouti	Africa	3,553	8,000	7.63	2.17
Indonesia	Asia	4,925	550,000	4.00	2.39
Latvia	Europe	23,409	6,000	4.17	3.28

Note: *Countries were classified using heteroskedasticity-robust (HC3) standard errors from the multivariable regression model adjusting for GDP per capita, epidemic scale, and world region. Negative residuals indicate lower-than-expected mortality (positive deviance), and positive residuals indicate higher-than-expected mortality. Countries with |standardized residual| ≥ 2 were considered extreme deviations.*

Gender disparities in HIV mortality

Global result from gender-disaggregated analysis of HIV mortality was very variable, and significantly different between the various geographic areas and countries examined. Although there were no statistical differences at the global level when comparing mortality prevalence ratios by sex, 1.88% for males and 1.97% for females (paired t-test p = 0.61; Wilcoxon signed-rank test p = 0.54), there were considerable variations of mortality prevalence ratios among regions. The distribution of mortality prevalence ratios, as illustrated in Fig. 3A, were substantially different by sex within each geographic region. In the African region, it appeared that males had a greater mortality risk than females, with median mortality ratios being 2.27% for males and 1.25% for females (male to female ratio 1.81), while females exhibited an increased mortality risk than males in the European, Asian and American regions (Fig. 3A). The smallest sex differences were observed in the Oceania region. Mapping of geographic locations also demonstrated that gender-based mortality from HIV were not uniformly distributed (Fig. 3B). Those countries showing the greatest differential in male mortality prevalence compared to female mortality prevalence were located primarily in specific geographic regions in Africa, while other countries/regions showed the inverse pattern. These demonstrate significant variability in gender-specific HIV mortality, which cannot be assessed using global average values.

Gender disparities in HIV infection and the male disadvantage paradox

Infection rates among both men and women exhibited significant variations from one country to another. In a number of nations in sub-Saharan Africa, HIV infection was more prevalent among females while in many other nations, primarily located in Europe, Asia, and the Americas, HIV infection was far more prevalent among males indicating that that gender disparities in HIV infection are strongly context-dependent and geographically patterned.

Figure 4. Gender disparities in HIV infections: male-to-female prevalence ratios by country (2024).

When examining infection rates and gender-specific mortality in the same nations, our results revealed a pronounced discordance in many settings. For example, while some countries clustered near the neutrality line indicating proportionality between infection burden and mortality by sex, a substantial number of countries occupied the upper-left quadrant of the plot, characterized by higher male mortality despite a greater burden of infection among women. This pattern defines a male disadvantage paradox which describes the phenomenon of men experiencing a disproportionate number of deaths due to HIV when compared to their infection rates. Figure 5 displays the joint distribution of the infection gap and the mortality gap by country

This paradox was evident in a number of African nations, where female infection predominance coexisted with excess male mortality. The wide dispersion of points around the neutrality line underscores substantial between-country heterogeneity in the relationship between gendered infection and mortality outcome

Exploratory analyses further indicated a strong association between national wealth and the magnitude of male disadvantage. Higher GDP per capita was strongly and inversely correlated with the male

disadvantage index (Spearman's $\rho = -0.70$, $p < 0.001$), suggesting that excess male mortality relative to infection burden was more pronounced in lower-income settings.

Discussion

Our study provides a country-wide evaluation of the current mortality from HIV infection in 105 nations by combining the national wealth and the size of the HIV epidemic, along with gender-differentiated outcome measurements. Our results indicate that there is still a strong relationship between wealth of a nation and the likelihood of survival of those living with HIV, yet that there is also considerable cross-nation variability in mortality remaining after accounting for wealth of the nation. This variability suggests that it will take more than just financial means to understand why some countries have different mortality rates from HIV infection when there is such effective treatment available today and that other structural and contextual factors continue to affect the overall mortality rates due to HIV in many countries.

