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Household wealth and HIV incidence over time, rural Uganda, 1994–2018

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Objective: To examine the relationship between household wealth and HIV incidence in rural Uganda over time from 1994 to 2018. In research conducted early in the epidemic, greater wealth (i.e. higher socioeconomic status, SES) was associated with higher HIV prevalence in sub-Saharan Africa (SSA); this relationship reversed in some settings in later years.

Design: Analysis of associations over time in a population-based open cohort of persons 15–49 years from 17 survey-rounds in 28 continuously followed communities of the Rakai Community Cohort Study (RCCS).

Methods: The RCCS sample averaged 8622 individuals and 5387 households per round. Principal components analysis was used to create a nine-item asset-based measure of household wealth. Poisson regression with generalized estimating equation (GEE) and exchangeable correlation structure was used to estimate HIV incidence rate ratios (IRRs) by SES quartile, survey-round, sex, and age group.

Results: From 1994 to 2018, SES rose considerably, and HIV incidence declined from 1.45 to 0.40 per 100 person-years (IRR = 0.39, 95% CI = 0.32–0.47, $P < 0.001$). HIV incidence was similar by SES category in the initial survey intervals (1994–1997); however, higher SES groups showed greater declines in HIV incidence over time. Multivariable analyses showed significant associations between HIV incidence and SES (IRR = 0.55 for highest compared with lowest quartile, 95% CI = 0.45–0.66, $P < 0.001$) controlling for time, sex, and age group.

Conclusion: Beyond the early years of the RCCS, higher SES was associated with lower HIV incidence and SES gradients widened over time. The poor, like other key populations, should be targeted for HIV prevention, including treatment as prevention.

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Keywords: AIDS, HIV incidence, socioeconomic status, sub-Saharan Africa, wealth

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Introduction

Poverty and wealth (lower and higher socioeconomic status, SES) are associated with health status across the lifecourse and for multiple health outcomes [1,2]. Higher SES is associated with better health, reflecting greater access to knowledge, prestige, power, and social connections [1]. An important exception to this pattern has been HIV risk in sub-Saharan Africa (SSA), where higher SES has been associated with increased HIV infection [3–9]. It has been suggested that wealthy individuals may engage in HIV risk behaviors, such as sex for money or multiple partners, although they may also have greater access to information, and prevention and treatment services.

Studies from SSA on the association of SES and HIV infection published between 2002 and 2010 have shown mixed results. Most studies have used cross-sectional designs and examined HIV prevalence as an endpoint. Commonly used measures of SES include household assets, individual educational attainment, and occupation [3–7], although two studies examined national income and income inequalities [8,9]. An early review (2002) from six countries not only demonstrated an association between higher educational attainment and higher HIV prevalence from rural Africa in men and women but also found greater declines in HIV prevalence over time among the more educated [5]. A 2005 review of 36 predominantly cross-sectional studies of SES and HIV among women found no association between SES and HIV infection in 15 studies, a positive association in 12 studies (higher SES associated with higher rates of HIV infection), a negative association in eight studies, and mixed results in one study; similar findings were found for longitudinal and cross-sectional studies [4]. A 2008 review of HIV risk and educational attainment in SSA involving 36 studies and 11 countries found no association or a positive association before 1996, whereas studies conducted after 1996 were more likely to find a lower risk of HIV infection among the most educated [6]. A 2008 analysis of Demographic and Health Surveys (DHS) from 2003 to 2004 in five SSA countries found a positive association between educational attainment and HIV prevalence [7]. A 2010 analysis of data from AIDS indicator surveys found an inconsistent relationship between HIV prevalence and household wealth across 12 SSA countries from 2003 to 2008 [3]. Two studies from 2007 and 2010 compared countries from SSA on national income and income inequalities [8,9], and found higher HIV prevalence among wealthier countries and countries with greater inequalities; these wealthier and more unequal countries were predominantly from southern Africa. Overall, these reviews do not present a consistent picture of HIV infection and SES.

Complicating the interpretation of these studies is the changing program and policy context for HIV prevention in SSA and the reality that SES and access to education have increased greatly over time [10]. Access to antiretroviral treatment (ART) became available in Rakai and elsewhere in SSA in the mid-2000s [11]. Whereas higher prevalence of HIV among wealthy individuals in the past may have reflected great risk for HIV infection, higher prevalence among the wealthy today may reflect greater access to ART and longer survival with treatment. In fact, we initially examined SES and HIV prevalence but abandoned that work as we realized the rising HIV prevalence among older adults (35+ years) reflected increasing access to ART and increasing longevity. Thus, incident HIV infections more closely reflect current HIV risk.

