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Spatial modeling of HIV prevalence in Kenya

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ABSTRACT

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. In this study, we model and map human immunodeficiency virus (HIV) prevalence in Kenya in relation to its spatial and behavioral determinants, using data from the 2003 Kenya Demographic and Health Survey (DHS). The 2003 Kenya DHS is one of the first population-based national surveys to link individual HIV test results for both males (age 15–54) and females (age 15–49) with the full set of behavioral, social, and demographic indicators included in the survey. The survey also collected spatial coordinates of the communities where survey respondents lived. These coordinates have been used to estimate spatial indicators such as distance to roads, distance to Lake Victoria, and population density. Using these spatial, social, demographic, and behavioral indicators, we developed a model to predict HIV prevalence. We apply this model to map HIV concentration areas at sub-provincial level, and we assess the existing HIV service coverage in relation to the spatial distribution of HIV prevalence. The study finds large sub-regional variations in the prevalence of HIV in Kenya. Areas of high concentration of HIV-infected people have a disproportionately low density of HIV-related services.

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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 HIV prevalence, 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 (Arroyo et al. 2006; Coffee et al. 2005; Tanser et al. 2000; Moses et al. 1990; Bongaarts et al. 1989).

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 communicable diseases, including TB in the United States (Moonan et al. 2004).

The first recorded case of HIV in Kenya was reported in the mid 1980s. The national HIV surveillance system was established in 1990, and since then HIV prevalence has been estimated annually (WHO and UNAIDS 2002). HIV prevalence among adults was estimated at 6.7 percent at the end of 2003, equaling about 1.1 million people living with HIV (UNAIDS 2004).

In Kenya, the sentinel prevalence estimates 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 sample does not include men, women who do not attend antenatal care are not included, and pregnant women are at higher risk of HIV infection. Additionally, 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 the 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. The DHS estimates are not directly comparable to the sentinel estimates because of differing data collection methodologies (Boerma, Ghys, and Walker 2003).

The 2003 Kenya DHS was one of the first population-based national surveys to link individual HIV test results with the full set of behavioral, social, and demographic indicators included in the survey. The testing was carried out among women and men of reproductive ages in randomly selected households across all provinces of Kenya. The survey also collected spatial coordinates of the communities where survey respondents lived. These individual, household, and geographic data provide a unique opportunity to explore the determinants of HIV infection in Kenya, as well as to analyze geographic distribution of HIV-infected people in relation to the availability of health facilities.

DATA AND METHODS

Data for this study come from the 2003 Kenya DHS. The DHS is the first population-based, nationally-representative survey in Kenya to link individual HIV test results with the full set of behavioral, social, and demographic indicators included in the survey. The survey collected information from 9,865 households in 400 sample enumeration areas selected from a list of enumeration areas in the master sample based on the 1999 national population census. The sample was designed to represent each of the eight provinces in Kenya. The survey was implemented in the local language of the respondents after translating the English questionnaires into 12 local languages. The data collection took place from April to September 2003. Seventeen teams of nine members each were involved in data collection. Details of the sampling design and survey implementation are provided in the main survey report (Central Bureau of Statistics, Ministry of Health, Kenya, and ORC Macro 2004).

One-half of the sample households were randomly selected to include interviews with men. In these households, a total of 4,303 women age 15–49 and 4,183 men age 15–54 were identified as eligible for individual interviews and for HIV testing. Of the eligible women and men, HIV tests were conducted for 76 percent of women and 70 percent of men. A few drops of capillary blood were collected on filter paper from a finger prick from respondents who voluntarily consented to the blood draw. The blood spots were subsequently dried and transported to a medical laboratory where they were tested for HIV. The HIV test results for individual males and females were anonymously linked to their information in the individual and household questionnaires. Parallel teams of mobile VCT counselors provided counseling and testing for the respondents and others in the community who wanted to know their HIV status, based on separate tests. The analysis presented in this study is based on 3,273 women age 15–49 and 2,917 men age 15–54 who were interviewed and tested for HIV in the survey.

The survey collected detailed information on marriage, fertility, family planning, sexual activity, nutritional status of women and young children, maternal and child health, and awareness and behavior regarding HIV/AIDS and STDs. 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, 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) or 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). For definitions of these indicators, see Table 1.

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. A description of these geographic variables is provided in footnotes to Table 1. 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. Distance to the coast of Lake Victoria in eastern Kenya was calculated for each community. The lake and road distance are measures of proximity to trade and migratory routes.

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 across Kenya 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 relationship between concentrations of HIV prevalence and the current distribution of services. The locations of all HIV 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). Access to counseling and testing services is critical in Kenya where four out of five 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

Sample distribution of adults tested for HIV

Table 1 shows the distribution of women and men tested for HIV in the survey by selected spatial, demographic, socioeconomic, and behavioral characteristics included in the analysis to predict HIV prevalence.

Table 1 Sample distribution (%) of adult women and men tested for HIV by selected spatial, demographic, socioeconomic, and behavioral characteristics, Kenya 2003

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Background factors			
Age			
15-19	23	25	25
20-24	21	18	20
25-29	16	14	16
30-34	14	12	13
35-39	11	11	11
40-44	9	9	9
45-49	7	5	6
50-54	-	6	-
Urban/rural residence			
Urban	22	23	22
Rural	78	77	78
Region			
Central	14	14	14
Coast	8	7	7
Eastern	16	16	16
Nairobi	8	9	8
North Eastern	2	2	2
Nyanza	16	16	16
Rift Valley	24	25	25
Western	13	12	13
Educational attainment			
No education	13	6	9
Below primary	35	35	35
Primary	25	23	24
Secondary and higher	28	36	32
Currently working			
No	41	28	36
Yes	59	72	64
Wealth index[1]			
Poorest	17	16	17
Poorer	20	18	19
Middle	20	19	19
Richer	21	22	21
Richest	23	25	24
Ethnicity			
Kikuyu	22	20	21
Kalenjin	11	13	12
Kamba	12	11	11
Luhya	16	16	16
Luo	12	13	12
Other	27	27	27

Continued…

Table 1-*Continued*

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Religion			
Protestant or other Christian	67	61	64
Catholic	25	27	26
Muslim	6	6	6
Other	2	6	4
Sociodemographic factors			
Marital union			
Never in union	29	45	38
Monogamous union	50	45	47
Polygamous union	11	5	8
Widowed, divorced, or separated	11	4	8
Birth within past five years			
No	27	-	-
Yes	73	-	-
Away from home more than one month within past year			
No	-	84	-
Yes	-	16	-
Sexual behaviors			
Age at first sex			
Never	16	15	16
0-14	18	41	28
15-17	34	16	26
18-19	16	16	16
20+	16	13	14
Higher risk sex within past year[4]			
No	88	73	80
Yes	12	27	20
Two or more sex partners within past year			
No	98	89	94
Yes	2	11	6
Exchanged gifts or favors for sex within past year			
No	96	-	-
Yes	4	-	-
Paid for sex within past year			
No	-	90	-
Yes	-	10	-
Condom use at last sex within past year			
Used condom or did not have sex	33	39	37
Did not use condom	67	61	63
Other behaviors			
STI or STI symptom within past year[3]			
No	97	97	97
Yes	3	3	3
Used alcohol within past month			
No	89	51	72
Yes	11	49	28
Current tobacco user			
No	98	76	88
Yes	2	24	12
Perceived risk of HIV infection			
No risk	34	35	35
Small risk	40	50	45

