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Population-Level AIDS Mortality Is Dominated by Prevalence Stock, Not Treatment Performance: A Boundary-Aware Decomposition of Provincial Disparities in China

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Article

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Additional Declarations: No competing interests reported.

Abstract

Background

Reported AIDS deaths in China are all-cause deaths among cumulatively reported people living with HIV (PLHIV). Provincial population-level AIDS mortality varies roughly 23-fold (90th-to-10th percentile); whether this reflects treatment failure or epidemic history has not been bounded.

Methods

We decompose the 2022 provincial gap using the identity mortality/100k = prevalence/100k × deaths per PLHIV. The southwest epidemic belt was defined exogenously, before inspecting mortality, as first- and second-order provinces on the injection-drug transmission chain radiating from Yunnan in the 1990s: Guangxi, Guizhou, Sichuan, Chongqing, and Yunnan. We stress-test the belt-to-other ratio under death-registration capture asymmetry c_other/(c_other − 0.20) for c_other = 1.0, 0.8, 0.67, 0.57; a cumulative-ever denominator allocating 50–70% of cumulative deaths to the belt; alternative belt definitions; exclusion of the six provinces whose PLHIV stock is extrapolated; and joint combinations of these. Bootstrap intervals (20,000 draws) quantify Poisson-level uncertainty. National 2015–2022 trends provide temporal corroboration and are compared with independent estimates from the Chinese HIV/AIDS Comprehensive Response Information Management System (CRIMS).

Results

In 2022 the belt had 4.69 AIDS deaths per 100,000 versus 0.61 elsewhere (ratio 7.7×). Decomposition attributes 79% (bootstrap 78–80%) of the gap to PLHIV prevalence (5.0×) and 21% to a per-PLHIV death rate of 1.53× (bootstrap 1.49–1.58). Across all single stress tests the per-PLHIV ratio ranges 1.3–2.4× and the stock share stays 65–88%; under joint worst-case combinations (cumulative denominator plus 20-point capture asymmetry) the stock share remains 62–75%. Restricting to 22 provinces with officially reported stock yields R_rate = 1.80× and a significant positive correlation (Spearman ρ = 0.44, P = 0.04). If belt per-PLHIV mortality fell to the other-group mean, belt deaths would fall by 34%; even after that equalization, a 5.0× prevalence-driven gap would remain. Nationally, prevalence per 100,000 doubled 2015–2022 while deaths per PLHIV fell 31%; net population mortality rose 43%.

Conclusions

Between two-thirds and four-fifths of the provincial AIDS mortality gap is structural epidemic history; the per-patient survival residual ranges from roughly one-fifth (primary estimate) to slightly over one-third (under the most adverse combined assumptions), with R_rate itself bounded at 1.3–2.4× across specifications. Population-level AIDS mortality conflates where PLHIV live with how well they are treated;

our results support moving provincial program ranking to a same-cohort, prevalence-adjusted metric such as deaths per PLHIV engaged in care.

CLINICAL TRIAL REGISTRATION

Clinical trial number: not applicable.

INTRODUCTION

As of 2022, China reported 1.22 million people living with HIV (PLHIV) and 19,000 AIDS deaths [2]. The free antiretroviral therapy (ART) programme, launched in 2003, has driven per-PLHIV mortality down from over 20% per year in the mid-2000s to roughly 1.5% today [4]. Yet provincial AIDS mortality per 100,000 varies more than 20-fold, from 0.17 in Tianjin to 6.9 in Guangxi. This spread is routinely interpreted as a treatment-performance gradient: provinces with high population-level AIDS death rates are assumed to deliver worse HIV care.

This interpretation may be misleading. Provincial AIDS mortality per 100,000 is, by identity, the product of PLHIV prevalence per 100,000 and the annual death rate per PLHIV. The first term reflects where the epidemic established itself decades ago; the second reflects how well current treatment performs. If the geographic distribution of the PLHIV stock varies more across provinces than per-PLHIV survival does, then population-level mortality disparities will be dominated by the historical epidemic footprint rather than by current treatment quality — even when treatment is uniformly good. Ranking provinces by population-level AIDS mortality would then systematically penalize programmes that have successfully diagnosed and kept alive large numbers of people.

