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The Epidemiology of HIV around Lake Victoria in Kenya, Uganda, and Tanzania

By

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Degree to be awarded: MPH

Epidemiology

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The Epidemiology of HIV around Lake Victoria in Kenya, Uganda, and Tanzania

By

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B.S., Georgia State University, 2018
MHS., Meharry Medical College, 2021

Thesis Committee Chair: Andrew C. Voetsch, PhD
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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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ABSTRACT

The Epidemiology of HIV around Lake Victoria in Kenya, Uganda, and Tanzania

By: Ebrima Sidibeh

Background: HIV remains a major public health concern, particularly in sub-Saharan Africa (SSA), where most of the global burden is concentrated. Communities surrounding Lake Victoria in East Africa are considered high-risk populations. We analyzed HIV and viral load metrics in Kenya, Uganda, and Tanzania using population-based HIV impact assessment (PHIA) surveys. Monitoring viral load is crucial to achieving targets like UNAIDS 90-90-90 and reducing the global HIV burden.

Objective: This study aims to describe HIV epidemiology around Lake Victoria using PHIA surveys, comparing age and sex-specific population viremia levels as a marker for transmission in SSA.

Methods: We conducted an analysis of cross-sectional data from PHIA surveys in Kenya, Uganda, and Tanzania from 2016 to 2019, focusing on adults aged 15-64 (or up to 80 in Tanzania). A stratified two-stage cluster sampling design was used, and data were collected through interviews and biological measures. The study received ethics approval in all three countries.

Results: Our analysis revealed substantial differences in HIV prevalence and viral load suppression (VLS) rates across the three countries. Uganda had the highest HIV prevalence (6.3%, 95% CI: 5.8%, 6.7%), followed by Kenya (4.9%, 95% CI: 4.5%, 5.3%), and Tanzania (4.9%, 95% CI: 4.5, 5.2). Kenya had the highest VLS rate (71.6%), Uganda had 59.6%, and Tanzania had the lowest (51.8%). Females consistently had higher HIV prevalence and VLS rates than males. Viremia estimates varied by age and gender, with younger males experiencing the lowest rates and older females attaining the highest. Lake regions within these countries consistently reported higher viremia, HIV prevalence and VLS rates compared to non-lake regions.

Conclusion: This study highlights the importance of population viremia as a proxy for HIV transmission, revealing disparities in community viral load around Lake Victoria and between genders. These findings emphasize the need for targeted interventions to address higher HIV prevalence in lake regions and improve VLS rates, particularly among young males. By addressing gender-specific challenges and age-related disparities in VLS, we can develop more effective strategies to reduce HIV transmission. A comprehensive, multi-sectoral approach is necessary to address the unique challenges faced by communities around Lake Victoria.

The Epidemiology of HIV around Lake Victoria in Kenya, Uganda, and Tanzania

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INTRODUCTION

In many regions of the world, particularly in sub-Saharan Africa, HIV remains a major public health concern. Approximately 38.4 million individuals worldwide were living with HIV/AIDS in 2021, with only 28.7 million receiving antiretroviral therapy (ART), making the HIV pandemic one of the biggest public health concerns of the current decade, alongside the ever-present threat of COVID-19.[1]A disproportionate burden of HIV infection occurs in Sub-Saharan Africa, which accounts for more than 70% of the global burden.[2] There are approximately 6000 new HIV infections worldwide daily. Two out of every three of these incident infections are found in Sub-Saharan Africa. Young women continue to suffer a disproportionate amount of the burden. Adolescent girls and young women (15 to 24 years old) have up to eightfold rate of incident (or new) HIV infection.[2] The rate of new HIV infections in sub-Saharan Africa has declined from 5.2 per 1,000 uninfected individuals aged 15-49 in 2000 to 1.1 per 1,000 uninfected individuals in 2021.[3] There were approximately 1.5 million new global HIV infections in 2021, which significantly exceeded the UNAIDs target of 500 thousand new infections in a year.[1]Understanding a new infection and its transmission patterns is crucial to interrupting the spread of new infections. HIV/AIDS causes social and economic growth barriers in developing nations across all sectors, including regions around Lake Victoria in Kenya, Uganda, and Tanzania[4-7] Fisherfolks in Kenya and Uganda have a greater risk of HIV infection than the general population and other high-risk populations.[7]

The prevalence and incidence of HIV are high in Lake Victoria's fishing communities in East Africa, particularly among the women who live and work there. These high-risk subgroups typically have higher rates of both new and prevalent infections than the general population.[6] High levels of frequent migration (motility), high prevalence of bars, lodges, and entertainment venues, commercial sex work, reduced access to education and health care services, transactional sexual relationships, and alcohol consumption have all been linked to high rates of HIV infection in fishing communities.[4,8-11] In two different studies conducted in Uganda and Tanzania, the prevalence of HIV among fisherfolk was 26% and 14%, respectively, [12,13] compared to the national HIV prevalence for Uganda and Kenya (5.2% and 4.5%, respectively, for adults aged 15-49 in 2021).[14] Several global initiatives aimed at slowing the spread and eradicating HIV infection have been put in place, including the UNAIDS 90-90-90 plan. This plan aims to ensure that by 2020, 90% of HIV-positive individuals are aware of their condition, 90% of these individuals are receiving continuous antiretroviral therapy, and 90% of these individuals have viral load suppression (VLS).

