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BMJ Open Investigating inequalities in HIV testing in sub-Saharan Africa: spatial analysis of cross-sectional population-based surveys in 25 countries

Pearl Anne Ante-Testard ^{1,2}, Gabriel Carrasco-Escobar,^{3,4} Tarik Benmarhnia,⁴ Laura Temime,^{1,2} Kévin Jean ^{1,2,5}

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For numbered affiliations see end of article.

Correspondence to

Dr Pearl Anne Ante-Testard;
pearlannemante@gmail.com

ABSTRACT

Objectives We aim to explore spatial variations in socioeconomic inequalities in HIV testing uptake in sub-Saharan Africa (SSA) at different geographical scales to identify potential geographical hotspots of inequalities. Additionally, to evaluate the potential benefits of HIV testing programmes, we assess whether local levels of HIV testing match the local levels of HIV prevalence.

Design A multi-country analysis of population-based cross-sectional surveys in SSA.

Setting We analysed data from 25 SSA countries with Demographic and Health Surveys between 2011 and 2019.

Participants Country-level analysis included 473 775 participants (312 104 women and 161 671 men) and cluster-level analysis included 328 283 individuals (241 084 women and 87 199 men). Women aged 15–49 years and men aged 15–54/59 years in selected households who were tested for HIV in the last 12 months were eligible. We quantified inequalities in self-reported recent HIV testing with the Slope Index of Inequality (SII) and the Relative Index of Inequality (RII) across geographical scales to capture sex-specific within-country spatial variations. We also conducted local Getis-Ord G_i^* statistics to consider the autocorrelation in fine-scale SII and RII across countries. To assess the efficiency of HIV testing programmes, we measured the correlation between recent HIV testing and HIV prevalence through Spearman correlation across geographical scales.

Results We observed varying inequalities in recent HIV testing in magnitude and spatial distribution on both absolute and relative scales in many countries for both sexes at national and subnational levels. Hotspots of absolute and relative inequalities were mostly observed in Western and Central Africa with a few regions in Eastern and Southern Africa. Despite significant sex-specific correlations between testing and prevalence in all countries when assessed at the national level, we report an absence of such a correlation at fine scale in 17 of 50 sex-country combinations.

Conclusions We highlight the importance of investigating the spatial variability of various HIV indicators and related inequalities across different geographical levels. Results may help inform an equitable distribution of HIV testing services.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ To the best of our knowledge, this is the first study to provide a comprehensive context of the socioeconomic inequalities in HIV testing in sub-Saharan Africa on both absolute and relative scales across different geographical levels.
- ⇒ Our analysis was based on large, representative surveys with high response rates.
- ⇒ Sensitivity analyses demonstrated consistent findings when using different cluster sizes and survey years for the hotspot analyses.
- ⇒ The outcome of interest (ie, recent HIV testing uptake) was self-reported which may be subject to recall and social desirability biases that may have led to over- or under-reporting.
- ⇒ The wealth index can only measure relative wealth within a country limiting comparisons across countries.

INTRODUCTION

The role of HIV testing in the fight against AIDS is crucial since it is the gateway to HIV prevention and care, especially in sub-Saharan Africa (SSA), the global epicentre of the disease. Over the years, testing has scaled up due to the increasing availability of antiretroviral therapy (ART) and in response to the UNAIDS 90-90-90 and 95-95-95 targets by 2020 and 2030, respectively.^{1,2}

Socioeconomic inequalities have been reported in HIV testing uptake in SSA. Numerous studies have found that people in higher socioeconomic position (SEP) were more likely to seek HIV testing or know their HIV status.^{3–8} However, most of these studies assessed testing inequalities at the national level. Very few studies have analysed the spatial distribution of these inequalities. To the best of our knowledge, such a local analysis has only been performed in a single country, Malawi.⁹

Spatial analysis at local scales has proved useful for the control and prevention of infectious diseases, by uncovering spatial variations in the transmission or the access to prevention.^{10–12} Regarding HIV, it has helped identify high transmission areas¹³ and understand access difficulties to healthcare facilities in underserved areas in Africa.¹⁴ However, it has not been frequently used in monitoring inequalities in the HIV response, particularly in HIV testing. Notably, uptake of HIV testing has been reported to be higher in countries with the greatest HIV burden at the national level. Nevertheless, whether this association also exists at a finer scale has not been empirically assessed. Observing such spatial variations is important not only for ensuring equity in epidemic control but also for prioritising areas with the greatest burden in terms of infection and/or inequalities.¹⁵ Mapping HIV testing uptake and their inequalities across different geographical scales and identifying their local hotspots has become especially relevant in a context of decreasing international funding for the HIV response.

Here, we aim: (1) to explore spatial variations in socioeconomic inequalities in HIV testing uptake across geographical scales in several SSA countries; and (2) to assess spatial correlations between HIV testing and HIV prevalence at the national and subnational levels as a way to approximate the potential benefits of existing programmes.

METHODS

Study design and data sources

We carried out a multicountry analysis of cross-sectional surveys in SSA countries, namely the Demographic and Health Surveys (DHS). The DHS are nationally representative surveys regularly conducted in the Global South collecting information on a broad range of indicators such as sociodemographic indicators, maternal and child health, malaria and HIV/AIDS. They are based on a two-stage sampling design, with Primary Sampling Units (PSU) selected in the first stage and households in the second. Women aged 15–49 years and men aged 15–54/59 years in participating households are eligible. Depending on the survey, data for men for the HIV indicators, biomarkers or both might be collected only from a subsample of the selected households. The information and serology on HIV/AIDS were collected in some DHS in which participants are asked for consent to be tested for HIV, which is done anonymously in most of the surveys. Individuals who consented are interviewed face-to-face by trained interviewers who use a standard questionnaire. The agencies and research institutes that conducted the surveys were responsible for acquiring ethical clearance in each country.