Continued…

Table 1-*Continued*

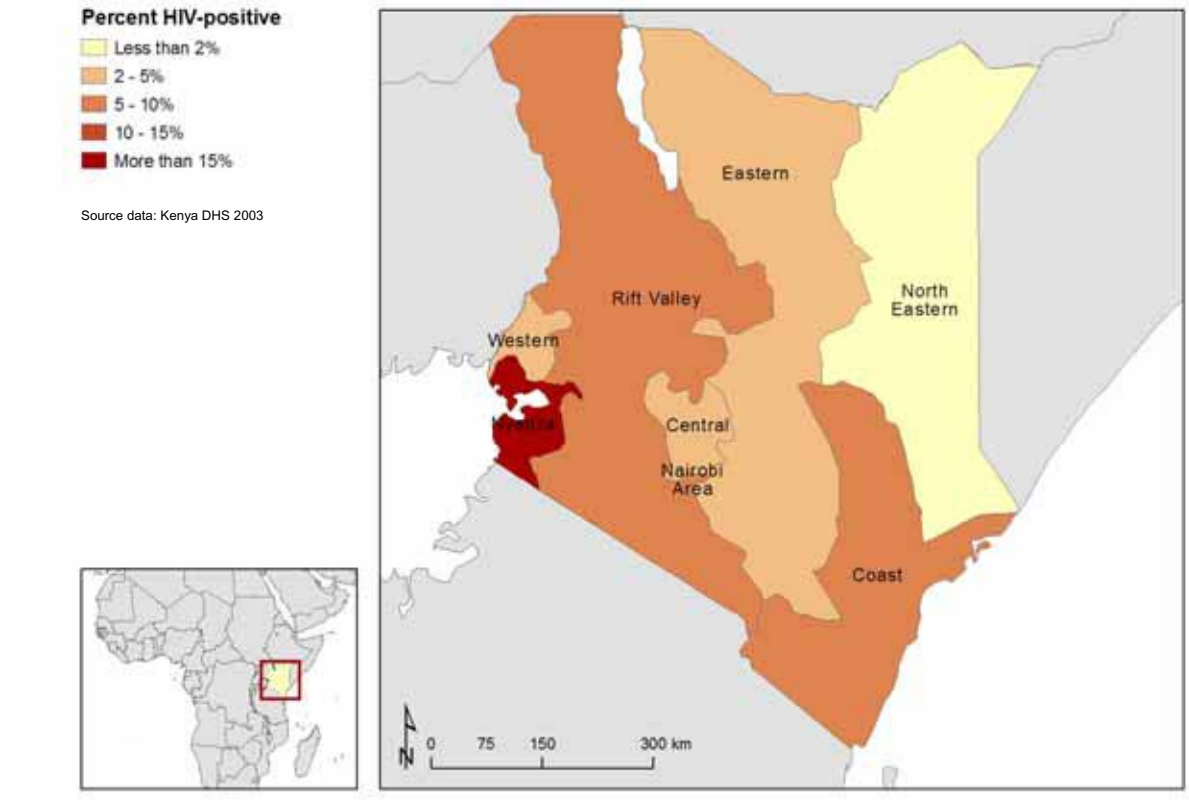
Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Moderate risk	16	10	14
High risk	9	5	7
Willing to care for family member with AIDS			
No	16	13	15
Yes	84	87	85
Participates in two or more household decisions[5]			
No	49	-	-
Yes	51	-	-
Regularly exposed to two or more media sources[2]			
No	66	46	57
Yes	34	54	43
Circumcised			
No	-	17	-
Yes	-	83	-
Spatial factors			
Distance to major road[6]			
Nearest quartile (0-0.52 km)	23	23	23
Second quartile (0.53-1.22 km)	26	25	25
Third quartile (1.23-3.25 km)	28	26	27
Farthest quartile (3.26-22.63 km)	24	26	25
Distance to Lake Victoria[7]			
Nearest quartile (0-62.04 km)	26	26	26
Second quartile (62.05-229.54 km)	31	31	31
Third quartile (229.55-300.35 km)	23	25	24
Farthest quartile (300.35-862.85 km)	19	18	19
Population density[8] (persons/km^2)			
< 25	8	8	8
25-99	11	11	11
100-499	53	51	52
500-999	15	16	15
1000+	13	14	14
Number of respondents[9]	3,273	2,917	5,996

[1]The Wealth Index measures a household's relative economic status based largely on household ownership of durable assets. For details on the methodology of calculating the index, see Rutstein and Johnson (2004).
[2]Media sources include newspaper, television, and radio. Regular exposure to a media source is defined as exposure at least once a week.
[3]Other category includes Embu, Kisii, Maasai, Meru, Mijikenda/Swahili, Somali, Taita/Taveta, Turkana, Kuria, and others.
[4]Higher risk sex is defined as sex with a nonmarital, noncohabiting partner.
[5]Mother's participation in decision-making includes decisions made by herself only, jointly with her husband, or jointly with someone else. Four household decisions are considered here: own health care, large household purchases, daily household purchases, and visits to family and relatives.
[6]Distance to nearest major road, in kilometers. Distances estimated using roads data from the Digital Chart of the World (NIMA 1997).
[7]Distance to Lake Victoria coastline, in kilometers. Distances estimated using lake boundaries from the ESRI world basemap (ESRI 2004).
[8]Estimated average population density, 2000 within 10 km of the sample cluster. Density estimated using UNEP/GRID density data (Nelson 2004).
[9]Number of respondents varies slightly for individual variables depending on the number of missing cases.

