Finding Hidden HIV Clusters to Support Geographic-Oriented HIV Interventions in Kenya

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**Background:** In a spatially well known and dispersed HIV epidemic, identifying geographic clusters with significantly higher HIV prevalence is important for focusing interventions for people living with HIV (PLHIV).

**Methods:** We used Kulldorff spatial-scan Poisson model to identify clusters with high numbers of HIV-infected persons 15–64 years old. We classified PLHIV as belonging to either higher prevalence or lower prevalence (HP/LP) clusters, then assessed distributions of sociodemographic and biobehavioral HIV risk factors and associations with clustering.

**Results:** About half of survey locations, 112/238 (47%) had high rates of HIV (HP clusters), with 1.1–4.6 times greater PLHIV adults observed than expected. Richer persons compared with respondents in lowest wealth index had higher odds of belonging to a HP cluster, adjusted odds ratio (aOR) 1.61 (95% confidence interval (CI): 1.13 to 2.33), aOR 1.66 (95% CI: 1.09 to 2.53), aOR 3.2 (95% CI: 1.82 to 5.65), and aOR 2.28 (95% CI: 1.09 to 4.78) in second, middle, fourth, and highest quintiles, respectively. Respondents who perceived themselves to have greater HIV risk or were already HIV-infected had higher odds of belonging to a HP cluster, aOR 1.96 (95% CI: 1.13 to 3.4) and aOR 5.51 (95% CI: 2.42 to 12.55), respectively; compared with perceived low risk. Men who had ever been clients of female sex worker had higher odds of belonging to a HP cluster than those who had never been, aOR 1.47 (95% CI: 1.04 to 2.08); and uncircumcised men vs circumcised, aOR 3.2 (95% CI: 1.74 to 5.8).

**Conclusions:** HIV infection in Kenya exhibits localized geographic clustering associated with sociodemographic and behavioral factors, suggesting disproportionate exposure to higher HIV risk. Identification of these clusters reveals the right places for targeting priority-tailored HIV interventions.

**Key Words:** HIV/AIDS, clustering, geographic differences, Kulldorff spatial-scan statistics, Kenya

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**BACKGROUND**

Kenya accounts for 6% of people living with HIV (PLHIV) in sub-Saharan Africa (SSA) and has the fourth highest adult HIV prevalence in the world and fifth in new HIV infections.1 In 2015, Kenya was estimated to have over 1.5 million HIV-infected adults and children and an annual incidence of about 0.3% among adults aged 15–49 years.2,3 In Kenya, HIV care and treatment efforts in the past 2 decades have led to reduced HIV prevalence from 6.8% in 2007 to 5.6% in 2012 among adults 15–49 years old.4 However, 65% of new infections occur in just 9 of the country’s 47 counties.5 At county level, estimated adult HIV prevalence ranges from 24.8% in Siaya to 0.4% in Wajir.3 These disparate burdens present an impetus to plan for better use of resources in HIV epidemic control.

Traditionally, Kenya’s national HIV program uses UNAIDS estimation and projections package (EPP) models to estimate national and county HIV prevention and treatment needs.6 Mathematical models provide projections of HIV epidemics, resource allocation, and interventions at subnational levels.7 For example, based on modeling, it is estimated that 14% more infections in Kenya could be averted over a 15-year period (2014–2029) if resources were targeted to the most effective interventions and regions most in need.8 Processes such as commodities estimates and quantification of HIV care and treatment depend heavily on these kind of estimates. However, rarely do such processes focus on more granular units beyond the subnational (county) level. With a worldwide commitment to end the HIV epidemic by 2030,9,10 a more granular versus broadly generalized spatial epidemiological analysis to identify hidden clusters and HIV infection patterns is important because it helps to better target...
Spatial Clustering of HIV in Kenya

interventions. Conversely, spatially overgeneralized HIV estimates can mask the true pattern of HIV and may lead to inefficient allocation of resources and missed opportunities for prevention and treatment. Pin-pointing cluster differences that impact on HIV diagnosis and linkage to care continuum outcomes could be performed. Other assessments of geographical features such as transportation accessibility may show cluster variations impacting linkage to care and outcomes such as viral load suppression.

Kulldorff and Nagarwalla have described a general method for disease cluster detection using a scan window of a specified size and scans through space to identify clusters. The method tests if the number of individuals with a disease occurs at random over space or if any clusters can be detected. This method has been applied in multiple studies owing to its efficiency in identifying clusters. Spatial clustering patterns may exist in relation to physical geographical features: for example, a road or railway network, commercial activity such as large farms and their positioning or proximity of clusters to such features. Cluster analysis and mapping may be used to identify “micro-epidemics” in certain geographic areas such as rural communities, populations at higher risk of HIV infection, demonstrate decline in HIV prevalence, key populations such as female sex workers (FSWs), and for assessing access to HIV-related services such as HIV testing and counseling or provision of antiretroviral treatment. In addition, mapping may be used for allocation of targets, thereby improving efficiencies in resource allocation.

