Proximity to sex work sites is not associated with higher HIV prevalence in the general population in Zimbabwe

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Abstract

In Zimbabwe, as in other East and Southern African countries, HIV prevalence is largely geographically heterogeneous. We determined if, and to what extent, this heterogeneity is associated with proximity to sex work sites by type of site (city, economic growth point, international, seasonal, or transport), using Demographic and Health Surveys location-specific HIV prevalence data—including 16,121 individuals (aged 15-49 years) from 400 sample locations—and Centre for Sexual Health and HIV/AIDS Research data on locations of 56 sex work sites throughout Zimbabwe. We conducted univariate and multivariate multilevel logistic regression to determine the association between sex work proximity—calculated as the shortest distance by road from each survey sample location to the nearest sex work site—and HIV seropositivity. We found no association between locations of sex work and heterogeneity in HIV prevalence in the general population, possibly explained by the mobile nature of both female sex workers and their clients as individual-level indicators of sex work were still significantly associated with HIV.

Introduction

Around two-thirds of people living with HIV reside in sub-Saharan Africa, marked as the epicenter of the HIV epidemic[1]. Throughout the subcontinent, the epidemic is geographically heterogeneous, with localized areas of high transmission around big cities, truck route pit-stops and locations with high levels of economic activity[2].

Sex work has been pinpointed as one of the major underlying drivers of the HIV epidemic in sub-Sahara Africa[3–5], estimated to account for about 18% of all HIV infections on the subcontinent[4]. Having multiple sex partners, inconsistent condom use, and barriers to accessing HIV services, among other reasons, puts this key population at higher risk of acquiring and spreading HIV[6]. Sites where female sex workers (FSWs) offer their services, here called “sex work sites”, are often situated at locations with high economic activity, such as truck stops, mining areas, commercial farming areas, country borders, and cities. These sex work sites are thought to be at the root of the observed geographic heterogeneity in HIV prevalence among the general population[7–9], yet this hypothesis has never been tested empirically.

Zimbabwe is one of the countries with the highest HIV burden. Incidence levels have decreased though, by 44% over the past decade, from 6.4/1000 people in 2010 to 3.8/1000 people in 2019[1,10], yet the decline in incidence seems to have stalled in recent years[11]. HIV prevalence among FSWs is over 50% according to the latest estimates (2018-20) by the Centre for Sexual Health and HIV/AIDS Research (CeSHHAR) Zimbabwe[12]. CeSHHAR is an organization focused on HIV implementation research which in addition runs Zimbabwe’s nationally scaled program for sex workers on behalf of the Zimbabwean government (www.ceshhar.org). It has mapped locations of 56 sex work sites, covering an estimated 95%

of all sex work sites in Zimbabwe[12]. These data, together with nationally-representative survey data from the Demographic and Health Survey (DHS) on HIV prevalence[2,13] create the unique opportunity to test whether the location of sex work sites is associated with HIV prevalence in the general population of Zimbabwe.

We aimed to determine if, and to what extent, geospatial heterogeneity in HIV prevalence among the general population in Zimbabwe is associated with proximity to FSW sites. We first calculated travel distance between DHS sample locations and sex work sites, and used univariate and multivariate logistic regression models to determine the association between distance to the nearest sex work site and HIV prevalence, controlling for demographic and sexual behavioural factors.

Methods

Data - CeSHHAR

CeSHHAR has registered the locations and characteristics of 56 sex work sites throughout Zimbabwe in 2017[12]. GPS coordinates of the sites were collected via Google Maps Coordinates[14]. Sex work sites are 'hotspots' for sex work, where sex work venues where the services are offered could be bars, shebeens, streets, brothels, beer halls, sport bars, nightclubs, or parking lots at border crossings, truck stops, mining areas, or marketplaces. Sex work sites were categorized into five types based on expert opinion: city (city, regional capital), economic growth point (rural areas with rapid economic growth), international (tourism, international business, border), seasonal (mining, farming, fishing, university, army base), or transport (truck stop, transport hub, border)[12]. Sites classified as more than one type were included in each group, with a maximum of three types per site. In this way, a site identified as e.g., truck stop and mining area was included as both a transport and a seasonal site.

Data - DHS

We used the most recent DHS from Zimbabwe that included voluntary HIV testing in adults, i.e., the survey conducted in 2015. About 400 locations (primary sampling units) were randomly sampled throughout the country, weighted by the population density per area, and about 25 randomly selected households were included at each location. All males and females aged 15-49 years with available HIV test result were included in our analysis. HIV status was determined in the DHS by testing a blood sample from a finger prick with an enzyme-linked immunosorbent assay (ELISA). GPS coordinates of sample locations were randomly displaced up to two kilometers for urban and up to five kilometers for rural locations, to ensure confidentiality of participants.

