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Short Report

Spatial variability in HIV prevalence declines in several countries in sub-Saharan Africa

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ABSTRACT

Evidence suggests substantial declines in HIV prevalence in parts of sub-Saharan Africa. However, the observed aggregate declines at the national level may obscure local variations in the temporal dynamics of the infection. Using spatial scan statistics, we identified marked spatial variability in the within-country declines in HIV prevalence in Tanzania, Malawi, Kenya, and Zimbabwe. Our study suggests that the declines in the national HIV prevalence in some of the SSA countries may not be representative of downward trends in prevalence in areas of high HIV prevalence, as much as the result of sharp declines in prevalence in areas of already low HIV prevalence. Our findings provide insights for resource allocation and HIV prevention interventions in these countries.

1. Introduction

Recent evidence suggests substantial declines in HIV prevalence in parts of West, Southern and East Africa (UNAIDS, 2010; UNAIDS WHO, 2011). HIV incidence appears to have declined by more than 50% between 2001 and 2011 in 25 low-and middle-income countries, mostly from sub-Saharan Africa (SSA) (UNAIDS, 2012). HIV prevalence has declined by about 10% from 2000 to 2012 in Cameroon and Zambia, and by about 30% in Kenya and Malawi (UNAIDS WHO, 2013). The drivers of such HIV prevalence declines are not well understood (Awad and Abu-Raddad, 2014). Several mechanisms have been proposed to explain these declines including reduction in sexual risk behavior (Awad and Abu-Raddad, 2014; Hallett et al., 2006; 2009; Kilian et al., 1999; UNAIDS, 1999), natural epidemic dynamics (Garnett et al., 2006), increased HIV-associated mortality (UNAIDS, 1999; Walker et al., 2008a), impact of interventions (Stoneburner and Low-Beer, 2004), and heterogeneity in host susceptibility to HIV infection (Nagelkerke et al., 2009).

Despite reported HIV prevalence declines at the national level, a number of studies have suggested striking geographical differences in HIV prevalence trends. For instance, two studies using antenatal-clinic data among young women in Zambia reported diverse declines during the period 1994–2008 in urban settings ranging between 10% and 68%, and in rural settings ranging between 0% and 86% (Kayeyi et al., 2012; Sandøy et al., 2006).

These studies highlighted the possibility that the observed declines in HIV prevalence could reflect aggregate measures at the national level, obscuring local variations in the temporal dynamics of the infection. Motivated by theoretical grounds (Abu-Raddad et al., 2008; Alsallaq et al., 2009; Anderson and May, 1991; Awad et al., 2012; Cuadros et al., 2013), and based on a recent characterization of HIV infection clustering in SSA (Cuadros et al., 2013), we hypothesized that HIV prevalence declines would be higher in areas with low HIV prevalence (closer to the epidemic threshold for HIV in the general population) compared to areas with high HIV prevalence (well above the epidemic threshold). In this article, we examined the plausibility of such hypothesis by characterizing the spatial variability in HIV prevalence declines in different countries in SSA.

2. Methods

The main source of data in our study was the Demographic and Health Surveys (DHS) for countries in SSA with at least two rounds including HIV serological biomarker survey and the geographical coordinates of each survey data point; that is all countries where

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we could conduct this analysis. As a result, a total of 10 countries from SSA were analyzed: Cameroon (2004, 2011), Ethiopia (2005, 2011), Kenya (2003, 2008–2009), Lesotho (2004, 2009), Malawi (2004, 2010), Mali (2001, 2006), Rwanda (2005, 2010), Senegal (2005, 2010–2011), Tanzania (2003–2004, 2007–2008, 2011–2012), and Zimbabwe (2005–2006, 2010–2011).

We used spatial scan statistics analyses (Kulldorff, 1997) to identify the geographical clusters with high numbers of HIV