This finding is consistent with previous global studies that indicated that having greater national income was independently associated with a decreased rate of mortality from HIV infection, even after adjusting for the scale of the epidemic and geographic location (7, 8). However, the attenuation of the GDP effect in multivariate models and the large amount of variation in mortality rates between countries with equal amounts of national wealth indicates that economic resources alone cannot account for the variations in mortality rates from HIV infection. Therefore, our results support the differentiation between the availability of resources and the actual outcomes that result at the population level and highlight that while two countries may have equal levels of national wealth, they may have very different mortality rates from HIV infection.

Epidemic scale was found to be an independent predictor of the intensity of HIV mortality, with larger epidemics having a lower ratio of mortality to prevalence of HIV infection after adjusting for wealth of the nation and regional context. Epidemic scale may serve as a proxy at the population level for cumulative systems adaptation and the continuous prioritization of HIV responses in countries that have had generalized epidemics for many years. Prior global studies have demonstrated that large-scale HIV responses are often associated with improved survival outcomes over time as a function of increased coverage of treatment and continuous programming on HIV response, regardless of the level of resources available in each country (8–10). Importantly, this finding should be interpreted as a population-level association rather than evidence of superior service delivery or care quality at the individual level.

The residual-based analysis identified which countries had HIV mortality rates that were far above and far below what would have been expected based upon their national wealth and epidemic characteristics. The identification of both positive deviance and significantly suboptimal performance of countries across all regions and levels of national wealth highlights that national wealth and epidemic burden do not provide a complete constraint of mortality rates from HIV infection. From a public health

perspective, our positive deviance analysis provides a useful hypothesis-generating framework, drawing attention to contextual and structural factors that may support better-than-expected outcomes without implying direct causality or transferability of specific practices (11). In contrast, countries with mortality rates that exceed expectation may reflect the cumulative effects of social, structural, and/or systemic barriers that reduce the effectiveness of the HIV responses in reducing mortality rates at the population level.

Gender-disaggregated analyses revealed that apparent global similarity in HIV mortality between men and women masked substantial regional and country-level heterogeneity. In sub-Saharan Africa, HIV mortality trends were substantially greater among males than females. Conversely, female mortality trends predominated in several other geographic locations. These patterns provide additional support to prior research demonstrating pronounced sex-based differences in HIV outcomes in a variety of settings, and demonstrate the inadequacy of global averages to capture gender-based health disparities (12–13).

The heterogeneity in male/female HIV mortality trends demonstrated in our study provides evidence of the importance of conducting regionally-stratified analyses to understand the ways in which gender interacts with social and structural determinants of HIV mortality.

By jointly examining gender-specific infection and mortality patterns, our study documents and provides a demonstration of the "male disadvantage paradox" in generalized epidemics settings. In many countries, especially in Africa, women accounted for a larger share of people living with HIV, yet men experienced disproportionately higher mortality. This dissonance implies that while infection burden can translate into a high likelihood of mortality, it is not always the case that survival outcomes will reflect the burden of infection and suggests the presence of gender-specific barriers across the HIV care continuum towards men in the African context. Prior research has identified lower rates of HIV testing among men, delayed entry into antiretroviral therapy, and poor retention in care as potential contributors to excess male mortality at the population level (14–17).

The strong inverse relationship between national wealth and the degree of male disadvantage also indicates that gender-based mortality inequities are increased in low-resource settings. Structural vulnerabilities associated with economic constraint may disproportionately affect men, who often exhibit lower engagement with preventive and curative health services. However, the observation of significant variability in male disadvantage among countries with similar GDP per capita indicates that economic development alone cannot eliminate gender disparities in HIV outcomes (18). This finding supports evidence from global public health regarding how social norms, access barriers and context determine health inequities beyond income gradients (6, 19–20).