Besides HIV status and GPS data, we included several demographic and (sexual) behavioural variables in our analyses: age, sex, male circumcision, number of lifetime sex partners, being a female sex work (FSW) client or being a stable partner of someone who reported to be a FSW client. FSW clients were defined based on whether a man (aged 15-49 years) had ever, or in the last year, paid for sex. Men who reported to have offered gifts and goods in exchange for sex, instead of money, were not defined as sex work clients in our analysis, due to lack of coherency comparing those answers to the other sex work related questions. Missing values for lifetime sex partners were imputed using multiple imputation[15].

In addition to the variables directly extracted from the DHS, we estimated the proportion of FSW clients in each sample location, the proportion of FSWs around each sample location and the human mobility level of people at each sample location. We calculated the proportion of FSW clients as the fraction of all 15–49-year-old men at each sample location, as proxy for utility of commercial sex work among men at the sample location. We estimated the proportion of FSWs among the female population around each DHS sample location (in a 50-kilometer radius) by dividing the number of FSW in the area, based on FSW size estimates from the CeSHHAR database[12], by the total female population in the area, based on population estimates provided by the WorldPop project[16] and ZimStat[17]. The estimates are illustrated on a map in **Supplementary Fig. 1**. We estimated the human mobility level of individuals in the DHS data based on whether an individual was identified as mobile in the past year through either being a seasonal worker, being away for at least one month, or being away more than two times in the past 12 months. The prevalence of mobility was then aggregated per DHS sample location, where sample locations with a mobility prevalence of 50% or more were marked as locations with high human mobility, and sample locations with less than 50% were marked as locations with low human mobility.

More details on survey protocols and questionnaires can be found on the DHS website (https://dhsprogram.com/).

Analysis

We first used generalized linear regression to explore the association between HIV prevalence and proximity to nearest sex work site locations, as well as between HIV prevalence and the proportion of FSW clients at a sample location. We then performed Ordinary Kriging to extrapolate HIV prevalence levels at each sample location to predict and visualize geospatial heterogeneity in HIV prevalence among adults throughout Zimbabwe[18]. The methods are described elsewhere[9].

To determine the association between HIV prevalence among the general population and proximity to sex work sites among the general population, we performed an individual-level logistic regression analysis with HIV status (positive or negative) as dependent variable and proximity of each DHS sample location to the nearest sex work site (distance to any sex work site as well as by type of site, e.g., distance to the nearest city site and distance to the nearest economic growth point site) as independent variables. We used a geospatial proximity tool to calculate the shortest distance by road paved and unpaved roads as available through Open Street Map [19] (in kilometers) from each DHS sample location to the nearest sex work site (illustrated in **Supplementary Fig. 2**). We repeated this for every type of sex work site, so, distance to the nearest city site, growth point site, transport site, etcetera. We then applied these distances to each individual in the DHS data based on their sample location. We explored the association between HIV prevalence and proximity to the nearest (type of) sex work site using categorical, untransformed continuous, log-transformed, and square root transformed proximity variables (**Supplementary Fig. 3**). We used the square root transformed proximity variables in the univariable and multivariable logistic regression models, because distance most closely resembled a normal distribution using this transformation.

The associations between HIV status and all demographic and sexual behavioural variables included in this study were first assessed univariately. In the multivariate multilevel analysis, the association between travel distance to sex work sites and HIV status was adjusted for individual-level and sample location-level demographic and sexual behavioural risk factors related to sex work: age, sex, male circumcision, lifetime sex partners, and being identified as a FSW client, estimated proportion of FSWs at each sample location, urban or rural classification of each sample location, and population mobility score of each sample location. The DHS sample location was included as a random effect. The final multilevel multivariate models were developed using a backward selection procedure and log likelihood tests, by excluding all variables that did not significantly improve the model fit (using likelihood tests, $p > 0.05$). Finally, we separately fitted univariate and multivariate models stratified by sample location mobility score and urban/rural classification to examine potential effect modification.

We used R software version 4.0.1 and ArcGIS Pro version 2.3 to perform the analyses.

Results

All 16,121 individuals between 15 and 49 years of age from the 2015 DHS data were included in our study (**Supplementary Table 1**). The overall HIV prevalence in the study population was 14.7%, the prevalence among men was 11.2%, and among women 17.5%. Over one in five men (21.6%, N=1,529) reported to have ever visited a FSW, and about half of them (11.6%, N=822) reported to have visited a FSW during the past year. HIV prevalence among men who ever visited a FSW was 20.5%, compared to

8.6% for men who never did. Less than half of the study population (41.8%) lived in urban areas, where HIV prevalence was higher as compared to rural areas: 19.9% versus 11.0%. HIV prevalence was comparable between men with a high human mobility score versus those with a lower human mobility score (11.5% versus 10.7%), but higher among women with a lower mobility score (18.7% versus 15.5%). HIV prevalence levels for the general population and by subpopulation, i.e., men, women, young people (15-24 years), stable partners of FSW clients, FSW clients, and FSWs, are shown in **Supplementary Fig. 4**.