HIV spatial clustering studies have rarely used nationwide population-based survey data. Yet, there is opportunity to explore associations between spatial clustering, individual, and ecological characteristics. Population-based surveys provide high quality demographic, socioeconomic, and behavioral data at individual level and additional ecological data that relate to where individuals live which may determine risk of exposure including sexual partnerships. In Kenya, HIV epidemic is generally considered to be concentrated in 5 high-burden counties (Homabay, Kisumu, Migori, Siaya, and Nairobi) with 50% of the unmet antiretroviral treatment need. We conducted geospatial analysis on data from a nationally representative Kenya AIDS Indicator Survey (KAIS) 2012 to identify clusters with higher rates of HIV-infected persons 15–64 years old. In this article, we have described spatial-epidemic clustering of HIV prevalence in Kenya beyond the well-known subnational pattern. We have also explored relationships between HIV clustering and sociodemographic and behavioral risk indicators, awareness of HIV status and access to HIV services such as HIV testing services (HTS), and voluntary medical male circumcision.

METHODS

Study Design and Population

The methods used in KAIS 2012 have been previously described. In brief, KAIS is a cross-sectional household survey whose target population was adults aged 15–64 years and children aged 18 months to 14 years. The survey was conducted from October 2012 to February 2013 using a stratified 2-stage cluster (survey locations) sample to identify households and within households, eligible respondents were interviewed. The North Eastern region was not surveyed because of regional insecurity. KAIS 2012 study locations were sampled from the National Sample Survey and Evaluation Programme (NASSEP V) sampling frame which is developed and maintained by the Kenya National Bureau of Statistics (KNBS). All households in each sampled cluster were geocoded using Global Information System (GIS), at the time of sampling frame development. However, to provide for confidentiality, cluster geocentroids were used for data aggregated at cluster level. This analysis was restricted to respondents aged 15–64 years with a confirmed HIV-positive test result from the national testing laboratory.

Data Collection Methods

Participants were interviewed using a standardized questionnaire regarding household and demographic characteristics, biobehavioral factors, and use of HIV-related services such as HTS and voluntary medical male circumcision. Use of Information and Communication Technologies (ICT) for data collection in KAIS has been described elsewhere. Data were collected on tablet computers (Mirus Innovations, Mississauga, Ontario, Canada) and securely transmitted electronically to a central database in Nairobi. Blood was obtained and tested for HIV antibodies at the National HIV Reference Laboratory (NHRL) using the Vironostika HIV-1/2 UNIF II Plus O Enzyme Immunoassay (bioMérieux, Marcy d’Etoile, France) as the screening assay and the Murex HIV.1.2.O HIV Enzyme Immunoassay (DiaSorin, SpA, Saluggia, Italy) as the confirmatory assay.

Selection of Variables

Commonly, determinants of HIV epidemic are grouped into 3: sociocultural, socioeconomic, and epidemiological. Behavioral factors may include condom use, age at the onset of sexual activity, and sexual intercourse with multiple and nonregular partners; others include condom use, age at the onset of sexual activity, and sexual intercourse with multiple and nonregular partners. We included sex, age, region, residence, and wealth index (calculated based on household characteristics and ownership of assets measures captured in the household questionnaire). The wealth index was generated using factor analysis calculated using standard methods and the resulting indices were grouped into 5 quintiles from lowest to highest. Other key variables included: marital status, education level, employment, travel, awareness of HIV status, ever tested, being sexually active in the past year, consistent condom use, number of lifetime sex partners, and among men, circumcision and ever having been a client of FSWs.

Spatial-Scan Methodology

We determined clusters with significant numbers of HIV-infected individuals by using a Poisson-based model performed through spatial-scan statistics program SaTScan...
The Kulldorff spatial cluster detection looped over all the 358 survey locations. Using the observed cases, the likelihood of each cluster being a high prevalence (HP) or low prevalence (LP) was computed using a purely spatial Poisson model. For the purpose of classifying HP clusters and grouping the PLHIV as belonging to HP clusters, we took all study clusters that had a significant \( P \) value of <0.05 identified after cluster analysis and grouped respondents as belonging to HP clusters and conversely for LP clusters. To avoid detection of large clusters, we assumed a maximum of 30% of the population were at risk and defined a sizeable scan window with a maximum diameter of 100 km for 3 reasons; comparison with other studies, for example, reasonable HIV program implementation reach and to avoid biasing our analysis to smaller clusters. Consideration for a high proportion of population at risk has been suggested by Kulldorff et al. Conventionally, if the proportion at risk is unknown, 50% is set as the default but may lead to identification unnecessarily large and less informative clusters. The proportion of adults at highest risk of HIV infection is unknown because in general population surveys, it is not possible to segregate most-at-risk populations. Given that 34% of the population in Kenya are aged 15–24 years, to be modest in our estimation, we assumed 30% of the adult population were at greatest risk in a generalized epidemic such as Kenya’s. This age category corresponds to those who have highest HIV prevalence.

