



Geospatial patterns of progress towards UNAIDS '95-95-95' targets and community vulnerability in Zambia: insights from population-based HIV impact assessments

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ABSTRACT

Introduction In sub-Saharan Africa, HIV/AIDS remains a leading cause of death. The UNAIDS established the '95-95-95' targets to improve HIV care continuum outcomes. Using geospatial data from the Zambia Population-based HIV Impact Assessment (ZAMPHIA), this study aims to investigate geospatial patterns in the '95-95-95' indicators and individual-level determinants that impede HIV care continuum in vulnerable communities, providing insights into the factors associated with gaps.

Methods This study used data from the 2016 ZAMPHIA to investigate the geospatial distribution and individual-level determinants of engagement across the HIV care continuum in Zambia. Gaussian kernel interpolation and optimised hotspot analysis were used to identify geospatial patterns in the HIV care continuum, while geospatial k-means clustering was used to partition areas into clusters. The study also assessed healthcare availability, access and social determinants of healthcare utilisation. Multiple logistic regression models were used to examine the association between selected sociodemographic and behavioural covariates and the three main outcomes of study.

Results Varied progress towards the '95-95-95' targets were observed in different regions of Zambia. Each '95' displayed a unique geographical pattern, independent of HIV prevalence, resulting in four distinct geographical clusters. Factors associated with gaps in the '95s' include younger age, male sex, and low wealth, with younger individuals having higher odds of not being on antiretroviral therapy and having detectable viral loads.

Conclusions Our study revealed significant spatial heterogeneity in the HIV care continuum in Zambia, with different regions exhibiting unique geographical patterns and levels of performance in the '95-95-95' targets, highlighting the need for geospatial tailored interventions to address the specific needs of different subnational regions. These findings underscore the importance of addressing differential regional gaps in HIV diagnosis, enhancing community-level factors and developing innovative strategies to improve local HIV care continuum outcomes.

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ The HIV epidemic in sub-Saharan Africa is still a leading cause of death despite the recommendation of lifelong antiretroviral therapy (ART) treatment for people living with HIV (PLHIV).
- ⇒ The UNAIDS has set the '95-95-95' targets for national HIV programmes to diagnose, provide ART and achieve viral load suppression in PLHIV, but questions remain about the uniformity of progress across countries and subnational regions.
- ⇒ This study investigates the geospatial patterns of '95-95-95' indicators and their relationship to HIV prevalence and individual-level determinants in Zambia, highlighting the need for tailored interventions to achieve the targets.

WHAT THIS STUDY ADDS

- ⇒ Our study identified significant disparities in HIV care continuum metrics across different population groups and geographical regions in Zambia.
- ⇒ We found that progress towards the '95-95-95' targets varied significantly across the different regions of Zambia, with each '95' showing a distinct geographical pattern.
- ⇒ Our study underscores the need for tailored interventions to address the specific needs of different subnational regions in Zambia and to achieve the '95-95-95' targets.

INTRODUCTION

Maintaining undetectable HIV viral load via lifelong antiretroviral therapy (ART) is recommended for all people living with HIV (PLHIV) as it has been shown to preserve health and reduce onward transmission.¹ However, despite these recommendations being adopted into clinical guidelines, HIV/AIDS remains a leading cause of death in sub-Saharan Africa (SSA), where two-thirds of the world's PLHIV reside.² This is due to substantial numbers of PLHIV remaining

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ This study highlights the importance of targeted interventions in specific geographical regions to address HIV care continuum gaps, as each '95' exhibited a unique geographical pattern that was distinct from HIV prevalence.
- ⇒ Our study suggests that reporting '95-95-95' targets at the national level may not be sufficient, and tailored approaches to healthcare strengthening may be necessary in different subnational regions of Zambia to improve progress towards HIV treatment targets.
- ⇒ The identification of distinct geographical areas with unique patterns of HIV diagnosis, ART status, and viral load suppression rates provides valuable information for policy-makers and healthcare providers to guide resource allocation and implementation of geo-targeted interventions based on specific local needs.

undiagnosed, being diagnosed but not receiving ART or receiving ART but not achieving viral load suppression.³ In response, the Joint United Nations Programme on HIV/AIDS (UNAIDS) established operational targets for national HIV programmes to diagnose $\geq 95\%$ of those living with HIV, provide ART to $\geq 95\%$ of those diagnosed, and achieve viral load suppression in $\geq 95\%$ of those receiving ART, known as the '95-95-95' targets.⁴ To assess progress towards these targets, population-based HIV impact assessments (PHIAs) have been conducted, providing nationally representative cross-sectional data on HIV diagnosis, treatment and viral load suppression, as well as demographic and health data.⁵ However, questions remain about the uniformity of progress across countries and the extent to which '95-95-95' indicators correlate with one another and with the epidemiology of the HIV/AIDS pandemic.