These ambitious targets to reduce the global HIV burden make the monitoring of viral load (VL) quite crucial. Measuring trends in HIV population viral load is one technique to keep track of progress towards the UNAIDS 90-90-90 treatment targets. The single most significant biological factor influencing the likelihood of transmission between an HIV-positive and an HIV-negative person is the level of HIV viral load in blood or semen.[15] An aggregate indicator of HIV viral RNA concentrations for people living with HIV within a given geography or community over a specified time period could serve as a sensitive biological indicator of the effectiveness of a treatment program and possibly provide an estimate of a geography's transmission potential.[16]

Population viremia, the prevalence of individuals with unsuppressed HIV in a given population, is frequently closely connected with the incidence of HIV in the larger population.[16]
The objective of this analysis is to describe the epidemiology of HIV around Lake Victoria in Kenya, Uganda, and Tanzania. Using Population-based HIV Impact Assessments (PHIA) surveys, we will compare age- and sex-specific population viremia levels as a marker for transmission potential in regions around Lake Victoria compared to non-lake regions in Kenya, Uganda, and Tanzania.

METHODS

Study Design and Setting

This study employed a cross-sectional design, using data from the Population-Based HIV Impact Assessments (PHIA) surveys in Kenya, Uganda, and Tanzania. The PHIA project was a multi-country initiative funded by the US President's Emergency Plan for AIDS Relief (PEPFAR). The PHIA survey was conducted in Kenya between May 2018 and February 2019 in 47 counties, where over 18,000 households were visited and nearly 28,000 adults were interviewed aged 15-64.[17] In Tanzania, the household-based national survey was conducted between October 2016 and August 2017 in 31 counties where over 15,000 households were visited to gather information in adults aged 15-80.[18] Uganda PHIA surveys were conducted between August 2016 and March 2017 in 10 regions, where the survey team visited over 12,000 households to collect information in adults aged 15-64.[19] The surveys were designed to provide estimates of HIV prevalence, incidence, subnational estimates of HIV viral load suppression, and other key indicators among adults.

Sampling

The sampling for all three countries was done by using a stratified two-stage cluster sampling design to select households and individuals.[20] At the first stage, clusters (enumeration areas) were selected based on probability proportional to size. In the second stage, households were selected using a systematic random sampling technique within the selected enumeration areas. For the first stage in Kenya, a probability proportional-to-size method was used to select 800 enumeration areas. These 800 EAs were then divided into 47 counties as part of a stratification process. Within each cluster, a random sample of 25 households was selected in the second stage. In Tanzania, the sampling frame consisted of all enumeration areas (EAs) in the country as determined by the 2012 Tanzania Population and Housing Census (2012 PHC), which comprised 106,642 EAs and was estimated to contain 9,362,758 households.[21] In the first stage of the sampling process, a Probability Proportional to Size (PPS) method was used to select 526 EAs (clusters), which were further stratified by 31 geographical regions. In the second stage, a random sample of households was selected within each EA using a PPS method, with an average of 30 households to be selected per EA. However, the actual number of households selected per

EA ranged from 15 to 61. In Uganda, the sampling frame was made up of all households in the country, which were estimated to be 7,800,000 and were in 80,000 EAs.[22] In the initial stage for Uganda, a probability proportional to size method was utilized to choose 520 EAs (clusters). The EAs were categorized into ten regions: Central 1, Central 2, Kampala, East-Central, Mid-Eastern, North-East, West Nile, Mid-North, Mid-West, and South-West. In the second stage, households were selected within each EA (or cluster) through a random sampling process that used an equal probability.

Study Population

We examined data from the Kenya (2018-19, n= 27,745), Tanzania (2016-17, n= 31,579), and Uganda (2016-17, n= 29,024) PHIA surveys.[17-19] Our study focused on adults aged between 15 and 64 years who underwent an HIV test during the survey. In Tanzania, the adult age extended to 80 years old. Children under the age of 15 were not included in our study. Eligibility criteria for the survey varied across the three countries. In Kenya, adults aged 17-64 years and emancipated minors aged 15-17 years who lived in selected households and adult visitors who slept in the household the night before the survey willing to provide written consent were eligible. Minors aged 15-17 years who were also willing to provide written assent, and their parents or guardians willing to provide written permission were eligible. In Tanzania, individuals aged 18 years and older were willing to provide verbal informed consent, while those aged 10-17 years willing to provide verbal assent, with verbal permission from their parents or guardians were eligible. In Uganda, women and men aged 18-64 years who were willing to provide verbal consent, while children and adolescents aged 8-17 years willing to provide verbal assent with verbal permission from their parents or guardians were considered eligible. Participants had to meet additional eligibility criteria such as having spent the previous night in the sampled household and being able to speak one of the languages used for the interview. The surveys were conducted in English and several local languages-15 in Kenya, 7 in Uganda, and 1 in Tanzania-ensuring accessibility and accurate information from participants across the region.[17-19] Individuals <15 years of age and those who did not meet the above criteria were excluded from our analysis. Electronic consent was obtained using a tablet computer where respondents gave verbal consent which was recorded. The head of the household provided consent for all household members to take part in the survey, but individual members had to give their own consent/assent for the interview. Those aged 18 and over then provided verbal consent for the biomarker component of the survey, which included HIV testing, with the return of rapid HIV test results during the same household visit. People who had a positive initial screening test with the rapid HIV test went through a second confirmatory test. If they tested positive in both the first and second tests, they were considered to be HIV positive.