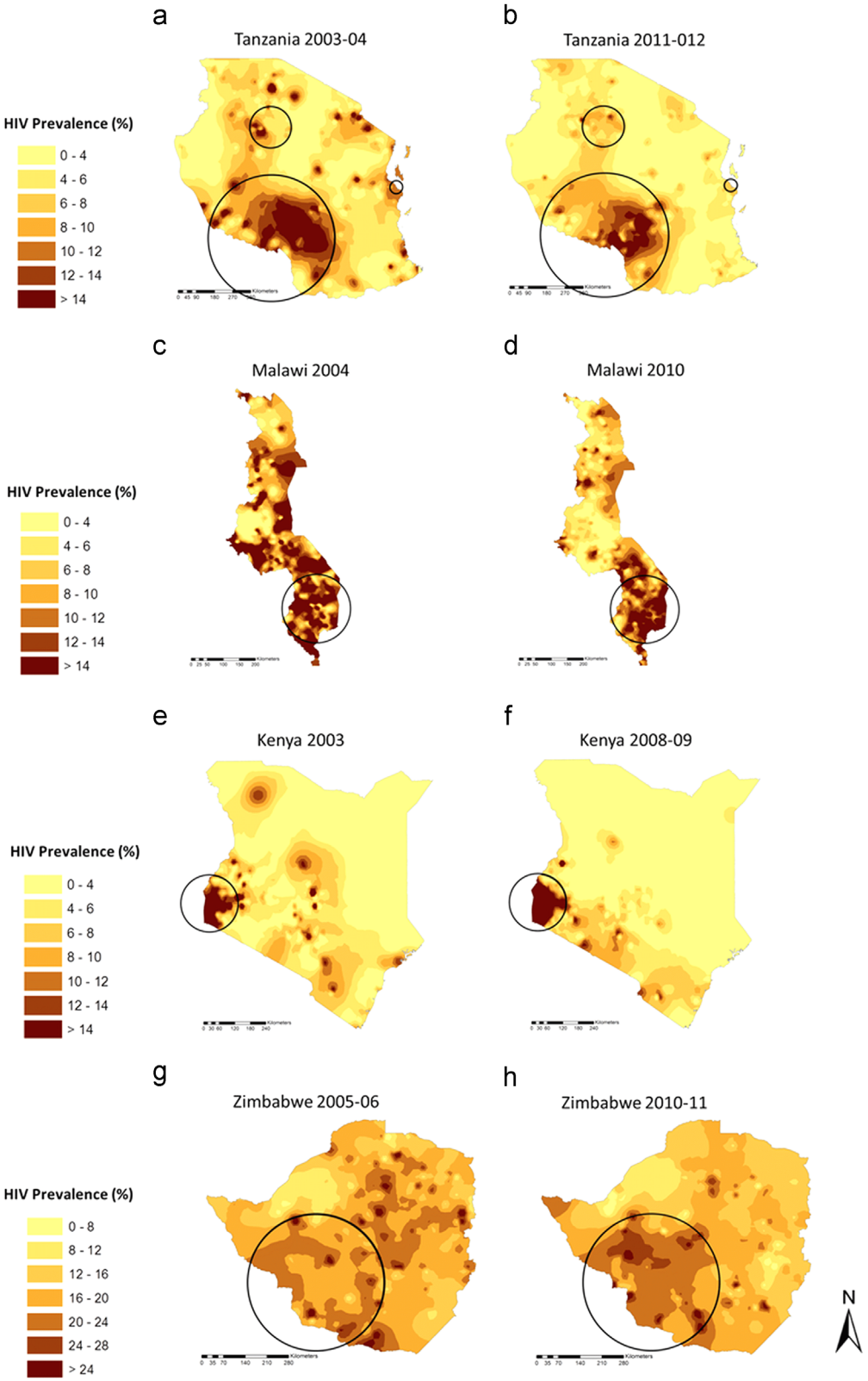

Fig. 1. Geographical clustering of HIV infection in Tanzania, Malawi, Kenya, and Zimbabwe. Spatial locations of the high HIV prevalence clusters in Tanzania ((a) and (b)), Malawi ((c) and (d)), Kenya ((e) and (f)), and Zimbabwe ((g) and (h)). Continuous surfaces of HIV prevalence within a country were generated using the inverse distance weighted mapping algorithm (ESRI, 2004).

infections in the most recent round of the DHS conducted in each country. This methodology identifies clusters with higher numbers of cases (here HIV infections) than expected under spatial randomness, and then evaluates their statistical significance by gradually scanning a circular window that spans the region of study. The area in the circular window varied in size from zero to a maximum radius. We used the default scanning setting of a maximum spatial cluster size of 50% of the study population.

For each potential cluster detected, a likelihood ratio test was computed assuming that the number of HIV infections in each circle is an independent Binomial random variable. Afterwards, an associated *P*-value was computed through Monte Carlo simulations and used to evaluate the statistical significance of each cluster. Clusters with a $P<0.05$ were identified as statistically significant, and included for further epidemiological description. The scan statistics were adjusted for the spatially heterogeneous population densities, and the analysis was conditioned on the total number of cases observed. HIV prevalence in these clusters was then estimated for the available previous DHS rounds. The trend in HIV prevalence was assessed at the national level and for the clusters with high HIV prevalence and outside these clusters, using the chi-square test for trend for Tanzania (as three rounds are available), and the chi-square test for the other countries (only two rounds are available for each country).

We also described several variables in the identified clusters of high HIV prevalence using the last DHS round conducted in each country. These variables included type of place of residence (urban or rural), age, highest educational level, wealth index, marital status, number of sexual partners during the last year, and being ever tested for HIV.