The geographical spread of HIV among the general population was highly heterogeneous (**Figure 1A**). Prevalence varied from just below 7% in north Zimbabwe and the eastern and northwestern borders, to over 21% and 24% at border crossings with South Africa and Botswana, respectively. Prevalence was also high (above 18%) in the Victoria Falls area, north of Harare (mining), and in the surrounding areas of Bulawayo (mining area, transport route).

The geographical locations and primary classification of the 56 sex work sites as registered by CeSHHAR are shown in **Figure 1B**. The nine city sites were located in or close to Harare, Zimbabwe's capital, and in or close to the other five bigger cities: Bulawayo and Gweru in central Zimbabwe; and Mutare, and Marondera in northeast Zimbabwe. The nine economic growth point sites and 32 seasonal sites were mostly located in the rural areas of the country. The 10 international sites were located at border crossings with Botswana (Plumtree), Mozambique (Mokumbura and Nyampanda), South Africa (Beitbridge), and Zambia (Chirundu and Kariba) and around tourist locations (Victoria falls) and the large cities. The 21 transport sites were mostly located on the national truck routes throughout the country as well as at the international border crossings.

Figure 2A shows the association between sample location-level HIV prevalence and untransformed distance to the nearest sex work site. There was a large variation in both general population HIV prevalence per sample location, ranging from 0% to 55%, and proximity to nearest sex work site, ranging from 360 meter to 220 km, yet, there was no statistically significant association between the two variables ($p = 0.92$). Similarly, **Figure 2B** shows that there was no significant association between the proportion of FSW clients at a sample location, ranging from 0% to 28%, and proximity to nearest sex work site ($p = 0.44$). Scatterplots of the association between HIV prevalence and square root-transformed proximity to the nearest sex work site by type of site are shown in **Supplementary Fig. 5**.

Table 1 shows the univariate and multivariate associations between square root transformed proximity to sex work sites and demographic and behavioural covariates, and individual HIV status. Univariately, proximity to the nearest sex work site overall was not associated with HIV prevalence (odds ratio (OR) = 0.995 [95% confidence interval (CI) 0.976–1.013], $p = 0.563$). When stratified by type of sex work site, only distance to economic growth point sites was borderline significantly associated with HIV status (OR =

0.984 [0.968–1.000]; p = 0.050), where farther distance from a sex work site was found to be associated with less people with HIV.

When controlling for demographic and behavioural variables in the multivariate models, proximity to sex work sites was not significantly associated with HIV seropositivity in the general population for any sex work site type: city site adjusted odds ratio (aOR) = 1.010 [95% confidence interval (CI) 0.992–1.028], p = 0.290; economic growth point site aOR = 0.982 [95% CI 0.962–1.002], p = 0.088; international site aOR = 0.995 [95% CI 0.979–1.012], p = 0.564; seasonal site aOR = 0.987 [95% CI 0.968–1.006], p = 0.176; and transport site aOR = 1.007 [95% CI 0.987–1.028], p = 0.500. In contrast, individual level covariates indicative of high-risk behaviour and engaging in commercial sex were significantly associated with HIV prevalence. Reported to have ever engaged in transactional sex (men only) showed a 44% increase in the odds of living with HIV (aOR = 1.445 [95% CI 1.188–1.745], p = <0.001). Similarly, reporting 9 or more lifetime sexual partners was associated with an over 2-fold increase in the odds of living with HIV compared to reporting 1-3 lifetime partners (aOR = 2.072 [95% CI 1.654–2.596], p = <0.001).

Multivariate logistic regression models stratified by rural/urban classification or stratified by mobility score of the DHS sample locations showed similar outcomes on the associations between proximity to sex work sites and HIV seropositivity (**Supplementary Tables 2 and 3**). Only for the urban sample, proximity to economic growth points was significantly associated with HIV seropositivity in the multilevel model (aOR 0.953 [95% CI 0.925–0.981], p = 0.001).

Table 1. Univariate and multivariate multilevel logistic regression analysis of HIV status among Zimbabwean males and females age 15-49. Both univariate and multivariate models are adjusted for DHS sample location random effects.