Data Collection

The PHIA survey team conducted interviews and utilized tablets, which were password-protected and equipped with a data collection application programmed with Open Data Kit 1.4.5 (ODK), to carry out interviews in private settings near selected homes.[20] The application comprised various forms, including eligibility screening, consent, household and individual

questionnaires, and point-of-care biomarker results and refusal.[20] During the individual adult interviews, participants engaged in face-to-face conversations where they were asked several questions covering topics such as demographic information, household attributes, uptake of HIV-related services, and behaviors associated with HIV-related risk. Responses were recorded by the PHIA survey team using tablets. Participants were requested to provide details about their history of HIV testing, previous test results, and their status regarding antiretroviral therapy. Detailed data collection methods can be found in the published final reports for the respective countries.[17-19]

Biologic measures

Participants in Kenya, Tanzania, and Uganda provided informed consent for HIV testing, and venous blood samples were collected for testing. Samples were labeled and stored in temperature-controlled cooler boxes, transported to a satellite laboratory, and processed into plasma aliquots and dried blood spots (DBS), which were frozen within 24 hours. HIV Home-based Testing and Counseling was conducted using sequential rapid testing algorithms with screening tests and confirmatory tests for HIV diagnosis. In-country testing was done using the Roche COBAS® AmpliPrep/COBAS® TaqMan HIV-1 test version 2.0 or the Abbott RealTime HIV-1 assay, and participants with VL<1,000 HIV-1 RNA copies/mL were classified as virally suppressed, while those with VL ≥1,000 copies/mL were categorized as unsuppressed or viremic.[23] The surveys used a comprehensive quality assurance and control testing program to ensure the accuracy and reliability of the data, including a standardized approach to train and certify laboratory staff, regular proficiency testing, and a robust internal quality control program. Overall, these measures helped ensure the accuracy and reliability of the VL testing results obtained in the PHIA surveys. A more detailed look at the biologic measures can be found in Voetsch et. al 2021 and in the published final reports for the three countries.[17-19,23]

Data Analysis

Data were analyzed using appropriate statistical methods, including estimation of weighted population proportions and confidence intervals. The analysis accounted for the complex survey design and was performed on the national and the county or regional level for all three countries. We pooled the lake regions/counties (i.e., areas on the respective country maps that border Lake Victoria) and the non-lake regions (i.e., areas on the respective country maps that do not border Lake Victoria) for each country during our analysis. The information provided in each survey is based on individuals who received a valid biomarker result for their HIV-1 status. Analytic weights were used to account for selection probabilities of primary sampling units, households, and individuals, and to adjust for non-response and biomarker participation. The weights were also adjusted to match each country's age and sex distribution based on a recent population projection. Population size was taken into consideration when estimating values for all countries combined. Participants who were HIV-positive were classified as aware of their status or diagnosed if they reported a previous positive test or had detectable antiretroviral drugs (ARV). Individuals who were HIV-positive and tested ARV-positive were classified as currently receiving antiretroviral therapy (ART).

Several variables were calculated, including mean viral load, total viral load, and the number of virally suppressed and unsuppressed people living with HIV by age and sex. With a cutoff of 1 c/mL as the threshold for detectability, the total VL was calculated by combining the viral loads of all PLHIV in each country. [24] The fraction of PLHIV with viral suppression and PLHIV without viral suppression who tested positive and negative for ARV was also assessed. VLS was calculated for all PLHIV, diagnosed PLHIV, and PLHIV on ART. Population viremia was estimated by dividing the HIV prevalence rate by the percentage of viremic PLHIV.

Human subject considerations

All surveys were reviewed and approved by the respective national ethics and regulatory review committees and the U.S. Centers for Disease Control and Prevention (CDC) Institutional Review Board. Informed consent was obtained from all participants before enrollment in the study, and all participants were assured of the confidentiality of their personal information. Additional measures were taken to ensure privacy and minimize risk, such as the use of unique participant identifiers, secure data storage, and limiting access to the data. Participation in the survey was voluntary, and participants had the right to decline or withdraw from the study at any time without consequence.

Data availability

The data from the Population HIV Impact Assessment surveys are available on the Columbia University ICAP website (https://phia-data.icap.columbia.edu/). Detailed information on these data sets can be found on the website. The population denominators used in the surveys were obtained from World Pop.

RESULTS

Kenya

Table 1 shows several national HIV and viral load (VL)-related measurements for all three countries. In Kenya, 27,745 PLHIV aged 15–64 were included in our analysis. The national prevalence of HIV was 4.9% (95% CI: 4.5%, 5.3%). Gender-specific analysis showed that most PLHIV in Kenya were female and accounted for over two-thirds of all PLHIV. The ratio of viremic female to male adults was 1.6, and the log10 transformed mean VL among unsuppressed PLHIV in Kenya was 4.5(95% CI: 4.4, 4.6). The mean VL among unsuppressed adults in Kenya was higher in males than in females. Overall, 71.6% of people aged 15-64 with HIV achieved VLS, with females in this age range having higher VLS than males (Table 1). The percentage of individuals virally suppressed also varied by age, with the lowest percentage among males aged

15–29 years and the highest among females aged 30+ years. The estimated total VL in Kenya was 48.9 billion copies/mL. Among PLHIV, 87.0% of individuals diagnosed with HIV had VLS, and 90.6% of those being treated for HIV achieved VLS. The age and sex-stratified analysis for diagnosed VLS and in-treatment VLS are shown in Table 1. The proportion of unsuppressed PLHIV among ARV-positive individuals in Kenya was 6.3% and the estimated population viremia varied by sex and age. The estimated population viremia in the country was 1.4% (95% CI: 1.2%–1.6%), and females had higher population viremia estimates than males in all age groups, as shown in Table 1.

