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Towards UNAIDS Fast-Track goals: Targeting priority geographic areas for HIV prevention and care in Zimbabwe

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Abstract

Introduction: Zimbabwe has made substantial progress toward the Joint United Nations Programme on HIV/AIDS (UNAIDS) targets of 90-90-90 by 2020, with 73% of people living with HIV diagnosed, 87% of those diagnosed on antiretroviral therapy (ART), and 86% of those on ART virally suppressed. Despite this exceptional response, more effort is needed to completely achieve the UNAIDS targets. Here, we conducted a detailed spatial analysis of the geographical structure of the HIV epidemic in Zimbabwe to include geographical prioritization as a key component of their overall HIV intervention strategy.

Methods: Data were obtained from Zimbabwe Demographic and Health Survey (ZDHS) conducted in 2015 as well as estimations from the Zimbabwe Population-Based HIV Impact Assessment (ZIMPHIA) 2016 report, and other published literature. Data were used to produce high-resolution maps of HIV prevalence. Using these maps combined with the population density maps, we mapped the HIV-infected population lacking ART coverage and viral suppression.

Results: HIV maps for both genders illustrated similar geographical variation of HIV prevalence within the country. HIV-infected populations lacking ART coverage and viral suppression were concentrated in the main cities and urban settlements such as Bulawayo, Harare, Ruwa, and Chitungwiza.

Conclusion: Our study showed extensive local variation in HIV disease burden across Zimbabwe for both females and males. The high-resolution maps generated here identified areas where high density of HIV-infected individuals are lacking ART coverage and viral suppression. These results suggest that there is need to tailor HIV programmes to address specific local needs to efficiently achieve epidemic control in Zimbabwe.

Keywords: UNAIDS 90-90-90 goals; Spatial analysis; HIV mapping; ART coverage; Viral suppression; Optimal resource allocation

Introduction

The Joint United Nations Programme on HIV/AIDS (UNAIDS) under its ambitious 2020 targets of 90-90-90 (90% of all people living with HIV know their HIV status, 90% of all people with diagnosed HIV infection receive sustained antiretroviral therapy (ART), and 90% of all people receiving antiretroviral therapy have viral suppression) [1], which has been escalated to 95-95-95 by 2030, has paved the way for more structured and effective responses to the HIV epidemic, particularly in South-Saharan Africa (SSA). Zimbabwe, a country that had one of the worst HIV epidemics in the world [2, 3], is working to achieve the 90-90-90 goals. Supported by rapid and effective mobilization against the epidemic, Zimbabwe has been able to halve its HIV prevalence over the last fifteen years [3]. Recently, the Zimbabwe Population-Based HIV Impact Assessment (ZIMPHIA) survey showed that the country is moving rapidly towards the 90-90-90 goals for 2020, with 73% of people living with HIV (PLHIV) diagnosed, 87% of those diagnosed on ART, and 86% of those on ART virally suppressed [4].

Despite notable progress made by Zimbabwe, HIV prevalence in the country remains high, with about 14% of adults aged 15-49 years old infected with the virus [5] and more than 33,000 new infections occurring every year [4]. This complex epidemiological context of the HIV epidemic, coupled with flatlining of financial resources from international donor organizations and limited domestic capacity to fund its own response represent a challenge for achieving and maintaining the UNAIDS 2020 goals, and the even more ambitious 95-95-95 UNAIDS targets by 2030. Therefore, enhanced targeting of spending and allocative efficiency of limited resources through novel methodological and strategic approaches would facilitate reaching these UNAIDS Fast-Track targets.

Recent research has consistently demonstrated substantial spatial variation in the HIV epidemic at different geographical scales, including at the province [6], district [7, 8], subdistrict, and more localized levels [9-18] in several SSA countries (including

Zimbabwe). The HIV landscape in Zimbabwe is not homogeneous, with the infection clustering in the southern part of the country, between the provinces of Bulawayo, Matabeleland North and Matabeleland South [19, 20]. These provinces also had lower ART coverage than provinces located in areas with low HIV prevalence (e.g., Mashonaland West, Central and Eats, and Masvingo) [4]. Studies focused on localized areas in Zimbabwe have also found substantial variation of the HIV epidemic. For example, east Zimbabwe had spatial clustering of HIV infection in urban areas around the small towns of Nyazura and Nyanga, as well as inequalities in accessibility and uptake of HIV services in these areas [21].