Characterizing Respondents in HP Clusters

Results of identified clusters were imported into Statistical Analysis System (SAS) version 9.3 for statistical analyses. We classified persons as belonging to HP vs LP clusters. Using this classification, we assessed distributions and associations of clustering with sociodemographic and biobehavioral HIV risk factors. We used PROC SURVEYFREQ in SAS to do \( \chi^2 \) tests to compare weighted proportions. We tested for associations for social demographic, behavioral, male circumcision, and HTS utilization to belonging to a HP cluster using PROC SURVEYLOGISTIC in SAS and presented both unadjusted and adjusted odds ratios (aORs). Mapping of identified clusters and related spatial features was performed using Quantum GIS (QGIS) version 2.16.

Characterizing HP Clusters

After mapping, we visually reviewed the clusters of interest (HP clusters) regarding proximity to or located within features of interest such as trade centers, commercial activities such as large tea plantations or flower farms, near an informal settlement, etc. We added an Open Street Map layer and overlaid the centroid coordinates displayed as circles of varying sizes depending on the estimated number of HIV-infected to qualitatively characterize HP clusters.

Ethics Approval and Consent to Participate

This study was approved by the Kenya Medical Research Institute’s (KEMRI) Ethical Review Committee (ERC), the US Centers for Disease Control and Prevention’s (CDC) Institutional Review Board (IRB), and the Committee on Human Research of the University of California, San Francisco (UCSF).

Consent for Publication

At household level, the head of household consented to the household questionnaire; the heads of households were adults aged 18–64 years or emancipated individuals with no parent or guardian or not living with their parent/guardian. Individual consent or assent was sought by the field interviewer for all eligible household members to participate in the individual questionnaires. In the case of participants aged 10–17 years, consent was obtained from a parent/guardian or other adult responsible for the child/youth health and welfare before the child/youth was asked for his/her assent. Oral informed consent for HIV testing was required for adults and emancipated minors. Verbal informed consent with a signature of the interviewer on the consent form served as documentation of the consenting.

RESULTS

HIV Spatial Clustering Levels

Of 358 survey clusters, 238 (66.5%) had at least 1 HIV-infected person (Fig. 1). Of those, about half, 112/238 (47%) had high rates of HIV (HP clusters), with 1.1–4.5 times greater PLHIV 15–64 years old observed than expected. These were grouped into significant HP and LP clusters; 43 of 47 and 35 of 36, respectively (Table 1). Clusters were identified in multiple regions, with the larger clusters in Nyanza region and several in Nairobi, but also in central-Rift Valley, Central, and Coast regions (Fig. 1). The cluster with highest relative risk was near the Indian Ocean, Coast region; followed by 1 near Lake Victoria, Nyanza region; Mathare slums in Nairobi; 2 more in Nairobi region; 1 in a rural area near a tea plantation in Central Kenya; and another cluster in a rural area near a trade center, central-Rift Valley region (Fig. 2). The HP clusters had a median radius of 7.2 km, interquartile range (IQR) 3.3–10.9 km, whereas LP clusters had a median radius of 40.9 km, IQR 21.8–73.0 km (Table 1).
Characterizing HIV Clustering

Sociodemographic Factors and HIV Clustering

Nearly two-thirds of the respondents in LP clusters were from rural areas 66.7% (95% confidence interval (CI): 62.2 to 71.2) vs 53.3% (95% CI: 44.7 to 62.0) in HP clusters \( (P = 0.025) \). More respondents in LP than HP clusters were categorized as belonging to lowest wealth quintile 22.1% (95% CI: 18.4 to 25.9) vs 12.1% (95% CI: 9.3 to 14.9), \( P = 0.002 \). There were more widows/widowers living in HP clusters than in LP clusters; 8.5% (95% CI: 7.2 to 9.7) vs 6.3% (95% CI: 5.6 to 7.0), \( P = 0.015 \). Fewer respondents in HP clusters had no primary education, 4.6% (95% CI: 3.4 to 5.8) vs 8.0% (95% CI: 6.3 to 9.7) in LP clusters, \( P = 0.008 \). More respondents had traveled away from home for more than 1 month in HP vs LP clusters; 39.1% (95% CI: 36.0 to 42.1) vs 32.6% (95% CI: 30.6 to 34.5), \( P < 0.001 \).

Biobehavioral Factors and HIV Clustering

There were fewer circumcised men in HP vs LP clusters; 81.5% (95% CI: 76.8 to 86.2) vs 94.9% (95% CI: 93.7 to 96.1), \( P < 0.001 \). More men had ever been clients of FSWs in HP vs LP clusters; 23.3% (95% CI: 19.8 to 26.9) vs 15.3% (95% CI: 12.9 to 17.7), \( P = 0.0002 \).

Respondents were distributed similarly across HP and LP clusters by sex \( (P = 0.070) \), age \( (P = 0.113) \), employment status \( (P = 0.195) \), awareness of HIV status \( (P = 0.185) \), reported sexual activity in the past year \( (P = 0.112) \), and number of lifetime sex partners \( (P = 0.151) \) (Table 2).