			Univariate analysis			Multivariate analysis		
Covariate	***N***	**HIV prevalence**	**OR [95% CI]**	**p-value**		**aOR [95% CI]**	**p-value**	
Proximity to the nearest female sex work site (km, square root transformed)								
All sites	16,121	14.7%	0.995 [0.976–1.013]	0.563		-		
Proximity to the nearest female sex work site (km, square root transformed) by type								
City	6,481[1]	14.5%	0.998 [0.986–1.009]	0.692		1.010 [0.992–1.028]	0.290	
Economic growth point	2,325[1]	15.5%	0.984 [0.968–1.000]	0.050	*	0.982 [0.962–1.003]	0.088	.
International	999[1]	12.2%	1.001 [0.990–1.012]	0.884		0.995 [0.979–1.012]	0.564	
Seasonal	4,124[1]	15.3%	0.988 [0.974–1.003]	0.124		0.987 [0.968–1.006]	0.176	
Transport	2,192[1]	14.5%	1.006 [0.990–1.023]	0.462		1.007 [0.986–1.028]	0.500	
Percentage of FSW clients as proportion of all men in survey at sample location								
<5%	3,493	12.8%	1	-		-		
5%-15%	10,125	15.1%	1.208 [1.022; 1.426]	0.026	*	-		
≥15%	2,503	15.8%	1.259 [1.012; 1.567]	0.039	*	-		
Percentage of FSWs as proportion of the female population in 50 km radius around sample location								
<5%	7,378	14.0%	1			1		
5%-15%	4,964	16.0%	1.173 [1.008–1.365]	0.039	*	1.155 [0.986–1.353]	0.075	.
≥15%	1,483	14.2%	1.017 [0.804–1.286]	0.889		1.118 [0.874–1.431]	0.375	

Sex								
Male	7,069	11.2%	1			1		
Female	9,052	17.5%	1.684 [1.535–1.849]	<0.001	***	2.540 [2.202–2.930]	<0.001	***
Age								
15-24 years	6,739	5.1%	1			1		
25-34 years	4,922	16.7%	3.848 [3.368–4.397]	<0.001	***	2.454 [2.085–2.890]	<0.001	***
34+ years	4,460	27.0%	7.324 [6.437–8.335]	<0.001	***	5.001 [4.261–5.868]	<0.001	***
Sex work client ever (males only)								
Yes	1,529	20.5%	2.710 [2.312–3.177]	<0.001	***	1.440 [1.188–1.745]	<0.001	***
No	5,540	8.6%	1			1		
Sex work client in the last year (males only)								
Yes	822	19.7%	2.101 [1.728–2.553]	<0.001	***	-		
No	6,247	10.1%	1			-		
Partner of FSW client (females only)								
Yes	787	19.7%	1.147 [0.949–1.386]	0.157		-		
No	8,265	17.3%	1			-		
Lifetime number of sex partners								
None	3,309	3.4%	0.172 [0.141–0.211]	<0.001	***	0.519 [0.407–0.662]	<0.001	***

1-3	9,651	16.0%	1			1		
4-9	2,251	22.8%	1.501 [1.337–1.685]	<0.001	***	1.999 [1.713–2.332]	<0.001	***
9+	910	23.2%	1.538 [1.300–1.818]	<0.001	***	2.072 [1.654–2.596]	<0.001	***
Circumcised (males only)								
Yes	1,150	7.4%	0.558 [0.440–0.708]	<0.001	***	0.654 [0.495–0.865]	0.003	**
No	5,916	11.9%	1			1		
Sample location-level human mobility prevalence								
High	6,334	13.4%	1.088 [0.995–1.190]	0.064	.	-		
Low	9,787	15.6%	1			-		
Type of place of residence								
Urban	6,737	19.9%	1.087 [0.996–1.187]	0.063	.	-		
Rural	9,384	11.0%	1			-		

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

[1] Number of individuals per type was calculated based on the primary classification of the sex work site that was closest to that individual. However, sex work sites could have up to three classifications assigned to them.

N = Number of observations, aOR = Adjusted Odds Ratio, CI = Confidence Interval, N/A = Not Applicable, ‘-’ = Covariate not present in multivariate regression model

Discussion

Our analysis of 56 sex work sites and 16,121 individuals from 400 DHS sample locations across Zimbabwe showed no apparent association between proximity to the nearest sex work site and HIV seropositivity among the general population, regardless of which type of sex work site was closest. In

contrast, individual-level indicators of sex work and high-risk behaviour were significantly associated with HIV seropositivity, with ever having been a FSW client being associated with an over 50% increase in the odds of living with HIV, and having 9 or more lifetime partners being associate with a more than 2-fold increase in the odds of living with HIV compared to reporting 1-3 lifetime partners.