Identifying areas where the burden of HIV infection is concentrated will help target prevention and treatment interventions to populations at higher risk of infection, and knowledge about high-risk areas is prerequisite to implementing successful surveillance programs and optimally allocating resources [13, 22-26]. However, most measures of HIV occurrence are frequently available only for large geographical administrative units such as districts or provinces, thereby obscuring important localized aspects of the HIV transmission process. Given the limited and declining resources devoted to HIV prevention, treatment, care and control as a result of donor fatigue and shifting donor priorities over time, it is crucial that intervention efforts are directed to vulnerable high-risk populations in local geographical areas of greatest HIV burden [27, 28]. Micro-level data on the spatial distribution of HIV prevalence could help prevent new HIV infections and increase treatment rates by prioritizing resources targeting localized high burden areas and aligning service delivery modalities to the specific needs of the local communities on these areas.

Given this context, the main objective of this study was to construct high-resolution maps of intra-national estimates of HIV measures (prevalence and density of HIV-infected population) in Zimbabwe based on spatial variables. In addition, a detailed spatial analysis of the current stage of the 90-90-90 indicators in Zimbabwe was conducted. This information is aimed to assist the country to strategically target localized geographic areas and populations in order to maximize programme outputs and boosting programme efficiency to achieve the UNAIDS targets in Zimbabwe.

Methods

Study area and data sources

The study area was Zimbabwe, a landlocked country in southern Africa. Zimbabwe has the sixth highest HIV prevalence in SSA, with approximately 1.2 million persons aged 15-64 years old living with HIV in 2016 [4]. The main source of data for this study was the Zimbabwe Demographic and Health Survey (ZDHS) conducted in 2015 [5]. Subjects were enrolled in the ZDHS via a two-stage sampling procedure to select households. A total of 400 ZDHS sample locations were selected. The global positioning system was used to identify and record the geographical coordinates of each ZDHS sample location (Figure 1). The study population was limited to adults aged 15 to 49 years, resulting in a total of 9,054 women and 7,082 men included in the study. Anonymous HIV testing was performed with the informed consent of all sampled individuals. Further details related to the ZDHS methodology, study design, and data can be found elsewhere [5, 29-31].

Population density throughout Zimbabwe was obtained from the WorldPop database [32] (Figure S1). Estimates for additional spatial variables, including the percent of PLHIV who were diagnosed, the percent of people diagnosed with HIV who were treated by ART, and the percent on ART who were virally suppressed, were obtained at provincial scale from the 2016 ZIMPHIA report [4]. Lastly, estimated number of new HIV infections and the average number of clients per ART treatment site at the province level were obtained from the report on Smart Investment to End HIV AIDS in Zimbabwe based on Hotspot Analysis [33].

Definitions of variables

Socio-economic, behavioral and environmental variables

To assess the association between socio-economic and behavioral factors and the prevalence of HIV infection, we selected a variety of demographic, socio-economic, and behavioral attributes from the ZDHS dataset and other sources. Fifteen variables measured for men and 14 for women included: wealth index, number of children under five years old in household (women only), male circumcision (men only), union status, number of unions, currently reside with husband/wife/partners, number of wives (men only), number of husband's other wives (women only), age at first sex, employment, condom use, number of sexual partners including spouse, ever been tested for HIV, and total number of lifetime sexual partners. Environmental variables included the normalized difference vegetation index (NDVI), distance to primary roads, distance to main cities, and population density (Supplementary Figure S1). The definition and descriptive statistics for each variable are presented in Supplementary Materials.

Selection of spatial variables and mapping

To map the geographical distribution of HIV prevalence in Zimbabwe as well as the geographic dispersion of HIV-infected males and females using spatial variables, we implemented a method previously developed to describe the spatial structure of HIV prevalence in several SSA countries [34]. Further details related to this methodology can be found in Supplementary Materials.