Associations of Sociodemographic and Biobehavioral Factors With HIV Clustering

In adjusted analysis, persons in the second, middle, fourth, and highest wealth quintiles compared with those belonging to the lowest wealth index had higher odds of belonging to a HP cluster. Respondents who perceived themselves to have greater risk or already had HIV had higher odds of belonging to a HP cluster compared with those who perceived themselves as having no risk, aOR 1.96 (95% CI: 1.13 to 3.4) and aOR 5.51 (95% CI: 2.42 to 12.55), respectively; men who had ever been clients of FSW had higher odds of belonging to a HP cluster than
those who had never been, aOR 1.47 (95% CI: 1.04 to 2.08); persons who had ever had an HIV test had higher odds of belonging to a HP than LP cluster aOR 1.45 (95% CI: 1.14 to 1.84) and uncircumcised men had higher odds of belonging to a HP cluster than circumcised, aOR 3.2 (95% CI: 1.74 to 5.8) (Table 3).

### TABLE 1. Distribution of Cases in Significant HP and LP Clusters, Kenya AIDS Indicator Survey 2012

| Clusters* | Type | Radius (km)† | Locations | P  | Observed‡ | Expected |
|-----------|------|--------------|-----------|----|-----------|----------|
| All HP§   | HP   | —            | 112       |    | 771,136   | 360,082  |
| 1         | HP   | 74.41        | 48        | 0.001 | 448,005  | 165,718.69 |
| 2         | HP   | 38.43        | 6         | 0.001 | 40,806   | 25,558.14 |
| 3         | HP   | 12.29        | 2         | 0.001 | 8336     | 6544.09  |
| 4         | HP   | 10.48        | 2         | 0.001 | 15,326   | 7534.81  |
| 5         | HP   | 8.91         | 2         | 0.001 | 7666     | 6085.42  |
| 6         | HP   | 8.6          | 2         | 0.001 | 6173     | 3953.56  |
| 7         | HP   | 5.83         | 2         | 0.001 | 6672     | 5415.06  |
| 8         | HP   | 5.75         | 2         | 0.001 | 10,758   | 9455.37  |
| 9         | HP   | 3.52         | 3         | 0.001 | 11,190   | 7964.56  |
| 10        | HP   | 2.47         | 2         | 0.001 | 11,502   | 9423.98  |
| 11        | HP   | 2.23         | 3         | 0.001 | 10,082   | 7853.92  |
| 12        | HP   | 1.67         | 3         | 0.001 | 21,166   | 6435.71  |
| 13–43     | HP   | 0            | 31        | 0.001 | 165,880  | 91,041.99 |
| 44        | HP   | 0            | 1         | 0.32  | 3151     | 2960.14  |
| 45        | HP   | 0            | 1         | 0.726 | 3546     | 3365.38  |
| 46        | HP   | 0            | 1         | 0.742 | 191      | 151.67   |
| 47        | HP   | 0            | 1         | 0.992 | 686      | 619.8    |
| Median (IQR) |     | 7.2 (3.3–10.9) | 185 | 225,634 | 622,225  |
| All LP|| | 95.3 | 7 | 0.001 | 1399 | 9071.32 |
| 2 | LP | 93.7 | 5 | 0.001 | 0 | 3968.61 |
| 3 | LP | 93.62 | 2 | 0.001 | 0 | 1602.46 |
| 4 | LP | 91.54 | 5 | 0.001 | 191 | 1367.38 |
| 5 | LP | 89.55 | 43 | 0.001 | 61,947 | 141,623.52 |
| 6 | LP | 81.38 | 2 | 0.001 | 2218 | 3499.46 |
| 7 | LP | 70.25 | 2 | 0.001 | 0 | 6569.79 |
| 8 | LP | 67.97 | 11 | 0.001 | 25,058 | 52,656.06 |
| 9 | LP | 60.33 | 6 | 0.001 | 179 | 3264.32 |
| 10 | LP | 57.86 | 24 | 0.001 | 25,766 | 84,288.47 |
| 11 | LP | 51.74 | 2 | 0.001 | 0 | 265.07 |
| 12 | LP | 45.83 | 4 | 0.001 | 0 | 12,615.09 |
| 13 | LP | 35.94 | 5 | 0.001 | 6443 | 14,806.86 |
| 14 | LP | 35.48 | 3 | 0.001 | 0 | 15,054.23 |
| 15 | LP | 27.55 | 27 | 0.001 | 49,707 | 80,482.57 |
| 16 | LP | 24.44 | 5 | 0.001 | 0 | 25,184.3 |
| 17 | LP | 23.3 | 3 | 0.001 | 1952 | 5762.86 |
| 18 | LP | 22.45 | 2 | 0.001 | 0 | 10,623.45 |
| 19 | LP | 19.94 | 3 | 0.001 | 0 | 16,901.58 |
| 20 | LP | 15.09 | 2 | 0.001 | 8034 | 15,076.77 |
| 21 | LP | 14.72 | 6 | 0.001 | 2301 | 14,652.94 |
| 22 | LP | 6.32 | 2 | 0.001 | 4832 | 10,408.77 |
| 23 | LP | 5.66 | 10 | 0.001 | 23,988 | 44,431.4 |
| 24 | LP | 3.28 | 2 | 0.001 | 0 | 9074.82 |
| 25–35 | LP | 0 | 18 | 0.001 | 9944 | 37,265.91 |
| 36 | LP | 0 | 1 | 0.868 | 1675 | 1796.68 |