DHS Global Positioning System coordinates were obtained from the DHS database. These coordinates were intentionally and randomly displaced to ensure confidentiality of the respondents. Urban clusters were displaced between 0 and 2 kilometres (km), while rural

clusters were displaced between 0 and 5 km. The spatial boundaries were also obtained from the DHS spatial database repository (<https://spatialdata.dhsprogram.com/home/>). The DHS data were linked to these spatial data.

For our analysis, we selected SSA countries with available DHS surveys between 2011 and 2019 that contained the variables of interest and spatial data. We selected the more recent survey (as of November 2021) in countries with more than one eligible survey.

Data/variables

SEP was defined as the relative rank of the participants in the cumulative distribution of the DHS wealth index. The wealth index is a composite measure of living standards based on household assets and living characteristics. The DHS divided the wealth index homogeneously into quintiles from poorest to richest.

The outcome of interest was the self-report of recent (<12 months) HIV testing uptake. Participants were asked if they recently had an HIV test and the time since the last test. Being HIV positive was defined as testing positive in the serological survey.

Statistical analysis

First, for each country and sex, we calculated the HIV prevalence and the proportion of recent HIV testing uptake while accounting for survey design and sampling weights at different geographical scales: (1) national, (2) first administrative subnational level (hereafter, province) and (3) cluster or PSU level (hereafter referred to as 'fine scale'). We weighted the HIV prevalence and proportion of recent HIV testing using the DHS sampling weights to account for undersampling or oversampling and to account for the differences in response rates by region.

Second, we measured national-level, province-level and PSU-level socioeconomic inequalities both on the absolute and relative scales. We estimated the Slope Index of Inequality (SII) and the Relative Index of Inequality (RII) to assess the absolute and relative inequalities, respectively.¹⁶ The SII and RII are regression-based measures commonly used to quantify and compare socioeconomic gradient in absolute and relative scales.¹⁷ It is highly recommended to report inequalities on both scales as conclusions may diverge depending on the scale used especially when monitoring changes.¹⁸ We assessed within-country inequalities based on the participants' relative rank in the cumulative distribution of the wealth index.

At the national and province levels, the SII and RII were obtained by fitting a modified Poisson regression (with robust variance) with a log link function¹⁹ to estimate the association between recent HIV testing at each wealth level and the hierarchical ranking of wealth. Generalised estimating equations were used to account for the clustering of observations.²⁰ The SII represents the absolute difference in the predicted proportions between the richest and the poorest participants, whereas the RII expresses the ratio of the predicted outcomes between these two extremes. For instance, an SII of

0.10 estimates the absolute difference of 10 percentage points of getting tested for HIV between the wealthiest and poorest participants. An RII of three estimates the relative probability of getting tested between the wealthiest and the poorest participants—the wealthiest were three times more likely to get tested than the poorest participants.

Due to the smaller sample sizes at the PSU-level (at least 10 individuals), we fitted a linear regression to estimate fine-scale inequality indicators. When performed on small samples, regressions may lead to negative RII values, which were truncated to zero during the estimation of the fine-scale RII.

Third, spatial autocorrelations of the fine-scale SII and RII across SSA and between sexes were assessed using the local Getis-Ord G_i^* statistic for PSUs with a sample size of at least 10. The Getis-Ord G_i^* statistic identifies local patterns and clusters of high-inequality or low-inequality across countries that may not be evident when using global statistics.²¹ More specifically, a distance-based neighbourhood structure was used for its computation. Neighbouring PSUs were defined based on the distance (d) that assigns a number of nearest neighbours (k) to each PSU. We selected the number of nearest neighbours that gave high spatial autocorrelation based on a global G statistic, which is suitable for samples with non-normal distribution, for each sex and inequality indicator. We categorised the local G_i^* statistic based on the sign (cold-spot or hotspot for negative and positive signs, respectively) and percentile (90%, 95%, 99%) to avoid bias due to multiple and dependent tests.²²

We assessed the spatial correlation of the proportion of recent HIV testing and level of HIV prevalence across various geographical scales through Spearman correlation. Indeed, HIV prevalence drives, at least partly, the local risk of incident HIV infection as it reflects the probability for one's sexual partner to be infected by HIV.²³

We conducted a complete-case analysis. We excluded participants with missing values for the SEP indicator (ie, wealth index) and outcome variable (ie, recent HIV testing) at the national, province and PSU level analysis. For the PSU-level analysis, we only included PSUs with at least 10 sample sizes to ensure statistical power.

Sensitivity analysis

SII and RII were calculated for PSUs with a sample size of at least 20 and 30 and their local spatial autocorrelations were assessed as sensitivity analysis. We also conducted similar analyses for countries with surveys between 2011 and 2014 and for countries with surveys between 2015 and 2019 to assess possible temporal trends in the spatial distribution of inequalities.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this study.