Spatial distribution of the 90-90-90 indicators

The spatial distributions of HIV incidence in 2013 and average number of clients per ART treatment site were estimated using data from the report on Smart Investment to End HIV AIDS in Zimbabwe Based on the Hotspot Analysis [33]. Data at the provincial levels on the percentage of PLHIV who have been diagnosed, the percent diagnosed with HIV who were receiving ART, and the percent of those receiving ART who were virally suppressed were generated by combining estimates from the 2016 ZIMPHIA report [4] with the geographical densities of HIV-infected males and females obtained in this study to determine the spatial distributions of the number of males and females who were lacking ART coverage and viral suppression in Zimbabwe in 2015.

Further details related to the methodology, study design, and data can be found in Supplementary Materials.

Results

Spatial variable selection

Supplementary Table S2 presents the results of the bivariate logistic regression and spatial correlation analysis. The variables selected in the final logistic regression models for males and females are shown in Table 1. For males, the final logistic model included currently in union, condom use, number of lifetime sexual partners, and population density. For females, the selected variables were poverty, number of unions, age at first sex below 20 years old, condom use, number of lifetime sexual partners, and population density. Maps of the variables selected for females (Figure S2) and males (Figure S3) are included in Supplementary Materials.

HIV prevalence distribution

The spatial distributions of HIV prevalence estimated using the final multivariable logistic regression models for females and males are presented in Figures 2A and 2D, respectively. These maps illustrate the distribution of the proportion of individuals that are HIV-positive among the entire adult population, with the highest proportion of the HIV-infected population (prevalence) located in the south-western part of the country. The estimated (pixel-level) HIV prevalence distribution for females ranged from 10.6% to 33.62%, with a median of 17.8%. For males, the estimated (pixel-level) HIV prevalence distribution ranged from 6.9% to 21.3%, with a median of 10.7%.

The geographic distributions of the estimated number of HIV-infected females and males are presented in Figures 2B and 2E, respectively. These maps illustrate the distribution of the density of HIV-infected individuals in Zimbabwe. Most of the HIV-infected individuals were located in urban settings (Harare, Norton, Chitungwiza, Ruwa and Bulawayo). There were an estimated 625,319 HIV-infected females and 419,964 HIV-infected males aged 15-49 years old in 2015. Figures 2C and 2F illustrate the location of high HIV burden areas for females and males, respectively, where both HIV prevalence and density of HIV-infected individuals were positively correlated. For females, the high burden areas corresponded to only 1.4% of the total area in Zimbabwe but contained 18.8% of the total number of HIV-infected females. Similarly, for males, these areas corresponded to 2.4% of the total area in Zimbabwe but contained 26.5% of the total number of HIV-infected males.

Gaps in ART coverage

Figure 3A-D illustrates the provincial-level spatial distribution of several epidemiological and treatment and care measures, including estimated HIV incidence in 2013 (Figure 3A), ART coverage (Figure 3B), and viral load suppression among HIV-infected individuals receiving ART (Figure 3C). Figure 3D presents the average number of clients per ART treatment site at the district level. The geographic distributions of the number of HIV-infected females and males aged 15-49 years old who were lacking ART coverage and viral suppression in 2015 are presented in Figures 3E and 3F, respectively. We estimated that a total of 353,613 females (56.5%) and 237,804 males (56.6%) aged 15-49 years old were lacking standard ART coverage and viral suppression in Zimbabwe in 2015 (Table 2).

Discussion

The study identified geographical variation of HIV prevalence for both men and women in Zimbabwe. The burden of infection is concentrated in the south-western part of the country, between the provinces of Matabeleland North and South, and Bulawayo, which is consistent with previous studies [19, 20]. Similar geographical patterns with high HIV prevalence for males were identified in urban areas, particularly in the eastern part of the country (Mutare and Chipinge). High numbers of

HIV-infected males and females occurred in northern and eastern Zimbabwe. The burden of HIV-infected individuals appears to be concentrated in urban settings (Harare, Norton, Chitungwiza, Ruwa and Bulawayo) with an HIV-infected population density higher than 1,000 HIV-infected females and males per 5 km^2. However, the distribution of HIV-infected females was more disperse compared to the distribution for males.