The HIV epidemic in Zambia is one of the most severe in the world, with an estimated 1.3 million PLHIV in 2020, according to UNAIDS.⁶ Despite progress in the HIV response, with a decline in new infections from 58 000 in 2010 to 38 000 in 2020, Zambia still faces significant challenges in achieving the '95-95-95' targets.⁵ Using geospatial data from the PHIA in Zambia, a country with a high HIV burden, we investigated the geospatial patterns in '95-95-95' indicators and their relationship to HIV prevalence and individual-level determinants that could impede HIV diagnosis, treatment, and viral load suppression in these vulnerable communities.

The main objective of this study is to provide insights into the extent to which progress towards '95-95-95' has been even or uneven across Zambia and identify regions that require differential emphasis on HIV diagnosis, treatment or viral load suppression to accelerate progress. Using geospatial and statistical analyses of individual-level determinants of engagement across the '95-95-95' continuum, this study aims to provide insights into the factors associated with gaps in the HIV care continuum not only in Zambia but also in other SSA countries. The study was conducted in collaboration with the Zambia Ministry of Health, highlighting the importance of

partnerships between governments and researchers in addressing the HIV epidemic in SSA.

METHODS

Data sources

This analysis uses individual-level questionnaires and biomarker data on adults ages 15–59 participating in the 2016 Zambia Population-based HIV Impact Assessment (ZAMPHIA), which is the most recent ZAMPHIA dataset publicly available.⁷ ZAMPHIA is a nationally representative cross-sectional survey of households across all 10 provinces of Zambia, as well as geospatial data on communities included in the survey. ZAMPHIA used a two-stage stratified sample design, first selecting 511 enumeration areas (EA) from the 2010 Census of Population and Housing in Zambia, and then inviting households in each EA to participate in the survey.^{5,8} Households consenting to participate in the survey received face-to-face structured household and individual interviews, home-based HIV testing with immediate return of results and further laboratory testing, and viral load testing. HIV testing used the Alere Determine HIV-1/2 rapid test (Abbott Laboratories, Lake Bluff, Illinois, USA) and positive results were confirmed using the Uni-Gold HIV-1/2 rapid test (Trinity Biotech, Wicklow, Ireland). Positive specimens were also tested for the presence of the antiretroviral drugs (ARVs) efavirenz, nevirapine, lopinavir, and atazanavir, as described elsewhere.⁷ The latitude and longitude of the approximate centroid of each EA was recorded using the global positioning system (GPS) (online supplemental figure 1).

Anonymised data from ZAMPHIA are available to researchers with approval from the Zambia Ministry of Health, US Centers for Disease Control and Prevention, and the International Center for AIDS Care and Treatment Program at Columbia University. Survey questionnaires, consent forms, and aggregated results are publicly available.⁷ At the time of submission of this work, the subsequent (2021) ZAMPHIA survey dataset was still under internal analysis by the survey team and requests for access by external researchers were unable to be granted. Accordingly, our methodological approach was designed to apply to subsequent ZAMPHIA survey data as they become available.

Main outcomes

HIV status

Positive HIV status was defined as positive results on initial and confirmatory HIV tests. Individuals with negative or discrepant HIV test results were not classified as HIV-positive.

Awareness of positive HIV status

For participants classified as HIV-positive, awareness of HIV status was assigned based on multiple survey indicators. Participants were assumed to be aware of their HIV positive status if any of the following were true: (1) they reported their HIV status as positive on the survey

questionnaire, (2) if ARVs were detectable in their blood sample or (3) HIV viral load was <1000 HIV RNA copies per millilitre in their blood sample.

ART status

For participants classified as aware of their positive status, ART status was assigned based on multiple survey indicators. Participants were assumed to be receiving ART if (1) they report to receive ART (2) one or more of the tested ARVs was detected or (3) HIV viral load was <1000 HIV RNA copies per millilitre.

Viral load suppression

For participants classified as receiving ART, viral load suppression was defined as having <1000 HIV RNA copies per millilitre in their blood sample.

Spatial analysis

Mapping of the care continuum

Spatial analysis combined the prevalence of individual-level care continuum variables with EA-level GPS coordinates (online supplemental figure 1). We performed Gaussian kernel interpolation to create spatially smoothed estimates of HIV prevalence, HIV status awareness prevalence among those HIV-positive, ART prevalence among those aware of status, and viral load suppression prevalence among those receiving ART. Estimates were aggregated at the district for each of Zambia's 116 administrative districts to increase relevance to health policy decision-making. We performed optimised hotspot analysis,^{9 10} to identify the geospatial structure of the prevalence of HIV along with the prevalence of the three UNAIDS targets, with the identification of hotspots (areas with high HIV prevalence and high percentages of HIV awareness, ART uptake and viral load suppression) and coldspots (areas with low HIV prevalence and low percentages of HIV awareness, ART uptake and viral load suppression).