RESULTS

Study population characteristics

Twenty-five countries were eligible based on data availability between 2011 and 2019: Angola, Burundi, Cameroon, Chad, Côte d'Ivoire, Democratic Republic of Congo (Congo DR), Ethiopia, Gabon, Ghana, Guinea, Lesotho, Liberia, Malawi, Mali, Mozambique, Namibia, Rwanda, Senegal, Sierra Leone, Tanzania, Togo, Uganda, South Africa, Zambia and Zimbabwe. There was a total of 473 775 participants (99%, 312 104 women and 161 671 men) at the country level (online supplemental tables S1 and S2) with 328 283 individuals (62.3%, 241 084 women and 87 199 men) from PSUs with a sample size of at least 10 and complete data to ensure statistical power at the PSU level (online supplemental table S1). The sample size in the provinces ranged between 375 and 11 342 among women and between 135 and 3236 among men. At a finer scale, sample size in PSUs ranged between 10 and 96 women and between 10 and 54 men. The distributions of PSU sample size and proportion of recent HIV testing are shown in online supplemental figure S1.

National-level estimates

Online supplemental table S2 also presents the national estimates of HIV prevalence, testing and inequalities in recent HIV testing. Overall, at the national level, HIV prevalence ranged from 0.5% (Senegal) to 30% (Lesotho) among women and from 0.5% (Congo DR, Ethiopia and Senegal) to 19% (Lesotho) among men. Self-reported uptake of recent testing ranged from 3% (Chad) to 65% (Zambia) among women and from 6% (Guinea and Senegal) to 53% (Zambia) among men. Women tended to have higher HIV prevalence and proportion of recent testing than men.

On the absolute scale, we observed pro-rich absolute inequalities in recent testing in 19 of 25 countries for women and 23 of 25 countries for men (SII>0) (online supplemental table S2). Absolute inequalities ranged between -10 (95% Confidence Interval -14 to -5) percentage points (% points) in Lesotho and 44 (95% CI 39 to 48) % points in Ethiopia among women. This means that the absolute difference between the richest and poorest quintiles was -10 (95% CI -14 to -5) % points (ie, pro-poor) among women in Lesotho and 44 (95% CI 39 to 48) % points in Ethiopia (ie, pro-rich). Meanwhile, among men, SII ranged between -3 (95% CI -7 to 1) % points in Rwanda and 42 (95% CI 36 to 47) % points in Cameroon.

We observed pro-rich relative inequalities in 19 of 25 countries for women and 23 of 25 countries for men (RII>1) (online supplemental table S2). Relative inequalities ranged between 0.85 (95% CI 0.79 to 0.92) in Lesotho and 22.66 (95% CI 16.15 to 31.78) in Mali among women. This translates to the richest women being 0.85 (95% CI 0.79 to 0.92) times as likely to report recent HIV testing than the poorest participants in Lesotho (ie, pro-poor), while 22.66 times (95% CI 16.15 to 31.78) more likely in Mali (ie, pro-rich). Among men, it ranged between 0.92

