Spatial Modeling of HIV Prevalence in Cameroon, Kenya, and Tanzania

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Introduction

The spread of HIV infection is often associated with geographic factors such as population mobility, accessibility and proximity to high transmission or urban areas, and geographic distribution of populations at greater risk of infection. Maps of trucking and trade routes, male circumcision, and population mobility in urban areas have shown that geographic factors are important in understanding the risk of HIV infection. These factors that increase the risk of HIV infection have been consistently identified in the literature on HIV.

There is little current research on HIV prevalence in Africa that has utilized Geographic Information Systems (GIS) technology to its full potential. A recent review of the applications of GIS in public health management and research in Africa found only one study applying a GIS analysis to factors related to HIV prevalence (Tanser and le Seuer 2002). This study estimated local-level HIV prevalence rates using data obtained from antenatal care providers, and found a correlation between HIV prevalence and proximity of local households to a primary or secondary road (Tanser et al. 2000). Another study used econometric techniques to estimate the spatial correlation of HIV infection across international boundaries (McCoskey 2003). However, geographic information systems have been used to estimate and analyze the spatial distribution of other infectious diseases, including TB in the United States (Moonan et al. 2004).

In Cameroon, Kenya, and Tanzania, HIV prevalence has regularly been estimated from sentinel sites, where blood samples are drawn from pregnant women and people with sexually transmitted illnesses (STIs). Data from samples of pregnant women have been shown to be a good proxy for prevalence in the overall population of women and men (WHO and UNAIDS 2000); however, there are known limitations. The samples do not include women who do not attend antenatal care clinics and they do not include men. Also, pregnant women tend to be at higher risk of HIV infection, HIV is known to reduce fertility, and knowledge of HIV status may reduce a woman's fertility choices. The sentinel samples cannot be used to estimate regional prevalence of HIV, although site-specific prevalence levels indicate that there are wide geographic differences in each country. Moreover, in sentinel surveillance little information is collected on the individual women, which limits further analysis of the data to understand the determinants of HIV infection. However, HIV estimates from the surveys are not directly comparable to the sentinel estimates because of differences in data collection methodologies (see Boerma et al. 2003).

This study examines HIV seroprevalence data collected in national household surveys in Cameroon, Kenya, and Tanzania during 2003-2004. The geographic coordinates of survey communities are used to model and map sub-provincial HIV prevalence and to assess availability of HIV-related health services in each country.

Data and Methods

Data for this study come from the 2004 Cameroon DHS, the 2003 Kenya DHS and the 2003-04 Tanzania HIV/AIDS Indicator Survey. The surveys were among the first population-based, nationally representative surveys in each country to link individual HIV test results with the full set of behavioral, social, and demographic indicators of the respondents and their households included in the surveys.

The surveys collected detailed information on marriage, fertility, family planning, sexual activity, nutritional status of women and young children, maternal and child health, and awareness, as well as behaviors regarding HIV/AIDS and STIs. From these data, we constructed a number of social, demographic, and behavioral indicators that are likely to be associated with the risk of HIV infection. These variables include: age, education, household wealth index, urban/rural residence, geographic region, marital union, childbirth in the last five years (women only), work status, media exposure, ethnicity, religion, circumcision (men only), STI or STI symptoms in the last 12 months, alcohol use, cigarette smoking, age at first sex, number of sex partners in the last 12 months, condom use at last sex in the last 12 months, paid for sex (men only), exchanged money, gifts, or favors for sex (women only), higher-risk sex in the last 12 months (sex with a non-marital, non-cohabiting partner), perceived risk of getting AIDS, willingness to care for a family member with AIDS, number of times slept away in the last 12 months (men only), away for more than one month in last 12 months (men only), and participation in household decision-making (women only). Not all variables were available for all three countries.

The survey also collected spatial coordinates of the communities where survey respondents lived. Using the latitude and longitude coordinates of the DHS communities, a series of geographic variables were constructed in a GIS environment with ESRI ArcMap 9. Overlaying the community points on the population density surface (Nelson 2004) provided the estimated average population density within 10 kilometers of each community. The distance from the community to the nearest major road in kilometers was generated. Distances to water bodies and major roads were used as measures of proximity to trade and migratory routes. The distance from the community to the nearest major road was generated, and for each country distances to major water bodies were calculated. For example, the distance to Lake Victoria was included as a factor in the analysis of data from Kenya.