We do not claim this identity is an empirical finding. By construction, a multiplicative identity will attribute a larger share of a wide ratio to whichever term varies more — and prevalence varies far more across Chinese provinces than per-PLHIV survival does. While the direction of dominance is mathematically predetermined, the magnitude of the residual is not, and it is this magnitude that determines whether treatment-quality interventions can meaningfully reduce population-level mortality disparities. Our contribution is therefore threefold: (i) to quantify how large the policy-relevant residual actually is after stress-testing every denominator choice we know of; (ii) to show that even full equalization of per-PLHIV mortality would leave a 5.0× prevalence-driven gap that treatment programmes cannot close; and (iii) to propose that provincial programme ranking move to a prevalence-adjusted, same-cohort metric. In 2022 AIDS mortality per 100,000 ranged from 0.17 (P10) to 3.88 (P90) across provinces, a 23-fold spread that is currently interpreted as a treatment-performance gradient.

METHODS

Data. Numerators are AIDS death counts from the national notifiable disease system, which uses a single national coding protocol [1, 3]. Denominators are provincial living-PLHIV counts from provincial

Health Commission World AIDS Day press releases and published ART cohorts, tiered by source quality (Supplementary Table S1); where a province reported a range we used the published lower bound (Sichuan, > 210,000). Provincial populations are from the National Bureau of Statistics [5].

Belt definition (pre-specified). We define the belt before inspecting mortality as the first- and second-order provinces on the injection-drug transmission chain that radiated from Yunnan in the 1990s [9]: Guangxi, Guizhou, Sichuan, Chongqing, and Yunnan. Chongqing enters the chain through Sichuan and Guizhou; it does not border Yunnan directly. This is a historical-geographic prior, not a data-driven high-mortality cluster. We report a data-driven cluster (adding Hunan, which a local Moran's I high-high analysis [10] would include) as a sensitivity check.

Decomposition. Let R_mort = belt mortality / other mortality. By identity, ln R_mort = ln R_prev + ln R_rate. Because death counts are censal (a census, not a sample), the intervals reported in Tables 1–2 are descriptive precision bounds: we resample the observed belt and other death counts as independent Poisson-normal draws (20,000 iterations) and report the 2.5–97.5 percentile range of the resulting R_rate and stock-share distribution. These convey how precisely the point estimates are determined by the counts themselves; they do not sample uncertainty from a superpopulation, and they do not incorporate denominator error, which is addressed separately through the boundary analysis below.

Boundary analysis. We stress-test R_rate: (a) capture asymmetry — if other-province death capture is c and belt capture is c − 0.20, R_rate is multiplied by c/(c − 0.20); c = 1.0, 0.8, 0.67 (CRIMS-implied national average) and 0.57. The reverse scenario (belt registration more complete than other provinces) would shrink R_rate and strengthen, not weaken, the stock conclusion; (b) cumulative-ever denominator — national cumulative-ever reported cases (1.641 million) instead of living stock (1.223 million), with belt cumulative-death share swept over 50%, 60%, and 70%; (c) alternative belt definitions (adding Hunan or Xinjiang, removing Chongqing); (d) Tier-1 robustness — dropping the six Tier-3 provinces whose stock is extrapolated rather than officially reported (Inner Mongolia, Liaoning, Jilin, Hainan, Tibet, Ningxia) plus the three Tier-2 secondary-source provinces (Hebei, Shanghai, Fujian), leaving 22 Tier-1 provinces with officially reported stock; (e) continuous 31-province scatter with Spearman correlation; and (f) joint worst case combining (a), (b), and (c).

External validation. CRIMS cohort data [4] report southwest concentration of HIV deaths; we compare direction and range, not point agreement. National 2015–2022 trends are decomposed separately as temporal corroboration.