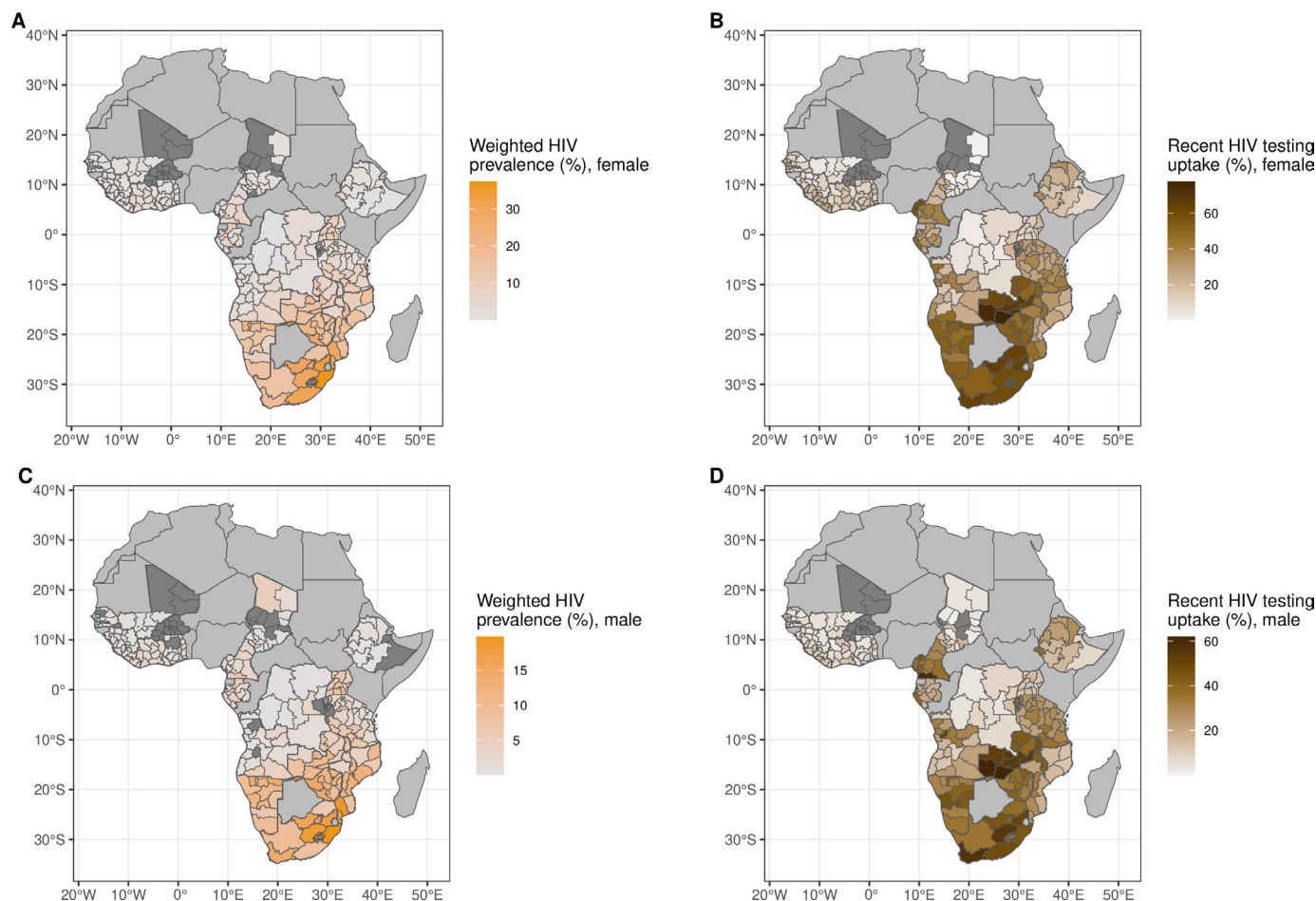


Figure 1 Province-level distribution of weighted HIV prevalence (A and C) and weighted percentage of self-reported recent (<12 months) uptake of HIV testing (B and D) among female (A and B) and male participants (C and D). Dark grey colours indicate unavailability of the HIV biomarker or HIV testing data for this province from the Demographic and Health Surveys.

(95% CI 0.82 to 1.04) in Rwanda and 14.74 (95% CI 8.89 to 24.44) in Mali.

Province-level estimates

The distribution of province-level HIV prevalence and proportion of recent HIV testing are mapped in figure 1. We observed within-country and between-country variations in their respective spatial distributions.

Figure 2 maps the provincial absolute and relative inequalities in recent HIV testing. We also observed spatial heterogeneities of these inequalities for all sexes and inequality scales. On the absolute scale, we observed pro-rich spatial distribution of SIIs in most of the provinces in SSA except for a few areas in Eastern and Southern Africa (ESA) such as South Africa (both sexes), Namibia (both sexes) and Malawi (both sexes). On the relative scale, higher pro-rich relative inequalities were observed more frequently in Western and Central Africa (WCA), while lower inequalities tended to be observed in ESA.

Spatial clustering analysis at fine scale

Global G statistic showed that using one nearest neighbour gave the highest spatial autocorrelation for both sexes (p value<0.001 for both sexes) and inequality indicators (online supplemental figure S2). We thus used $k=1$ to

calculate for the local Getis-Ord G_i^* statistics. Hotspots and coldspots of inequalities across SSA depended on the inequality scale used and sex (figure 3). Overall, hotspots on both scales were more marked in WCA and a few ESA countries such as Ethiopia (for both sexes), Uganda (for women) and Lesotho (only on the absolute scale for men).

On the absolute scale, we observed numerous pockets of high SII values in western Africa with a few areas in eastern Africa. Hotspots of absolute inequalities in recent HIV testing were observed in Cameroon, Chad, Côte d'Ivoire, Ghana, Guinea, Mali, Togo, Sierra Leone and Ethiopia for both sexes and Gabon and Liberia for men. Coldspots or pockets of low SIIs were mostly observed in ESA including Zambia, Zimbabwe, Burundi, and small areas in Mozambique and Namibia for both sexes and in Rwanda and South Africa for women.

On the relative scale, we observed hotspots of RII values mostly in WCA with a few areas in eastern Africa. Coldspots were noted in the majority of ESA countries including Burundi, Lesotho, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe for both sexes and Rwanda for women.