Table 2 shows the pooled HIV and viral load-related metrics for the lake and non-lake counties in Kenya. The HIV prevalence in the lake counties was more than four times higher than in the non-lake counties and the difference was significant (i.e., non-overlapping confidence intervals). Gender-specific analysis showed that females had a higher prevalence of HIV than males, accounting for approximately two-thirds of all PLHIV in the lake regions and more than two-thirds of all PLHIV in the non-lake regions. The female-to-male ratio of unsuppressed PLHIV was lower in the Lake counties than in the non-Lake counties. Furthermore, a little over 80% of PLHIV in the Lake counties achieved VLS, compared to approximately two-thirds in the non-Lake counties. Among those diagnosed with HIV, VLS was even higher, at 90.9% in the lake counties and 84.5% in the non-lake counties. The number of people who attained VLS while getting treatment was also higher in lake counties. The proportion of unsuppressed PLHIV among ARV-positive individuals in Kenya was lower in the lake counties than in the non-lake counties. During our analysis, we found that population viremia estimates were greater in the Lake counties than in the non-Lake counties. The difference in viremia estimates between the lake and non-lake counties was significant (i.e., non-overlapping confidence intervals) (Table 2). We also found gender and age differences in viremia, with the highest viremia estimate observed among males 30 and older, as shown in Table 2.

Tanzania

The national data for HIV and VL-related metrics for Tanzania are shown in Table 1. There were 31,579 adults living with HIV, aged 15–80. The HIV prevalence for the country was 4.9% (95% CI: 4.5, 5.2), and the gender-specific analysis revealed that females accounted for a higher percentage of all PLHIV. The ratio of female to male unsuppressed PLHIV was 1.4, and the log10-transformed mean VL among unsuppressed PLHIV in Tanzania was 4.7 (95% CI: 4.6, 4.7). The mean VL among unsuppressed PLHIV in Kenya was higher in males than in females. Among PLHIV, 51.8% achieved VLS, with females faring better than males (Table 1). VLS rates also varied with age, with the lowest rates found in males aged 15–29 and the highest rates found in females aged 30+. Tanzania had an estimated total VL of 108.9 billion copies/mL. 79.0% of PLHIV who were diagnosed with HIV achieved VLS, and 87.1% of individuals undergoing HIV treatment attained VLS. The age and sex-stratified analysis for diagnosed VLS and in-treatment VLS are shown in Table 1. In Tanzania, 10.9% of ARV-positive people had unsuppressed VL and the population viremia estimates varied by age and sex. The estimated population viremia was 2.3 (95% CI: 2.1%–2.6%) and females had greater population viremia estimates across all age categories than males (Table 1).

Table 2 presents the pooled HIV and viral load-related metrics for the lake and non-lake regions of Tanzania. According to the study findings, the prevalence of HIV was greater in the lake regions than in the non-lake regions (Table 2). Unlike Kenya, the difference in HIV prevalence between the lake and non-lake regions wasn't significant (i.e., overlapping confidence intervals). Females had a greater prevalence of HIV, accounting for almost two-thirds of all PLHIV in the lake regions and over two-thirds in the non-lake regions. The female-to-male ratio of unsuppressed PLHIV was higher in the lake regions than in the non-lake regions. VLS rates were higher in the lake regions than in the non-lake regions (Table 2). Furthermore, higher rates of VLS were seen among individuals diagnosed with HIV and those undergoing treatment in the lake regions compared to the non-lake regions. The proportion of unsuppressed PLHIV among ARV-positive individuals was lower in lake regions. Our study revealed that the estimated population viremia was higher in the lake regions than in the non-lake regions. However, the difference in viremia estimates wasn't significant. Population viremia estimates varied by age and gender, with the highest rates found in females aged 30+, as shown in Table 2.

Uganda

The national HIV and VL-related metrics for Uganda are displayed on Table 1. There were 29,024 PLHIV aged 15 to 64. The HIV prevalence in the country was 6.3% (95% CI: 5.8, 6.7), and a gender-specific analysis found that females accounted for a larger proportion of all PLHIV (Table 1). The female to male ratio of unsuppressed PLHIV was 1.5, and the log10-transformed mean VL among unsuppressed PLHIV in Uganda was 4.6 (95% CI: 4.5, 4.7). Males had a higher mean VL than females among unsuppressed adults in Uganda. 59.6% of PLHIV achieved VLS, with women faring better than men. VLS rates varied by age, with males aged 15–29 having the lowest rates and females aged 30+ having the highest rates (Table 1). The estimated total VL in Uganda was 72.4 billion copies/mL. 76.3% of diagnosed PLHIV achieved VLS, and 83.7% of those undergoing HIV treatment achieved VLS. The age and gender stratified analyses for diagnosed VLS and in-treatment VLS are shown in Table 1. In Uganda, 11.6% of ARV-positive people had unsuppressed VL and estimates of population viremia varied by age and gender. The estimated population viremia was 2.5% (95% CI: 2.3%, 2.8%). Females had higher population viremia estimates than males across all age groups, except for individuals aged 30+.