RESULTS

Primary decomposition. The five-province belt (Guangxi, Guizhou, Sichuan, Chongqing, Yunnan) contained 252 million people and 638,300 living PLHIV; the other 26 provinces contained 1.16 billion people and 584,700 PLHIV (national total 1,223,000). Belt AIDS mortality was 4.69 per 100,000 versus 0.61 elsewhere (R_mort = 7.7×). Decomposition gave R_prev = 5.0× (79% of log gap, bootstrap 78–80%) and R_rate = 1.53× (bootstrap 1.49–1.58; 21%) (Table 1, Fig. 1).

Table 1
Log decomposition of belt-to-other AIDS mortality, 2022.

Measure	Belt (5 provinces)	Other 26	Ratio	Share of log gap
AIDS deaths / 100,000	4.69	0.61	7.7×	100%
PLHIV prevalence / 100,000	253	50.4	5.0×	79% (78–80) bootstrap
Deaths per PLHIV / year	1.85%	1.22%	1.53× (1.49–1.58) bootstrap	21%

Boundary analysis (Table 2). The independent 31-province press-release sum (1,370,859, 12% above the national residual) raised R_rate to 1.92× and lowered the stock share to 68%. Under capture asymmetry with belt under-reporting, R_rate rose to 1.92–2.36× and the stock share fell to 65–71%; the reverse assumption (belt reporting more completely than other provinces) would shrink R_rate and strengthen the stock conclusion. The cumulative-ever denominator gave R_rate 1.28–1.57× and stock share 78–88% across the 50–70% belt cumulative-death allocation. Alternative belt definitions shifted the stock share between 77% and 88%. Dropping the six Tier-3 extrapolated-stock provinces (Inner Mongolia, Liaoning, Jilin, Hainan, Tibet, Ningxia) and the three Tier-2 secondary-source provinces (Hebei, Shanghai, Fujian) left 22 Tier-1 provinces with officially reported stock and still yielded R_rate = 1.80× with a 69% stock share. A triple worst case — cumulative denominator with 50% belt allocation, 20-point capture asymmetry at c = 0.67, and belt expanded to include Hunan — gave R_rate = 2.41× and a stock share of 62%. Across every specification the per-PLHIV excess remained between 1.3× and 2.4× and the stock share never fell below three-fifths.

Table 2
Stress tests of the per-PLHIV rate ratio and stock share.

Specification	Per-PLHIV ratio (belt/other)	Stock share of log gap
Primary (national residual denominator)	1.53× (1.49–1.58)	79% (78–80)
Independent 31-province press sum	1.92×	68%
Cumulative-ever denominator, belt cum-death share = 50%	1.57×	78%
Cumulative-ever denominator, belt cum-death share = 60%	1.41×	83%
Cumulative-ever denominator, belt cum-death share = 70%	1.28×	88%
Capture asymmetry c_other = 1.0, c_belt = 0.8	1.92×	71%
Capture asymmetry c_other = 0.8, c_belt = 0.6	2.04×	69%
Capture asymmetry c_other = 0.67, c_belt = 0.47 (CRIMS-level)	2.18×	67%
Capture asymmetry c_other = 0.57, c_belt = 0.37	2.36×	65%
Belt ± Hunan / ± Xinjiang / − Chongqing	1.30–1.70×	77–85%
Tier-1 only (22 officially-reported provinces)	1.80×	69%
Joint worst case: cum share 50% + c_other = 0.67 capture	2.23×	66%
Triple worst case: cum 50% + c = 0.67 + belt expanded to include Hunan	2.41×	62%

Continuous 31-province pattern. Across all 31 provinces, Spearman correlation between prevalence and per-PLHIV death rate was weak and not significant (ρ = 0.28, P = 0.12; Fig. 3). Restricting to the 22 provinces with officially reported stock strengthened the association to ρ = 0.44 (P = 0.04). The six lowest-prevalence provinces averaged 0.99% deaths per PLHIV; the six highest averaged 1.65% — a 1.66× contrast, well below the 7.7× population-level ratio. The other-26 grouping is itself heterogeneous: Beijing reported 0.11 deaths per 100,000 while Xinjiang, though outside the belt, had prevalence of 384 per 100,000 with a low per-PLHIV rate of 0.72%.