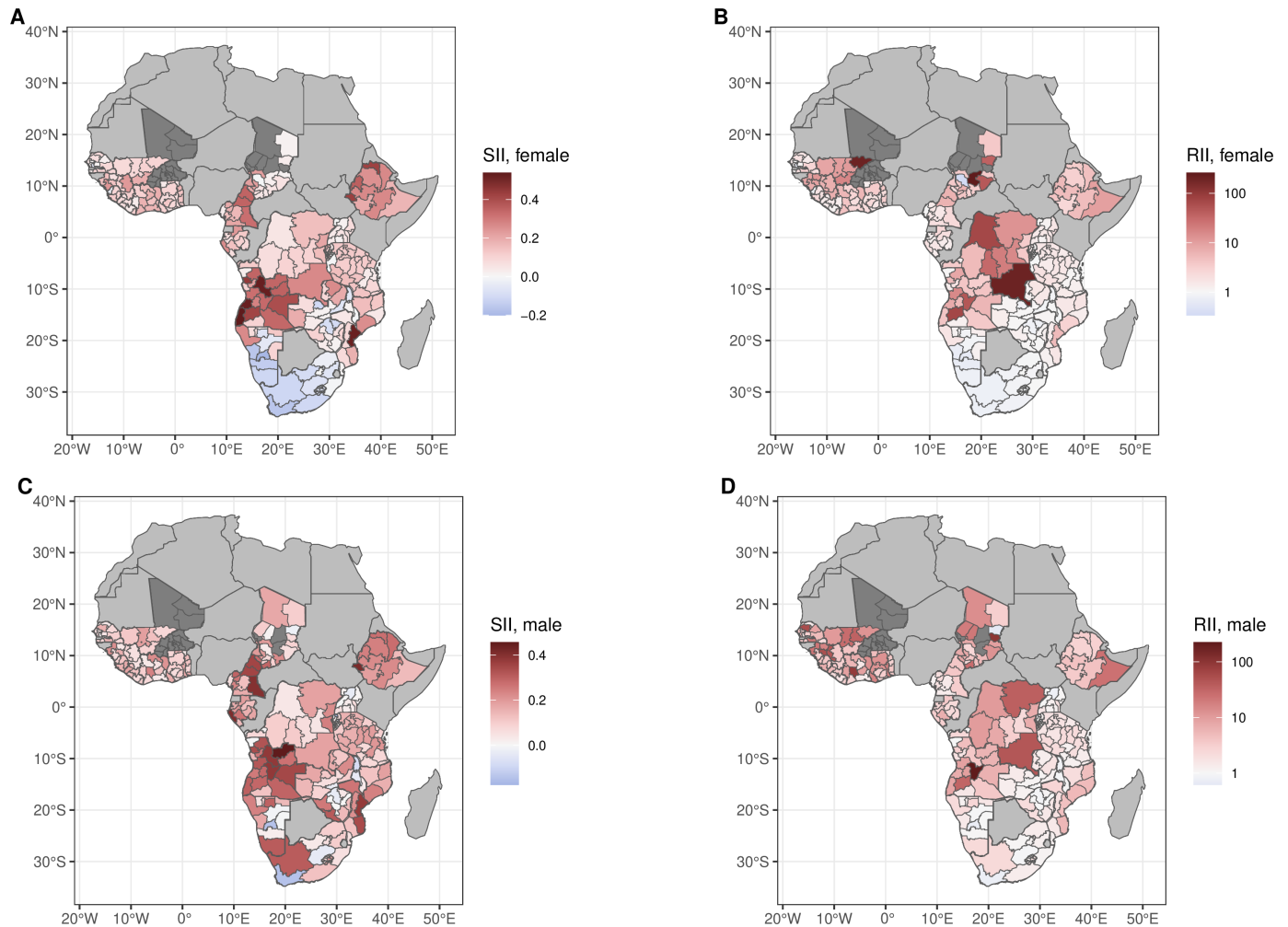


Figure 2 Province-level distribution of wealth-related inequalities in self-reported recent (<12 months) uptake of HIV testing at the absolute scale (A and C) and relative scale (B and D) among female (A and B) and male participants (C and D) across 25 sub-Saharan African countries. Dark grey colours indicate unavailability of the HIV testing variable. Capped RII values between 0.1 and 300. RII, Relative Index of Inequality; SII, Slope Index of Inequality.

Moreover, we observed diverging patterns of hotspots and coldspots for each sex in the same country. There were hotspots of SIIs and RIIs in Uganda among women, while coldspots in a few areas were noted among men. In Cameroon, distinct patterns in inequality indicators were observed, revealing hotspots of absolute inequalities and coldspots of relative inequalities for both sexes.

Spatial correlation between HIV testing and HIV prevalence

We assessed the spatial correlation between HIV testing and HIV prevalence across geographical scales—whether testing services are reaching those with high HIV risk in the population. At the national level, HIV prevalence and proportion of recent HIV testing were found to be positively correlated among women and men (online supplemental figure S3).

However, this observation was not sustained at subnational levels. Within-country correlation of province-level HIV prevalence and proportion of testing showed that in many countries, both variables were uncorrelated (ie, the level of HIV testing did not always match the magnitude of HIV prevalence). Out of 50 settings (2 sex-specific

results for each of the 25 countries), we observed only 9 that had statistically significant positive correlations (p value<0.05) or what we termed as having ‘efficient HIV testing services’ (online supplemental figure S4): both sexes (Ethiopia, Lesotho and Tanzania), females (Ghana and Zambia) and males (Sierra Leone).

At the PSU level, HIV prevalence correlated with the level of recent HIV testing in 33 settings (figure 4). We observed significant positive correlation in both sexes (Cameroon, Guinea, Mozambique, Namibia, Senegal, Tanzania, Togo, South Africa, Zambia and Zimbabwe), females (Angola, Burundi, Cote d’Ivoire and Rwanda) and males (Gambia, Lesotho, Chad and Uganda). Meanwhile, in Angola (male), Congo DR (female), Lesotho (female), Liberia (male) and Mali (female), HIV prevalence and recent testing had a significant negative correlation (ie, PSUs with higher HIV prevalence had lesser uptake of recent HIV testing).

Sensitivity analysis

Results of the local spatial clustering analysis were consistent when subsetting by cluster size of at least 20 or 30