These findings highlight the importance of population-level structural conditions and gender-responsive public health strategies in reducing HIV-related mortality. Efforts to address excess male mortality and to learn from countries that outperform expectations may offer valuable pathways for advancing equity and effectiveness in the global HIV response. Our finding reinforce the value of population-level

comparative analyses in identifying structural inequities and prioritizing target areas for public health action in the global HIV response

Strengths and Limitations

Our study has several notable strengths. First, it leverages the most recent globally harmonized HIV estimates available (2024), providing timely insights into post-pandemic patterns of HIV mortality at a critical juncture in the global response. Second, the use of a standardized mortality-to-prevalence ratio enables meaningful comparison of mortality intensity across countries with widely differing epidemic sizes, facilitating population-level assessment of survival outcomes. Third, the analytical framework integrates multivariable modeling with residual-based deviance analysis, allowing identification of countries that substantially outperform or underperform expectations given their economic and epidemiological context. This approach moves beyond descriptive comparisons and provides a novel lens for examining health system performance at the population level. Fourth, the explicit incorporation of gender-disaggregated mortality and infection indicators enables identification of the male disadvantage paradox, an underexplored dimension of HIV inequality in cross-national analyses. The combination of statistical modeling, stratified analyses, and geospatial visualization strengthens the interpretability and policy relevance of the findings by highlighting both global gradients and regional heterogeneity. Finally, the use of transparent, reproducible analytical workflows and publicly available data enhances the robustness and replicability of the study, supporting its contribution to comparative global public health research. However, a number of limitations must be recognized. First, the ecological nature of the analysis precludes making causal inferences and does not allow attributing the associations observed to mechanisms occurring at an individual level. Second, relying upon aggregated national indicators limits the ability to assess directly the delivery of health services, the quality of care and the implementation of policies. Accordingly, interpretations related to health system performance should be understood as population-level proxies rather than direct measures of service provision. Third, national averages may mask sub-national heterogeneity in HIV outcomes.

Conclusion

This multi-country study provides evidence that HIV-related death in the modern treatment era is influenced by more than national wealth. National wealth is still associated with better survival rates; however, there is significant variation among countries with similar incomes reflecting differences in health system organization, service delivery capacity, and programmatic maturity.

The results highlight the importance of epidemic scale as a marker of service readiness, suggesting that countries managing larger HIV burdens may benefit from more established and efficient care delivery platforms. At the same time, the results of the model-based deviance analyses indicate that there are many countries which exceed or fall short of their expected performance based upon their economies and their HIV epidemics, highlighting the importance of health system performance beyond the limitations imposed by structure.

In addition, gender-disaggregated analyses demonstrate that while there appears to be a global equality in HIV mortality, there is a large degree of inequality in terms of regions and countries. The fact that many countries continue to experience a greater risk of death due to HIV among males, although the prevalence of HIV among males is less than that among females, highlights gaps in service access, engagement and retention for males. The male disadvantage paradox must be addressed through the purposeful design of HIV service delivery models to facilitate equitable, gender-responsive pathways to care.

Taken collectively, the results of this study provide strong support for the need for HIV strategies which focus on how services are provided, delivered and modified according to the characteristics of the local epidemic and the population. Increasing HIV outcomes globally will require a commitment to both continued funding and learning from high performing health systems, reducing gaps in service delivery and incorporating equity focused approaches, specifically, gender responsive approaches into national HIV responses. Future research integrating facility-level service delivery indicators with national surveillance data will be essential to translate these population-level insights into actionable health system reforms.

Declarations

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Ethics approval and consent to participate: This study is a secondary analysis of publicly available, aggregated, and anonymized country-level data obtained from UNAIDS and the World Bank. The data contain no individual-level identifiers and pose no risk to human participants. In accordance with institutional and international research ethics guidelines, formal ethical approval and informed consent were not required for this analysis.

Consent for publication: Not applicable.

Clinical trial number: Not applicable.

Availability of data and materials: All data used in this study are publicly available from UNAIDS (https://aidsinfo.unaids.org/) and the World Bank databases (https://data.worldbank.org/indicator/NY.GDP.MKTP.CD). The processed datasets and analytical scripts

supporting the findings of this study are available with the corresponding author upon reasonable request.