Temporal corroboration. Nationally, PLHIV prevalence per 100,000 rose from 42.0 (2015) to 86.6 (2022), while deaths per PLHIV fell from 2.24% to 1.55% (Fig. 2). The product rose from 0.94 to 1.34 deaths per 100,000 (+ 43%) — an apparent deterioration fully accounted for by the growing treated-and-alive denominator.

External validation. Independent CRIMS cohort data [4] indicate a southwest per-PLHIV mortality excess in the 1.6–2.0× range, directionally consistent with our 1.53×; exact point agreement depends on belt definition and stock allocation and is not claimed.

Counterfactual. If belt per-PLHIV mortality fell from its observed 1.85% to the other-group mean of 1.22% (a reduction of approximately 34%, i.e. 1 − 1.22/1.85), belt AIDS deaths would drop from 11,800 to about 7,800 annually. This is an optimistic upper bound: belt cohorts are older and diagnosed later, so full convergence to the other-group mean may not be achievable through treatment alone. Even if achieved, a 5.0× prevalence-driven mortality gap between belt and other regions would remain — that residual is epidemic history, not treatment failure.

DISCUSSION

Principal findings. Three findings. First, under every plausible stress test, roughly two-thirds to four-fifths of the 7.7-fold provincial AIDS mortality gap is the size and geographic distribution of the PLHIV stock. The residual per-PLHIV excess is bounded at 1.3–2.4× across specifications and is consistent in direction with independent CRIMS data.

Second, the national 2015–2022 time trend shows the same structure: per-PLHIV survival improved by 31% while population-level mortality rose 43% because the treated population doubled. Ranking regions by population-level AIDS mortality systematically penalizes programs that have put more people on treatment and kept them alive.

Third, the residual 1.3–2.4× belt excess, though modest, is not explained by background mortality (belt crude death 7.3‰ vs other 7.4‰). It likely reflects older infected cohorts, later diagnosis, and comorbidity — compositional differences in who is on treatment, not treatment quality per se.

Policy implication. Program evaluation should not use population-level AIDS mortality as a treatment-performance KPI. The per-PLHIV death rate extracted here is not a new metric; it is the same rate already reported within ART cohorts, repositioned as a provincial comparator. We recommend deaths per PLHIV engaged in care — with numerator and denominator drawn from the same ART information system — as the preferred KPI, because it is unaffected by provincial differences in HIV testing/diagnosis intensity. A prevalence-adjusted mortality index (PAMI) built from routinely reported counts (deaths per 100,000 divided by living-PLHIV prevalence per 100,000) is a feasible transitional measure, but it inherits a known diagnostic paradox: a province with high case-finding will over-state its denominator and appear to have a lower death rate. We therefore present PAMI as a stopgap, not an endpoint.

The counter-intuitive core is worth stating plainly: a province that puts more people on ART and keeps them alive has, by construction, more deaths per 100,000. For illustration, if Province A had 100,000 PLHIV at a 1% annual death rate it would record 1,000 AIDS deaths per 100,000; Province B with 10,000 PLHIV at a 2% rate would record 200 — A has five times the population-level mortality but half the per-patient death rate. Ranking by the crude rate penalizes the more successful program.

Generalizability. The decomposition is identity-based and applies wherever both cumulative-death numerators and living-PLHIV denominators are reported; the precise stock-share fraction will vary by epidemic age. The Chinese pattern is consistent with — though not identical to — reports from generalized epidemics in southern Africa, where provincial mortality variation is likewise dominated by prevalence and age structure rather than by measured ART coverage gaps [6, 7, 8]; those settings differ by scale (generalized vs. concentrated) and by TB co-infection burden, so the exact residual fraction should not be borrowed directly.

Resource allocation. Beyond performance measurement, PAMI can guide resource deployment: provinces with high stock but low PAMI are already performing well and need sustained supply; provinces with high stock and high PAMI need programmatic support, not punishment; provinces with low stock and high PAMI should be investigated for late diagnosis or aging cohorts. The current 1.3–2.4× belt excess, while modest, marks where incremental treatment investment would buy the most lives.