Table 1
Description of the identified HIV clusters in the most recent Demographic and Health Survey (DHS) round conducted in Tanzania, Malawi, Kenya, and Zimbabwe.

Country	Cluster radius (km)	Number of DHS data points	Percentage of the population within the cluster (95% CI)	Percentage of the population that live in urban settings within the cluster (95% CI)
Tanzania				
Cluster 1	307	91	14.3 (13.8–14.8)	13.6 (12.7–14.6)
Cluster 2	6	29	6.0 (5.7–6.4)	85.3 (83.1–87.3)
Cluster 3	70	15	3.0 (2.8–3.3)	13.6 (10.9–16.7)
Total within clusters	–	135	23.3 (22.7–23.9)	39.4 (37.9–40.8)
Malawi				
Cluster1	162	301	34.9 (34.1–35.)	16.9 (15.9–18.0)
Kenya				
Cluster 1	68	69	19.4 (18.4–20.3)	18.5 (16.4–20.7)
Zimbabwe				
Cluster 1	168	99	21.8 (21.1–22.5)	40.3 (38.8–42.1)

3. Results

Our analyses identified discernible patterns in the spatio-temporal dynamics of HIV prevalence in four of the countries included in our study: Tanzania, Malawi, Kenya, and Zimbabwe (Table S1 in Supplementary material). No statistically significant patterns were discerned in Cameroon, Ethiopia, Lesotho, Mali, Rwanda, and Senegal.

We identified three clusters of high HIV prevalence in Tanzania, and one cluster in each of the remaining countries; Malawi, Kenya, and Zimbabwe (Fig. 1). Table 1 includes a general description of the clusters identified in each country. Cluster sizes ranged from 6 km radius in size for a cluster located in Tanzania, to 307 km radius in size for a cluster located also in Tanzania. Most of the population within the identified clusters lived in rural areas, with the exception of Cluster 2 in Tanzania, located in the urban area of Dar es Salaam. The bar charts in Fig. 2 illustrate the national HIV prevalence in each DHS round, and HIV prevalence within and outside of the identified high HIV prevalence clusters.

The national HIV prevalence in Tanzania declined by 27% from 2003 to 2011 ($P<0.001$), however no decline was observed within the clusters of high HIV prevalence collectively ($P=0.14$). Individually (Fig. 1a and b), HIV prevalence remained stable in the southern cluster ($P=0.5$), declined but not significantly in the eastern cluster ($P=0.3$), and increased significantly in the northern cluster ($P=0.01$). Meanwhile, HIV prevalence outside the high HIV prevalence clusters declined by 30% ($P<0.001$).

The national HIV prevalence in Malawi declined with borderline significance by 12% ($P=0.09$), but no decline was observed within the cluster of high HIV prevalence ($P=0.76$; Fig. 1c and d). Meanwhile, HIV prevalence outside the high HIV prevalence cluster declined by 32% ($P<0.001$).

The national HIV prevalence in Kenya declined but not significantly by 6% ($P=0.62$). A significant increase of 20.1% in HIV prevalence was observed within the high HIV prevalence cluster ($P=0.01$; Fig. 1e and f). HIV prevalence outside the high HIV prevalence cluster declined but not significantly by 11.3% ($P=0.11$).

The national HIV prevalence in Zimbabwe declined by 16.7% ($P<0.001$). A significant increase of 18.5% in HIV prevalence was observed within the high HIV prevalence cluster ($P<0.001$; Fig. 1g and h). Meanwhile, HIV prevalence outside the high HIV prevalence cluster declined by 15.4% ($P<0.001$).

There were generally minor differences in the characteristics of the population living within versus outside the clusters, with apparently no discernable associations of epidemiological significance (Tables S2–S5 in Supplementary materials). The percentage of the population who has ever tested for HIV was higher within the clusters versus outside the clusters, but only by a small margin. The percentage of the population that lived in urban areas within the clusters was generally higher than that outside the clusters; 16.2% versus 11.7% in Malawi, 39.3% versus 18.9% in Tanzania, and 52.0% versus 31.1% in Zimbabwe. However, the opposite pattern