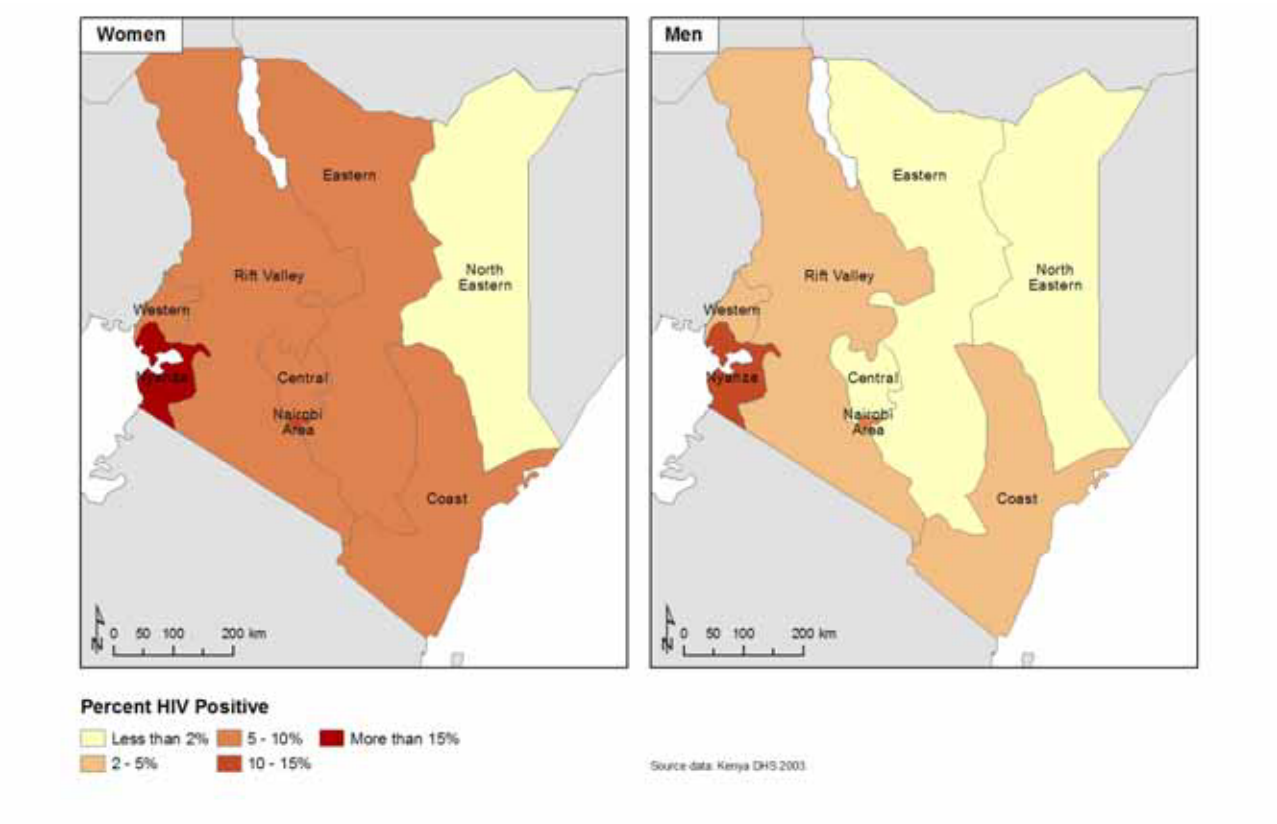
HIV prevalence and its correlates

The survey found that 6.7 percent of Kenyan adults (age 15–49) are infected with HIV. Prevalence of HIV among women age 15–49 is nearly 9 percent, while for men age 15–54 it is under 5 percent (Table 2). Map 1 shows a regional distribution of HIV prevalence for the total adult population across Kenya. Regional level HIV estimates from the DHS show clear differences across provinces, with the Nyanza province exhibiting the highest level of HIV infection and the North Eastern province exhibiting the lowest level. Separate maps for women and men exhibit a similar geographic pattern (Map2), with HIV prevalence rising from a very low level in the North Eastern province to a very high level in the Nyanza province in the west. In all regions, women have a substantially higher prevalence of HIV than men.

Map 1. Estimated HIV prevalence by region, all adults (age 15–49), Kenya 2003



Map 2. Estimated HIV prevalence by region, women (age 15–49) and men (age 15–54), Kenya 2003



For both women and men, there is an inverted U-Shaped relationship between age and HIV prevalence (Table 2). Young women in Kenya are particularly vulnerable to HIV infection compared with young men. HIV prevalence is higher among urban, more educated, and working adults. Household wealth status is also positively associated with HIV prevalence in both women and men. Muslim adults have a much lower prevalence of HIV than those from other religions. Among the ethnic groups, the Luo community stands out as having the highest prevalence.

Women and men in polygamous unions and those who are widowed, divorced, or separated have higher HIV prevalence than men and women who are in monogamous unions or those who have never been married. Circumcised men have a much lower prevalence of HIV than uncircumcised men. Women and men who reported having a sexually transmitted infection (STI) or STI symptoms in the past 12 months have considerably higher rates of HIV infection than other adults. Women and men who reported having two or more sex partners, those who reported engaging in higher-risk sex, and those who reported not using a condom at last sex in the past 12 months also have considerably higher HIV prevalence than other

adults. For women, having a child in the past five years and participation in household decision-making, and for men, paid sex in the past 12 months are associated with higher HIV prevalence.

Table 2 HIV prevalence in adult women and men by selected spatial, demographic, socioeconomic, and behavioral characteristics, Kenya 2003

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Kenya	8.7	4.6	6.7
Background factors			
Age	*p = 0.0000*	*p = 0.0000*	*p = 0.0000*
15-19	3.0	0.4	1.6
20-24	9.0	2.4	6.0
25-29	12.9	7.3	10.4
30-34	11.7	6.6	9.4
35-39	11.8	8.4	10.1
40-44	9.5	8.8	9.1
45-49	3.9	5.2	4.4
50-54	-	5.7	-
Urban/rural residence	*p = 0.0000*	*p = 0.0000*	*p = 0.0000*
Urban	12.3	7.5	10.0
Rural	7.5	3.7	5.6
Region	*p = 0.0000*	*p = 0.0000*	*p = 0.0000*
Central	7.6	2.1	4.9
Coast	6.6	4.5	5.8
Eastern	6.2	1.6	4.0
Nairobi	11.9	8.0	9.9
North Eastern	0.0	0.0	0.0
Nyanza	18.3	12.3	15.1
Rift Valley	6.9	3.4	5.3
Western	5.8	3.6	4.9
Educational attainment	*p = 0.0026*	*p = 0.0681*	*p = 0.0028*
No education	4.4	2.3	3.9
Below primary	9.3	3.7	6.4
Primary	10.6	5.9	8.5
Secondary and higher	8.2	5.1	6.6
Currently working	*p = 0.0312*	*p = 0.0000*	*p = 0.0002*
No	3.5	1.7	5.1
Yes	10.7	5.8	7.6
Wealth index	*p = 0.0000*	*p = 0.0005*	*p = 0.0000*
Poorest	3.9	3.9	3.6
Poorer	8.5	4.0	6.5
Middle	7.1	2.5	4.8
Richer	9.7	4.1	7.1
Richest	12.2	7.4	9.8
Ethnicity	*p = 0.0000*	*p = 0.0000*	*p = 0.0000*
Kikuyu	6.7	2.8	4.9
Kalenjin	4.9	1.9	3.4
Kamba	8.6	1.7	5.4
Luhya	8.0	5.2	6.6
Luo	25.8	18.4	21.8
Other	5.1	2.2	3.8
Religion	*p = 0.0163*	*p = 0.6961*	*p = 0.0224*
Protestant or other Christian	9.2	4.7	7.0
Catholic	8.9	4.7	7.0
Muslim	2.7	2.9	2.9
Other	10.2	5.2	6.5

Continued…

Table 2-*Continued*

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Sociodemographic factors			
Marital union	*p = 0.0000*	*p = 0.0000*	*p = 0.0000*
Never in union	4.7	1.6	2.8
Monogamous union	7.2	6.6	6.9
Polygamous union	11.5	9.9	11.6
Widowed, divorced, or separated	23.6	11.1	20.7
Birth within past five years	*p = 0.0000*	-	-
No	3.5	-	-
Yes	10.7	-	-
Away from home more than one month within past year	-	*p = 0.1770*	-
No	-	4.9	-
Yes	-	3.5	-
Sexual behaviors			
Age at first sex	*p = 0.0000*	*p = 0.0027*	*p = 0.0000*
Never	1.6	0.9	1.3
0-14	12.9	5.1	7.6
15-17	10.3	5.0	8.7
18-19	9.7	5.3	7.5
20+	6.9	6.0	6.6
Higher risk sex within past year	*p = 0.0000*	*p = 0.5631*	*p = 0.0017*
No	7.5	4.5	6.2
Yes	17.2	5.0	8.8
Two or more sex partners within past year	*p = 0.0005*	*p = 0.0002*	*p = 0.0031*
No	8.4	4.1	6.5
Yes	21.0	8.6	10.4
Exchanged gifts or favors for sex within past year	*p = 0.3034*	-	-
No	8.6	-	-
Yes	11.2	-	-
Paid for sex within past year	-	*p = 0.0048*	-
No	-	4.3	-
Yes	-	7.9	-
Condom use at last sex within past year	*p = 0.0108*	*p = 0.0000*	*p = 0.0000*
Used condom or did not have sex	6.9	2.2	4.4
Did not use condom	9.6	6.2	8.1
Other behaviors			
STI or STI symptom within past year	*p = 0.0001*	*p = 0.0000*	*p = 0.0000*
No	8.3	4.4	6.4
Yes	19.0	14.6	17.3
Used alcohol within past month	*p = 0.0000*	*p = 0.0004*	*p = 0.0018*
No	7.6	3.3	6.1
Yes	17.4	6.0	8.3
Current tobacco user	*p = 0.1297*	*p = 0.9024*	*p = 0.0210*
No	8.8	4.7	7.0
Yes	3.6	4.6	4.8
Perceived risk of HIV infection	*p = 0.0000*	*p = 0.0551*	*p = 0.0000*
No risk	5.5	3.4	4.6
Small risk	9.5	5.3	7.2
Moderate risk	10.7	4.2	8.4
High risk	14.5	7.8	12.0
Willing to care for family member with AIDS	*p = 0.3264*	*p = 0.0186*	*p = 0.0904*
No	7.7	2.2	5.4
Yes	9.0	5.0	7.0
Participates in two or more household decisions	*p = 0.0001*	-	-
No	6.7	-	-
Yes	10.5	-	-