Data-access gap and future directions. This paper has three structural limitations that are not analytical choices but data-access constraints. First, provincial living-PLHIV stock and ART coverage are not published as time series: the National Health Commission releases only the national count at each year's World AIDS Day, and provincial PLHIV denominators exist only as one-off press-release snapshots (we used 2022). As a result, a provincial panel regression or a difference-in-differences around the 2003 free-ART scale-up is not feasible for outside researchers; these variables sit inside CRIMS and the national ART information system, accessible only within China CDC. Second, provincial viral-suppression and late-diagnosis (CD4 at presentation) data are not publicly released, so the 1.3–2.4× belt residual cannot be further split into treatment quality versus cohort composition. Third, behavioral and social mediators — testing access, stigma, injection-network disruption, MSM disclosure, and health-system trust — are collected in provincial bio-behavioral surveys but are not released in geocoded form. We therefore recommend that China CDC, as a matter of program transparency, publish an annual provincial panel of living PLHIV, ART coverage, viral suppression, and CD4-at-engagement; such a panel would let outside researchers move from descriptive decomposition to causal evaluation. In the meantime, our result — that between two-thirds and four-fifths of provincial AIDS mortality disparity is prevalence-driven, with a tractable treatment residual of roughly one-fifth to slightly over one-third depending on specification — should be read as a ceiling on what provincial treatment programs alone can close, not as an estimate of treatment effect.

LIMITATIONS

Provincial PLHIV denominators come from press releases; our boundary analysis explicitly allows for a 20-point death-registration asymmetry and alternative cumulative-ever denominators, and the stock conclusion remains (floor approximately 62%). We note an additional measurement asymmetry we cannot bound: if belt provinces have higher testing intensity, their PLHIV denominator may be over-diagnosed relative to other provinces, which would bias R_rate downward. To size this: if belt testing

intensity were 20% higher than other provinces, R_rate would be underestimated by ~ 17% (1/1.2 − 1), implying a true belt-to-other ratio of ~ 1.8× rather than the observed 1.53× — i.e., the true residual is at least as large, and possibly modestly larger, than reported. Death counts are censal, so intervals convey Poisson-level precision rather than sampling uncertainty. The ecological design cannot attribute the residual excess to aging, comorbidity, or late presentation, and province-level associations may not hold at the individual level. Provincial stock is reliably available only for 2022, so the national time decomposition is temporal corroboration rather than a provincial panel; 2023 provincial stock figures were not yet released at the time of writing and will allow a repeat cross-section once published. This is a descriptive decomposition, not a causal estimate: the belt–other contrast does not identify treatment effects, and we do not have provincial ART coverage or viral-suppression data to pursue that link.

Declarations

Author Contribution

H.M.: conceived and designed the study, collected and analyzed the data, prepared all figures and tables, wrote and revised the manuscript, and approved the final version.

ETHICS

This study used aggregated, publicly reported provincial counts; no individual-level data were accessed. No institutional review was required. The author declares no conflicts of interest.

DATA AVAILABILITY

All data generated or analysed during this study, and the code required to reproduce every reported result, are publicly available in the Zenodo repository under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence: Ma H. Replication data and code for: Population-Level AIDS Mortality Is Dominated by Prevalence Stock, Not Treatment Performance — provincial decomposition, China, 2015–2022. Zenodo; 2026 (version 1, published 25 October 2026). Direct link: https://zenodo.org/records/23640555 . DOI: https://doi.org/10.5281/zenodo.23640555 .

The deposit comprises four provincial-level CSV files (province_plhiv_stock_mortality_2022.csv, aids_mortality_panel.csv, covariate_analysis.csv, national_disease_decomposition.csv); two Python scripts that reproduce all numerical results, the 20,000-replicate bootstrap confidence intervals and Figures 1–3 (replication_analysis.py, make_figures.py); and a README.md file manifest with quick-start instructions. All underlying input values are published, aggregate provincial counts released by the Chinese Center for Disease Control and Prevention and the National Bureau of Statistics in publicly available annual reports and official press releases. No individual-level or identifiable data were used, and no restrictions apply to access to the deposit.