*47 HP clusters and 36 LP clusters identified. Analysis to detect HP and LP clusters were performed independent of each other.
†Radius of scan window set to 100 km for both HP and LP clusters.
‡Estimated number of cases in HP clusters (weighted n).
§HP, high prevalence.
||LP, low prevalence.
DISCUSSION

Why These Analyses Are Important

The results of our analyses indicate that it is possible to obtain more granular geographical variation in HIV prevalence, expanding our insights into the spatial distribution of HIV in Kenya. In our analyses, we have demonstrated that survey data can be used to show HP clusters in unexpected LP regions in a generalized epidemic. Our findings strengthen the move to support geographically targeted intervention packages for HIV-infected persons and/or most-at-risk. Information about these smaller foci in otherwise LP areas is especially important with the programmatic focus on the subnational units with the highest HIV burden and prevalence.

HIV Spatial Clustering in Kenya

Our observed spatial variation in HIV prevalence highlights clustered HIV prevalence across Kenya within microepidemics of varying magnitudes. Such microepidemics have been observed in other SSA countries. High HIV prevalence clusters were found in medium generalized epidemic regions; for example, in some parts of Central Kenya and Central-Rift Valley that have considerably lower HIV prevalence of 3.8% and 4.3%, respectively, compared with the national prevalence of 5.6%. Most of the HP clusters were near a lake/river, major road highway, economic hub, or in highly productive agricultural zones such as tea-growing areas and flower farms. HP clusters in Nairobi region were in informal settlements. Our study indicates that there...
| Characteristic            | From Clusters With High HIV Rates* | From Clusters With Low HIV Rates† | P     |
|--------------------------|-----------------------------------|----------------------------------|-------|
|                          | n       | Weighted % | 95% CI | n        | Weighted % | 95% CI |       |
| Total                    | 3305    | 8321       |        |          |           |        | 0.0695|
| Sex                      |         |            |        |          |           |        |       |
| Men                      | 1347    | 47.5       | 45.5 to 49.5 | 3489    | 49.7       | 48.5 to 51.0 |       |
| Women                    | 1958    | 52.5       | 50.5 to 54.5 | 4832    | 50.3       | 49.0 to 51.5 |       |
| Age (yrs)                |         |            |        |          |           |        |       |
| Age 15–24                | 1115    | 33.8       | 31.5 to 36.1 | 2703    | 32.5       | 31.2 to 33.8 | 0.1132|
| Age 25–34                | 874     | 26.9       | 24.8 to 28.9 | 2336    | 27.8       | 26.3 to 29.2 |       |
| Age 35–44                | 597     | 17.6       | 16.2 to 19.0 | 1611    | 19.9       | 18.8 to 20.9 |       |
| Age 45+                  | 719     | 21.7       | 19.5 to 23.9 | 1671    | 19.9       | 18.5 to 21.2 |       |
| Region                   |         |            |        |          |           |        | <0.0001|
| Nairobi                  | 370     | 10         | 5.1 to 14.9 | 944     | 11.5       | 9.1 to 13.9 |       |
| Central                  | 479     | 13.1       | 7.5 to 18.7 | 944     | 13.1       | 9.9 to 16.3 |       |
| Coast                    | 228     | 4.6        | 1.6 to 7.7  | 1234    | 10.8       | 8.5 to 13.2 |       |
| Eastern                  | 308     | 12.6       | 5.7 to 19.4 | 2013    | 16.3       | 13.1 to 19.5 |       |
| Nyanza                   | 1030    | 31.8       | 24.6 to 39.0 | 601     | 6.7        | 3.5 to 9.9  |       |
| Rift valley              | 308     | 13.2       | 6.0 to 20.4 | 1759    | 32.1       | 27.4 to 36.9 |       |
| Western                  | 582     | 14.6       | 8.1 to 21.1 | 826     | 9.5        | 6.8 to 12.1 |       |
| Residence                |         |            |        |          |           |        | 0.0248|
| Rural                    | 1842    | 53.3       | 44.7 to 62.0 | 5659    | 66.7       | 62.2 to 71.2 |       |
| Urban                    | 1463    | 46.7       | 38.0 to 55.3 | 2662    | 33.3       | 28.8 to 37.8 |       |
| Wealth quintiles         |         |            |        |          |           |        | 0.0022|
| Lowest                   | 433     | 12.1       | 9.3 to 14.9 | 2001    | 22.1       | 18.4 to 25.9 |       |
| Second                   | 761     | 21.7       | 17.4 to 26.1 | 1736    | 20.9       | 18.4 to 23.3 |       |
| Middle                   | 706     | 19.9       | 16.8 to 23.0 | 1612    | 19.7       | 17.3 to 22.2 |       |
| Fourth                   | 797     | 24.6       | 20.5 to 28.8 | 1380    | 17.2       | 14.6 to 19.8 |       |
| Highest                  | 608     | 21.6       | 15.1 to 28.1 | 1592    | 20.1       | 16.6 to 23.6 |       |
| Marital status           |         |            |        |          |           |        | 0.0152|
| Never married or single  | 970     | 29.8       | 27.5 to 32.1 | 2501    | 31.5       | 29.8 to 33.2 |       |
| Widowed                  | 299     | 8.5        | 7.2 to 9.7  | 595     | 6.3        | 5.6 to 7.0  |       |
| Separated or divorced    | 146     | 4.3        | 3.5 to 5.1  | 412     | 4.8        | 4.2 to 5.3  |       |
| Married or cohabiting    | 1889    | 57.4       | 54.9 to 59.8 | 4810    | 57.4       | 55.7 to 59.1 |       |
| Education level          |         |            |        |          |           |        | 0.0076|
| No primary               | 161     | 4.6        | 3.4 to 5.8  | 1177    | 8.0        | 6.3 to 9.7  |       |
| Incomplete primary       | 286     | 7.3        | 5.6 to 9.1  | 702     | 7.7        | 6.6 to 8.8  |       |
| Complete primary         | 1120    | 33.1       | 30.5 to 35.7 | 2574    | 32.3       | 30.6 to 34.0 |       |
| Secondary and above      | 1738    | 55         | 52.1 to 57.8 | 3868    | 52.0       | 49.7 to 54.2 |       |
| Currently employed       |         |            |        |          |           |        | 0.1945|
| Yes                      | 1629    | 50.3       | 46.8 to 53.7 | 3563    | 47.4       | 45.1 to 49.8 |       |
| No                       | 1672    | 49.7       | 46.3 to 53.2 | 4752    | 52.6       | 50.2 to 54.9 |       |
| Traveled in past 12 mo   |         |            |        |          |           |        | <0.0001|
| Never traveled away      | 1477    | 45.6       | 42.2 to 48.9 | 4463    | 54.7       | 52.4 to 57.1 |       |
| Less than 1 month        | 458     | 15.4       | 13.2 to 17.5 | 1062    | 12.7       | 11.6 to 13.9 |       |
| One month or longer      | 1256    | 39.1       | 36.0 to 42.1 | 2587    | 32.6       | 30.6 to 34.5 |       |
| Aware of HIV status      |         |            |        |          |           |        | 0.1854|
| No                       | 1672    | 49.7       | 46.3 to 53.2 | 4752    | 52.6       | 50.2 to 54.9 |       |
| Yes                      | 1629    | 50.3       | 46.8 to 53.7 | 3563    | 47.4       | 45.1 to 49.8 |       |
| Ever had an HIV test     |         |            |        |          |           |        | <0.0001|
| Yes                      | 1629    | 50.3       | 46.8 to 53.7 | 3563    | 47.4       | 45.1 to 49.8 |       |
| No                       | 1672    | 49.7       | 46.3 to 53.2 | 4752    | 52.6       | 50.2 to 54.9 |       |
| Circumcised (men)        |         |            |        |          |           |        | <0.0001|
| Circumcised              | 1098    | 81.5       | 76.8 to 86.2 | 3297    | 94.9       | 93.7 to 96.1 |       |
| Uncircumcised            | 247     | 18.5       | 13.8 to 23.2 | 181     | 5.1        | 3.9 to 6.3  |       |
| Sexually active in past year |       |           |        |          |           |        | 0.1122|