Geospatial visualisation of care continuum clustering

Multivariable spatial visualisation of the care continuum, HIV prevalence, HIV status awareness, ART status and viral load suppression were ascertained using a geospatial k-means clustering approach, partitioned districts so that within-cluster similarity is maximised and between-cluster similarity minimised (or dissimilarity maximised). We categorised districts into k=4 clusters using the open-source spatial data science tool GeoDa, V.1.20 environment,¹¹ as described elsewhere.^{12–14} For each cluster, we reported the mean of each care continuum variable. IQRs represent the variation across the districts included in the cluster. Maps of care continuum metrics by district and cluster were generated using ArcGIS Pro V.3.1.¹⁵

Mapping of healthcare availability, access and social determinants of healthcare utilisation

For each cluster, we additionally assessed levels of healthcare availability and access using data from the Africa COVID Community Vulnerability Index ([\[precisionforcovid.org/africa\]\(https://precisionforcovid.org/africa\)\).¹⁶ The index combines several factors associated with healthcare availability \(health system strength, health system capacity and access to healthcare\) and community vulnerability and access to healthcare \(household crowding, improved housing, sanitation, access to transportation and road connectivity\), as well as socioeconomic factors that can act as determinants of healthcare utilisation \(access to information, education, poverty and unemployment\). Maps of the results were generated using ArcGIS Pro V.3.1.¹⁵](https://</p></div><div data-bbox=)

Statistical analysis

We assessed the association at individual level between selected sociodemographic and behavioural covariates and the three main outcomes of study by fitting three different models for HIV status awareness, ART status, and viral load suppression. Behavioural and sociodemographic covariates included gender, age, wealth index, religion (traditional, catholic, other), age at the first sexual contact, marital status, place of residence (urban or rural), work in the last 12 months and away from home in the last 12 months. OR was calculated by exponentiating the coefficient of multiple logistic regression.

We conducted the individual-level analysis separately using each of the three HIV care continuum outcomes as dependent variables. For model 1: HIV status awareness, the survey data were subsampled to include HIV-positive individuals only; for model 2: ART status, the survey data were subsampled to include HIV-positive individuals aware of their status only; and for model 3: viral load suppression, the survey data were subsampled to include HIV-positive individuals aware of their status and on ART treatment. Population subsets for each model were generated using the 'subset' argument to the `sygl()` function in the R package `survey`. We fitted survey-weighted multiple logistic regression models with the `syglm()` function to account for the multistage sampling survey design of ZAMPHIA.¹⁷

This analysis uses available deidentified data from the ZAMPHIA, which was funded by PEPFAR with technical assistance through the US Centers for Disease Control and Prevention under the terms of the cooperative agreement #U2GGH001226.

Patient and public involvement

There were no patients involved in this research.

Author reflexivity statement

An author reflexivity statement is included as online supplemental appendix.

RESULTS

National-Level HIV care continuum

Nationally, HIV prevalence estimated among adults ages 15–59 in Zambia was 12.3% (95% CI 11.8% to 12.8%). HIV prevalence among female adults was 14.9% (95% CI 14.3% to 15.7%), and among male adults was 9.4% (95% CI 8.9% to 9.9%). HIV prevalence among adults