Continued…

Table 2-*Continued*

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Regularly exposed to two or more media sources	*p = 0.6922*	*p = 0.0020*	*p = 0.3049*
No	8.5	3.3	6.4
Yes	8.9	5.7	7.0
Circumcised	-	*p = 0.0000*	-
No	-	12.5	-
Yes	-	3.0	-
Spatial factors			
Distance to major road	*p = 0.0098*	*p = 0.0014*	*p = 0.0000*
Nearest quartile (0-0.52 km)	10.4	6.1	8.3
Second quartile (0.53-1.22 km)	8.1	4.1	6.0
Third quartile (1.23-3.25 km)	10.1	6.2	8.2
Farthest quartile (3.26-22.63 km)	6.1	2.7	4.4
Distance to Lake Victoria	*p = 0.0001*	*p = 0.0001*	*p = 0.0000*
Nearest quartile (0-62.04 km)	12.2	7.5	10.0
Second quartile (62.05-229.54 km)	7.4	4.1	5.7
Third quartile (229.55-300.35 km)	8.5	4.0	6.1
Farthest quartile (300.35-862.85 km)	6.3	2.7	4.5
Population density (persons/km^2)	*p = 0.0040*	*p = 0.0002*	*p = 0.0000*
< 25	4.7	1.7	2.9
25-99	8.2	3.1	5.6
100-499	9.1	5.3	7.3
500-999	7.1	2.9	4.7
1000+	12.0	7.5	9.7
Number of respondents	3,273	2,917	5,996

For variable definitions, see Table 1.

As expected, women and men living closer to a major road are more likely to be HIV infected than those living farther away. Distance to Lake Victoria is also negatively associated with HIV prevalence, with higher prevalence among those living closer to the lake and lower prevalence among those living farther away from the lake. Also as expected, HIV prevalence is higher among women and men living in more densely populated areas.

Adjusted effects of characteristics used in predicting HIV prevalence

Table 3 shows the adjusted effects of the characteristics used to predict HIV prevalence separately for women, men, and for the total adult population (women and men combined). Adjusted effect for a given predictor variable controls for the effects of all other covariates included in the table. For the combined sample, with other factors controlled, age, sex, education, wealth index, geographic region, marital status, ethnicity, and alcohol use within past month are statistically significant predictors of HIV prevalence. Because of the high correlation between ethnicity and circumcision, the latter was omitted from the final model. Controlling for other factors, Luos are significantly more likely to be HIV positive than other ethnic groups. This relationship holds true for men and women modeled separately, and in the combined model.

In separate analyses for women and men, the adjusted effects of wealth index, alcohol use, and educational attainment are statistically significant only for women; and the effects of media exposure and age at first sex are significant only for men. Moreover, the effect of living in the Nyanza province relative to the Central province is much stronger for men.

Table 3 Odds ratio estimates of effects of selected spatial, demographic, socioeconomic, and behavioral factors on the risk of HIV infection in adult women and men, Kenya 2003

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Background factors			
Sex			
Male†	-	-	1.00
Female	-	-	2.28***
Age			
15-19†	1.00	1.00	1.00
20-24	2.41**	9.74**	3.04***
25-29	4.00***	26.21***	5.62***
30-34	3.34**	23.18***	4.71***
35-39	3.04**	32.53***	5.22***
40-44	2.16+	27.05***	4.48***
45-49	0.78	15.96**	1.87
50-54	-	16.51**	-
Urban/rural residence			
Urban†	1.00	1.00	1.00
Rural	0.81	1.19	0.93
Region			
Central†	1.00	1.00	1.00
Coast	0.47	0.99	0.55
Eastern	0.45	0.96	0.52
Nairobi	0.72	2.57	0.95
North Eastern	-	-	-
Nyanza	1.00	3.06+	1.54
Rift Valley	0.82	1.44	0.96
Western	0.73	1.29	0.90
Educational attainment			
No education†	1.00	1.00	1.00
Below primary	1.64	1.65	1.75*
Primary	1.80+	1.23	1.87*
Secondary and higher	1.28	0.86	1.21
Currently working			
No†	1.00	1.00	1.00
Yes	0.77	1.03	0.89
Wealth index			
Poorest†	1.00	1.00	1.00
Poorer	2.04*	1.17	1.81*
Middle	2.39**	0.85	1.76*
Richer	2.76**	1.45	2.37**
Richest	3.62***	1.55	2.84***
Ethnicity			
Kikuyu†	1.00	1.00	1.00
Kalenjin	1.15	0.51	0.92
Kamba	1.84	0.57	1.38
Luhya	1.48	1.74	1.58
Luo	5.19***	4.97***	4.91***
Other	1.43	0.75	1.20

Continued…

Table 3-*Continued*

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Religion			
Protestant or other Christian†	1.00	1.00	1.00
Catholic	0.93	0.91	0.97
Muslim	0.35*	1.26	0.60+
Other	1.45	1.85	1.59
Sociodemographic factors			
Marital union			
Never in union†	1.00	1.00	1.00
Monogamous union	0.77	1.36	1.30
Polygamous union	1.11	1.70	1.92+
Widowed, divorced, or separated	3.07**	2.82*	4.30***
Birth within past five years			
No†	1.00	-	-
Yes	1.82	-	-
Away from home more than one month within past year			
No†	-	1.00	-
Yes	-	0.55+	-
Sexual behaviors			
Age at first sex			
Never†	1.00	1.00	1.00
0-14	1.80	0.33+	1.21
15-17	1.54	0.25*	1.09
18-19	1.64	0.29+	1.14
20+	1.26	0.42	1.07
Higher risk sex within past year			
No†	1.00	1.00	1.00
Yes	1.53	1.10	1.25
Two or more sex partners within past year			
No†	1.00	1.00	1.00
Yes	0.84	1.31	0.99
Exchanged gifts or favors for sex within past year			
No†	1.00	-	-
Yes	0.69	-	-
Paid for sex within past year			
No†	-	1.00	-
Yes	-	1.35	-
Condom use at last sex within past year			
Used condom or did not have sex†	1.00	1.00	1.00
Did not use condom	1.07	1.37	1.23
Other behaviors			
STI or STI symptom within past year			
No†	1.00	1.00	1.00
Yes	1.46	1.08	1.48
Used alcohol within past month			
No†	1.00	1.00	1.00
Yes	2.02**	1.45	1.65**
Current tobacco user			
No†	1.00	1.00	1.00
Yes	0.49	0.78	0.71
Perceived risk of HIV infection			
No risk†	1.00	1.00	1.00
Small risk	1.26	1.14	1.20
Moderate risk	1.26	0.78	1.06
High risk	1.44	1.25	1.16

Continued…

Table 3-*continued*

Characteristic	Women (15-49)	Men (15-54)	All (15-49)
Participates in two or more household decisions			
No†	1.00	-	-
Yes	0.94	-	-
Regularly exposed to two or more media sources			
No†	1.00	1.00	1.00
Yes	0.92	1.65+	1.16
Spatial factors			
Distance to major road			
Nearest quartile (0-0.52 km) †	1.00	1.00	1.00
Second quartile (0.53-1.22 km)	0.88	0.68	0.77
Third quartile (1.23-3.25 km)	1.24	1.50	1.28
Farthest quartile (3.26-22.63 km)	0.80	1.01	0.83
Distance to Lake Victoria			
Nearest quartile (0-62.04 km) †	1.00	1.00	1.00
Second quartile (62.05-229.54 km)	1.16	1.26	1.18
Third quartile (229.55-300.35 km)	1.00	0.77	0.98
Farthest quartile (300.35-862.85 km)	1.67	2.02	1.91
Population density (persons/km2)			
< 50†	1.00	1.00	1.00
50-99	1.13	0.92	1.07
100-499	0.84	0.87	0.81
500-999	0.80	0.53	0.71
1000+	1.00	0.94	0.99
Pseudo R-squared	0.19	0.24	0.19
Number of respondents	3,040	2,730	5,612

+p<0.1; *p<0.05; **p<0.01; ***p<0.001
† Reference category
North Eastern province was excluded from the final models because of the small sample size and extremely low HIV prevalence.