Geospatial analyses are increasingly being used to illustrate and explain the heterogeneous spread of HIV[9,13,20]. For example, Palk and Blower showed that the heterogeneous spread of HIV in Malawi is associated with having a high number of lifetime sex partners. Likewise, Bulstra *et al.* showed that the large geographic heterogeneity in HIV prevalence among young adults in East and Southern Africa could be linked to areas of high economic activity[9]. In these and other studies [9,13,20–22], sex work was univocally hypothesized as an important underlying driver of the geospatial HIV heterogeneity. However, this hypothesis was never quantified empirically due to the lack of suitable data on locations of sex work, sex workers, and sex work clients in areas with nationally representative survey data available. In household surveys such as the DHS, sex workers are often not identifiable as being a sex worker[23]. Clients are identifiable, although reliant on self-reporting, but the places where they consume sex are often unknown. The places where sex workers and clients engage in sex work are often not equal to places where they live[24] and sex workers are usually mobile, often spending days, weeks or even months away from home[25]. Using our unique combination of geolocated individual-level survey data on HIV seropositivity and risk in the general population, and the mapped locations of over 95% of all sex work sites in Zimbabwe, we showed that the hypothesized direct link between proximity to sex work locations and heterogeneity in HIV prevalence among the general population does not hold for the situation in Zimbabwe.

It is important to note that our results do not refute the well-grounded notion that sex work is a major driver of HIV transmission in Zimbabwe and other settings with generalized epidemics[8,22]. On the contrary, our findings clearly demonstrate that at an individual-level indicators of practicing commercial sex as a client are significantly associated with increased risks for HIV. The lack of a geospatial association could be explained by mobility of both FSWs and clients[25,26]. A previous study on FSW in Zimbabwe found that different types of mobility exist among this group; with around 20% of FSWs traveling at least a couple of times a year over smaller distances, and 10% travelling long-distance while staying away from home for weeks or sometimes months [25]. Clients of sex work also do not usually visit FSWs close to where they live, but rather visit FSWs when they spend some time away from home[8]. For instance, many of the international sites, transport sites, and growth points are located around highways and at border crossings where truck drivers and itinerant workers are an important source of clients. Both the mobility of FSWs and of their clients could explain the lack of a clear association between proximity to sex work sites and HIV seropositivity in the general population. The lower HIV prevalence levels at DHS

sample locations with high human mobility levels might support this assumption. Also, international migration and visiting sex work sites across the borders with South Africa, for example, might play an important role, whereas we only cover residents and sex work sites in Zimbabwe.

Our study had some limitations. The overall number of respondents in the DHS between 15-49 years accepting HIV testing was 85%[27]. Respondence among men was slightly lower; 81% compared to 88% among women. It is often hypothesized that those who decline have higher HIV risk. However, younger people (15-34 years), often at higher risk of acquiring HIV, were somewhat more likely to participate in the HIV testing in the 2015 DHS. Also in rural areas, with often higher proportions of clients, response rates were generally higher. We therefore do not expect non-respondence to have influences our findings. There was a small discrepancy in years of the different data sources: the DHS was conducted in 2015, while the CeSHHAR data were from 2017. The sex work locations from the CeSHHAR data were determined based on clinic data collected between 2015 and 2017 as well as locations identified based on expert opinion[12]. Although some new locations might have arisen over the course of time and others might have become inactive, most locations were known to CeSHHAR since before 2015. However, the remaining difficulty in pinning down a clear definition of sex work sites and sex work itself must be recognized. Also, since the DHS are cross-sectional data and data on HIV status with no information on lag-time since seropositive status, we cannot make definite claims about causal effects between sex worker visits and contraction of HIV infection.

Our findings show that effective programmatic planning of the HIV response cannot solely depend on the observed geospatial heterogeneity in HIV prevalence, as previously suggested[9,13,20]. While planning testing and treatment services based on geospatial distribution of HIV prevalence within the general population would still suffice, allocating services for key populations requires careful mapping of hotspots and sites independent of general population HIV prevalence levels[12,28]. The lack of a spill-over effect of HIV to the general population in areas surrounding sex work locations is essential information for local policy makers, and emphasizes that interventions at these areas should primarily be focused on sex workers and clients. Given the often-high mobility levels of these subpopulations, good accessibility of services is crucial, especially since sex workers and clients might prefer to access HIV and primary care clinics at places away from home or utilize several different clinics depending on where they work and engage in commercial sex.

Conclusions

We found no evidence of a relationship between the proximity of FSW sites and HIV prevalence. Programmatic planning (key population) interventions to curb HIV transmission can therefore not be taken merely based on geospatial heterogeneity of the epidemic, but requires careful mapping and

considerations of transmission dynamics related to key-populations implicitly. The absence of a geospatial association can be explained by the mobile nature of both FSWs and their clients, as individual level indicators of sex work were still significantly associated with HIV. Given that spill-over of HIV into the general population surrounding sex work location seems limited, prevention and control interventions for HIV at these locations should primarily focus on sex workers and clients, with special emphasis on including and retaining mobile FSWs and their clients into services.