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CLINICAL TRIAL REGISTRATION

Clinical trial number: not applicable.

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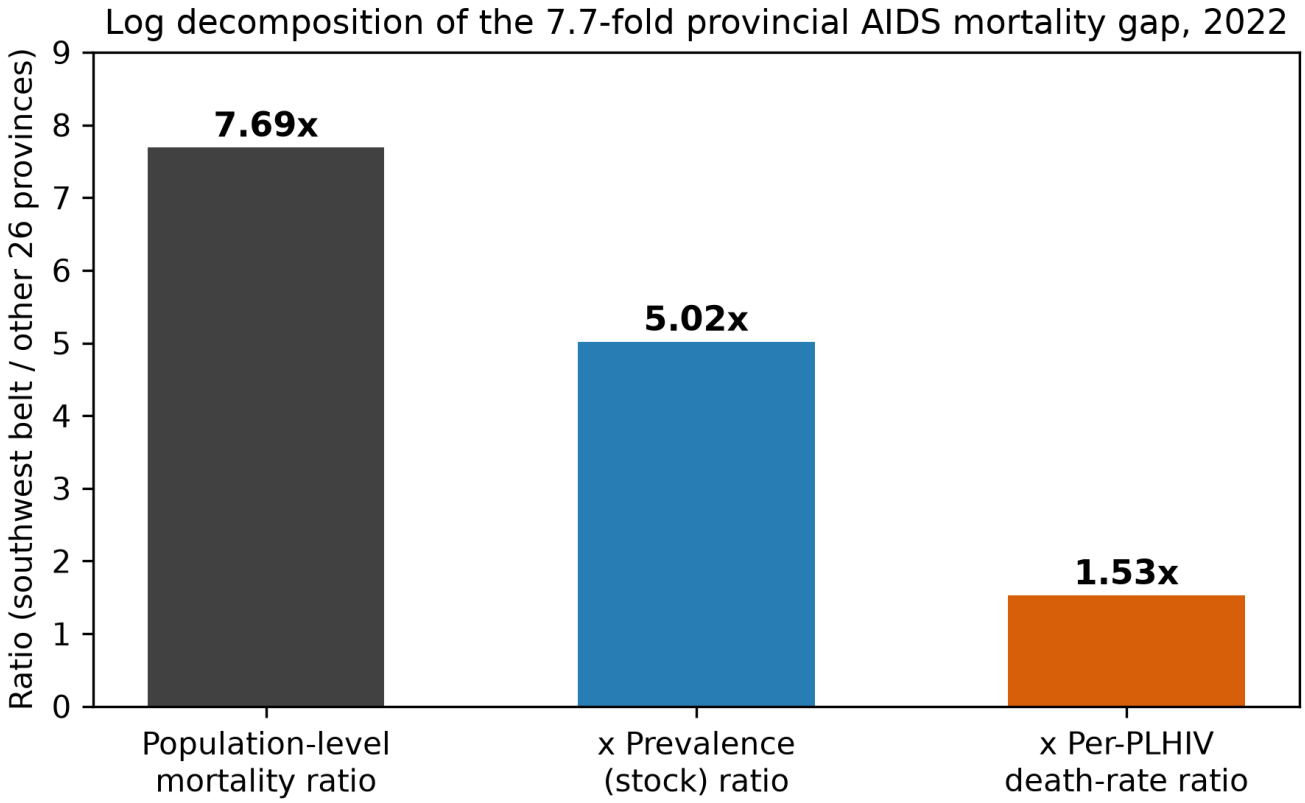
Figures



Stock (prevalence) explains 79% of the log gap; residual per-PLHIV excess is 1.53x (95% CI 1.49-1.58).

Figure 1

Log decomposition of the belt-to-other AIDS mortality ratio, 2022.