Consistent with the inverted U-shaped relationship between age and HIV prevalence discussed above, the adjusted odds of HIV infection are higher in the 25–39 age range than at younger and older ages. Also, consistent with relatively younger ages at infection in women, the adjusted odds of HIV infection peak at age 25–29 for women and at age 35–39 for men. Adults with some primary education have significantly higher risk of HIV than illiterate adults and those with no education. A similar pattern is also observed separately for women, but the effects of education are not statistically significant in the separate model for men. With other factors controlled, household wealth status is a significant predictor of HIV status for the combined sample and separately for women, but not for men. Rural residence is negatively associated with the risk of HIV infection.

Widowed, divorced, and separated women and men are at a much greater risk of HIV infection, independent of other factors included in the models. Adults in polygamous unions are also at a higher risk, but this effect is not statistically significant separately for women and men. Men who are regularly

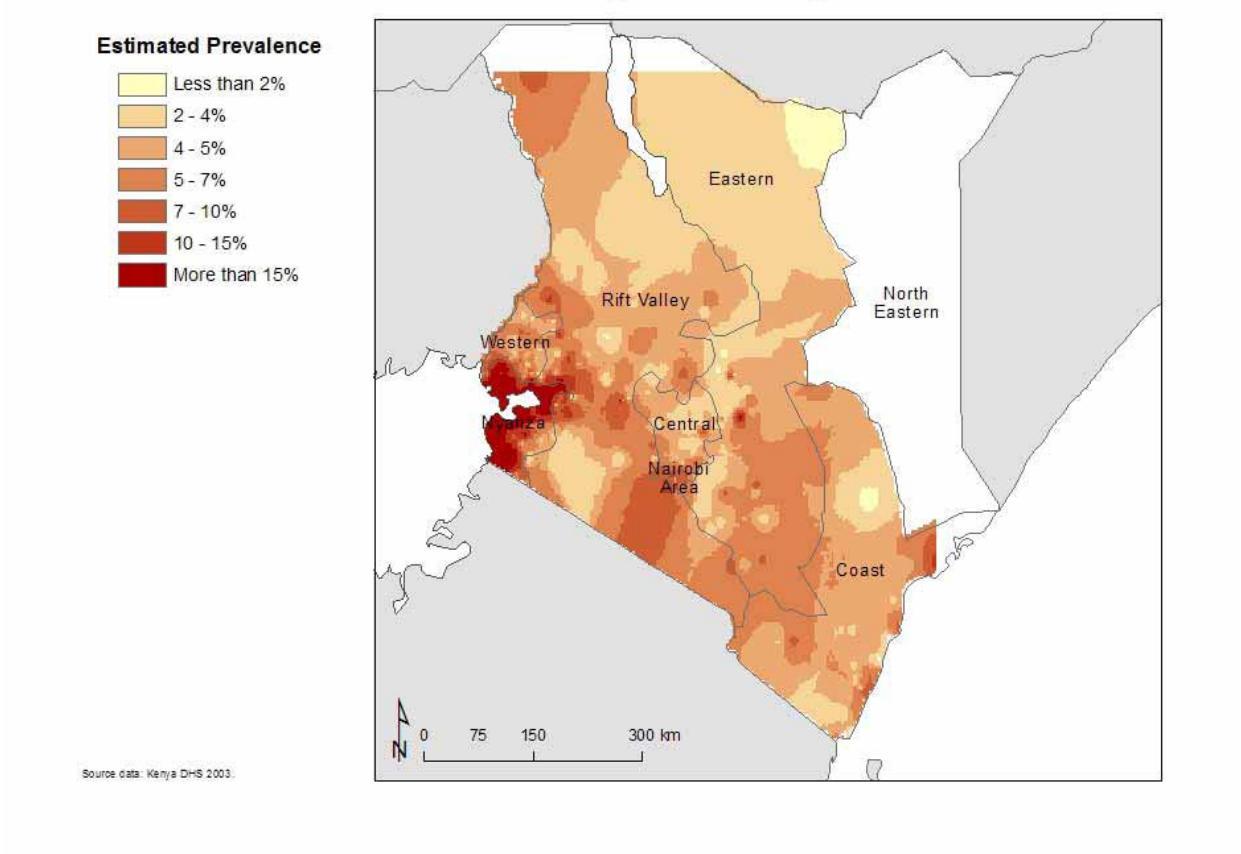
exposed to two or more media sources are at a significantly higher risk of HIV infection, but such exposure to mass media has no adjusted effect on the risk of HIV infection in women. With other factors controlled, Luo ethnicity remains strongly positively associated with the risk of HIV infection in both women and men. Muslim women are at a significantly lower risk of HIV infection than other women. Men willing to care for a family member with AIDS are significantly more likely to be HIV infected.

After controlling for other factors, none of the spatial variables are significantly associated with HIV prevalence.

Spatial mapping of predicted HIV prevalence

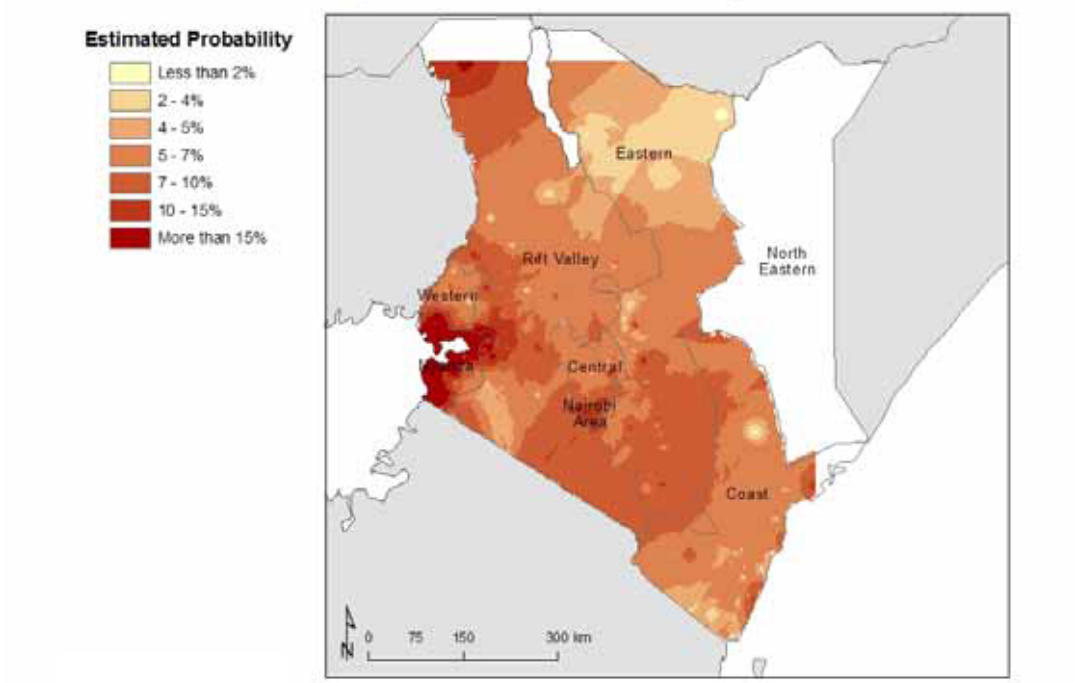
The predicted prevalence estimates for women, men, and the total adult population were aggregated to simple averages at the community–or sample cluster–level. Using the IDW method described above, HIV prevalence was predicted for areas not measured in the survey, in order to produce a smoothed map of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