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Authors' contributions

Komi Selassi Gayi (K.S.G.) conceptualized the study, developed the analytical framework, conducted the literature review, performed data extraction and statistical analyses, interpreted the findings, and drafted the original manuscript.

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J. Kezia Angeline (J.K.A.) contributed to data visualization, figure preparation, and methodological refinement.

Jennifer H. Gladius (J.H.G.) and Alex Joseph (A.J.) provided senior academic supervision, contributed to methodological guidance, and critically revised the manuscript for important intellectual content.

All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Figures

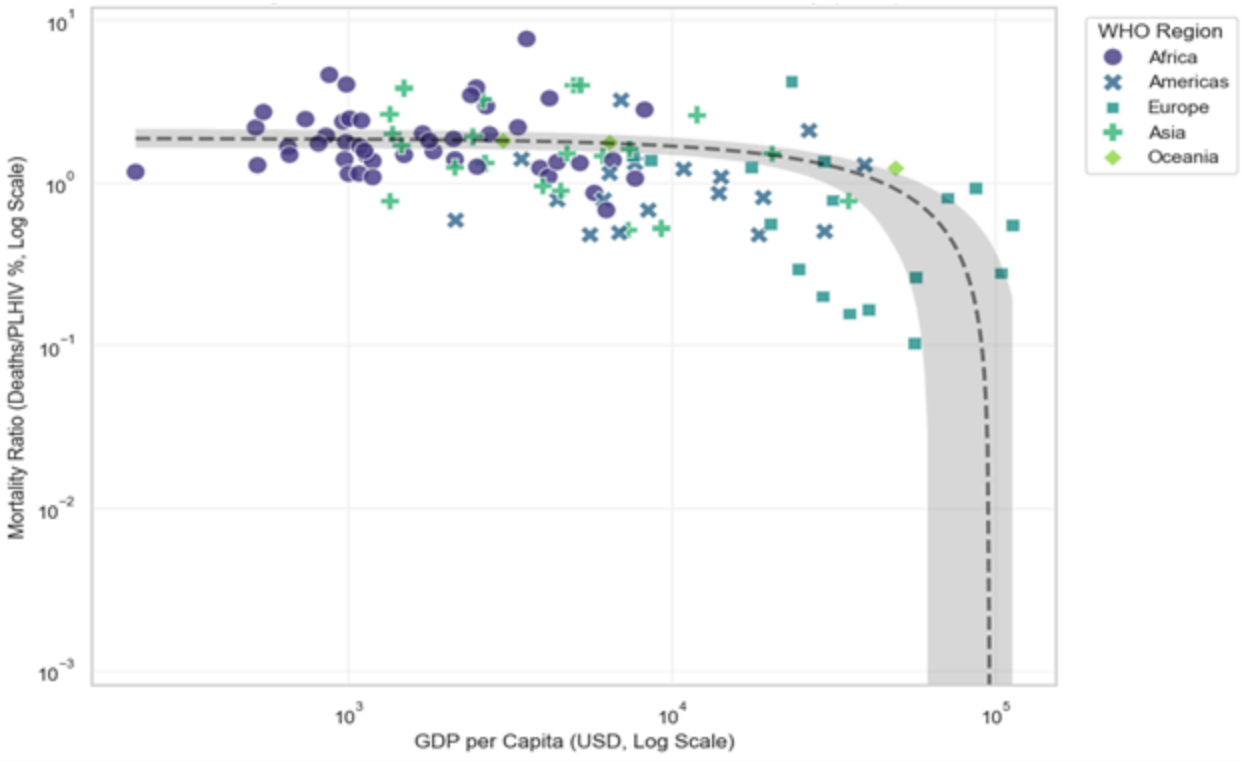


Figure 1

Association between GDP per capita and HIV mortality-to-prevalence ratio across 105 countries (log–log scale).