Our results suggest that sexual behavior could be a key driver of the HIV prevalence distribution in Zimbabwe. Behavioral factors such as high number of lifetime sexual partners (> 2 lifetime sexual partners), condom use, and sexual debut (age at first sex below 20 years old in females) showed a distinct geographical distribution that was associated with the spatial prevalence of HIV infection for both females and males. These results are consistent with previous data from Malawi [35], in which risky sexual behavior described by high number of lifetime sexual partners explained much of the spatial variation in HIV prevalence. In addition, several other studies have identified sexual risk behaviors such as early age of first sex [36], multiple partnerships [37, 38], and long-term concurrent partnerships [39, 40] to be linked to HIV infection in Zimbabwe. Moreover, condom use has been found to be associated with high risk of HIV infection, including in Zimbabwe [4, 21, 41].

Mobility and migration are common factors linked to the spread of HIV in countries in southern Africa [40, 42]. Distance to main roads has been identified as a factor associated with the risk of HIV infection linked to mobile individuals [34, 43, 44]. However, we did not find a statistically significant association between distance to main roads and the prevalence of HIV infection for either males or females in Zimbabwe. According to our results, areas adjacent to main roads had lower poverty levels compared to areas distant to main roads. A similar pattern was observed for sexual debut in females, in which female populations living distant to main roads had higher percentage of females engaging in sexual contact at early ages. Females living in high areas of poverty are a vulnerable population and may engage in risky sexual behaviors such as commercial sex or establish a partnership with older males [45-47].

Therefore, along with ART access and HIV testing, the female population living in these communities could be targeted for combination interventions, including pre-exposure prophylaxis (PrEP) and behavioral interventions such as condom distribution, prevention counseling, family planning and mass media programmes. Moreover, these poorer, hard-to-reach communities could benefit from the implementation and delivery of mobile units for HIV services, which have been demonstrated to be effective in delivering and enhancing HIV services uptake, particularly in isolated areas [48, 49].

For males, we identified geographical hotspots (high numbers of HIV-infected males in areas with high HIV prevalence) in the southern and eastern parts of the country, close to the borders with Botswana, Mozambique and South Africa. These high burden areas for males are linked to commercial transport corridors, increased diamond mining activities, and mobility between the neighboring countries of Botswana, Mozambique and South Africa, among other factors that could be fueling the burden of HIV infections in these areas [50]. Therefore, other combination interventions besides HIV testing and counseling and ART, such as PrEP, voluntary medical male circumcision (VMMC), and condom distribution could be provided to the male population living in these areas. The benefits of focusing on this high HIV burden area for males may also extend into lower-prevalence locations, particularly for female partners, given the extensive migration that occurs in these areas.

According to the UNAIDS Global Report in 2015 [2], Zimbabwe is among thirteen countries in SSA that has registered a dramatic decline of new HIV infections of at least 50% among adults (15-49 years) between 2001 and 2011. Nevertheless, Zimbabwe still faces a high HIV burden. Despite its push towards UNAIDS goals, more effort is needed to completely achieve the goals and diminish the current HIV epidemic in Zimbabwe. Here we presented a novel methodological approach to investigate the drivers of the spatial variation of the epidemic and assessed the potential geographical gaps in HIV services and care delivery that could hinder Zimbabwe in meeting UNAIDS targets.

Zimbabwe remains committed to achieving UNAIDS targets and adopted 2013 ART guidelines in order to increase and improve access to services [2]. As a result, service delivery in terms of coverage with ART and prevention of mother-to-child transmission have increased by up to five times between 2004 and 2013 [33]. Despite the substantial effort invested by the government of Zimbabwe and its partners to reach UNAIDS goals, several important gaps could prevent it from successfully attaining and maintaining the desired targets by 2030. Although there are small geographical differences in the geographical distribution of HIV prevention, treatment and care services, the delivery of these services has not been completely aligned in concordance with the spatial heterogeneity of the epidemic. Our analysis indicated that more than 230,000 males and 350,000 females are lacking treatment and care in Zimbabwe. A significant fraction of these individuals (22%) were located in the high burden areas (HIV hotspots) identified, which occupy only about 2% of the total area of Zimbabwe. In fact, ART coverage is slightly lower in the provinces with high HIV prevalence (Matabeleland North and South).