Map 3. Geographic distribution of predicted HIV prevalence, all adults (age 15–49), Kenya 2003

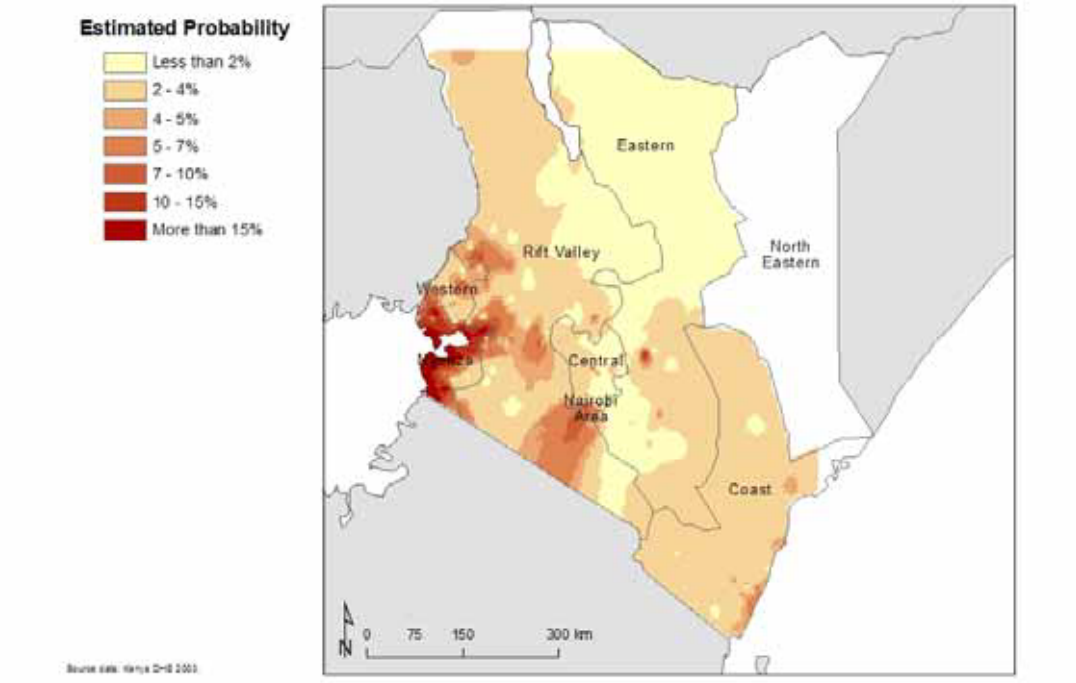


Map 4. Geographic distribution of predicted HIV prevalence, women (age 15–49) and men (age 15–54), Kenya 2003

Women



Men



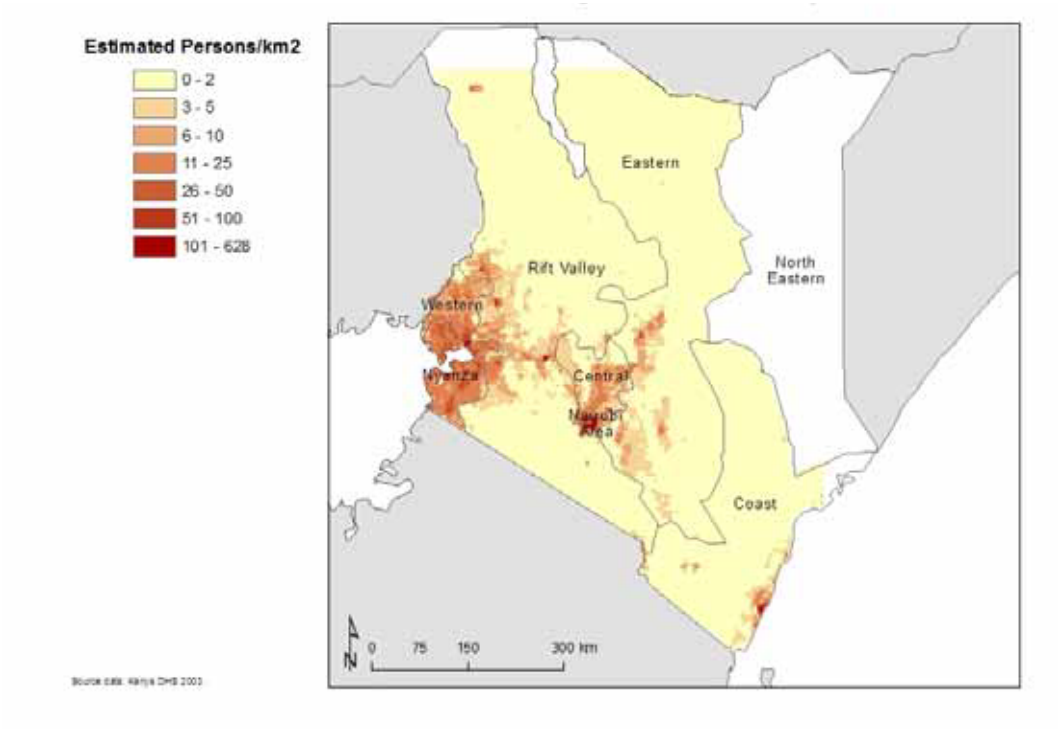
The modeled surface of HIV shows substantial variation within each province. This is in sharp contrast to Maps 1 and 2 which show gross provincial level estimates. For example, the Eastern province, which is geographically the largest province in Kenya, has an overall predicted HIV prevalence of about 4 percent among adults, but within the province there are areas of very low prevalence (less than 2 percent), as well as areas of very high prevalence (more than 15 percent). The northern part of the Eastern province is very sparsely populated, and the prevalence is relatively low. Map 4 similarly shows large within region variations in HIV prevalence separately for women and men.

Assessing HIV service distribution

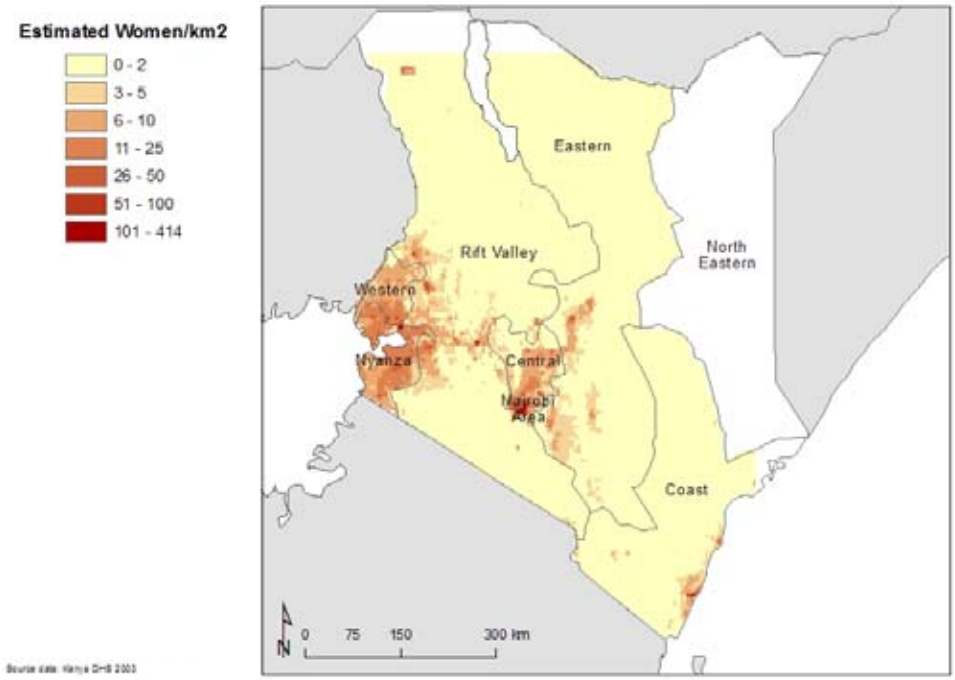
In 2004, there were 895 facilities that provided HIV services in Kenya, according to the "AIDS in Kenya" report (Ministry of Health, 2005). These sites were registered with the National AIDS Control Programme as providing services in 2004/05. The sites were georeferenced using the WHO/Ministry of Health Service Availability Mapping dataset or the village location itself provided in the MOH report. Of the 895 facilities, 630 provide prevention of mother to child transmission (PMTCT) services, 153 provide antiretroviral therapy (ART), and 393 offer voluntary counseling and testing (VCT) services.