The pooled HIV and viral load-related data for Uganda's lake and non-lake regions are shown in Table 2. The HIV prevalence was higher in lake regions than in the non-lake regions. Like Tanzania, the difference in HIV prevalence between the lake and non-lake regions isn't significant. Females had a higher HIV prevalence, accounting for almost two-thirds of all HIV patients in both the lake regions and non-lake regions. In the lake regions, the female-to-male ratio of unsuppressed PLHIV was greater than in the non-lake regions. VLS rates were higher in the lake regions than in the non-lake regions (Table 2). Individuals in the lake regions diagnosed with HIV and receiving HIV therapy had higher rates of VLS than those in the non-lake regions. Furthermore, lake regions had a lower proportion of unsuppressed PLHIV among ARV-positive people than non-lake regions. The estimated population viremia was higher in the lake regions than in the non-lake regions. However, the difference in viremia estimates wasn't significant.

Estimates of population viremia varied by age and gender, with males aged 30 and up having the highest rates, as shown in Table 2.

DISCUSSION

We conducted a descriptive analysis to evaluate the HIV epidemiology around Lake Victoria by comparing age and sex-specific population viremia levels as a marker to better understand transmission dynamics in this region. Population viremia is a helpful proxy for HIV transmission because it reflects the combined impact of HIV prevalence, access to ART, and the effectiveness of ART in suppressing viral replication.[25] Population viremia varied by sex and age in all three countries, with Uganda having the highest population viremia (2.5% (95% CI: 2.3%, 2.8%)). Population viremia estimates in all three countries were higher in the lake regions surrounding Lake Victoria than in the non-Lake regions. Thus, a larger percentage of individuals per capita in the lake regions have unsuppressed HIV; higher levels of unsuppressed viral load are a proxy for higher risk of ongoing HIV transmission within the population. We report a notable gender disparity in population viremia; females had consistently higher estimates of population viremia than males. The high proportion of people living with HIV viremia in this region raises the possibility that distinct social, economic, or behavioral factors are frustrating HIV control measures in the Lake Victoria area.[26] Some of the risk factors for HIV transmission in the lakes' fishing settlements include high rates of mobility, multiple sexual partnerships, and limited access to healthcare.[9] Our study findings further our understanding of the issues surrounding HIV epidemiology around Lake Victoria by providing valuable insights into the HIV transmission dynamics in this region.

Our study provides a comprehensive comparison of VLS, diagnosed VLS, and in-treatment VLS among individuals aged 15-80 years in Kenya, Tanzania, and Uganda. The analysis revealed differences in the VLS rates across the three countries, which subsequently impact the population viremia and potentially HIV incidence. Kenya results were consistently higher than Tanzania and Uganda in all three VLS metrics (overall VLS, diagnosed VLS, and in-treatment VLS) for both sexes and across all age groups. The higher VLS rates in Kenya may be attributed to more effective implementation of HIV/AIDS management strategies, such as widespread availability of ART and stronger adherence to treatment guidelines.[27,28] In contrast, Tanzania and Uganda displayed lower VLS rates, which may suggest challenges in ART access, adherence, and monitoring. The population viremia estimates reflect these differences in VLS metrics. Kenya has the lowest population viremia, followed by Tanzania and Uganda. Population viremia is an essential indicator of HIV transmission risk, as individuals with higher viral loads are more likely to transmit the virus.[29] Thus, the lower population viremia rates in Kenya suggest reduced HIV transmission potential compared to Tanzania and Uganda. Generally, higher VLS percentages and lower population viremia percentages are linked to reduced HIV transmission, as individuals with suppressed viral loads have a lower likelihood of transmitting the virus.[27] Consequently, the observed VLS and population viremia disparities in the three countries could imply varying HIV incidence rates. However, it is crucial to note that HIV incidence is influenced by multiple factors, including structural determinants, sexual behavior, availability and use of preventive measures, and sociodemographic factors.[30-32] Further research is needed to

examine the direct relationship between VLS and population viremia rates and HIV incidence in these three contiguous countries.

There were notable differences in VLS among PLHIV in the lake and non-lake regions across the three countries. A closer examination of the data suggested that VLS rates were generally higher in the lake regions for all three countries. Despite the higher VLS rates, population viremia, which represents the proportion of individuals with unsuppressed HIV, was consistently higher in lake regions across all countries and subgroups. In Kenya, the biggest difference in VLS was observed in the 15-29 age group, with higher VLS rates in lake regions for both males and females compared to their counterparts in non-lake regions. This pattern was also observed in Uganda, where VLS rates in lake regions were consistently higher across all subgroups, with the largest difference among males aged 15-29. However, in Tanzania, the difference in VLS between lake and non-lake regions was less pronounced, except for males aged 15-29, where VLS is higher in non-lake regions. The higher VLS rates in lake regions and higher population viremia suggest that the UNAIDS 90-90-90 targets for diagnosing, treating, and achieving viral suppression may not be sufficient to reduce HIV incidence in these areas. Factors such as high-risk behaviors, social determinants of health, and inadequate access to preventive measures could contribute to these disparities.[31,32] Furthermore, it is crucial to consider the differences in VLS and population viremia rates among subpopulations and age groups within these communities, as the results show variations, particularly among younger individuals. The disparities in VLS and population viremia between lake and non-lake regions emphasize the need for a deeper understanding of the unique challenges faced by these communities.