Declarations

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Author contributions

MK, CAB, SJdeV, and JACH designed the study. FC, EF, and SC were co-responsible for collection and preparation of the CeSHHAR data. MK, CAB, and SC prepared the data and conducted the analyses. MK, CAB, and JACH wrote the initial draft manuscript. All authors have reviewed and provided input to the manuscript.

Competing interests

The authors have declared no conflict of interest.

References

1. Joint United Nations Programme on HIV/AIDS (UNAIDS). *Joint United Nations Programme on HIV/AIDS. UNAIDS data 2020.* (2020).

2. Bulstra, C. A. *et al.* Mapping and characterising areas with high levels of HIV transmission in sub-Saharan Africa: A geospatial analysis of national survey data. *PLoS Med.* **17**, e1003042 (2020).

3. Alary, M. & Lowndes, C. M. The central role of clients of female sex workers in the dynamics of heterosexual HIV transmission in sub-Saharan Africa. *AIDS* **18**, (2004).

4. Wolf, J. *et al.* HIV Due to Female Sex Work: Regional and Global Estimates. *PLoS One* **8**, 1–7 (2013).

5. Nagelkerke, N. J. *et al.* Transition dynamics of HIV disease in a cohort of African prostitutes: a Markov model approach. *AIDS* **4**, 743–747 (1990).

6. Shannon, K. *et al.* Global epidemiology of HIV among female sex workers: Influence of structural determinants. *Lancet* **385**, 55–71 (2015).

7. Prüss-Ustün, A. *et al.* HIV due to female sex work: regional and global estimates. *PLoS One* **8**, e63476 (2013).

8. Steen, R. *et al.* Economy, migrant labour and sex work: interplay of HIV epidemic drivers in Zimbabwe over three decades. *AIDS* **0**, (2018).

9. Bulstra, C. A. *et al.* Mapping and characterising areas with high levels of HIV transmission in sub-Saharan Africa: A geospatial analysis of national survey data. *PLoS Med.* **17**, e1003042 (2020).

10. ZIMPHIA. *Zimbabwe population-based HIV impact assessment*. (2020).

11. United Nations Joint Programme on HIV/AIDS (UNAIDS). UNAIDS Data 2019. 476 (2019).

12. Fearon, E. *et al.* Estimating the Population Size of Female Sex Workers in Zimbabwe: Comparison of Estimates Obtained Using Different Methods in Twenty Sites and Development of a National-Level Estimate. *J. Acquir. Immune Defic. Syndr.* **85**, 30–38 (2020).

13. Cuadros, D. F. *et al.* Mapping the spatial variability of HIV infection in Sub-Saharan Africa: Effective information for localized HIV prevention and control. *Nature* **7**, 1–11 (2017).

14. Google Maps. https://www.google.com/maps/preview.

15. Buuren, S. van & Groothuis-Oudshoorn, K. MICE: Multivariate imputation by chained equations in R. *J. Stat. Softw.* **3**, 1–68 (2010).

16. WorldPop. Available at: http://www.worldpop.org.uk/.

17. Agency, Z. N. S. ZimStat.

18. Miller, H. J. Tobler's First Law and Spatial Analysis. *Ann. Assoc. Am. Geogr.* **94**, 284–289 (2004).

19. The Humanitarian Data Exchange. Open Street Map Zimbabwe roads.

20. Palk, L. & Blower, S. Geographic variation in sexual behavior can explain geospatial heterogeneity in the severity of the HIV epidemic in Malawi. *BMC Med.* **16**, 22 (2018).

21. Dzomba, A., Govender, K., Mashamba-Thompson, T. P. & Tanser, F. Mobility and increased risk of HIV acquisition in South Africa: A mixed-method systematic review protocol. *Syst. Rev.* **7**, 1–7 (2018).

22. Tanser, F., de Oliveira, T., Maheu-Giroux, M. & Bärnighausen, T. Concentrated HIV sub-epidemics in generalized epidemic settings. *Curr. Opin. HIV AIDS* **9**, 115 (2014).

23. Edwards, J. K. *et al.* Estimating sizes of key populations at the national level: considerations for study design and analysis. *Epidemiology* **29**, 795 (2018).

24. Platt, L. *et al.* Associations between sex work laws and sex workers' health: A systematic review and meta-analysis of quantitative and qualitative studies. *PLoS Med.* **15**, e1002680 (2018).