In this study, we examined the association of household SES and HIV incidence over 24 years (1994–2018) among persons 15–49 years using longitudinal data from a demographic cohort in greater Rakai, Uganda. This study had two goals: to assess the influence of SES on HIV incidence over time and to create a new asset-based index (ABM) of SES that would be useful in future research. We hypothesized that HIV incidence would be associated with higher SES in early surveys and lower HIV incidence in more recent surveys – consistent with prior research suggesting a changing relationship over time between SES and HIV infection [6].

Methods

The Rakai Community Cohort Study

Established in 1994, the Rakai Community Cohort Study (RCCS) is an open, population-based cohort of individuals of age 15 to 49 years residing in agrarian and trading villages in southcentral Uganda. Each round of the RCCS begins with a census of households with data on household composition provided by the head of household. The census is used to enumerate individuals who are eligible for enrollment into the cohort. As an open cohort, newly age-eligible 15-year-olds and recent in-migrants are enrolled at each round. RCCS census includes data on household assets and home construction, which were used to create our new ABM of SES. Over time, the RCCS has dropped some lower prevalence communities and added higher prevalence communities. To maintain comparability over time, this study used data from 28 agrarian communities and trading centers, which have been followed continuously over time, from round 1 to 18. These 28 communities averaged 5387 households per round and included 22 018 unduplicated households from 17 survey rounds (Table 1). These households included an average of 8622 individuals per round and 43 600 unique individuals (Table 2). Households and individuals are followed up approximately annually.

Data collection

At each survey, new and returning cohort participants are consented, interviewed, and asked to provide blood for HIV and sexually transmitted infection testing [11]. For unemancipated minors (<18 years), minor assent and parental/guardian permission is obtained; 18+ year olds

Table 1. Percentage of households having specific household assets and modern construction of dwelling, 28 communities, census rounds 1–18, Rakai, Uganda.

	R01	R02	R03	R04	R05	R06	R07	R08	R09	R10	R11	R12	R13	R14	R15	R1 6	R17	R18
Start of survey data collection	February 1994	August 1995	June 1986	June 1997		April 1999	March 2000	March 2001	July 2002	September 2003	January 2005	August 2006	June 08	January 2010	August 2011	July 2013	February 2015	October 2016
End of survey data collection	July 1995	April 1996	May 1997	April 1998		February 2000	February 2001	May 2002	July 2003	November 2004	June 2006	April 2008	November 2009	June 2011	May 2013	January 2015	September 2016	May 2018
Radio	50%	55%	56%	59%		61%	64%	66%	69%	73%	77%	79%	81%	81%	81%	76%	78%	73%
Bicycle	51%	52%	51%	51%		48%	49%	47%	47%	48%	47%	48%	48%	46%	44%	40%	36%	33%
Car	2%	2%	2%	2%		2%	2%	2%	2%	2%	2%	3%	3%	3%	4%	5%	5%	5%
Motorcycle	4%	4%	5%	6%		6%	7%	6%	6%	7%	9%	11%	15%	18%	18%	20%	22%	22%
Latrine	92%	94%	94%	91%		92%	94%	95%	95%	97%	97%	96%	97%	98%	98%	97%	98%	98%
Electricity	3%	2%	2%	2%		4%	4%	5%	6%	5%	8%	8%	8%	11%	21%	27%	38%	48%
Modern roofing	81%	83%	85%	87%		89%	91%	93%	94%	95%	96%	97%	98%	98%	99%	99%	100%	100%
Modern flooring	28%	29%	29%	31%		34%	37%	39%	41%	42%	46%	49%	51%	55%	65%	69%	73%	75%
Modern wall construction	36%	38%	40%	43%		48%	51%	56%	60%	63%	68%	72%	75%	79%	87%	89%	92%	93%
Number of households	3685	3841	4133	4127		5110	5451	5898	4763	4817	5173	5391	5228	5766	6628	6949	7352	7270

Includes households with data on SES in 28 communities followed continuously over time from round 1 to round 18, 1994–2018. These included an average of 5387 households per round and 22 018 unique households. R01–R18, rounds 1–18.

Table 2. Distribution of socioeconomic among individuals 15–49 years and enrolled the Rakai Community Cohort Study.