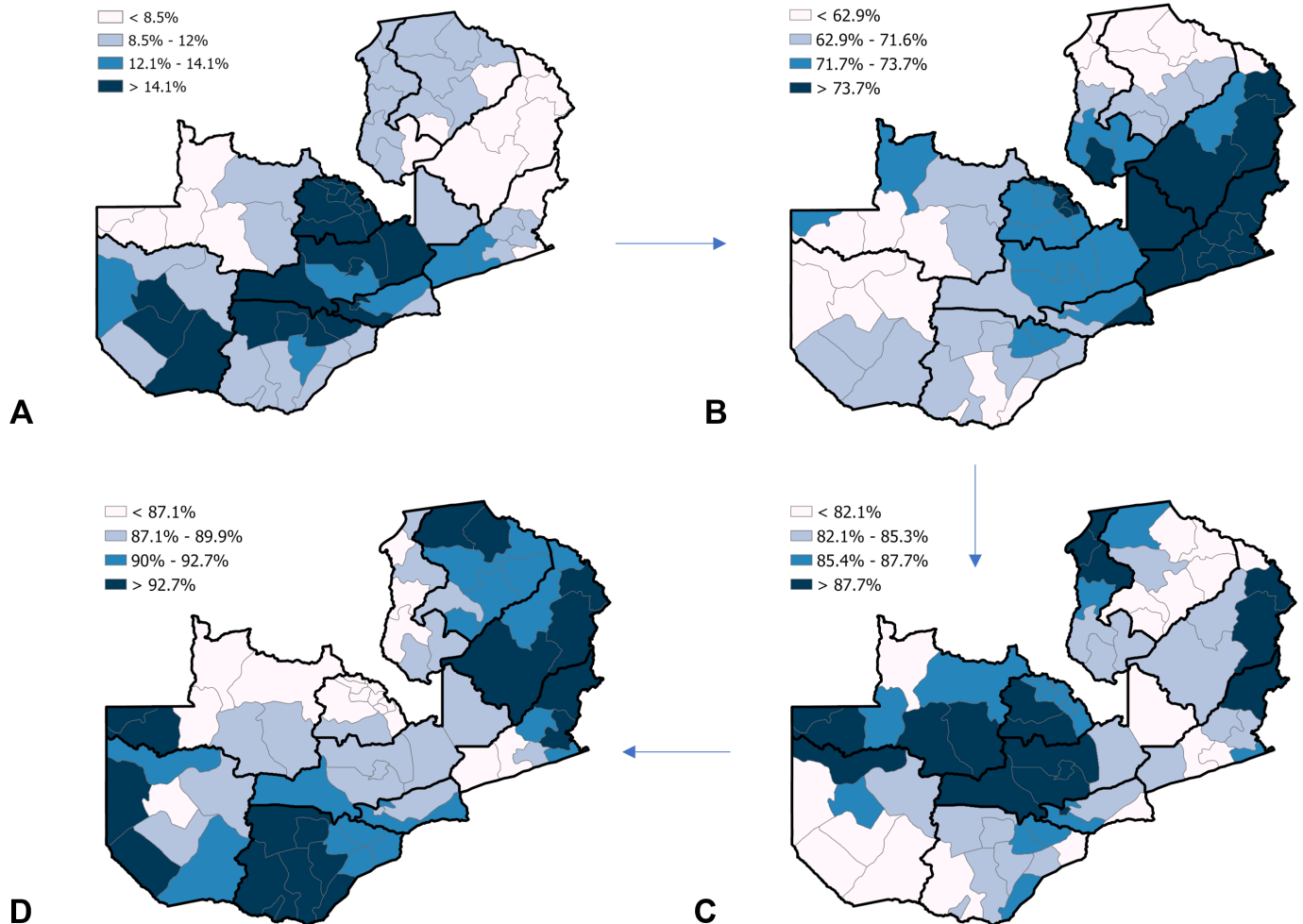


Figure 1 Prevalence distributions of (A) HIV prevalence; (B) prevalence of HIV positive individuals aware of their status; (C) prevalence of HIV positive individuals aware of their status on ART treatment and (D) prevalence of HIV positive individuals aware of their status on ART treatment that are viral load suppressed. ART, antiretroviral therapy.

in rural areas was 15.7% (95% CI 14.9% to 16.5%) and in urban areas was 9.5% (95% CI 8.9% to 10.1%). HIV prevalence was highest in the 45–54 age group at 23.9% (95% CI 21.7% to 26.2%) and lowest in the 15–24 age group at 3.9% (95% CI 3.4% to 4.3%). Nationally, 72.3% (95% CI 70.3% to 74.2%) of HIV-positive adults were aware of their status, 87.3% (95% CI 85.5% to 89.1%) of those aware of their status were receiving ART, and 89.5% (95% CI 87.7% to 91.2%) of those receiving ART had suppressed viral load (online supplemental figure 2).

Geospatial patterns of the HIV care continuum

Geospatial patterns of the HIV prevalence and care continuum engagement differed markedly across stages of the HIV care continuum (figures 1,2). HIV prevalence (figures 1A and 2A) was highest in the central axis of the country, spanning the Copperbelt and Central provinces and parts of the Central and Western provinces, with an identified hotspot where prevalence exceeded 14% of all adults. HIV prevalence was lowest in the north-western and eastern parts of the country, especially Muchinga province.

Awareness of positive HIV status among those living with HIV (figures 1B and 2B) was the largest gap in the HIV care continuum across geographies. It exhibited a markedly different geospatial pattern than the pattern of HIV prevalence, with a gradient from low status awareness in the west to high status awareness in the east. Awareness of status was lowest in the western half and north-eastern quadrant of the country, and highest in the south-eastern quadrant. In the central axis of the country where HIV prevalence is concentrated, awareness of status was at an intermediate level relative to elsewhere in the country.

ART coverage and viral load suppression (figure 1C,D) also exhibited unique geospatial patterns. ART coverage among those aware of their status was highest in a band from the centre to the west of the country and in portions of its northeastern and eastern borders and was lowest in the south and portions of the east (figure 1C). Viral load suppression among those receiving ART clustered in the east, west and south, and lowest in the north and centre of the country (figures 1D and 2D).

Taken together, these geographical patterns of HIV prevalence, status awareness, ART status and viral load