25. Davey, C. *et al.* Mobility and sex work: why, where, when? A typology of female-sex-worker mobility in Zimbabwe. *Soc. Sci. Med.* **220**, 322–330 (2019).

26. Deane, K. D., Samwell Ngalya, P., Boniface, L., Bulugu, G. & Urassa, M. Exploring the relationship between population mobility and HIV risk: Evidence from Tanzania. *Glob. Public Health* 1–16 (2016). doi:10.1080/17441692.2016.1178318

27. USAID. *Zimbabwe Demographic and Health Survey 2015*. (2016). doi:10.1017/CBO9781107415324.004

28. Davey, C. *et al.* Mobility and sex work: why, where, when? A typology of female-sex-worker mobility in Zimbabwe. *Soc. Sci. Med.* **220**, 322–330 (2019).

Figures

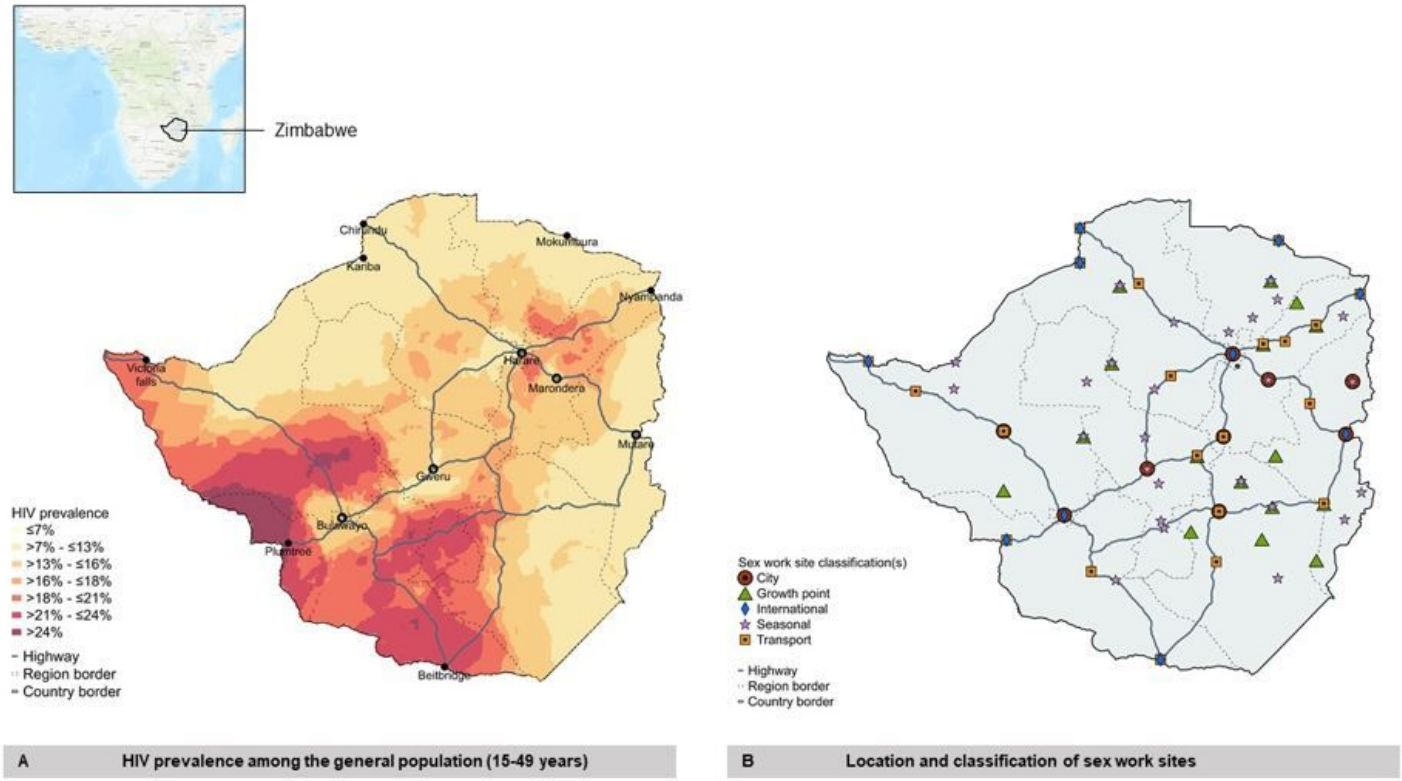

Figure 1

HIV prevalence among the general population in Zimbabwe (panel A) and female sex work (FSW) sites in Zimbabwe by type (panel B). HIV prevalence estimates are acquired using Ordinary Kriging (shown by 5 km2) and are based on the Zimbabwe 2015 DHS data of males and females (aged 15-49 years). DHS data obtained though https://dhsprogram.com/. Sex work site locations are obtained via CeSHHAR Zimbabwe (http://ceshhar.org/). Twenty-one sites were identified as transport sites, 32 as seasonal sites, 10 as international sites, nine as city sites and nine as economic growth point sites.