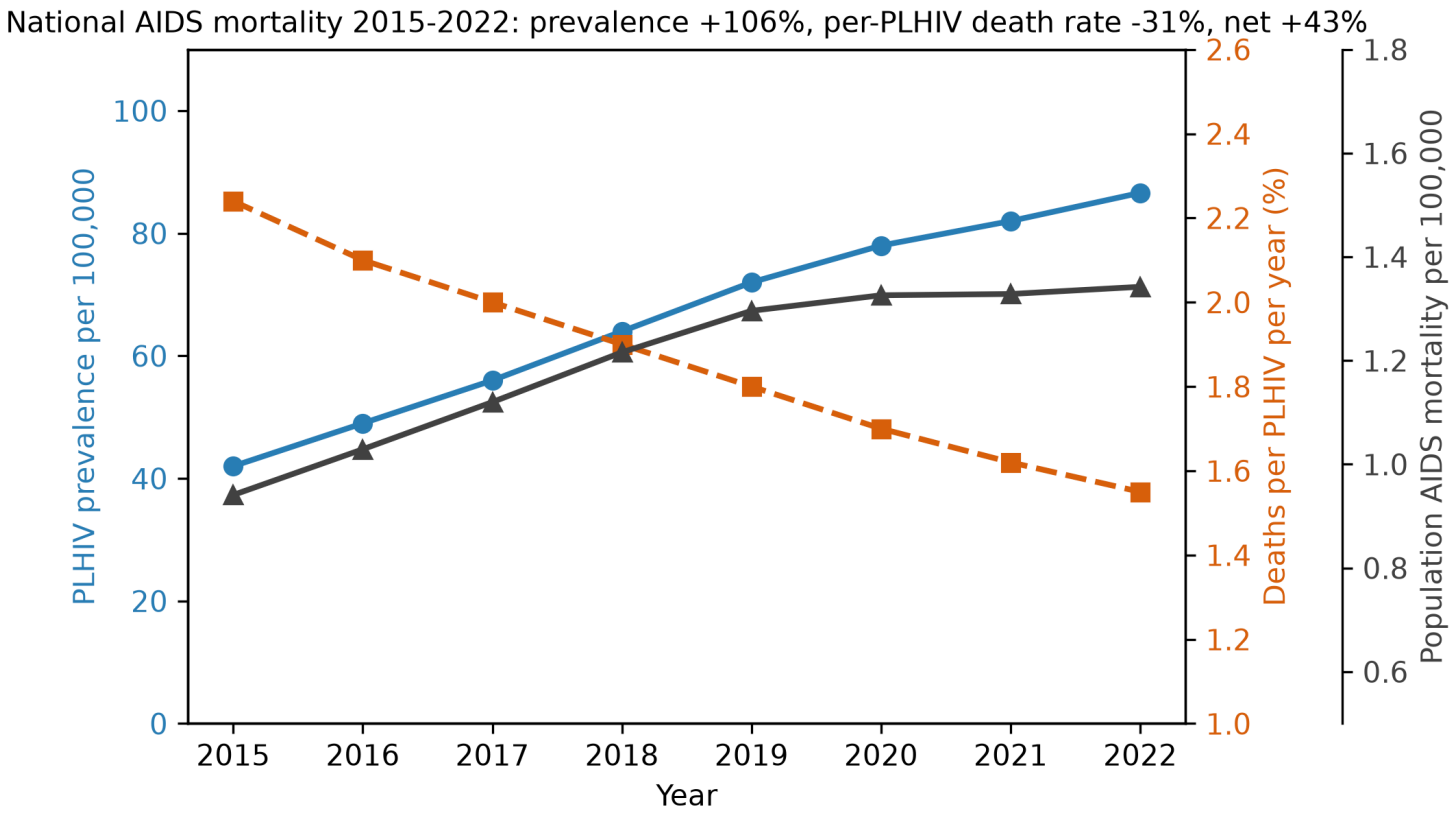


Figure 2

National AIDS mortality 2015–2022 decomposed into prevalence, deaths per PLHIV, and net population mortality.