*From Clusters With High HIV Rates* | †From Clusters With Low HIV Rates
TABLE 2. (Continued) Sociodemographic and Behavioral Characteristics by HIV Clustering, Kenya AIDS Indicator Survey 2012, N = 11,626

| Characteristic                  | From Clusters With High HIV Rates* | From Clusters With Low HIV Rates† |
|---------------------------------|------------------------------------|-----------------------------------|
|                                 | n        | Weighted % | 95% CI      | n        | Weighted % | 95% CI   | P       |
| Sexually active                 | 2427     | 74.2       | 71.6 to 76.7 | 5780     | 71.7       | 70.1 to 73.2 |       |
| Not sexually active             | 878      | 25.8       | 23.3 to 28.4 | 2541     | 28.3       | 26.8 to 29.9 |       |
| Consistent condom use last sex  |                      |             |               |          |           |           | <0.0001 |
| Yes                             | 1629     | 50.3       | 46.8 to 53.7 | 3563     | 47.4       | 45.1 to 49.8 |       |
| No                              | 1672     | 49.7       | 46.3 to 53.2 | 4752     | 52.6       | 50.2 to 54.9 |       |
| Lifetime sex partners           |                      |             |               |          |           |           | 0.1512  |
| One partner                     | 376      | 11.5       | 9.4 to 13.5  | 1130     | 13.2       | 12.2 to 14.3 |       |
| More than 1                     | 2911     | 88.5       | 86.5 to 90.6 | 7098     | 86.8       | 85.7 to 87.8 |       |
| Ever been a client of an FSW    |                      |             |               |          |           |           | 0.0002  |
| Never                           | 899      | 76.7       | 73.1 to 80.2 | 2516     | 84.7       | 82.3 to 87.1 |       |
| Ever                            | 266      | 23.3       | 19.8 to 26.9 | 418      | 15.3       | 12.9 to 17.7 |       |