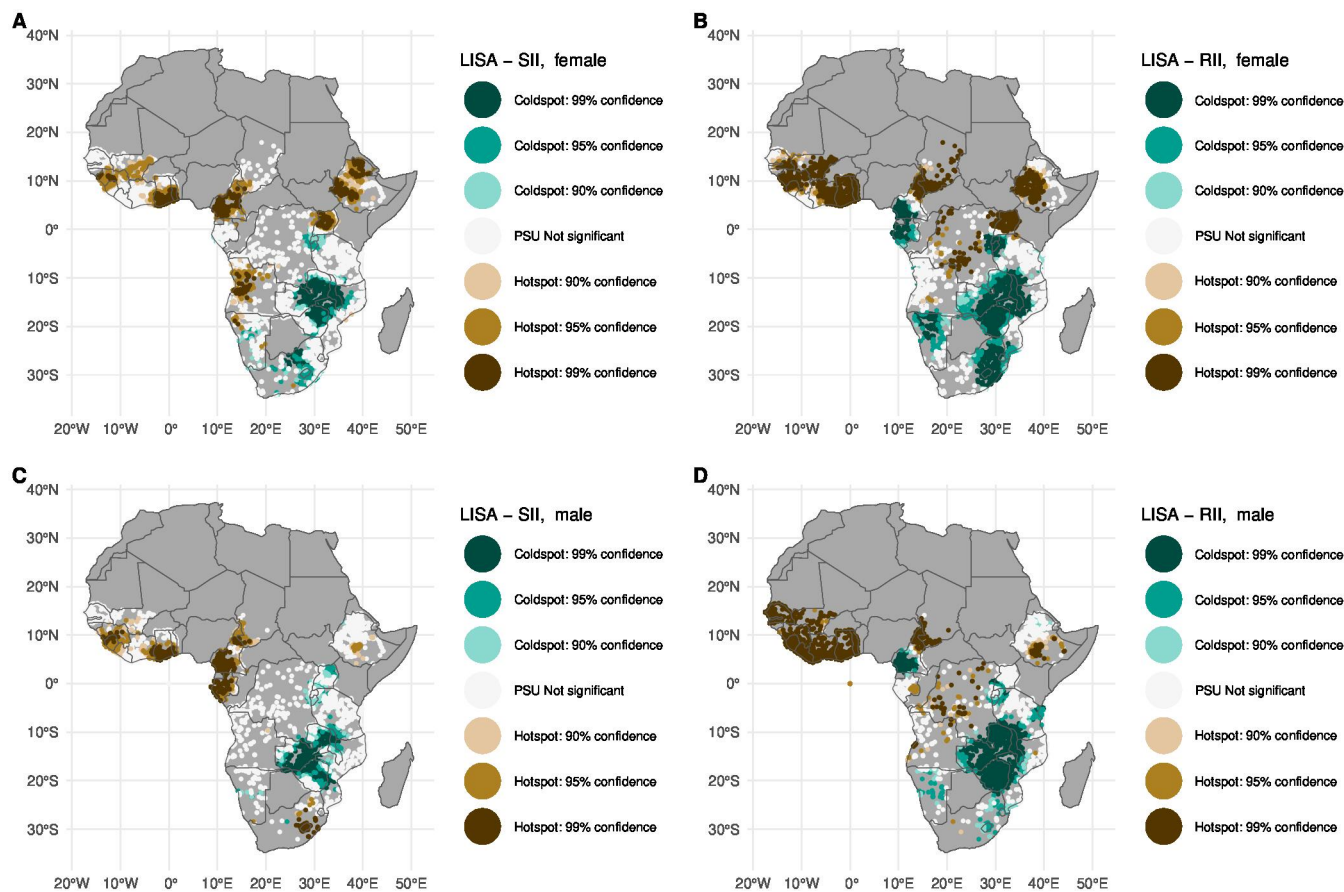


Figure 3 Local spatial autocorrelation of socioeconomic inequalities in self-reported recent (<12 months) uptake of HIV testing as Local Getis-Ord G_i^* at Primary Sampling Unit (PSU) level (one nearest neighbour) across 25 sub-Saharan African countries between 2011 and 2019. Spatial clustering at the absolute scales (A and C) and relative scales (B and D) among female (A and B) and male participants (C and D). Only PSUs with a sample size of at least 10 and with more than one wealth quintile were included. LISA, Local Indicator of Spatial Autocorrelation; RII, Relative Index of Inequality; SII, Slope Index of Inequality.

(online supplemental figures S5 and S6). Areas with pockets of high and low inequalities were also consistent when conducting spatial clustering analysis across countries with surveys between 2011 and 2014 and between 2015 and 2019 separately (online supplemental figures S7 and S8).

DISCUSSION

In this study, we quantified and mapped absolute and relative socioeconomic inequalities of recent HIV testing at different geographical scales. We also conducted spatial clustering analysis of such inequalities and explored the spatial correlation between HIV testing and HIV prevalence at various geographical scales across SSA. Our results show existing inequalities at the national, province and PSU levels. Heterogeneities in the spatial distribution of these inequalities at subnational levels and hotspot areas varied depending on the inequality scales and sex groups. Most hotspots of inequalities were observed in WCA with a few areas in ESA such as Ethiopia, Uganda and South Africa. Meanwhile, coldspots were rather observed in ESA. We also revealed that, while HIV testing programmes seemed efficient in reaching those areas with

high HIV prevalence at the national level, they seemed to be less efficient at the subnational levels in most of the countries. Indeed, the provinces and PSUs with higher recent testing uptake did not match the level of HIV prevalence in many of the countries for both sexes.

We tended to observe higher HIV prevalence and proportion of recent HIV testing among women and countries located in ESA. As expected, we report higher pro-rich inequalities among men in the majority of countries and in WCA. These findings were consistent with previous studies.^{5 7} Higher HIV burden among women in SSA may be explained by their higher vulnerability compared to men due to several biological, societal, and economic factors.²⁴

We also highlighted that recent HIV testing was not shared equally across wealth levels in SSA (within and between countries) and that such inequalities were not randomly distributed across space. Indeed, our results also showed varying spatial patterns of recent HIV testing inequalities between absolute and relative scales and between women and men. This highlights the necessity for HIV testing programmes to be tailored depending on the level of inequality to be addressed and the needs of each