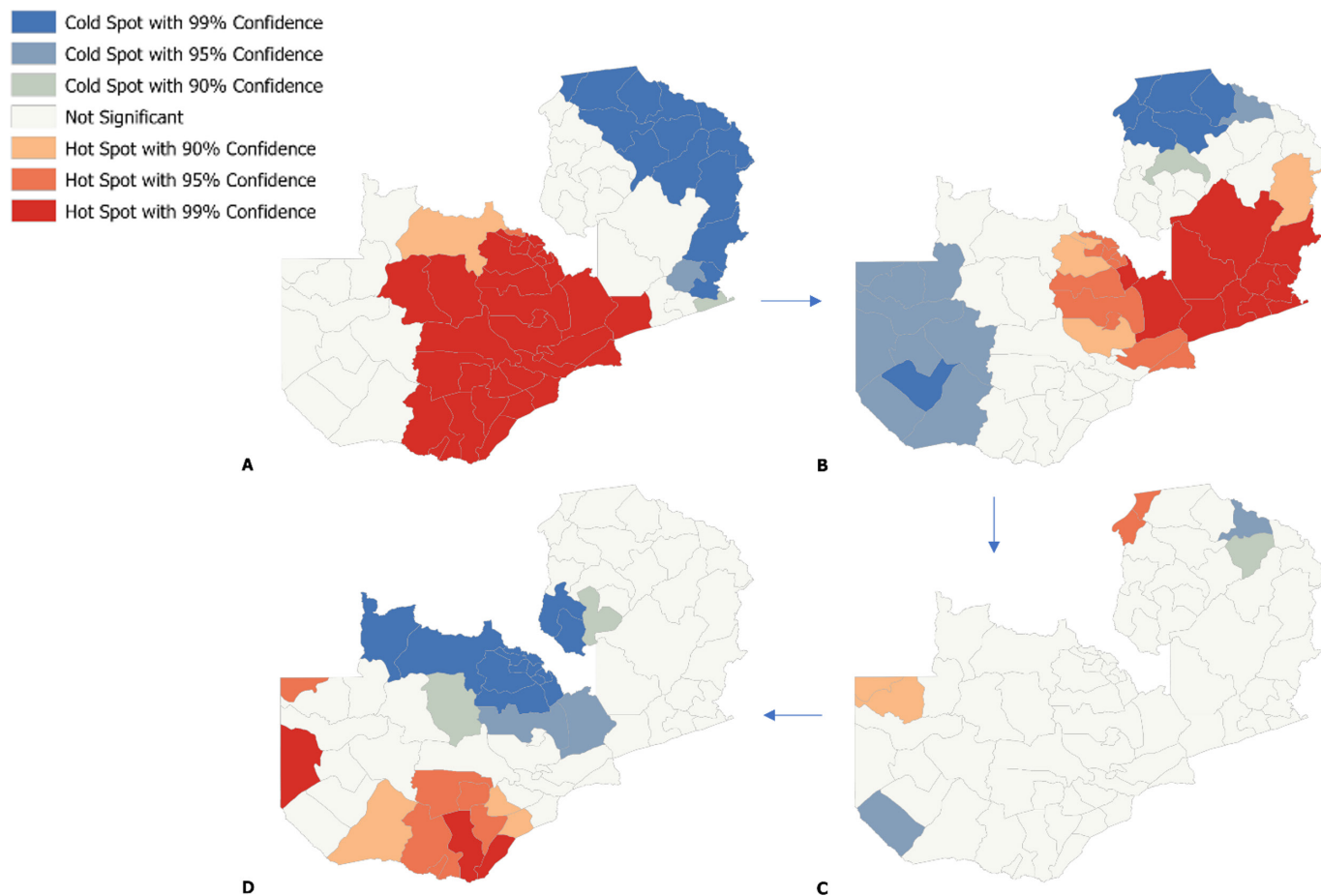


Figure 2 Hotspot maps of (A) HIV prevalence; (B) prevalence of HIV positive individuals aware of their status; (C) prevalence of HIV positive individuals aware of their status on ART treatment and (D) prevalence of HIV positive individuals aware of their status on ART treatment that are viral load suppressed. ART, antiretroviral therapy.

suppression could be clustered into four regions with distinct patterns (figure 3). Cluster 1 had the highest HIV prevalence (mean: 14.1%, IQR: 11.2–16.4) and had a relatively high proportions of status-aware PLHIV on ART (mean: 85.4%, IQR: 83.2–87.7) and viral load suppression among those on ART (mean: 86.7%, IQR: 85.7–88.6).

Cluster 2 includes districts with a range of HIV prevalence (mean: 12.1%, IQR: 10.2–14.5) and has low HIV status awareness (mean: 63.7%, IQR: 58.1–68.7), low ART coverage among those aware of status (mean: 84.2%, IQR: 81.7–86.9) and relatively high viral load suppression (mean: 93.14%, IQR: 91.1–95.3). Community vulnerability index was high in cluster 2 compared with the national average (online supplemental figure 3), with many districts in the top quartile for all three key indicators of health systems (online supplemental figure 3A), transportation and housing (online supplemental figure 3B) and socioeconomic factors (online supplemental figure 3C).

Cluster 3 had moderate HIV prevalence (mean: 9.2%, IQR: 8.5–10.2) and the lowest HIV status awareness (mean: 57.7%, IQR: 48.2–66.7) and ART coverage (mean: 83.4%, IQR: 78.8–87.6) of any cluster. Like cluster 2, this cluster had a high average community vulnerability index, with

nearly all of cluster 2 in the top quartile of health systems vulnerability (online supplemental figure 3A), and some subregions in the quartile for vulnerability in terms of transportation and housing (online supplemental figure 3C) or socioeconomic factors (online supplemental figure 3A). The high community vulnerability in terms of health systems could explain low rates of HIV diagnosis, and low ART coverage among those diagnosed.