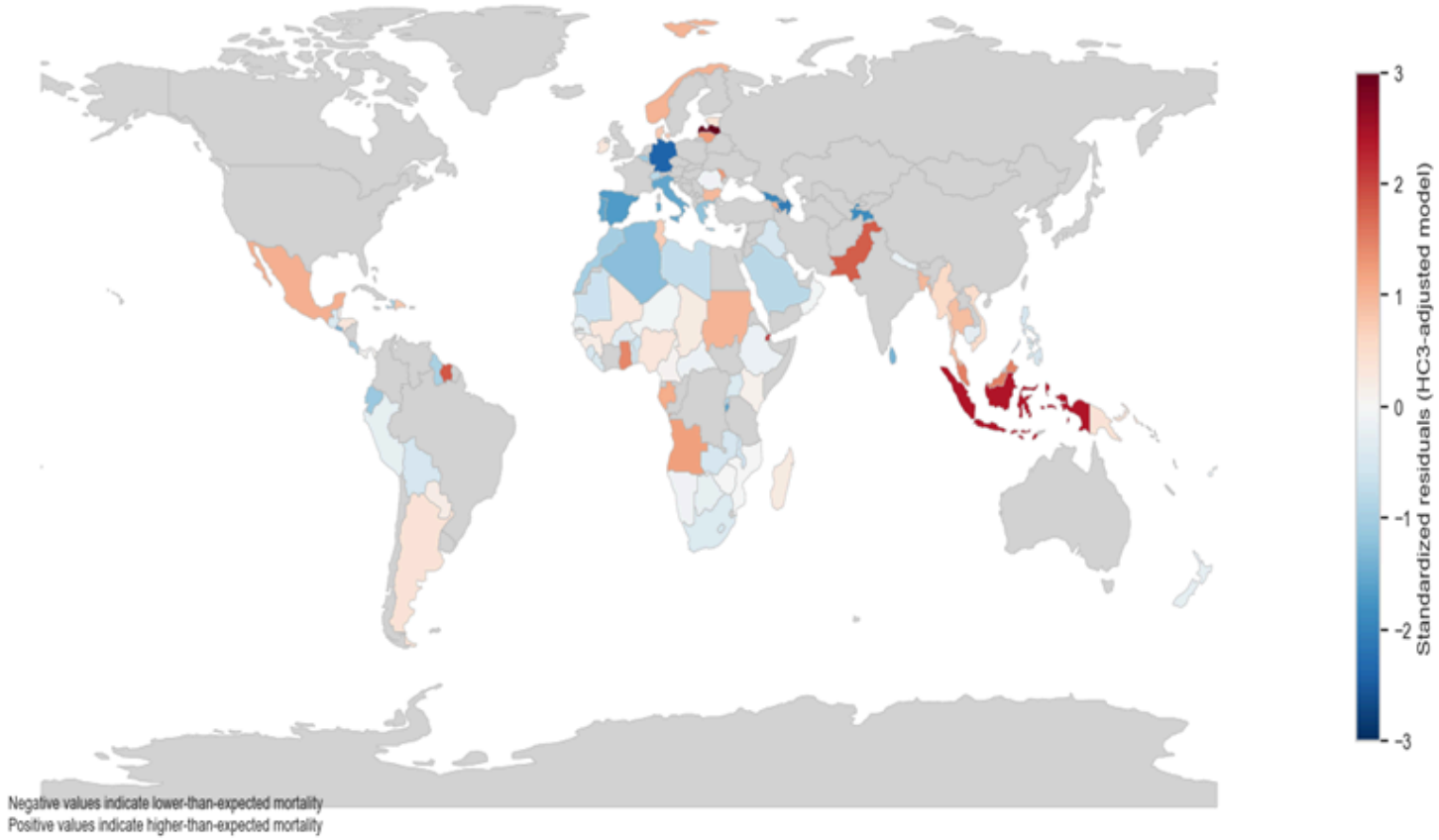


Figure 2

Countries with higher- and lower-than-expected HIV mortality after multivariable adjustment (2024).