These spatial indicators, along with the social, demographic, and behavioral indicators listed above were then used in a multivariate logistic regression model to predict HIV prevalence among women and men who were interviewed and tested in the survey. Because of the sharp differences in HIV prevalence and associated risk behaviors between women and men, we estimated separate models for women age 15–49, men age 15–54, and for a combined group of women and men age 15–49. The models were estimated using the STATA statistical software (Stata Corporation 2003).

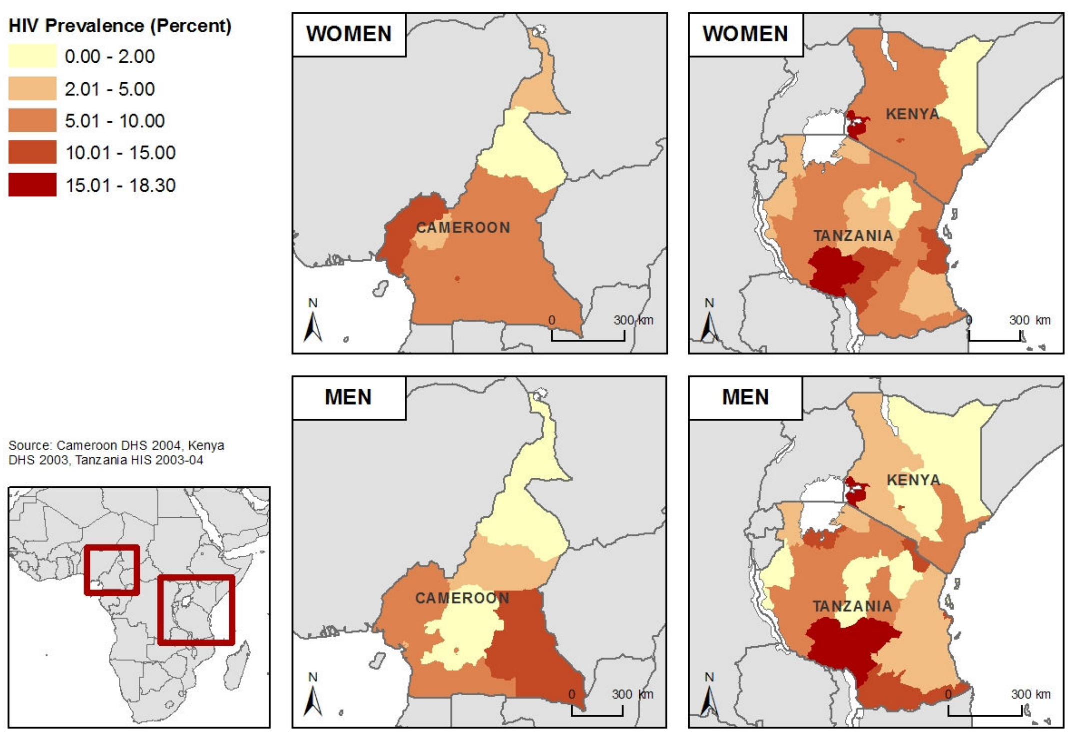
The predicted HIV prevalence was aggregated to the community level and plotted according to the latitude/longitude coordinates of the community. The inverse distance weighting (IDW) method was used to interpolate the prevalence levels using ArcMap 9 Spatial Analyst. IDW is a method that uses surrounding measurements to predict values for unmeasured locations. In this procedure, values closest to the prediction location have greater influence on the interpolated values than those farther away. For each predicted value, a minimum of 2 and a maximum of 12 surrounding points were used to predict the value. The result is the smoothed surface of predicted HIV prevalence which takes into account various spatial, social, demographic, and behavioral factors included in the models. Prevalence estimates for men and women were modeled and mapped separately.