ABM of SES	R01	R02	R03	R04	R06	R07	R08	R09	R10	R11	R12	R13	R14	R15	R16	R17	R18
Lowest	0.39	0.35	0.34	0.34	0.29	0.27	0.24	0.21	0.18	0.15	0.13	0.10	0.08	0.07	0.06	0.05	0.04
Low-middle	0.28	0.29	0.28	0.27	0.26	0.27	0.25	0.26	0.25	0.23	0.22	0.22	0.19	0.18	0.17	0.14	0.13
High-middle	0.19	0.21	0.23	0.23	0.27	0.27	0.29	0.30	0.33	0.35	0.36	0.35	0.35	0.36	0.35	0.33	0.33
Highest	0.14	0.15	0.15	0.17	0.18	0.19	0.22	0.23	0.25	0.28	0.29	0.33	0.37	0.40	0.43	0.48	0.50
Individual *N*	5899	5979	6543	6326	8202	8711	9443	7173	7237	8036	8509	8500	9460	10 713	11 517	12 171	12 150

Individual N includes individuals with data on SES in the 28 communities continuously followed over rounds 1–18 (R01–R18), 1994–2018. Individual *N* includes an average of 8622 individuals per round and 43 600 unique individuals.

and emancipated minors provide their own informed consent. At each round, community-wide HIV education, individual and couple's HIV counseling and testing, and referral for healthcare are offered. Data collection is closely monitored by field supervisors to assure data integrity. Ethical approval was obtained from the Research Ethics Committee (REC) of the Uganda Virus Research Institute (UVRI), the Uganda National Council for Science and Technology, and Institutional Review Boards at Johns Hopkins and Columbia Universities, and Western IRB Olympia WA.

Household members are enumerated by age, sex, relationship to the head of household and parents, educational attainment, marital status, and duration of residence in the household. A household is defined as an individual or group of individuals who eat their primary meals together and live together. Although a household usually constitutes a family or extended family, it may include nonfamily members and may be composed of multiple separate structures forming a compound. Fishing communities were introduced in Round 15 but were excluded from these analyses. 'Mobile' households, that is, those who do not have a permanent structure, were also excluded from analyses.

Eligible individuals (age 15−49 years) are interviewed and offered HIV testing several weeks after the census is conducted [11]. HIV testing is performed using a validated three rapid test algorithm for all consenting participants. Test results and posttest counseling are offered by on-site counselors at the time of survey. Enrollment into the RCCS is ~95% of those present at time of survey, but ~25% of censused residents are absent at each round – for work, school, or other travel. Testing rates for those who are interviewed are high (>95%).

Incident HIV cases were defined as infections occurring after a prior negative result. We assessed HIV incidence by comparing HIV test results from two directly adjacent survey rounds or two survey rounds with one intervening round. For example, to be considered an incident case, an individual who had a positive test at round 18 would need to have a negative result at round 17 or 16. Thus, we excluded from incidence analyses those individuals who were HIV positive at entrance to the cohort or in any previous round or those who had only one HIV test. Incident analyses included an average of 4754 individuals per round and 21 143 unique individuals (Table 3).

Measurement of socioeconomic status using household assets

Measurement of SES via household income can be problematic in low-income and middle-income countries where income data are not available. As such, asset-based measures (ABM) of SES are frequently used as alternatives to household income measures [12,13]. Household assets are generally a valid proxy for household wealth, readily measured in household surveys, and commonly employed in national surveys, such as the DHS and Demographic Surveillance System (DSS) surveys [12,13].

The household census collected consistent information on nine household assets from 1994 to 2018; these included five assets related to modern home construction (modern materials used for the construction of roof, walls, and floor; access to a latrine; and access to electricity) and four household possessions (car, motorcycle, bicycle, and radio). Assets are reported by the head of household or observed by interviewers and were recoded and analyzed as dichotomous variables: for example, owning versus not owning a car. Modern home construction materials include iron, tiles, cement, and brick as compared with traditional materials, such as mud, wattle, and thatch. Modern latrines could include a pit-latrine or a modern flush toilet. Later survey rounds collected data on additional possessions but those were not analyzed for this article. Our measure of SES builds upon a prior index using home construction [14].

Principal component analysis (PCA) has been used by the WHO to ascertain SES of households [15]. The first principal component from PCA is commonly understood as a measure of household SES [15]; household assets used in PCA indices correlate highly ($r = 0.74$) with more complex monetary value methods [12].

A single ABM over all RCCS rounds would be useful in tracking changing SES over time, but round-specific ABM may more accurately reflect current SES; thus, we measured SES both ways. We first created a single SES measure over all rounds of the survey, using the nine assets identified above. This measure allows one to quantify change in SES over time. An ABM score was also calculated for each household at each round of the cohort. SES scores were standardized using a z transformation for better interpretation. z scores were divided into approximate quartiles to develop four SES categories: lowest, low-middle, high-middle, and the highest. Only households in which there were no missing data for any of the nine asset variables were included in our analyses; this reduced our sample size by about 12%. We assessed the correlation between the ABM, the educational attainment of the head of household and the most educated member of the household per survey. We would expect that an ABM of SES should be associated with educational attainment.