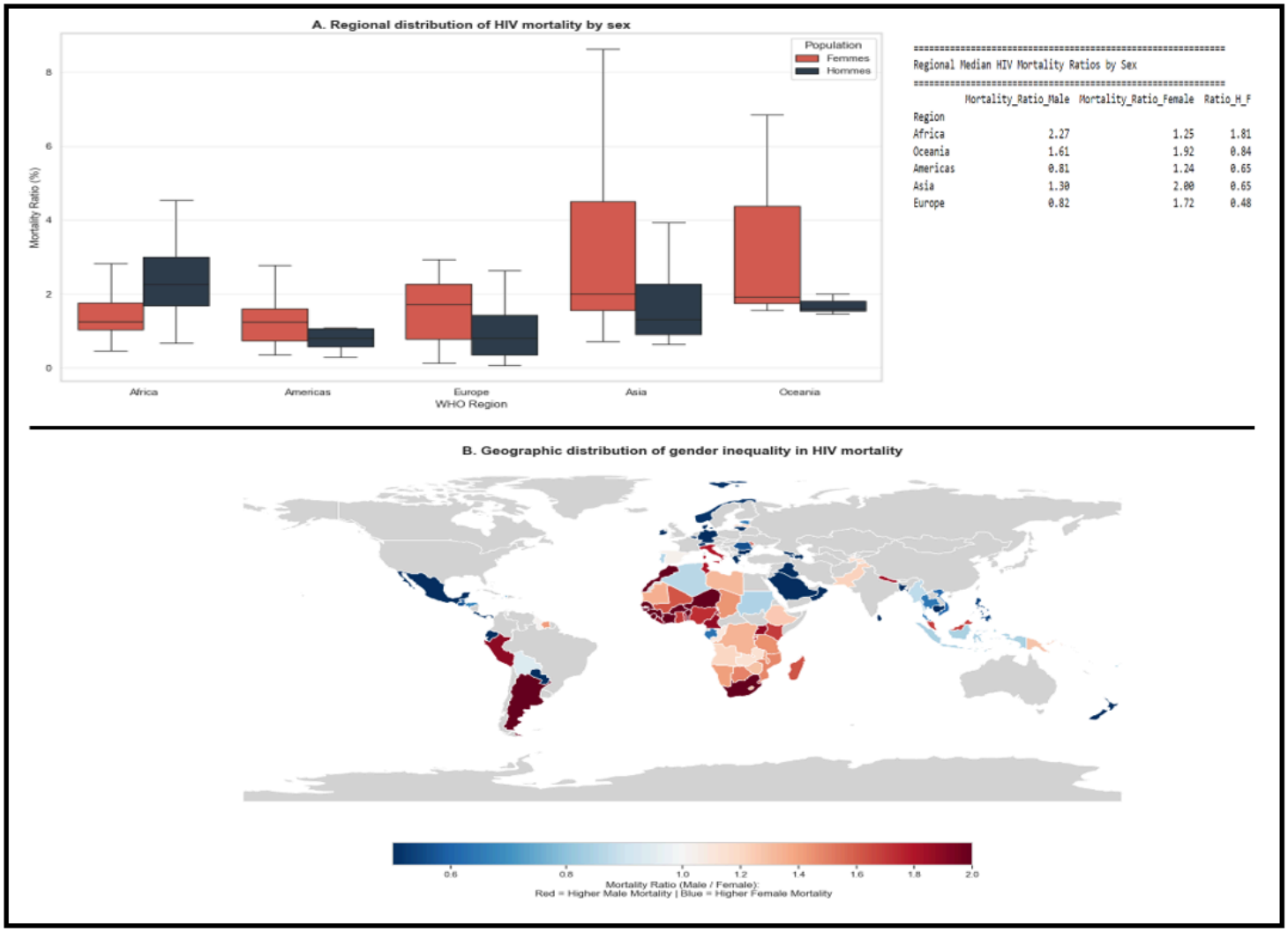


Figure 3

Gender disparities in HIV mortality across regions and countries (2024).