The provinces of Harare and Bulawayo, with about 113,000 and 33,000 HIV-infected individuals lacking ART coverage and viral suppression, respectively, might be particularly affected by lacking sufficiently focused HIV services coverage to meet demand. Despite the fact that these provinces received two of the highest budgets allocated for HIV treatment in Zimbabwe in 2012 (Figure S4 C) [33], these regions also have the highest estimated average number of clients per ART site which could be interpreted as low coverage levels in these provinces. This observation together with the high HIV prevalence and high population density of PLHIV in Harare and Bulawayo, suggest the need to intensify the delivery of HIV services and care among other programme interventions to these areas. Furthermore, HIV spending is the lowest in the areas with the highest HIV prevalence in Zimbabwe, which could reflect failures in the HIV service coverage for the population living in these areas and could compromise the achievement of the UNAIDS targets. However, it is important to note that the number of clients per ART site was taken to be the average number of clients receiving service per site, which was calculated using the number of sites per district and the number of PLHIV within each district (data provided in the Hotspot Analysis report). There are factors that could affect this estimate, such as ART clients who travel and receive services from other health centers beyond their district boundaries. Using the total number of sites and the exact number of people on ART could provide more accurate estimates of HIV services coverage.

Several study limitations could have affected our results. Given the multiple logistical difficulties in conducting the ZDHS, some of the variables included in our study could have been affected by inherent biases in the data, such as variability in response rates to HIV testing and under-sampling of mobile individuals and key core groups at risk [51, 52]. For instance, some high-risk subpopulations, such as female sex workers, injecting drug users, men who have sex with men, and mobile individuals, could have been missed by the ZDHS. It is not clear though whether these high-risk subpopulations were under-sampled or if it affected our findings. Epidemics among these high-risk subpopulations could lead to onward transmission of the HIV infection among spouses and clients of female sex workers. Moreover, our results could be affected by patterns of migration, information not provided by ZDHS but that could improve the accuracy of spatial estimation. Like the ZDHS, ZIMPHIA was a population-based nationally representative survey, and some of the variables extracted from this sample could have been affected by inherent biases in the data, such as variability in response rates to HIV testing and self-reporting HIV testing and ART treatment. Moreover, data were aggregated to the province level, reducing the spatial resolution. In addition, data from ZIMPHIA were reported for the entire adult population and were not stratified by gender. Also, following the recent World Health Organization (WHO) ART guidelines recommendations, we assumed that all adults living with HIV regardless of WHO clinical stage and at any CD4 cell count were eligible for ART [53], and the calculation of the numbers of HIV-infected individuals as well as individuals lacking ART coverage were based in pixel-level estimates using the map surfaces developed. An additional potential bias is the global positioning system displacement process of the DHS sampling data points, used to preserve their confidentiality [54]. This process could have an impact on the precision of HIV estimations, particularly affecting the location of areas with high HIV burden by several kilometers.

Conclusions

We conducted a detailed spatial analysis of the geographical structure of the HIV epidemic in Zimbabwe to include geographical prioritization as a key component for HIV control. Behavioral and socio-economic factors such as lifetime number of sexual partners, age at first sex and poverty, were associated with the spatial distribution of HIV prevalence for both males and females in Zimbabwe. As Zimbabwe rapidly approaches the UNAIDS 90-90-90 targets, saturation capacity for HIV infected individuals receiving ART in some areas underscores the need for precise geographic targeting of interventions. Also, social and behavioral programmes coupled with more robust prevention interventions such as PrEP in areas with high poverty that overlapped with a high fraction of vulnerable women, as well as interventions targeting the male population like VMMC in areas with intense economic activity and migration such as mining activities are needed in Zimbabwe. Special attention should therefore be given to developing and implementing tailored prevention programmes that take into consideration the degree of exposure risk, especially in areas identified as HIV hotspots and potential hotspots. In the HIV response of a country, a spatial model and high-resolution maps of HIV indices and continuum of care provide valuable information in support of a complex decision process that may also include, among several other elements, budgetary constraints along with political priorities beyond health outcomes. However, the type of geospatial analysis we conducted in this study could be a complementary component of the decision making process via continual engagement with stakeholders and other important decision-makers. The model results presented in this study provide information aimed at increasing intervention coverage in those areas with the greatest need, in addition to increasing the functionality and capacity of the existing service delivery centers in a country like Zimbabwe.