Our results have applications and potential uses, emphasizing the importance of monitoring population-level viremia as a key indicator for HIV prevention and control efforts. Variations in HIV prevalence, VLS, and population viremia were observed across the three countries and between lake and non-lake regions. By identifying areas with high community viral load, public health officials can better allocate resources and tailor interventions to reduce HIV transmission in these regions. The study highlights the importance of age and sex-stratified analyses to better understand the underlying factors contributing to these differences. Furthermore, our findings underscore the need for targeted interventions, particularly in lake regions, where HIV prevalence and population viremia were consistently higher than non-lake regions. The study draws attention to the need for improving VLS rates among specific subpopulations, such as younger males, who consistently exhibited lower VLS rates compared to their female counterparts. The differences observed between lake and non-lake regions can inform policymakers and stakeholders in their efforts to address the disparities in HIV prevalence and incidence across various geographical settings. Overall, these results can inform the design of more targeted and effective HIV prevention and treatment strategies in the Lake Victoria region, ultimately contributing to the global effort to combat the HIV epidemic.

This study has several limitations. Our selection of lake and non-lake areas bordering Lake Victoria was based on PHIA survey maps that identified political boundaries in the respective countries that bordered the lake. However, we did not have more refined boundary data to enhance the precision of our analysis. Employing geospatial data to identify the location of participants in these regions could reduce misclassification of lake-bordering status and might yield less biased results. Although population viremia serves as a useful proxy for HIV

transmission, it does not encompass the complete picture of HIV transmission dynamics. To obtain a more accurate measure of HIV incidence in specific geographical regions, additional factors should be considered such as migration and population mobility, gender inequalities and access to HIV testing and treatment.[33-35] It is important to recognize that the cross-sectional nature of PHIA surveys might not directly capture temporal trends, such as changes in HIV transmission over time. However, it is worth noting that there are repeated survey results soon to be available for Uganda and Tanzania. Furthermore, Kenya has already conducted three rounds of surveys and is anticipating a fourth. Once the public data becomes available, we'll have the opportunity to examine and identify trends across these countries, providing valuable insights into the evolution of HIV transmission over HIA surveys use a multi-stage cluster sampling design, which could introduce sampling bias if certain sub-populations are underrepresented or overrepresented. Participation in the PHIA surveys is voluntary, and some individuals may opt out due to fear of stigma or other reasons. This non-response could result in selection bias and impact the representativeness of the findings.

Our study emphasizes the significance of population viremia as a proxy for HIV transmission and reveals disparities in this measure in community viral load across different regions, particularly around Lake Victoria in Kenya, Uganda, and Tanzania, as well as between genders. These findings underscore the urgent need for targeted interventions to address the higher prevalence of HIV in lake regions and improve VLS rates, especially among key populations such as males aged 15 to 29. Addressing gender-specific challenges and age-related disparities in VLS will be crucial to mitigating these disparities. Healthcare systems should focus on enhancing the accessibility and quality of HIV testing, treatment, and care services, while community-based programs should be designed to increase HIV awareness, promote prevention strategies, and tackle socio-cultural factors that contribute to the epidemic. Efforts should also be made to strengthen monitoring and evaluation systems to track progress towards epidemic control. With the continued implementation of effective strategies to lower community viral load, we can substantially reduce the risk of HIV transmission and ultimately move closer to achieving the goal of ending the HIV epidemic. A comprehensive, multi-sectoral approach is required to address the unique challenges faced by communities around Lake Victoria, with a focus on evidence-based interventions that support the most vulnerable populations to achieve HIV control.

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APPENDIX

Table 1. Weighted national metrics for HIV prevalence, viremia, and viral load in Kenya, Uganda, and Tanzania, 2016-2019.

	Kenya	Tanzania	Uganda
Age range (years)	15-64	15-80	15-64
HIV prevalence % (95% CI)	4.9 (4.5, 5.3)	4.9(4.5, 5.2)	6.3(5.8, 6.7)
No. PLHIV, total	1,303,267	1,532,483	1,195,299
No. PLHIV suppressed	932,846	793,894	712,653
No. PLHIV unsuppressed	370,421	736,760	482,647
PLHIV by gender, n (%)			
Male	410,607 (31.5)	518,664 (33.8)	425,788 (35.6)
Female	892,660 (68.5)	1,013,819 (66.2)	769,511 (64.4)
Ratio female: male unsuppressed PLHIV	1.6	1.4	1.5
Mean VL (log10), all PLHIV (95% CI)	1.9 (1.8, 2.0)	2.7 (2.6, 2.8)	2.4 (2.3, 2.5)
Mean VL (log10), unsuppressed PLHIV (95% CI)			
Both sexes (15-64 years)	4.5(4.4, 4.6)	4.7 (4.6, 4.7)	4.6 (4.5, 4.7)
Male (15-64 years)	4.5 (4.4, 4.7)	4.9 (4.8, 4.9)	4.8 (4.7, 4.9)
Female (15-64 years)	4.5(4.4, 4.6)	4.5 (4.4, 4.6)	4.5 (4.4, 4.6)
Total VL (billion copies/mL)	48.9	108.9	72.4
Total VL (log10)	10.7	11.0	10.9
VLS among all PLHIV (%)			
Both sexes (15-64 years)	71.6	51.8	59.6
Male (15-64 years)	65.1	41.4	53.6
Female (15-64 years)	74.6	57.2	62.9
Male (15-29 years)	44.0	21.8	30.7
Female (15-29 years)	65.1	45.8	48.5
Male (30+ years)	69.3	45.1	59.0
Female (30+ years)	77.8	60.7	70.6