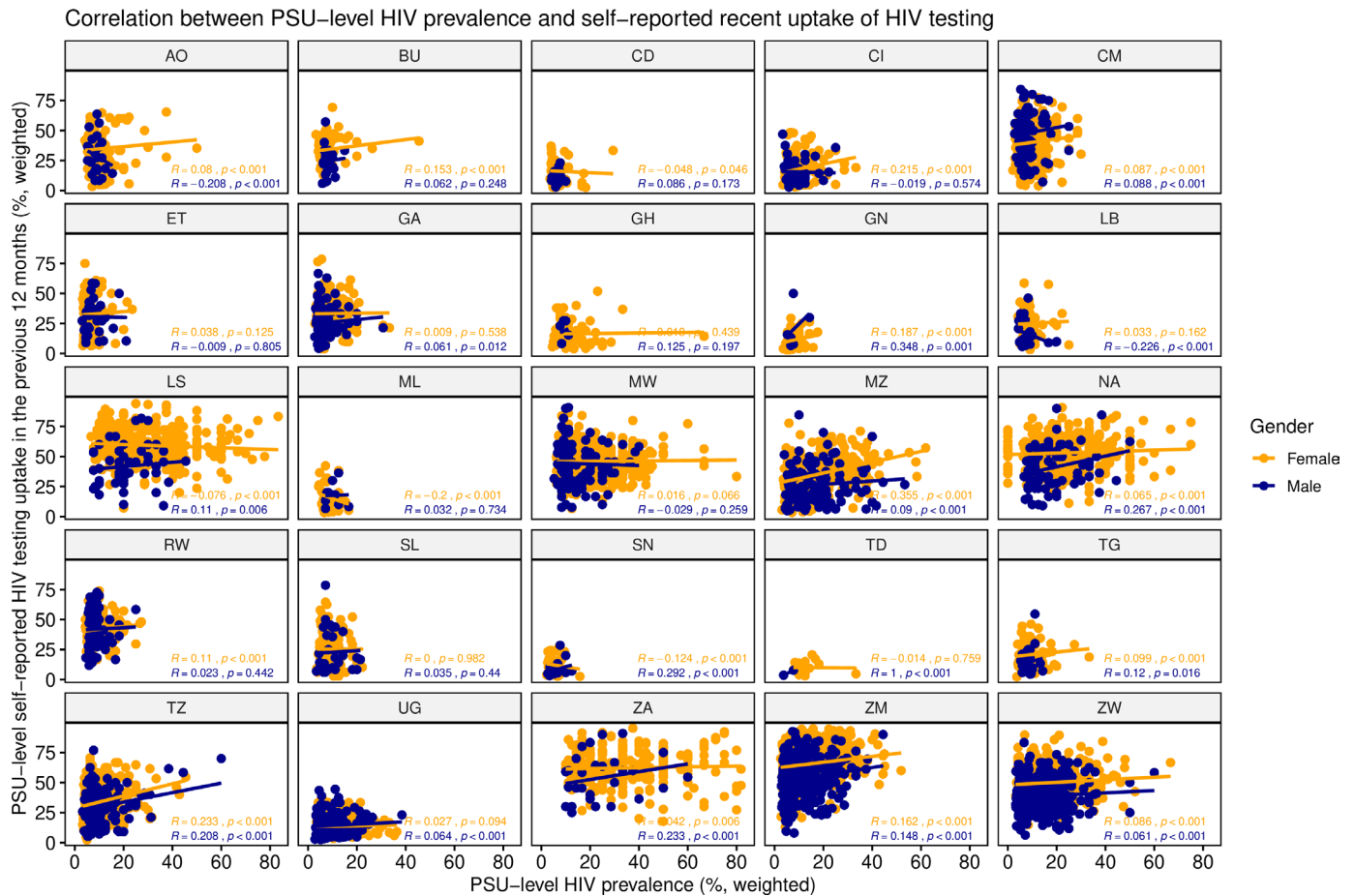


Figure 4 Correlation (Spearman correlation coefficient R and p value) between the percentage of HIV prevalence and percentage of self-reported recent (<12 months) uptake of HIV testing at the Primary Sampling Unit (PSU) level in 25 sub-Saharan African countries stratified by sex. Only PSUs with a sample size of at least 10 and with more than one wealth quintile were included. Each point represents a PSU. Refer to online supplemental table S2 for full country names.

sex. Our results showed that in certain countries, such as Namibia, national-level inequality estimates revealed low relative inequality for men, and even demonstrated pro-poor inequality on both absolute and relative scales for women, implying that pro-rich inequalities are not inevitable and can be addressed. However, despite achieving equitable HIV testing levels in these countries, localised hotspots of inequalities were still evident, suggesting that national-level estimates might mask lingering pro-rich disparities at smaller scales. The response of HIV testing programmes appears to be driven more by the level of the HIV prevalence itself rather than by the country's Gross Domestic Product per capita or macroeconomic factor²⁵ which may trigger fundings and large prevention programmes. This also aligns with a previous study, wherein countries characterised by a low HIV prevalence tended to exhibit lower uptake of HIV testing and higher levels of pro-rich inequalities in HIV testing.³

However, one could argue that pro-rich inequalities are not necessarily unfair, especially if those with higher SEP also tend to be the ones who are more at-risk of acquiring HIV. Several early studies reported higher levels of HIV prevalence among higher SEP.^{26 27} However, this initial inverse social gradient, an unusual feature as compared

with most of the diseases, is likely in a process of reversion. Last-generation HIV prevalence surveys now report higher levels of HIV prevalence among the poorest in some countries such as Côte d'Ivoire, Ethiopia, Lesotho and Zimbabwe. Moreover, a recent cohort study relying on a two-decade follow-up in rural Uganda documented a changing socioeconomic gradient over time, with a higher risk of incident HIV infection among the poorest.²⁸ Thus, suggesting that these pro-rich inequalities might indeed be unfair and contributing to the reversing social gradient that is probably ongoing in some settings.