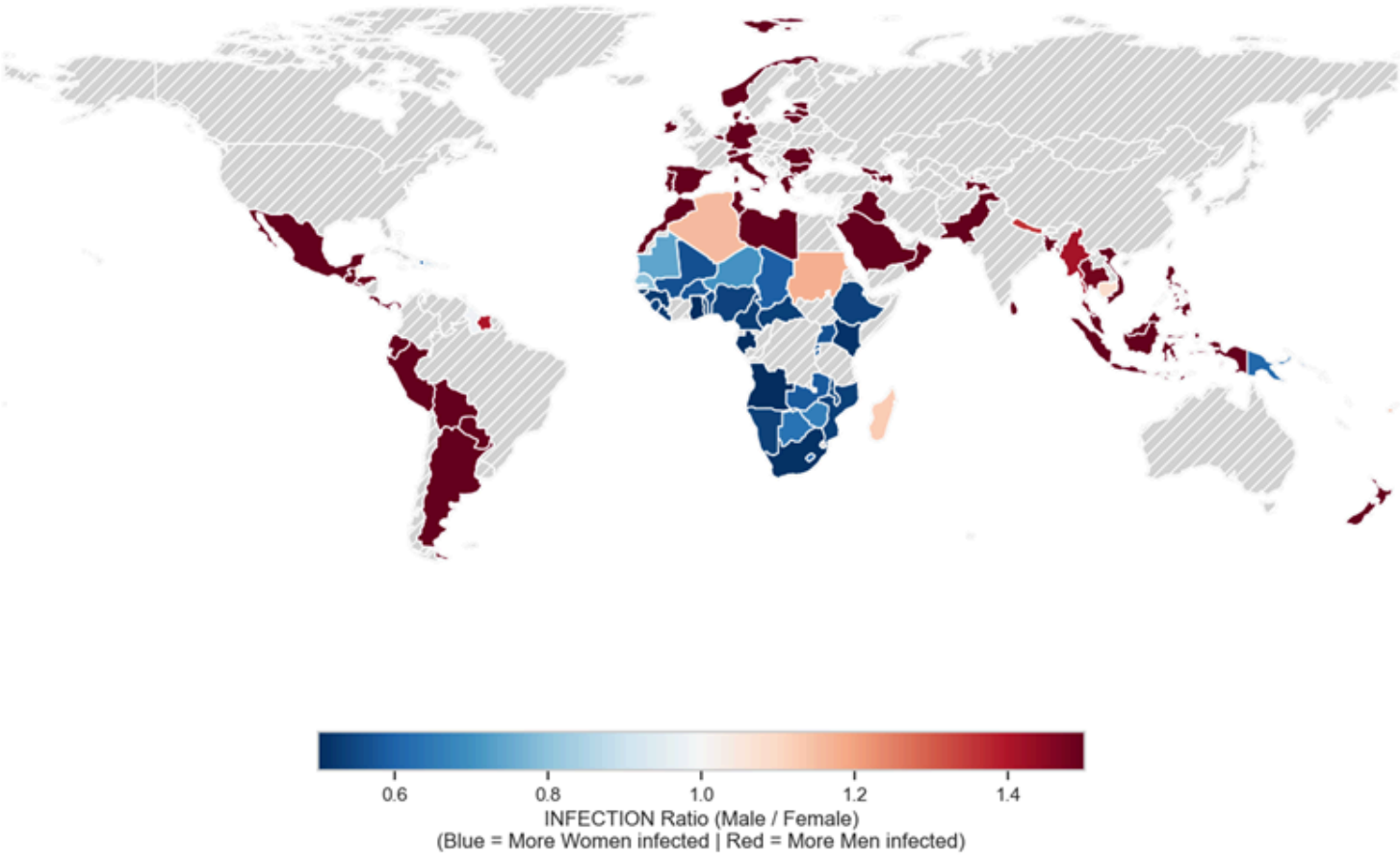


Figure 4

Gender disparities in HIV infections: male-to-female prevalence ratios by country (2024).