Diagnosed VLS (%)			
Both sexes (15-64 years)	87.0	79.0	76.3
Male (15-64 years)	85.3	73.4	71.3
Female (15-64 years)	87.7	81.3	78.8
Male (15-29 years)	68.2	56.2	44.0
Female (15-29 years)	79.6	72.1	48.5
Male (30+ years)	88.1	75.4	74.2
Female (30+ years)	90.2	83.8	81.1
In-treatment VLS (%)			
Both sexes (15-64 years)	90.6	87.1	83.7
Male (15-64 years)	90.9	83.2	81.5
Female (15-64 years)	90.5	88.6	84.7
Male (15-29 years)	72.7	67.0	55.0
Female (15-29 years)	84.0	85.4	78.9
Male (30+ years)	93.8	84.8	84.1
Female (30+ years)	92.4	89.3	86.8
Among ARV-positives, proportion unsuppressed (%)	6.3	10.9	11.6
Population viremia %, (95% CI)			
Both sexes (15-64 years)	1.4 (1.2, 1.6)	2.3 (2.1, 2.6)	2.5 (2.3, 2.8)
Male (15-64 years)	1.1 (0.9, 1.3)	2.0 (1.7, 2.2)	2.2 (1.9, 2.4)
Female (15-64 years)	1.7 (1.5, 1.9)	2.7 (2.5, 2.9)	2.8 (2.6, 3.1)
Male (15-29 years)	0.6 (0.4, 0.8)	0.9 (0.6, 1.1)	1.1 (0.8, 1.3)
Female (15-29 years)	1.2 (0.9, 1.4)	1.7 (1.4, 2.0)	2.4 (2.1, 2.7)
Male (30+ years)	1.6 (1.3, 1.9)	3.1 (2.7, 3.4)	3.7 (3.2, 4.2)
Female (30+ years)	2.2 (1.9, 2.5)	3.6 (3.2, 4.0)	3.4 (3.0, 3.8)

HIV: human immunodeficiency virus; PLHIV: people living with HIV; VL: viral load; VLS: viral load suppression; ARV: antiretroviral; log10: log base 10; CI: confidence interval

Table 2: Pooled metrics of HIV prevalence, viremia, and viral load in Kenya, Tanzania, and Uganda, stratified by Lake and non-lake regions/counties 2016-2019.

	Kenya		Tanzania		Uganda	
	Lake Counties (5)	Non-lake counties (42)	Lake regions (5)	Non-lake regions (21)	Lake regions (3)	Non-lake regions (7)
Age range (years)	15-64	15-64	15-80	15-80	15-64	15-64
HIV prevalence% (95%CI)	15.5 (13.8, 17.2)	3.5 (3.2, 3.9)	5.4 (4.5, 6.3)	4.9 (4.5, 5.2)	7.1 (6.2, 7.9)	5.8 (5.4, 6.2)
No. PLHIV, total	471,865	831,403	381,265	114,7428	480,397	714,902
No. PLHIV suppressed	383,479	549,367	205,241	587,803	302,180	410,473
No. PLHIV unsuppressed	88,386	282,036	174,195	559,625	178,218	304,429
PLHIV by gender, n (%)						
Male	157,124 (33.3)	253,483 (30.5)	150,319 (39.4)	368,345 (32.1)	174,340 (36.3)	251,448 (35.2)
Female	314,741 (66.7)	577,919 (69.5)	230,945 (60.6)	779,083 (67.9)	306,057 (63.7)	463,454 (64.8)
Ratio female: male unsuppressed PLHIV	1.5	1.6	1.3	1.5	1.6	1.4
Mean VL (log10), all PLHIV (95% CI)	1.5 (1.3, 1.7)	2.1 (2.0, 2.2)	2.6 (2.4, 2.9)	2.7 (2.6, 2.9)	2.3 (2.1, 2.5)	2.5 (2.4, 2.7)
Mean VL (log10), unsuppressed PLHIV (95% CI)						
Both sexes (15-64 years)	4.5 (4.3, 4.7)	4.5 (4.4, 4.6)	4.6 (4.5, 4.7)	4.7 (4.6, 4.7)	4.5 (4.4, 4.7)	4.7 (4.6, 4.7)
Male (15-64 years)	4.4 (4.2, 4.7)	4.6 (4.4, 4.7)	4.8 (4.6, 5.0)	4.9 (4.8, 5.0)	4.7 (4.6, 4.9)	4.8 (4.7, 4.9)
Female (15-64 years)	4.5 (4.4, 4.7)	4.5 (4.4, 4.6)	4.4 (4.3, 4.5)	4.5 (4.5, 4.6)	4.4 (4.3, 4.5)	4.6 (4.5, 4.6)
Total VL (billion copies/mL)	11.6	37.3	20.3	88.5	28.4	44.0
Total VL (log10)	10.1	10.6	10.3	11.0	10.5	10.6
VLS among all PLHIV (%)						
Both sexes (15-64 years)	81.3	66.1	53.8	51.2	62.9	57.4
Male (15-64 years)	77.5	57.4	49.2	38.1	60.2	49.1
Female (15-64 years)	83.1	69.9	56.8	57.4	64.5	61.9
Male (15-29 years)	58.2	38.1	48.5	15.1	33.0	29.2
Female (15-29 years)	76.1	55.1	47.8	45.4	48.1	48.8
Male (30+ years)	80.4	61.9	49.3	43.2	66.2	53.9
Female (30+ years)	86.9	73.7	60.1	61.0	72.5	69.4
Diagnosed VLS (%)						
Both sexes (15-64 years)	90.9	84.5	81.9	78.1	81.4	73.0