Finally, to illustrate the value of within-region estimates of HIV, we used the locations of health facilities that provide HIV-related services to describe the spatial relationships between concentrations of HIV prevalence and the current distribution of services. The locations of health service sites were available from the Ministry of Health and WHO Service Availability Mapping geocoded data on health facilities (Kenya Ministry of Health and WHO 2004, MEASURE Evaluation/Tanzania 2005, and MEASURE DHS/Calverton MD 2004). Access to counseling and testing services is critical in these countries where HIV-infected adults do not know their HIV status, either because they were never tested or they were tested and did not receive the results. Estimated numbers of HIV infected adults were tabulated by multiplying a surface of population count by the predicted HIV prevalence surface. The result is a gridded map of estimated number of HIV infected adults age 15–49. The service locations were plotted against the estimated number of infected people, and simple tabulations were carried out.

Results

HIV prevalence among women and men in Cameroon, Kenya, and Tanzania

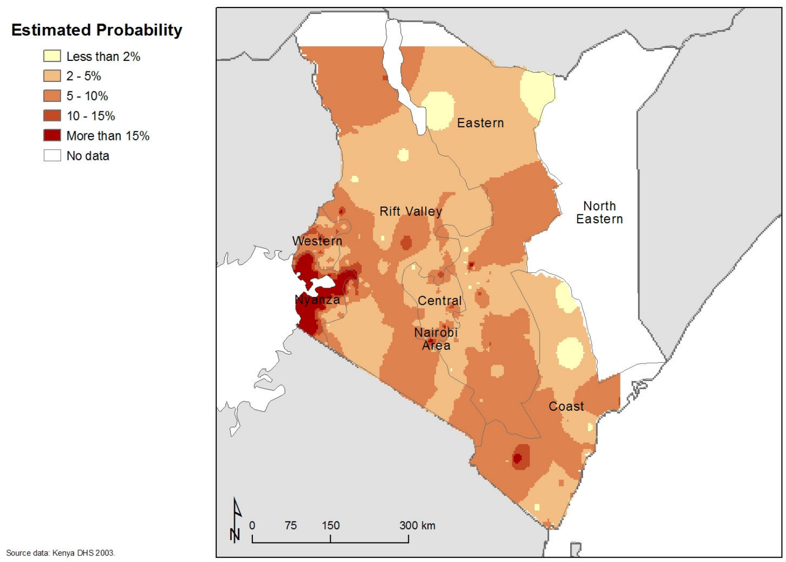
Map 1. HIV Prevalence among women and men: Cameroon, Kenya and Tanzania, 2003-04.



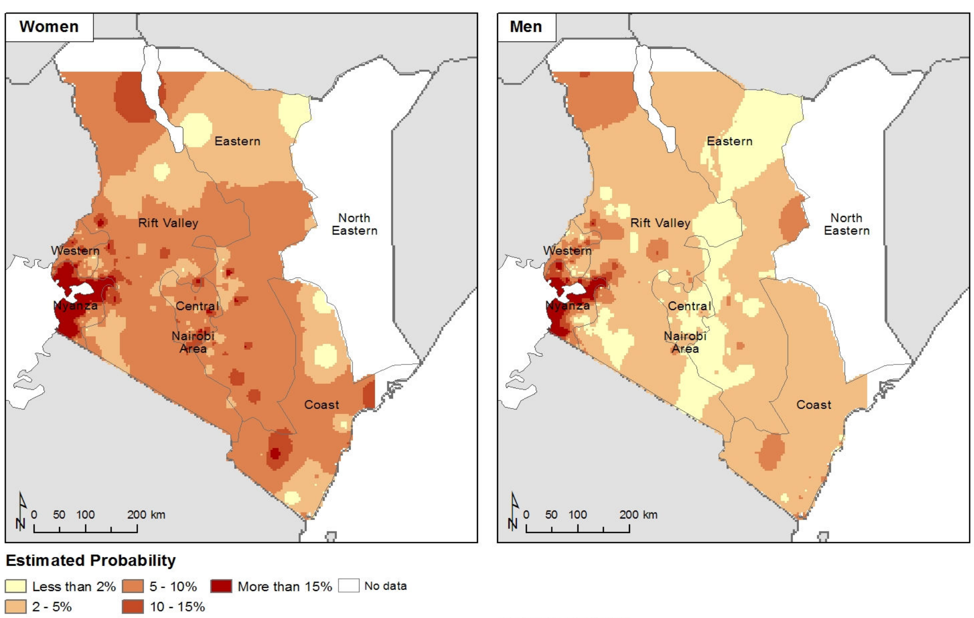
Spatial mapping of predicted HIV prevalence in Kenya (analysis for Cameroon and Tanzania to be added)