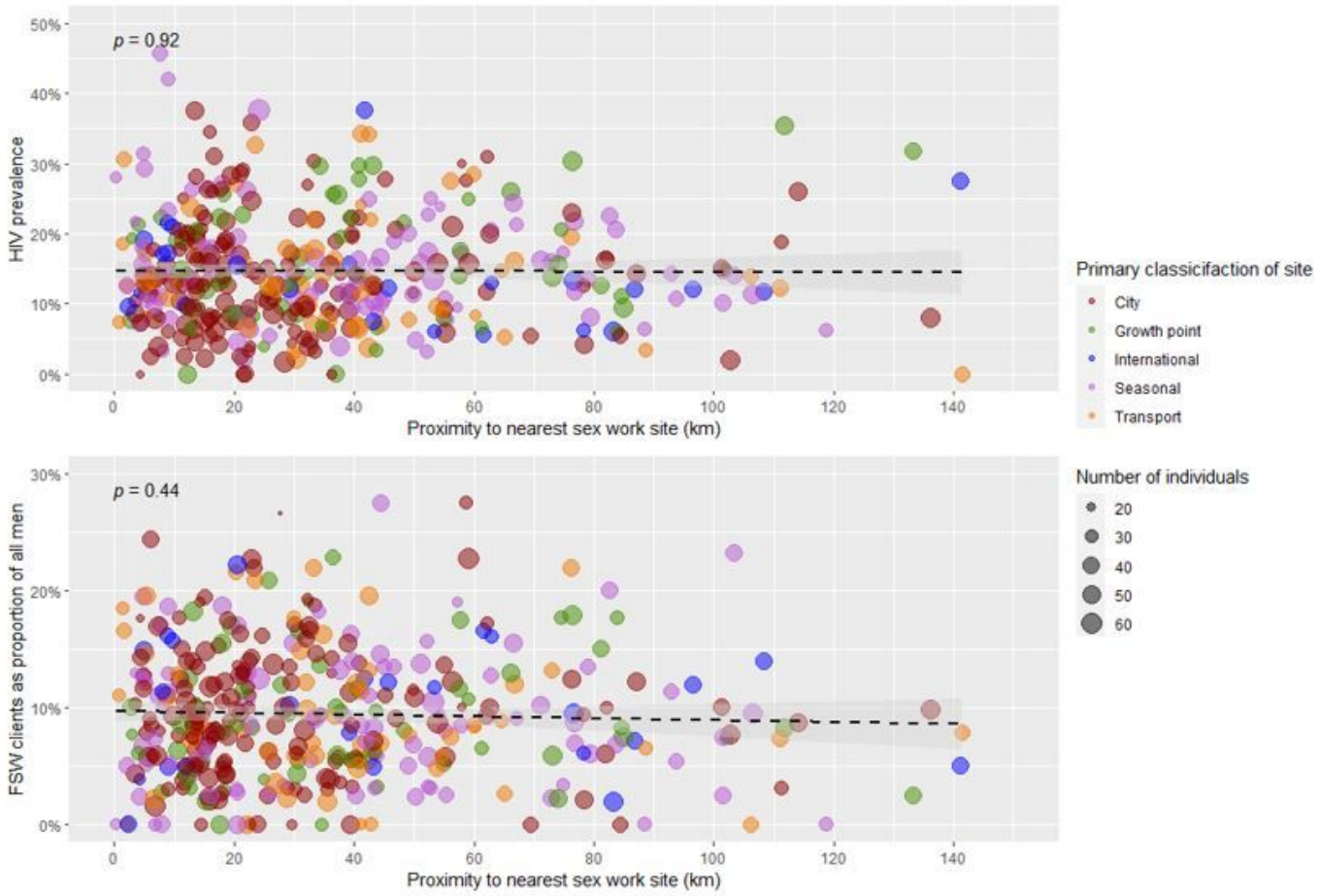

Figure 2

HIV prevalence among the general population (age 15-49 years) (panel A) and the proportion of all men who ever visited a FSW (panel B) in relation to proximity to the nearest sex work site, by DHS sample location. Colors represent the primary classification of the sex work site. Sizes of the bubbles represent the number of individuals in each DHS sample location, numbers shown in legend are approximations. Dashed lines represent smoothed generalized logistic regression fits for the associations, for all types of sex work sites together. Four outliers, with a proximity to the nearest sex work site of over 140 km, were excluded.

Supplementary Files

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