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Authors' contributions

D.F.C. contributed the study and its design, conducted the statistical and spatial modeling analyses, and wrote the first draft of the paper. J.L., Z.M., G.N.M., and A.B. contributed to study conception and design, conduct of the statistical modeling analyses, interpretation of the results, and writing of the manuscript. B.S, F.T. and O. M. contributed to study conception and design, interpretation of the results, and writing of the manuscript

Additional files

Additional file 1: Supplementary Materials

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Tables

Table 1. Variables in the final logistic regression models for males and females

Gender	Variable	Estimate	SE	P-value	Moran's I	P-value
Males	Intercept	-4.045000	0.2498	< 0.001	-	-
	Union status	0.015410	0.0029	< 0.001	0.09	< 0.001
	Condom use	0.015990	0.0030	< 0.001	0.16	< 0.001
	Lifetime number of sexual partners (> 2)	0.010170	0.0027	< 0.001	0.05	< 0.001
	Population density	-0.000002	0.0000	0.95	-	-
Females	Intercept	-2.677000	0.1547	0.00	-	-
	Poverty (poorer and poorest)	-0.002433	0.0011	0.03	0.39	< 0.001
	Number of unions (more than once)	0.013410	0.0024	0.00	0.04	< 0.001
	Age at first sex below 20	0.006553	0.0022	0.00	0.21	< 0.001
	Condom use	0.015020	0.0024	0.00	0.15	< 0.001
	Lifetime number of sexual partners (> 2)	0.009509	0.0024	0.00	0.31	< 0.001
	Population density	-0.000012	0.0000	0.66	-	-

Table 2. Pixel-level epidemiological indices estimation for each gender nationally in Zimbabwe and in its high HIV burden areas

	Country level		**High burden areas**	
	Males	***Females***	***Males***	***Females***
Pixel-level HIV prevalence	10.7%	17.8%	12.1%	19.9%
Total population	3,887,171	3,636,386	918,456	590,094
Number of PLHIV	419,964	625,319	111,386	117,821
Number of PLHIV diagnosed	306,573	456,482	81,311	86,009
Number of PLHIV diagnosed on ART	242,305	360,462	63,649	69,067
Number on ART virally suppressed	182,160	271,706	47,736	51,800
Number of PLHIV lacking ART coverage and viral suppression	237,804	353,613	63,650	88,365

Figures

Figure 1. The overall study area (top left panel) and Zimbabwe Demographic and Health Survey (DHS) sample locations. Maps were created using ArcGIS® by ESRI version 10.3 (http://www.esri.com) [55]

Figure 2. High resolution maps of HIV prevalence in Zimbabwe for (A) females and (D) Males in 2015; geographic dispersion of HIV-infected (B) females and (E) males in Zimbabwe. High HIV burden areas are illustrated in red for (C) females and (F) males. Maps were created using ArcGIS® by ESRI version 10.3 (http://www.esri.com) [55]

Figure 3. Province-level maps of (A) new HIV infection in 2015, B) ART coverage, and (C) percentage of viral load suppression among all HIV-infected individuals identified in the population-based ZIMPHIA survey. Map in (D) presents estimates of the average number of clients per ART site per district in 2015. Geographical dispersion of males (E) and females (F) lacking ART coverage and not virally suppressed in 2015. Maps were created using ArcGIS® by ESRI version 10.3 (http://www.esri.com) [55]