The predicted prevalence estimates for women, men, and the total population were aggregated to simple averages at the community–or sample cluster–level. Using the IDW method described above, HIV prevalence was predicted for areas not measured in the survey, in order to produce a smoothed map of HIV prevalence, as shown for the total population, women and men in maps 2 and 3 for Kenya.

Map 2. Geographic distribution of predicted probability of HIV infection, all adults (age 15–49), Kenya 2003



Map 3. Geographic distribution of predicted probability of HIV infection, women (age 15–49) and men (age 15–54), Kenya 2003.



Assessing HIV service distribution in Kenya

Using the smoothed map of estimated probability of HIV infection shown in Map 3, the percent estimates were applied to a smoothed map of population count in Kenya, and adjusted to reflect the 15–49 age group surveyed in the DHS. The derived map provides the estimated number of HIV infected people across the country. The results are presented in Table 1. The areas with 5 to 10 percent prevalence contain the highest number of estimated HIV-positive persons, at 366,914. The areas with less than 2 percent prevalence contain only 1,130 estimated HIV-positive persons. Overall, there are an estimated 901,140 HIV-positive adults age 15–49 in Kenya. This figure is slightly lower than the UNAIDS 2004 estimate of 1.1 million HIV-positive persons in Kenya.

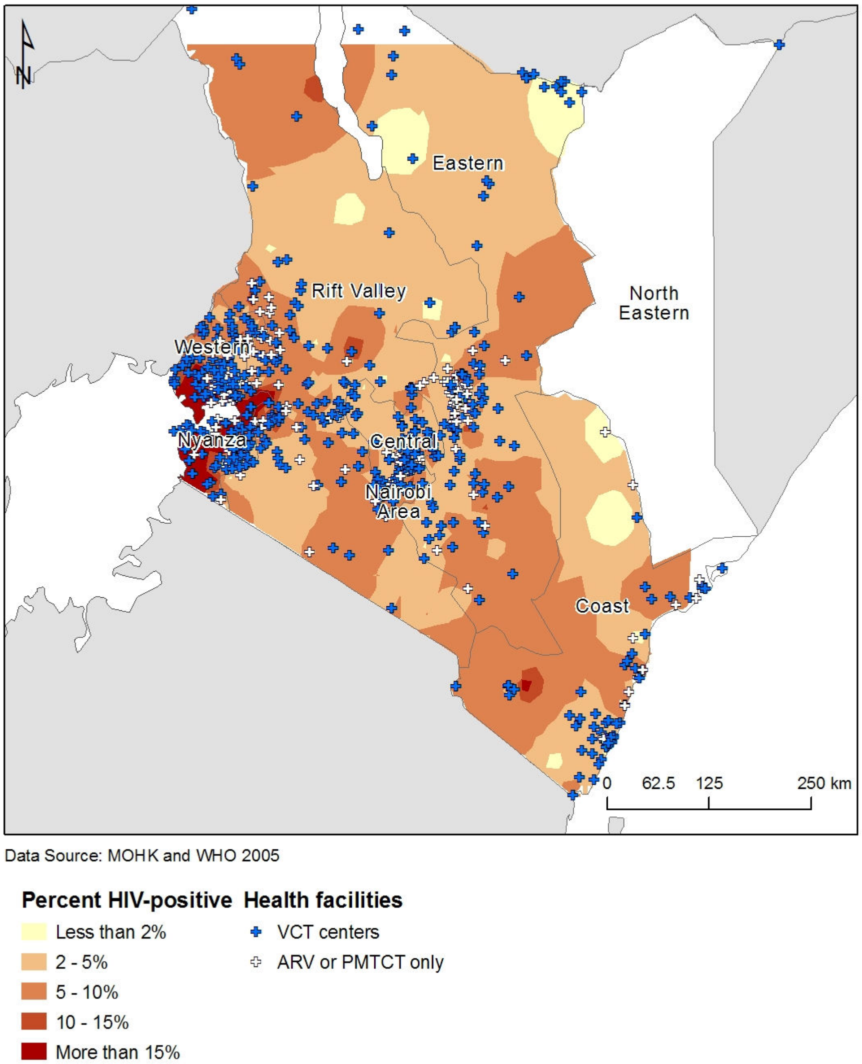
Table 1. Distribution of HIV-related health facilities in HIV prevalence zones, Kenya.