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 adults across the country. Overall, there are an estimated 864,347 HIV-positive adults age 15–49 in Kenya. This figure is comparable to the UNAIDS 2004 estimate of 1.1 million HIV-positive persons, which includes all age groups. Maps 5 and 6 show the distribution of the number of HIV-positive adults and HIV-positive women, respectively. The geographic areas where prevalence is over 10 percent is much smaller than the areas of prevalence under 10 percent. This suggests that high HIV prevalence is highly concentrated in small geographic areas of the country. The areas with 5 to 10 percent prevalence contain the highest number of estimated HIV-positive adults, at 376,607. However this population is disbursed across a relatively much larger geographic area. The areas with less than 2 percent prevalence are small; containing less than a thousand estimated HIV-positive adults.

Map 5. Geographic distribution of estimated number of HIV-positive adults (age 15–49) per square kilometer, Kenya 2003

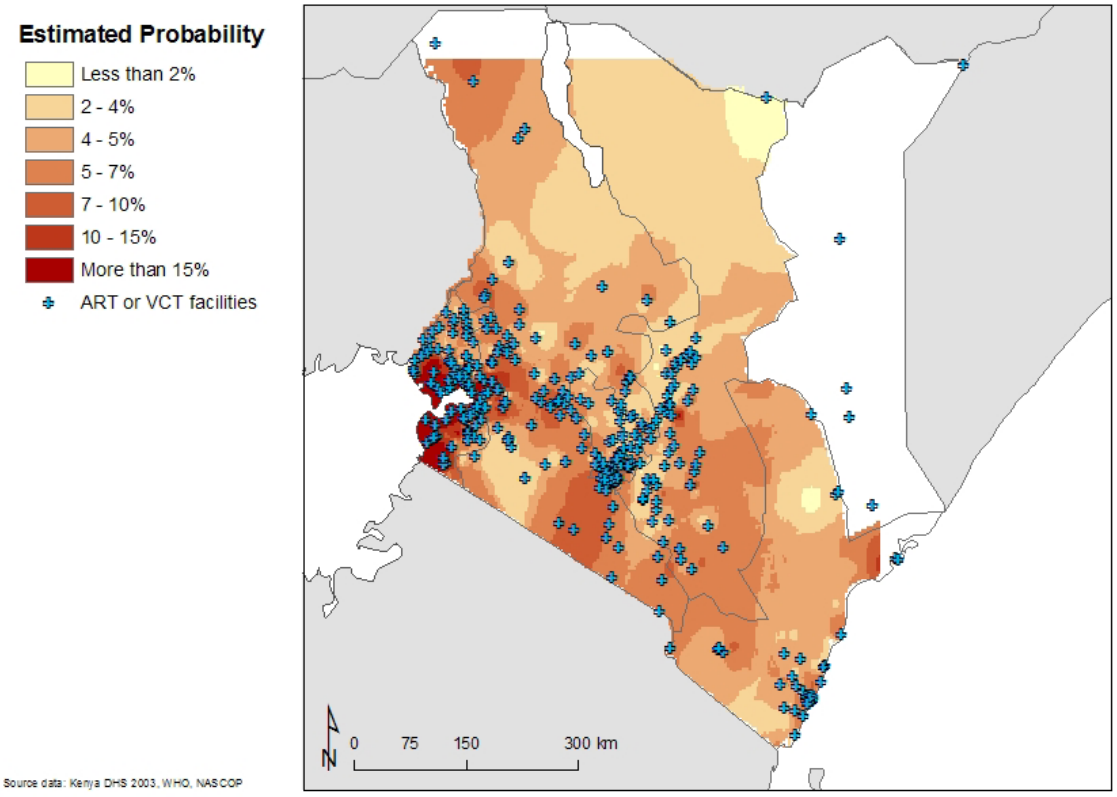


Map 6. Geographic distribution of estimated number of HIV-positive women (age 15–49) per square kilometer, Kenya 2003



Map 7 shows the distribution of facilities providing HIV-related services in Kenya in relation to the smoothed surface estimates of HIV prevalence among adults (age 15–49). To analyze the geographic fit between HIV prevalence and HIV services, cross tabulations were carried out for each of the five prevalence zones, ranging from less than 2 percent to more than 15 percent. For each prevalence zone, the number of facilities offering PMTCT, VCT, and ART services was compared to the estimated number of HIV-infected adults.

Map 7. Predicted HIV prevalence among adults (age 15–49) and distribution of NASCOP-registered facilities offering VCT or ART services, Kenya 2003



Among the 153 ART sites, 100 are located in areas of 5 to 10 percent HIV prevalence (Table 4a). In the areas of greater than 10 percent prevalence, the total number of ART sites is only 18. Looking at the ratio of ART sites per 100,000 HIV-positive adults, a disproportionate number of facilities is evident in the areas where HIV prevalence is below 10 percent. Areas with over 10 percent prevalence have relatively few ART sites per 100,000 HIV-positive adults.

Like the ART coverage, the VCT coverage per 100,000 HIV-positive adults is also much lower in areas with HIV prevalence above 10 percent. When we look at all HIV-related facilities (ART, VCT, and PMTCT) together, a similar pattern of service availability relative to the number of HIV-infected adults is observed. This pattern is not surprising; given that the low prevalence areas cover a much larger geographic area of the country, so more facilities are needed to reach sparsely-populated areas. When the ratio of HIV-related services HIV-positive adults is considered, again the areas with greater concentration of HIV-infected adults have fewer facilities per capita. 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.