Finally, cluster 4 had the lowest HIV prevalence (mean: 6.9%, IQR: 5.3–8.4) and the highest HIV status awareness (mean: 81.1%, IQR: 74.4–87.1) and viral load suppression (mean: 92.3%, IQR: 92.5–93.3) of any cluster. Much of this cluster was also in the top quartile for community vulnerability in terms of health systems (online supplemental figure 3A) and transportation and housing (online supplemental figure 3B), despite relatively strong performance along the HIV care continuum.

Factors associated with HIV care continuum status

To explore why each of the three ‘95s’ exhibits such different geospatial patterns, we conducted statistical analyses for assess individual-level predictors of gaps in each ‘95’ (figure 4) outside of the geographical sectors explored in the previous analysis. Overall, we found that gaps in all three ‘95s’ were associated with

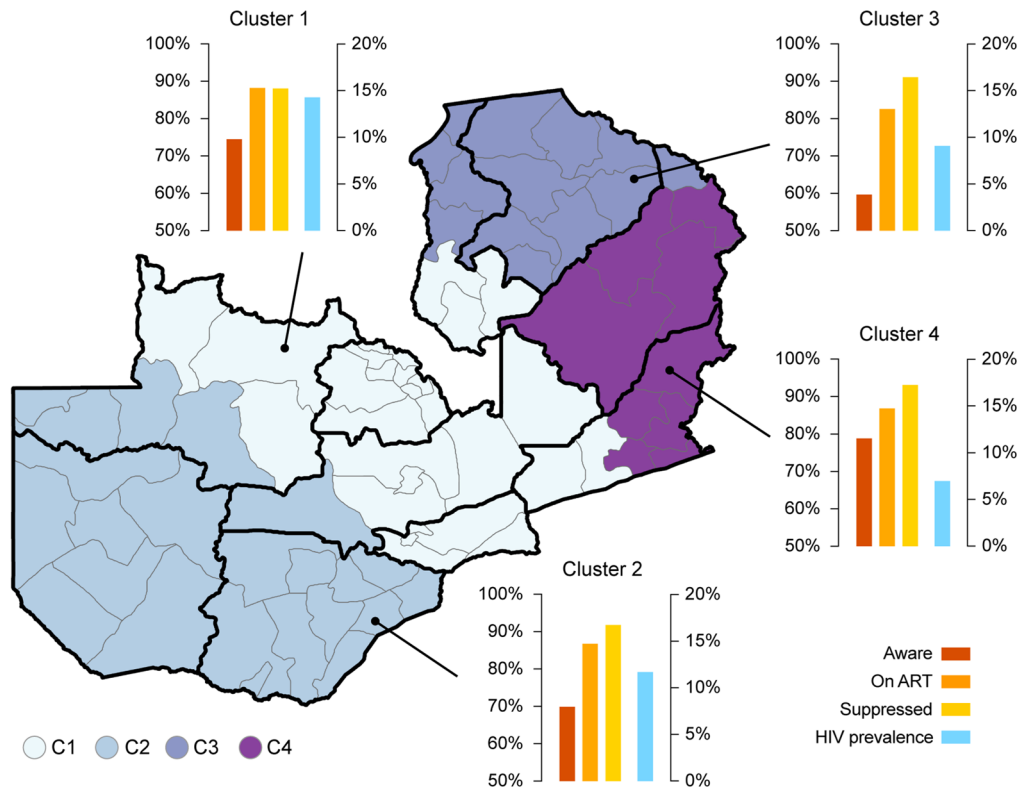


Figure 3 Spatial structure of the HIV epidemic and HIV care continuum in Zambia.

younger age, male sex and low wealth (though sex and wealth were not statistically significant for ART use among those diagnosed). Marital status and residence were only associated with diagnosis, while travel away from home was only associated with viral load suppression among those on ART. None of the ‘95s’ were significantly associated with education, religion, employment, or age at first sex.

For gaps in the first ‘95’, we found that gender, age, wealth index, marital status and place of residence were significantly associated with the odds of HIV status awareness. Males had higher odds of being unaware of the HIV

status compared with females, and odds of being unaware of status was highest in the youngest age group analysed (15–24) and declined with age. Odds of being unaware of positive HIV status were highest in the lowest wealth quintile, in individuals who were divorced/separated/widowed or never married, and those with rural residences.

For gaps in the ‘second 95’, we found that only age was associated with not on ART. Younger PLHIV individuals aware of their status had higher odds of not being on ART. Other factors that were significantly associated with lack of diagnosis were not significantly associated with lack of ART after diagnosis.