Prevalence zone	Area (km^2)	Density (persons/km^2)	Population estimate	Estimated # of HIV-infected adults	HIV counseling and testing facilities	All facilities offering HIV-related services[1]
Less than 2%	20,626	8.58	176,992	1,130	20	24
2 - 5%	220,439	55.74	12,286,700	214,581	386	464
5 - 10%	167,372	74.47	12,463,900	366,914	278	358
10 - 15%	6,529	211.64	1,381,730	84,628	18	28
More than 15%	11,200	219.97	2,463,580	233,888	46	61
Modelled area	426,166	67.52	28,772,902	901,140	748	935

[1] Includes facilities offering HIV counselling, ARV therapy, and PMTCT services

To analyze the geographic fit between HIV prevalence and HIV services, the modeled area was divided into five prevalence zones, ranging from highest (more than 15 percent) to lowest (less than 2 percent). For each zone, the number of facilities offering VCT services, the number of facilities offering any HIV-related service, and the estimated number of HIV-infected persons were tabulated. Table 1 presents the results of these tabulations. In addition, the locations of HIV-related health services were mapped in relation to geographic distribution of HIV-infected adults (Map 4). The HIV counseling and testing facilities are overwhelmingly concentrated in the areas with a prevalence of 2 to 10 percent. All facilities offering HIV services are also concentrated in the areas with 2 to 10 percent prevalence. These areas include more than half of the estimated HIV positive population in Kenya. Geographically, these areas are large, covering more than 90 percent of the modeled area. In the areas with prevalence estimated over 15 percent, with an estimated 233,888 HIV-positive people, there are only 46 facilities providing HIV services. Although these areas are geographically small and densely populated, the ratio of facilities to HIV-positive persons in these high-prevalence areas is much lower than in other areas.

Map 4. Predicted HIV prevalence among adults and facilities offering HIV services, Kenya 2003



Conclusions

A clear understanding of geographic distribution of HIV-infected people and maintaining up-to-date lists and locations of facilities providing HIV-related services are essential for monitoring the epidemic and for providing treatment, care, and support services to the infected and their families.

This study demonstrates the value of using geographic indicators to help predict HIV prevalence among adults using data from population-based national surveys with HIV-testing in Cameroon, Kenya, and Tanzania. Applying these predictions to model the spatial distribution of HIV prevalence allows for the exploration of sub-regional concentrations of high and low prevalence.

The smoothed surface estimates of HIV prevalence carried out in this study have numerous potential applications. While the surface estimates cannot provide district-level (or other small area) HIV prevalence estimates, they can provide sub-regional information that is useful for planning and programmatic interventions. The study found large sub-regional variations in the prevalence of HIV in each country. The estimation of the numbers of HIV-infected people at the sub-regional level can also be useful for examining the availability of health services in relation to the geographic distribution of HIV-infected people. The preliminary results from Kenya suggest that areas of high concentrations of HIV-infected people have a disproportionately low density of HIV-related services nearby.

According to the three surveys, a majority of adults did not know their HIV status. While educational campaigns and other programmatic interventions are critical in communicating the importance of knowing one's status, having access to HIV counseling and testing services is also essential. Foresight in expanding such services should take into account the geographic distribution of HIV prevalence. However, geographic access is not the only factor; quality and availability are also critical. Even if services are nearby, hours of operation may be limited, or the quality of care may be poor. The recently completed Service Provision Assessment (SPA) facility survey in Kenya and the upcoming SPA survey in Tanzania will provide information on the quality and availability of HIV-related services in selected facilities. These data were not yet available for the present analysis.

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