Male (15-64 years)	88.7	82.6	78.4	71.0	78.7	66.0
Female (15-64 years)	91.9	85.2	84.1	80.6	82.9	76.2
Male (15-29 years)	71.4	66.1	84.3	42.5	54.3	40.1
Female (15-29 years)	88.9	70.7	76.8	70.7	78.9	69.4
Male (30+ years)	91.2	85.5	77.7	74.3	80.3	69.6
Female (30+ years)	93.3	88.7	86.3	83.2	84.2	79.0
In-treatment VLS (%)						
Both sexes (15-64 years)	94.0	88.4	89.5	86.3	86.0	82.0
Male (15-64 years)	93.9	88.6	84.5	82.5	85.3	78.7
Female (15-64 years)	94.0	88.3	92.6	87.5	86.4	83.5
Male (15-29 years)	76.3	70.3	84.3	52.8	59.8	52.9
Female (15-29 years)	91.3	76.7	83.1	86.3	85.5	75.4
Male (30+ years)	96.4	91.8	84.6	84.9	87.0	81.8
Female (30+ years)	95.2	90.2	95.6	87.8	86.7	86.9
Among ARV-positives, proportion unsuppressed (%)	3.2	8.3	9.6	11.3	8.9	13.5
Population viremia % (95% CI)						
Both sexes (15-64 years)	2.9 (2.3, 3.6)	1.2 (1.0, 1.4)	2.5 (1.9, 3.0)	2.4 (2.1, 2.6)	2.6 (2.1, 3.1)	2.5 (2.2, 2.8)
Male (15-64 years)	2.4 (1.7, 3.2)	0.9 (0.8, 1.1)	2.1 (1.5, 2.7)	2.0 (1.7, 2.2)	2.2 (1.7, 2.7)	2.2 (1.9, 2.5)
Female (15-64 years)	3.3 (2.6, 4.1)	1.5 (1.3, 1.7)	2.8 (2.2, 3.5)	2.7 (2.5, 3.0)	3.0 (2.5, 3.5)	2.8 (2.5, 3.0)
Male (15-29 years)	1.1 (0.3, 1.8)	0.5 (0.3, 0.7)	0.5 (0.0, 0.9)	1.0 (0.7, 1.3)	1.2 (0.7, 1.8)	1.0 (0.7, 1.3)
Female (15-29 years)	2.9 (2.0, 3.9)	0.9 (0.7, 1.1)	1.8 (1.1, 2.5)	1.7 (1.4, 2.0)	2.6 (2.0, 3.3)	2.3 (2.0, 2.7)
Male (30+ years)	4.2 (2.8, 5.6)	1.4 (1.1, 1.6)	3.9 (2.7, 5.0)	2.9 (2.5, 3.3)	3.4 (2.5, 4.3)	3.9 (3.3, 4.5)
Female (30+ years)	3.8 (2.7, 3.0)	2.0 (1.7, 2.3)	3.9 (2.9, 4.9)	3.6 (3.2, 4.0)	3.4 (2.6, 4.1)	3.4 (2.9, 3.8)

HIV: human immunodeficiency virus; PLHIV: people living with HIV; VL: viral load; VLS: viral load suppression; ARV: antiretroviral; log10: log base 10; CI: confidence interval; **Kenya lake counties**: 4-Busia, 8-Homa Bay, 17-Kisumu, 27-Migori, and 38-Siaya; **Kenya non-lake counties**: 1 – Baringo, 2 – Bomet, 3 – Bungoma, 5 - Elgeyo Marakwet, 6 – Embu, 7 – Garissa, 9 – Isiolo, 10 – Kajiado, 11 – Kakamega, 12 – Kericho, 13 – Kiambu, 14 – Kilifi, 15 – Kirinyaga, 16 – Kisii, 18 – Kitui, 19 – Kwale, 20 – Laikipia, 21 – Lamu, 22 – Machakos, 23 – Makueni, 24 – Mandera, 25 – Marsabit, 26 – Meru, 28 – Mombasa, 29 – Muranga, 30 – Nairobi, 31 – Nakuru, 32 – Nandi, 33 – Narok, 34 – Nyamira, 35 – Nyandarua, 36 – Nyeri, 37 – Samburu, 39 – Taita Taveta, 40 - Tana River, 41 – Tharaka, 42 - Trans-Nzoia, 43 – Turkana, 44 - Uasin Gishu, 45 – Vihiga, 46 – Wajir, and 47 - West Pokot; **Tanzania lake regions:**18- Kagera, 19- Mwanza, 20- Mara, 24- Simiyu, 25- Geita; **Tanzania non-lake regions:**1 – Dodoma, 2 – Arusha, 3 – Kilimanjaro, 4 – Tanga, 5 – Morogoro, 6 – Pwani, 7 - Dar es Salaam, 8 – Lindi, 9 – Mtwara, 10 – Ruvuma, 11 – Iringa, 12 – Mbeya, 13 – Singida, 14 – Tabora, 15 -Rukwa, 16 – Kigoma, 17 – Shinyanga, 21 – Manyara, 22 – Njombe, 23 – Katavi, and 26 – Songwe; **Uganda lake regions:**1-Central1, 4-East central, and 10-South west; **Uganda non-lake regions:** 2 - Central2, 3 – Kampala, 5 - Mid-East, 6 - North East, 7 - West Nile, 8 - Mid-North, and 9 - Mid-West