There are various criteria for health programmes that can be used to evaluate their public benefit which include efficiency. Efficiency is concerned with the optimal production and distribution of scarce health resources and is critical for sustainability and maximising health gains.²⁹ In this study, we did not conduct a formal impact evaluation of HIV testing programmes, but rather to investigate the spatial correlations between HIV testing and HIV prevalence across geographical scales to capture their potential benefits. Community-level HIV prevalence has been found to be a strong predictor of HIV incidence in a recent meta-analysis.²³ The seemingly suboptimal efficiency of HIV testing programmes at subnational

levels may suggest the failure of HIV programmes in some settings to reach those who are at higher risk of HIV. However, risk may have been affected when people with HIV (PWH) undergo ART which ensures viral suppression, thus preventing transmission. Another potential reason why the level of HIV testing did not match the level of HIV risk is that in settings with high prevalence, people with known HIV infection (possibly under treatment) do not necessarily need to seek HIV testing. A further similar survey might be useful to assess recent HIV testing among the at-risk population only (ie, excluding PWH under ART), however our data do not allow us to do so.

This study carries several limitations. First, the self-reported nature of HIV testing uptake may be subject to recall and social desirability biases resulting to over- or under-reporting. Second, differential accuracy in self-reporting between socioeconomic groups might have biased our results. Evidence in cancer screening suggests that over-reporting of self-reported screening is common among marginalised groups such as racial minorities.³⁰ If this also applies to HIV testing, this may have led to an underestimation of the pro-rich inequalities and overestimation of the pro-poor inequalities. While self-reported lifetime HIV testing was found to be highly sensitive (96–99%),³¹ testing in the past 12 months may be prone to telescoping bias that may have led to over-reporting.³² Third, the wealth index can only measure relative wealth within a country. However, it can measure long-term SEP and has also been found to be stable especially in the Global South. Lastly, some available DHS surveys were conducted before 2014 and may not have captured more recent patterns of inequalities.

Despite these limitations, to our knowledge, this is the first study to provide a comprehensive context of the socioeconomic inequalities in HIV testing in SSA by quantifying and mapping them at different geographical levels on both absolute and relative scales and by assessing the spatial efficiency of HIV testing at different levels. Additionally, it had high participation rates which ranged between 73–100% (online supplemental table S1) at the country level. This study revealed the importance of monitoring inequalities at different geographical scales. First, national estimates are often used for funding allocations by donors, prioritisation of programmes and comparison of inequality metrics. Second, province-level estimates are essential for programme implementation, and for within-country funding allocations. Lastly, fine-level estimates allow us to visualise small-scale heterogeneities to precisely target communities in need. This knowledge could help health institutions develop well-targeted HIV testing and treatment programmes. HIV testing and treatment provision is key for both primary and secondary prevention.

CONCLUSIONS

This study highlighted the spatial heterogeneity in socioeconomic inequalities in HIV testing while also

identifying hotspots of inequalities across several sub-Saharan African countries. Our results show the need to monitor inequalities and assess the efficiency of HIV testing services in reaching those who are at-risk of HIV at smaller geographical scales, beyond national estimates that may mask disparities. By providing estimates of such inequalities at national-level, province-level and PSU-level, and by localising their hotspots, these findings may help policymakers, local and international organisations to prioritise areas and groups that need HIV testing efforts, while increasing efficiency.

Author affiliations

¹Laboratoire MESuRS, Conservatoire National des Arts et Métiers, Paris, Île-de-France, France

²Unité PACRI, Institut Pasteur, Conservatoire National des Arts et Métiers, Paris, Île-de-France, France

³Health Innovation Laboratory, Institute of Tropical Medicine “Alexander Von Humboldt”, Universidad Peruana Cayetano Heredia, Lima, Peru

⁴Scripps Institution of Oceanography, University of California, San Diego, California, USA

⁵MRC Centre for Global Infectious Disease Analysis, Department of Infectious Disease Epidemiology, Imperial College London, London, UK

Twitter Pearl Anne Ante-Testard @p_antetestard

Contributors PAA-T, LT and KJ conceived and discussed the study with inputs from GC-E and TB. PAA-T collated and processed the Demographic and Health Surveys. PAA-T conducted the analysis with inputs from GC-E, TB, LT and KJ. PAA-T produced output figures and tables with inputs from GC-E, TB, LT and KJ. All authors contributed to the interpretation of the results. PAA-T wrote the initial draft with inputs from LT and KJ. All authors contributed to subsequent revisions. All authors read and approved the final version of the manuscript. PAA-T takes the overall responsibility of the contents as guarantor.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Ethical approval is not required for this study. The national implementing agencies or research institutes that conducted the surveys were responsible for ethical clearance which assured informed consent from the participants prior to their involvement and guaranteed confidentiality of information.

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Data availability statement Data are available upon reasonable request. All codes are available at https://github.com/pearl-antetestard/HIVtesting_spatialanalysis_SSA. Raw data from the Demographic and Health Surveys used in this study are publicly available for academic research (www.dhsprogram.com). Formatted and processed data supporting the findings of this study are available from the corresponding author on request.

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ORCID iDs

Pearl Anne Ante-Testard <http://orcid.org/0000-0002-3416-0817>

Kévin Jean <http://orcid.org/0000-0001-6462-7185>

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