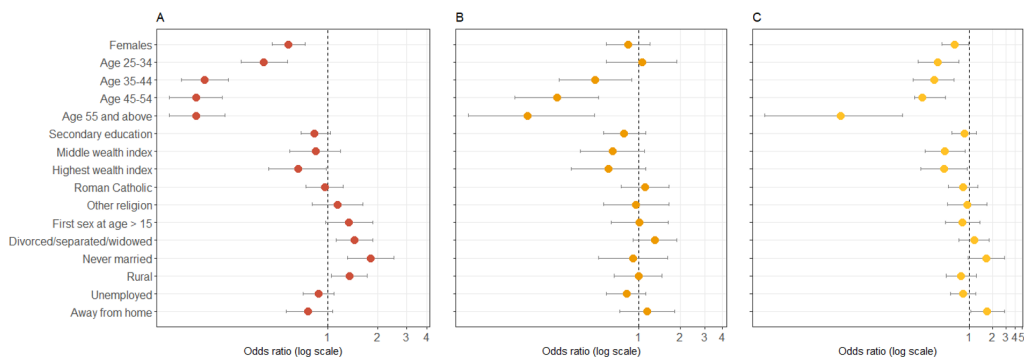


Figure 4 Results from the multivariable regressions for the three different models, (A) Model 1: HIV status awareness, the survey data were subsampled to include HIV-positive individuals only; (B) for model 2: ART status, the survey data were subsampled to include HIV-positive individuals aware of their status only and (C) for model 3: viral load suppression, the survey data were subsampled to include HIV-positive individuals aware of their status and on ART treatment. ART, antiretroviral therapy.

For gaps in the ‘third 95’, we found that gender, age, wealth index, and travel away from home were significantly associated with detectable viral load. Odds of having detectable viral load while on treatment were highest for men, younger individuals (ages 15–24—the youngest age group included in this analysis), those in the lowest wealth quintile, and those who had travelled away from for at least 1 month during the past 12 months. Fewer than 50% of HIV positive males aged 15–34 and females aged 15–24 know their HIV status. Likewise, less than 65% of HIV positive on ART treatment males aged 15–24 and less than 80% females with the same age had their viral load suppressed (online supplemental figure 2).

DISCUSSION

Our study provides valuable insights into the current state of the HIV epidemic in Zambia, highlighting key determinants and geographical disparities of HIV status awareness, ART status and viral load suppression among HIV-positive individuals. Among adults living with HIV in Zambia, 72.3% had knowledge of their HIV status, with 87.3% of those aware of their HIV status receiving ART treatment and 89.5% of those receiving ART treatment achieving viral load suppression. However, significant disparities in these metrics were observed across different population groups and geographical regions.

Consistent with previous research, our spatial analysis identified pockets of high HIV prevalence in certain regions, such as the Copperbelt and Lusaka provinces.^{18–21} Our study also revealed four distinct clusters with unique geographical patterns, exhibiting different levels of performance in the ‘95-95-95’ targets. These clusters included regions with high HIV prevalence, relatively high diagnosis rates, and moderate ART and viral load suppression along the central axis of the country; regions with moderate HIV prevalence, lower diagnosis rates in the south and west, and moderate ART and viral load suppression rates; regions with moderate HIV prevalence, very low rates of diagnosis in the northeast, and low ART and viral load suppression rates; and regions with low HIV prevalence, high performance across all three ‘95s’ in the east. Specifically, cluster 1, located in the Copperbelt, Central and Lusaka provinces, has high HIV prevalence rates, relatively high performance in all ‘95s’, and better healthcare access and infrastructure compared with other regions.^{22–23} Cluster 2, located in the Western and Southern provinces, has moderate HIV prevalence rates but lower rates of diagnosis, ART uptake and viral suppression than cluster 1, with limited healthcare access and infrastructure, especially in the Western province.^{24–26} Cluster 3, located in the Luapula and Northern provinces, has moderate HIV prevalence rates but very low rates of diagnosis, ART uptake and viral load suppression, with similar limited healthcare access and infrastructure to cluster 2.²⁷ Finally, cluster 4, located in the Muchinga and Eastern provinces, has the lowest

HIV prevalence rates in the country but relatively high performance in all ‘95s’, especially in the Eastern province, which has relatively good healthcare access and infrastructure.^{21–28} These results underscore the need for tailored interventions to address the specific needs of different subnational regions. Regions with high HIV prevalence may require more resources for HIV testing and diagnosis, while innovative approaches to ART delivery may be necessary in areas with limited healthcare access and infrastructure.

Our study suggests that reporting ‘95-95-95’ targets at the national level may not be sufficient to address subnational care continuum gaps. As noted previously, the largest gaps in each ‘95’ occurred in different geographical regions. Progress towards these targets has been uneven across the country, and gaps vary for each of the ‘95s’. These results highlight the challenges of achieving the ‘95-95-95’ targets in Zambia, with diagnosing HIV being the most significant obstacle. Therefore, it may be necessary to adopt a tailored approach to healthcare strengthening in different parts of Zambia to improve progress towards HIV treatment targets. We observed that HIV care continuum gaps are not solely related to HIV prevalence, as regions with high HIV prevalence did not necessarily perform better than others, indicating the need for tailored interventions to address the specific needs of different subnational regions in the country to achieve the ‘95-95-95’ targets.

Enhancing community-level factors, such as transportation and housing, may also be critical in improving HIV care continuum outcomes in vulnerable populations. In addition, our study found that care continuum gaps coincided with regions experiencing high community vulnerability, particularly in the domains of healthcare and housing/transportation, indicating that community-level factors are among the drivers of HIV care engagement. Further spatial assessments of community vulnerability could refine our understanding of the contributors to care continuum gaps.