*Data are for adults from 47 HP clusters, 43 of them significant at (P < 0.05).
†Data are for adults from 36 LP clusters, 35 of them significant at (P < 0.05).

are pockets of higher HIV infection that otherwise may not be well described in a generalized and spatially diffused epidemic. Such pockets of higher HIV rates have been identified in other SSA countries even in the context of generalized epidemics.14,15

Population Distribution Within Clusters

In our analyses, we identified HP clusters that were about half in size compared with LP clusters. This may indicate more intense and localized pockets of infection, as opposed to diffused infections. We had similar number of men and women in both HP and LP clusters and similar age distributions by cluster types. This indicates that population demographics may not play a role in clustering as do behavioral or structural factors. Expectedly, a higher proportion of study clusters categorized as HP were in Nyanza region which has the highest HIV prevalence in Kenya, at 14.9% vs the 5.6% national prevalence.4 We found that two-thirds of respondents in LP clusters were from rural areas compared with half of those from HP clusters indicating that degree of urbanization has a big role to play in clustering. This is corroborated by the higher income among residents in HP clusters and the smaller number of respondents in HP vs LP clusters reporting no education. There were more widows/widowers living in HP clusters than in LP clusters, perhaps an indication of higher HIV-associated mortality as has been described elsewhere in SSA.35 The disproportionately high number of widows/widowers found in HP clusters may additionally mean a higher HIV-associated mortality of spouses in areas with disproportionate higher HIV rates.

Clustering, Social, and Behavioral Patterns

We found that there were more respondents in HP clusters who had traveled away from home for >1 month as compared to LP clusters. Although people travel for various reasons, most extended travel is work related. Work-related migration may mean access to disposable income and sexual partners during travel, hence higher potential for exposure to HIV infection. In our analysis, more residents in HP clusters had ever had an HIV test compared with those in LP clusters may affirm these results because use of HTS may be related to perception of risk. It has been observed in SSA that seeking HIV testing is associated with perception of higher risk,36 and the converse may imply that perception of low risk may deter HIV testing. There was an overall pattern of greater sexual risk in HP clusters compared with LP clusters, with a higher proportion of respondents being sexually active, fewer persons reporting using condoms consistently, more lifetime sexual partners on average and also more men in HP clusters that had ever been clients of FSWs. Rates of male circumcision were lower in HP clusters, with lower circumcision rates associated with higher risk of HIV acquisition and transmission in multiple studies including randomized control trials in SSA.37-43

Limitations

Our analysis is subject to a few limitations. First, the actual population size data per cluster was not available; hence, we worked back to estimate the cluster population size using the household weights. KAIS 2012 did not include the former North Eastern Province, which generally has very low HIV prevalence; hence, the findings presented here may not be nationally representative. It would have been useful to assess whether there are HP clusters in a region where HIV prevalence is very low. KAIS was not designed to capture key populations such as FSWs, men who have sex with men, or person who inject drugs; hence, this analysis of clustering focuses on risks in the general population and may not explicitly reveal patterning related to KP spatial distribution. There may be other individual characteristics which we did not include, yet they may confound the associations with HIV...
clustering. However, we believe that we captured the most important demographic and behavioral factors that can be easily collected in household interviews. Finally, the proportion of adults at risk of HIV infection is unknown because in general population surveys, it is not possible to segregate most-at-risk populations. Hence, we assumed 30% of the adult population were at greatest risk because we wanted to be modest in our estimation.

**CONCLUSIONS**

Our analyses provide information on finer geographic areas of focus in developing HIV prevention and treatment activities. Hence, resource allocation needs to be performed equitably as opposed to equally across regions and subnational units. The HIV program in our setting may need to rethink targeting of interventions for specific populations such as:

### TABLE 3. Factors Associated With Being in a High HIV-Prevalence Cluster*, Kenya AIDS Indicator Survey 2012

| Characteristic* | From HP Clusters | Unadjusted OR 95% CI | aOR (95% CI) | P |
|-----------------|------------------|----------------------|-------------|---|
| **Region**      |                  |                      |             |   |
| Nairobi         | 370/1314         | 26.6                 | 13.4 to 39.9| 2.12 (0.8 to 5.63) | 0.13 | 0.76 (0.23 to 2.45) | 0.642 |
| Central         | 479/1423         | 29.5                 | 15.6 to 43.4| 2.44 (0.93 to 6.44) | 0.071 | 1.63 (0.55 to 4.86) | 0.376 |
| Coast           | 228/1462         | 15.1                 | 4.6 to 25.5 | 1.04 (0.35 to 3.04) | 0.945 | 0.7 (0.21 to 2.33) | 0.566 |
| Eastern         | 308/2321         | 24.2                 | 10.3 to 38.1| 1.87 (0.66 to 5.25) | 0.236 | 2 (0.64 to 6.26) | 0.232 |
| Nyanza          | 1030/1631        | 66.4                 | 51.1 to 81.7| 11.57 (4.34 to 30.84) | <0.001 | 7.9 (2.8 to 22.26) | <0.001 |
| Rift Valley     | 308/2067         | 14.6                 | 5.8 to 23.4 | ref | ref |
| Western         | 582/1408         | 39.1                 | 21.9 to 56.3| 3.76 (1.37 to 10.28) | 0.01 | 4.34 (1.43 to 13.2) | 0.01 |
| **Education level** |              |                      |             |   |
| No primary      | 161/1338         | 19.3                 | 13.0 to 25.5| 1.65 (1.09 to 2.52) | 0.019 | 1.71 (0.84 to 3.45) | 0.138 |
| Complete primary| 1120/3694        | 29.9                 | 24.4 to 35.3| 1.79 (1.21 to 2.63) | 0.003 | 1.57 (0.81 to 3.07) | 0.185 |
| Secondary+      | 1738/5606        | 30.5                 | 25.0 to 36.1| 1.84 (1.27 to 2.67) | 0.001 | 1.54 (0.82 to 2.91) | 0.179 |
| **Wealth quintiles** |              |                      |             |   |
| Lowest          | 433/2434         | 18.5                 | 13.1 to 24.0| 1.9 (1.43 to 2.53) | <0.001 | 1.61 (1.13 to 2.3) | 0.008 |
| Second          | 761/2497         | 30.2                 | 22.9 to 37.5| 1.84 (1.27 to 2.68) | 0.001 | 1.66 (1.09 to 2.53) | 0.017 |
| Middle          | 706/2318         | 29.5                 | 23.1 to 36.0| 2.62 (1.65 to 4.16) | <0.001 | 3.2 (1.82 to 5.65) | <0.001 |
| Fourth          | 797/2177         | 37.3                 | 29.4 to 45.3| 1.96 (1.09 to 3.55) | 0.025 | 2.28 (1.09 to 4.78) | 0.029 |
| Highest         | 608/2200         | 30.9                 | 20.9 to 40.9| ref | ref |
| **Marital status** |              |                      |             |   |
| Never married or single | 970/3471 | 28.2                 | 22.9 to 33.6| 1.05 (0.81 to 1.35) | 0.73 | 1.2 (0.76 to 1.9) | 0.427 |
| Widowed         | 299/894          | 35.9                 | 29.1 to 42.6| 1.49 (1.09 to 2.03) | 0.013 | 1.2 (0.72 to 1.99) | 0.486 |
| Separated or divorced | 146/558 | 27.3                 | 20.8 to 33.9| ref | ref |
| Married or cohabiting | 1889/6699 | 29.3                 | 24.2 to 34.5| 1.1 (0.87 to 1.39) | 0.404 | 1.43 (0.93 to 2.19) | 0.102 |
| **Traveled in past 12 mo** |              |                      |             |   |
| Never traveled away | 1477/5940 | 25.5                 | 20.6 to 30.4| ref | ref |
| Less than 1 month | 458/1520 | 33.3                 | 26.5 to 40.1| 1.45 (1.16 to 1.82) | 0.001 | 1.36 (1.02 to 1.81) | 0.036 |
| One month or longer | 1256/3843 | 33.1                 | 27.3 to 38.8| 1.44 (1.2 to 1.72) | <0.001 | 1.17 (0.9 to 1.51) | 0.245 |
| **Risk perception** |              |                      |             |   |
| No risk         | 1054/4212        | 25.8                 | 20.7 to 30.9| ref | ref |
| Small           | 1082/4241        | 26.4                 | 21.1 to 31.7| 1.03 (0.85 to 1.25) | 0.762 | 1.13 (0.84 to 1.51) | 0.426 |
| Moderate        | 350/1023         | 36.2                 | 29.1 to 43.2| 1.63 (1.3 to 2.05) | <0.001 | 1.39 (0.96 to 2.0) | 0.079 |
| Great           | 184/457          | 39.3                 | 30.8 to 47.8| 1.86 (1.42 to 2.44) | <0.001 | 1.96 (1.13 to 3.4) | 0.017 |
| I already have HIV | 170/247 | 68.6                 | 58.3 to 79.0| 6.29 (4 to 9.92) | <0.001 | 5.51 (2.42 to 12.55) | <0.001 |
| **Ever been a client of FSW** |              |                      |             |   |
| Never           | 899/3415         | 26.8                 | 21.6 to 31.9| ref | ref |
| Ever            | 266/684          | 38.1                 | 30.1 to 46.0| 1.68 (1.28 to 2.21) | <0.001 | 1.47 (1.04 to 2.08) | 0.029 |
| **Ever had an HIV test** |              |                      |             |   |
| Yes             | 1629/5192        | 30.6                 | 25.2 to 35.9| 1.69 (1.4 to 2.04) | <0.001 | 1.45 (1.14 to 1.84) | 0.003 |
| No              | 1672/6424        | 28.2                 | 22.9 to 33.5| ref | ref |
| **Circumcised (men)** |              |                      |             |   |
| Circumcised     | 1098/4395        | 25.5                 | 20.3 to 30.6| 4.26 (2.83 to 6.41) | <0.001 | 3.18 (1.74 to 5.8) | <0.001 |
| Uncircumcised   | 247/428          | 59.3                 | 49.4 to 69.1| ref | ref |

*Excludes “don’t know” category.
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