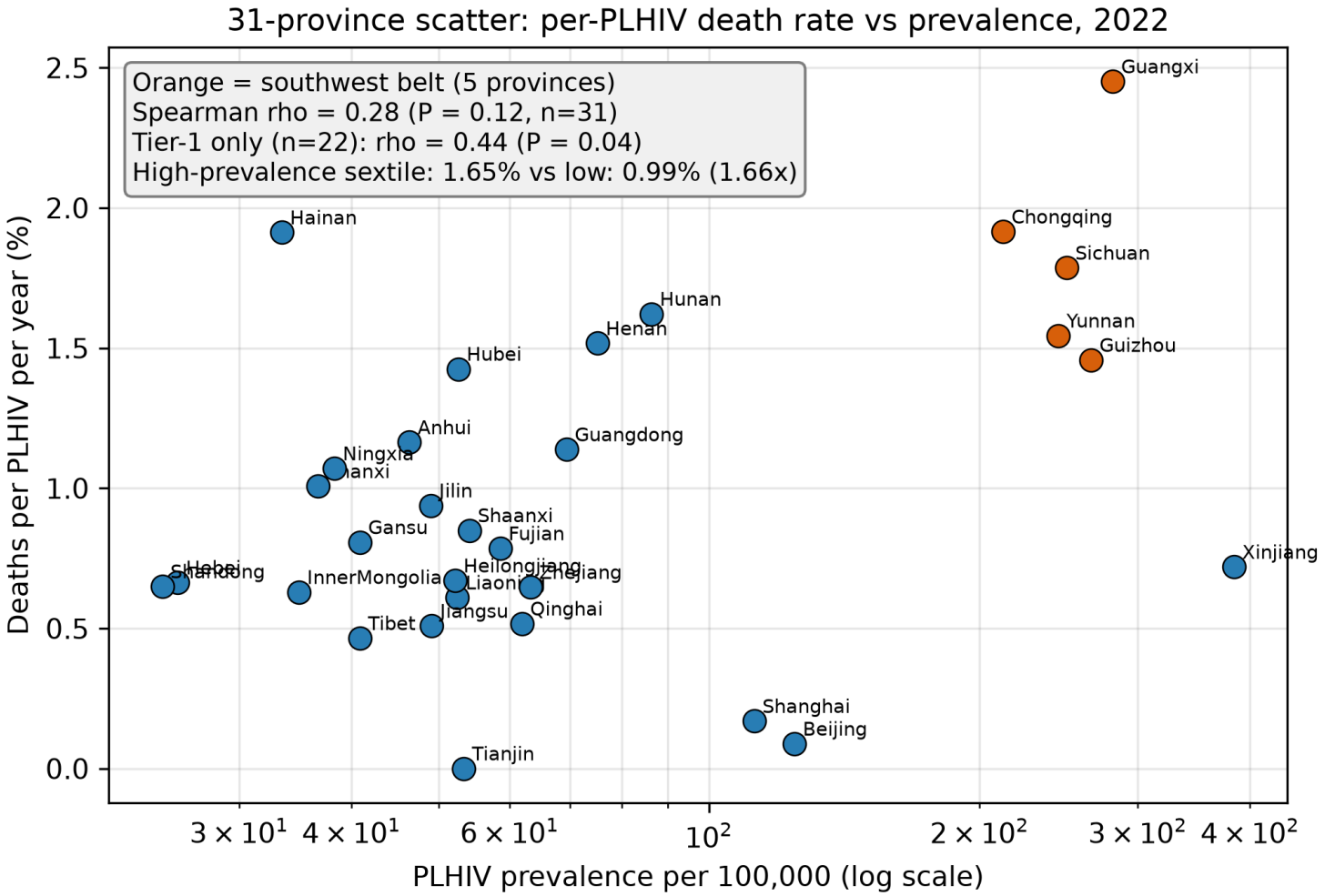


Figure 3

Thirty-one-province scatter of deaths per PLHIV against prevalence (log scale). Orange = southwest belt; open circles = Tier-3 extrapolated provinces.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Tables.xlsx
- nationaldiseasedecomposition.csv
- covariateanalysis.csv
- aidsmortalitypanel.csv
- provinceplhivstockmortality2022.csv