Individual-level factors associated with gaps in the care continuum varied depending on the specific ‘95’ target. Lack of HIV diagnosis was more likely among individuals residing in rural areas and those who were unmarried, while lack of viral load suppression was associated with travel away from home. However, several factors were consistently associated with gaps across all three ‘95s’, including poverty, male gender and young age. Females had lower odds of being unaware of their HIV status compared with males, and the odds of being unaware of HIV status decreased with age. Individuals in the highest wealth quintile had lower odds of being unaware of their HIV status than those in the lowest quintile. Age was the only factor associated with not being on ART treatment, and older individuals aware of their HIV status had lower odds of not being on ART treatment compared with those aged 15–24. Similarly, older individuals had lower odds of not being viral load suppressed compared with those aged 15–24 on ART. Individuals in the lowest

wealth quintile had higher odds of not being viral load suppressed, and those on ART treatment who were away from home for at least 1 month during the past 12 months had higher odds of not being viral load suppressed. A comprehensive approach is needed to address gaps in the care continuum. Targeted interventions may be required to increase HIV status awareness and ART uptake among males, rural populations and individuals from lower wealth quintiles. Additionally, innovative service delivery models, such as mobile ART clinics, may be necessary to improve viral load suppression among individuals who travel away from home, such as providing mobile ART clinics or other innovative service delivery models.

As a second PHIA study (2021) has recently been conducted in Zambia, our research should be repeated once results are available to provide updated estimates. The comparison between both surveys conducted at different time points will provide valuable insights about not only the national progress towards the UNADS targets, but also will assess the subnational evolution of the targets, with particular focus on the improvement in the areas lagging in any of the targets identified in this study. Comparing the results from the 2016 and 2021 PHIA surveys in Zambia would offer valuable insights into the progress made and the effectiveness of interventions over this 5-year period. Considering the previously identified subnational differences in each of the UNAIDS targets identified in this study, the comparison can guide future strategies by highlighting where efforts have been successful and where additional focus is required. Comparisons at both national and subnational levels will highlight areas of improvement and lack of progress. This trend analysis would allow the identification of patterns, particularly in regions showing little progress or regression. Likewise, this comparison would provide the assessment of interventions implemented between surveys and their effectiveness against changes in relevant targets. For lagging regions, comparisons between surveys will unveil potential causes or barriers and successful strategies from other regions. Likewise disaggregate data by demographics would be useful for identifying at-risk groups and refine intervention focus. This analysis will also aid in refining methodologies for future PHIA surveys, ensuring they are more tailored and effective.

Our study is subject to several important limitations. First, our findings are based on the 2016 ZAMPHIA survey, which represents the most current data publicly available with population-based estimates of '95-95-95'. Second, our analysis was limited to the district level, and subdistrict-level geographical differences may exist. While the PHIA survey provided estimates for certain geographical subgroups and administrative regions, it was not designed to generate small-area estimates. Future research could improve estimates by incorporating routine health systems data that are larger and more timely, though potentially more biased and incomplete. Finally, our assessment of community vulnerability factors

was only qualitative and at a coarse spatial scale. More detailed spatial estimates of community vulnerability could better explain the distinct geographical patterns observed for each '95' and suggest strategies to address community-level barriers to HIV engagement along the care continuum.

CONCLUSIONS

The findings of our study revealed significant spatial heterogeneity in the HIV care continuum in Zambia. Despite similar individual-level factors associated with each stage of the continuum, our results demonstrated distinct geographical patterns for each '95', which were not necessarily linked to high HIV prevalence areas. Our study underscores the need for targeted interventions to improve HIV status awareness, ART uptake and viral load suppression in vulnerable populations. Although HIV diagnosis represents the most significant gap in the care continuum, a tailored approach may be required in different subnational regions to achieve the '95-95-95' targets. Further investigation into the drivers of care continuum gaps, including community vulnerability, can inform the development of innovative strategies to enhance HIV care continuum outcomes. Such strategies should take into account the unique challenges faced by different regions and populations, such as rural residence, low income and limited healthcare access, to improve the effectiveness of HIV care and treatment programmes. Addressing these gaps in the HIV care continuum is critical for reducing the burden of HIV and achieving global HIV targets to ensure that no one is left behind.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Human subjects and ethical approval for the ZAMPHIA survey was granted by the Zambia National Health Research Ethics Board (Ref: MH/101/23/10-1), the Tropical Diseases Research Centers Ethics Review Committee (Ref: STC/2015/9), and the Institutional Review Boards at the Centers for Disease Control and Prevention (CDC; Atlanta, Georgia, USA). All participants provided written informed consent or assent for the original survey.

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Data availability statement Data are available in a public, open access repository. Data are available in a public, open-access repository. The data that support the findings of this study are available from the Population-Based HIV Impact Assessment (PHIA; <https://phia-data.icap.columbia.edu/>), but restrictions apply to the availability of these data, which were used under licence for the current study and so are not publicly available. We sought and were granted permission to use the core data set for this analysis by PHIA.

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