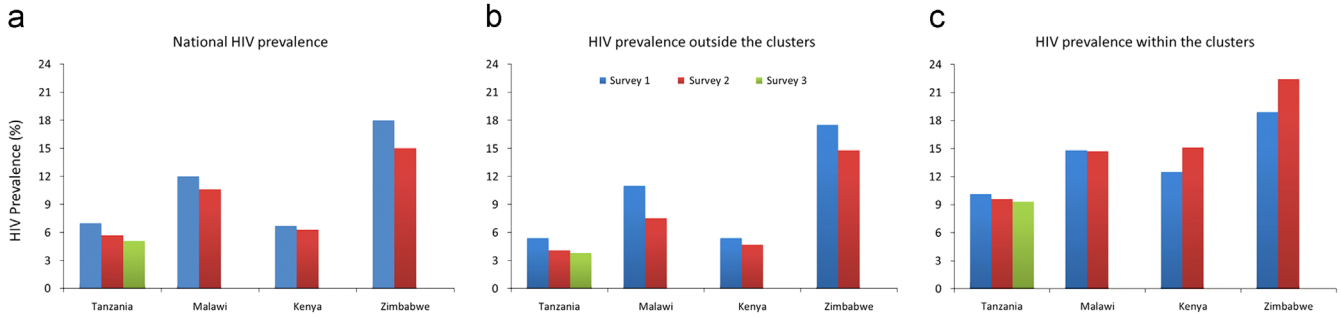

Fig. 2. Temporal trends in the clustering of HIV infection in Tanzania, Malawi, Kenya, and Zimbabwe. Bar charts illustrating the temporal trend in national HIV prevalence (a), in HIV prevalence outside the high HIV prevalence clusters (b), and in HIV prevalence within the high HIV prevalence clusters (c).

was observed in Kenya; 22.3% of the population were urban within the cluster versus 32.8% of the population were urban outside the cluster.

4. Discussion

Our results suggest striking spatial variability in the declines in HIV prevalence in Tanzania, Malawi, Kenya, and Zimbabwe. Even in the presence of declining national HIV prevalence, HIV prevalence within clusters of high prevalence either did not decline or increased (Fig. 2). HIV national prevalence declines in Malawi, Tanzania, and Zimbabwe were driven by rapid changes in prevalence outside of the core areas of intense HIV transmission, while HIV prevalence within the high HIV prevalence clusters in Kenya and Zimbabwe has increased.

The drivers of such spatial variability in HIV prevalence declines are not clear. We could not identify epidemiologic associations of significance to explain the variability in HIV prevalence trends. Though HIV testing appeared higher within the high HIV prevalence clusters, the differences were small, and may be explained by a higher coverage of recent interventions in areas of higher HIV prevalence. Further research work is needed to examine the differences between areas of rapid declines and those of limited or no declines using studies specifically designed to examine these effects.

Several mechanisms may contribute to explaining these findings. The spatial differences in HIV prevalence declines may reflect dynamical effects related to how far is HIV transmission in the general population from the epidemic threshold of sustainability (Abu-Raddad et al., 2008; Alsallaq et al., 2009; Anderson and May, 1991; Awad et al., 2012; Cuadros et al., 2013). They may also reflect heterogeneity in epidemic phases or changes in sexual risk behavior, or uptake of prevention and treatment interventions. Moreover, migration patterns of high-risk individuals could also affect the spatio-temporal distribution of the infection (UNAIDS, 2005; Walker et al., 2008b).

We examined the spatio-temporal patterns of HIV prevalence in all SSA countries where at least two rounds of DHS with biomarker and geographic information were available. We could not, however, identify variable statistically-significant spatio-temporal patterns in Cameroon, Ethiopia, Lesotho, Mali, Rwanda, and Senegal. Therefore, our findings for Tanzania, Malawi, Kenya, and Zimbabwe may not be generalizable to other countries in SSA. It is not clear, however, whether the lack of geographical differences in HIV prevalence declines in the other countries reflects lack of effect, or that the changes in prevalence have not yet been substantial enough to be identified, with statistical significance.

Several limitations could have affected our results. The cross-sectional nature of the data used in this study and the limited availability of geographic and biomarker information have restricted our ability to consider more countries in SSA, and to examine temporal trends over longer periods of time. Given the multiple logistical difficulties in conducting the DHS, some of our measures could have been affected by inherent biases in the data such as the variability in response rates to HIV testing and under-sampling of mobile individuals and key subpopulations at risk (Marston et al., 2008; Mishra et al., 2008). An additional potential bias is the global positioning system displacement process of the DHS sampling data points, used to preserve the confidentiality of the data points (Burget et al., 2013), This process may have impacted the precision of the geographical location of the clusters by few kilometers.

5. Conclusion

Our findings suggest that the national HIV prevalence declines in several countries in SSA may not be representative of general declines in prevalence within these countries. The national declines in prevalence appear to be driven by sharp declines in prevalence in areas of already lower HIV prevalence. In some of the areas with already high HIV prevalence within a country, the prevalence appears to be sustained or even increasing. National estimations of HIV prevalence may obscure local variations and areas with stable or increasing intense HIV transmission. Further research work to generate sub-national estimations of HIV prevalence and to understand the drivers of the spatio-temporal variability, may increasingly become relevant as HIV programs are planned and implemented. Spatially-targeted prevention interventions could be the legacy of the waning HIV prevalence in this part of the globe.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.healthplace.2014.03.007.

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