Table 4a Distribution of NASCOP-registered facilities in HIV prevalence zones, Kenya 2003

Prevalence zone	Area (km^2)	Population estimate (all ages)	HIV+ persons estimate (15-49)	NASCOP registered ART Sites	ART sites/ 100,000 HIV+ persons	NASCOP registered VCT Sites	VCT Sites/ 100,000 HIV+ persons	Sites offering ART, VCT or PMTCT	Sites/ 100,000 HIV+ persons
Less than 2%	86,430	113,550	734	1	136	2	273	5	681
2 - 5%	2,822,940	12,083,720	215,676	34	35	111	104	269	256
5 - 10%	1,211,524	12,693,380	376,607	100	52	233	121	512	267
10 - 15%	42,355	1,503,700	78,878	1	1	5	6	15	19
15% or more	99,545	2,229,070	192,453	17	9	42	22	96	50
Modelled area	4,262,793	28,623,420	864,347	153	18	393	45	897	104

16 facilities located outside the area modeled for prevalence among persons 15-49: 2 in Coast Province, 8 in North Eastern Province, 4 in Western Province, and 1 each in Nyanza Province and Rift Valley Province

Table 4b Distribution of NASCOP-registered facilities in zones of HIV prevalence among women, Kenya 2003

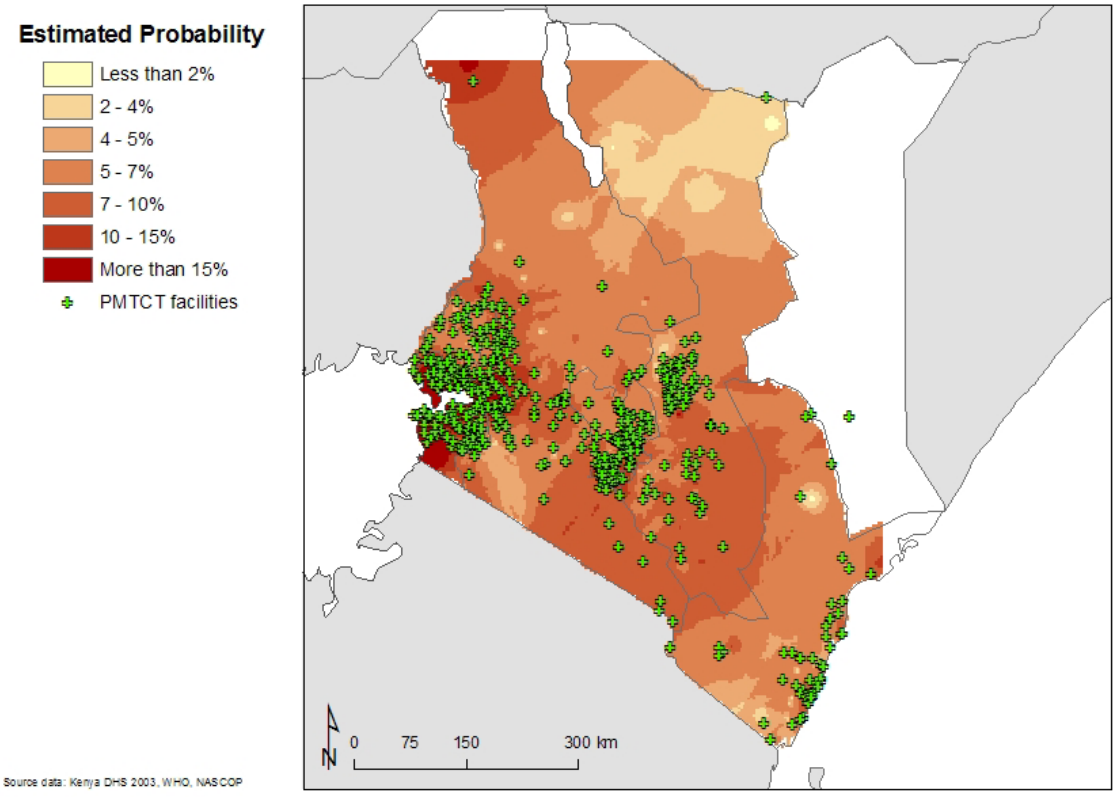
Prevalence zone	Area (km^2)	HIV+ women estimate (15-49)	NASCOP-registered PMTCT Sites	PMTCT sites/ 100,000 HIV+ women	Sites offering ART, VCT or PMTCT*	Sites/100,000 HIV+ women
Less than 2%	4,700	9	0	0	0	0
2 - 5%	831,510	11,857	20	334	25	474
5 - 10%	3,163,671	314,066	357	228	500	318
10 -15%	143,713	148,855	176	118	266	179
15% or more	119,840	133,786	77	58	104	78
Modelled area	4,263,433	608,573	630	104	895	147

18 facilities fall outside the area modeled for prevalence among women 15-49: 2 in Coast Province, 8 in North Eastern Province, 3 in Nyanza Province, 1 in Rift Valley Province, and 4 in Western Province.

The smoothed map of predicted HIV prevalence for women age 15–49 was applied to a map of total population count in Kenya, and adjusted to reflect the 15–49 age group surveyed in the DHS (Map 8). A derived map provides the estimated number of HIV-infected women age 15–49 across the country. Prevalence among women is higher as compared to men, thus the distribution is slightly different when men are excluded. The areas of highest prevalence cover a relatively larger geographic area. The

estimated number of HIV-positive women is almost the same for areas above 10 percent as those for areas between 5 and 10 percent, yet the geographic area of high prevalence is substantially smaller. The PMTCT sites are concentrated in areas of 5 to 10 percent prevalence, followed by the areas with 10 to 15 percent prevalence. The ratio of PMTCT sites to HIV-positive women shows a disproportionate concentration of sites in the lower-prevalence areas, particularly in the 2 to 5 percent prevalence areas. Geographically, the lower-prevalence areas are quite large, which suggests that the sites may be quite far apart.

Map 8. Predicted HIV prevalence among women (age 15–49) and distribution of facilities offering PMTCT services, Kenya 2003



A comparison of all services against the distribution of HIV-positive women presents a slightly different picture than that for all HIV-positive adults (Table 4b). The bulk of the sites are in areas of 5 to 15 percent prevalence. When comparing the number of sites per 100,000 HIV-positive women, the distribution shows that areas of low prevalence, 2 to 5 percent, have the highest ratio of sites to the affected population. The ratio drops as the prevalence increases.

DISCUSSION

This study demonstrates the value of using predictions of HIV prevalence to model the spatial distribution of HIV in Kenya. The study finds large sub-regional variations in the prevalence of HIV in Kenya. The results allow for the exploration of sub-regional concentrations of high and low prevalence. 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 also demonstrates how these results can be combined with other data on HIV services in order to assess health service coverage in high and low HIV prevalence areas. The estimation of the numbers of HIV-infected people at the sub-regional level can also be used for examining the availability of health services in relation to the geographic distribution of HIV-infected people. The results of this study suggest that in Kenya areas of high concentration of HIV-infected people have a disproportionately low density of HIV-related services.

Areas where HIV prevalence is less than 10 percent contain more than half of the estimated number of HIV-positive adult population in Kenya. Geographically, these areas comprise over three-quarters of the modeled area. Most of the facility-based HIV services are located in these areas. However, about 30 percent of the estimated HIV-positive adult population is located in areas where HIV prevalence is above 10 percent. These areas are geographically small, and fall in and around urbanized areas in the country. The number of facility-related services per 100,000 HIV-positive adults is much smaller in these areas. While we might expect that facilities in densely-populated areas may have the capacity to serve more clients, there is no empirical data available to assess that assertion. In the case of ART services, most of the facilities providing this service are hospitals. We expect there to be variation in the capacity and quality of services offered according to location and operating authority. UNAIDS estimates that of those with HIV, 15 percent have advanced HIV infection requiring ART. With reliable service statistics, it would be possible to further estimate the percentage of people who need treatment and are receiving treatment. This would be extremely useful in monitoring services and to address gaps in service provision.

Among women, almost one-half of the estimated HIV-positive women are in areas of high HIV prevalence, of 10 percent or more. The ratio of sites per 100,000 HIV-positive women leads to the question of how well the needs for services are being met for women in high-prevalence areas. Without empirical evidence or service statistics, it is not possible to assess whether indeed the facilities in densely-populated areas are better equipped or have greater capacity to serve more clients. Only 40 percent of the PMTCT and VCT facilities are located in those areas. While not all 15–49 year old women would need

PMTCT services, it would be useful to consider regional differences in birth rates in order to meet the needs in high-prevalence areas.

According to the DHS survey, a majority of Kenyan adults did not know their HIV status. Availability of fewer facilities per capita in high-prevalence areas is a concern. 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 and concentrations 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 facility survey in Kenya 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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