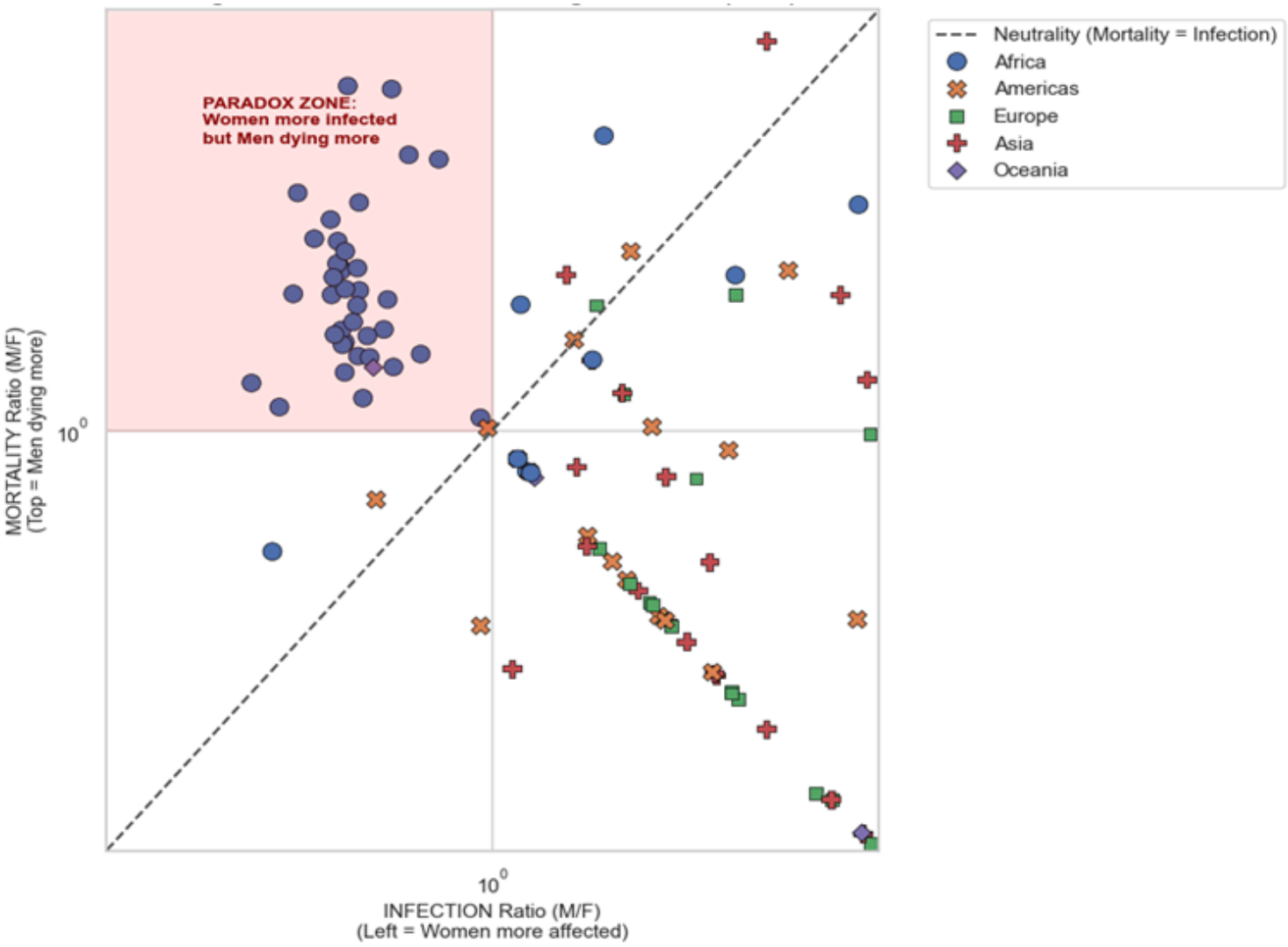


Figure 5

Discordance between gender-specific HIV infection and mortality across countries (2024).