We also created round-specific measures of SES, which are reported separately in a Methodological Appendix, http://links.lww.com/QAD/C209 available from the first author. In our supplemental analyses, we examined change in the specific weightings of each asset variable over time, as the importance of specific household assets may change over time. Many factors demonstrated a consistent relationship to SES over time. Thus, the PCA weights for round-specific measures of SES were similar to the overall ABM of SES.

Table 3. Incidence of HIV (per 100 person-years) by round, socioeconomic status, sex, and age group.

	R02	R03	R04	R06	R07	R08	R09	R10	R11	R12	R13	R14	R15	R16	R17	R18	Model-based IRR	95% CI for IRR	*P* value for IRR
N	2542	3096	3349	2680	3660	4383	4468	4630	4805	4915	5485	5652	6086	6197	7034	7089			
Round	1.45	1.25	1.79	0.91	1.03	1.25	1.17	1.18	1.10	1.18	1.22	1.08	0.84	0.66	0.66	0.40	0.39	0.32–0.47	$P<0.001$
SES																			
Low SES	0.88	1.24	2.12	1.11	0.91	1.63	1.68	1.62	1.71	1.18	1.96	0.95	0.98	0.31	0.99	1.00	0.70	0 0.43–1.13	$P=0.148$
Low-middle SES	1.78	1.46	1.92	0.80	1.49	1.62	1.53	1.55	1.35	1.81	1.58	1.30	1.06	1.01	0.89	0.38	0.52	0.36–0.75	$P<0.001$
High-middle SES	1.90	0.98	1.78	0.93	0.87	1.12	0.91	1.05	1.03	0.97	1.06	1.29	1.06	0.90	0.82	0.43	0.55	0.37–0.80	$P=0.002$
Highest SES	1.53	1.17	0.98	0.74	0.65	0.66	0.68	0.74	0.70	0.99	0.96	0.82	0.58	0.42	0.49	0.34	0.36	0.23–0.54	$P<0.001$
Sex																			
Men	0.93	1.38	1.97	0.78	0.86	1.23	1.18	1.27	1.06	1.04	1.29	0.97	0.79	0.51	0.44	0.35	0.31	0.24–0.42	$P<0.001$
Women	1.84	1.15	1.64	1.00	1.15	1.26	1.16	1.11	1.12	1.29	1.17	1.17	0.89	0.79	0.85	0.44	0.46	0.36–0.59	$P<0.001$
Age group																			
15–24 years	1.31	0.76	2.04	0.71	1.18	1.34	1.32	1.05	0.97	1.12	0.84	1.14	0.74	0.73	0.71	0.20	0.37	0.27–0.52	$P<0.001$
25–34 years	1.48	2.02	1.94	1.22	1.31	1.03	1.30	1.70	1.39	1.47	1.60	1.23	1.03	0.91	0.92	0.59	0.46	0.34–0.61	$P<0.001$
35–49 years	1.63	1.11	1.20	0.75	0.43	1.41	0.75	0.61	0.80	0.83	1.06	0.82	0.73	0.36	0.38	0.40	0.33	0.22–0.49	$P<0.001$
HIV incidence stratified by sex																			
Men																			
Lowest SES	0.66	1.34	2.80	0.95	0.52	1.19	1.65	2.16	1.85	1.18	1.90	0.89	1.05	0.60	0.76	0.94	0.65	0.33–1.31	$P=0.233$
Low-middle SES	0.85	1.76	1.67	0.65	2.17	1.94	2.00	1.57	0.94	1.82	1.79	0.95	0.86	0.98	0.51	0.50	0.43	0.26–0.72	$P=0.001$
High-middle SES	1.10	0.95	2.11	1.08	0.27	1.07	0.59	1.00	1.19	0.86	1.24	1.13	1.05	0.38	0.52	0.48	0.43	0.24–0.78	$P=0.005$
Highest SES	1.53	1.43	0.96	0.31	0.30	0.70	0.61	0.77	0.61	0.66	0.78	0.86	0.53	0.43	0.36	0.18	0.28	0.15–0.55	$P<0.001$
Women																			
Lowest SES	1.06	1.16	1.56	1.23	1.21	2.00	1.71	1.15	1.60	1.18	2.02	1.01	0.91	0.00	1.24	1.07	0.75	0.39–1.44	$P=0.386$
Low-middle SES	2.45	1.21	2.12	0.90	1.02	1.36	1.18	1.53	1.66	1.81	1.39	1.63	1.25	1.04	1.26	0.26	0.61	0.36–1.02	$P=0.057$
High-middle SES	2.52	1.00	1.54	0.82	1.29	1.16	1.12	1.08	0.92	1.05	0.91	1.43	1.06	1.32	1.08	0.39	0.65	0.39–1.08	$P=0.094$
Highest SES	1.53	0.99	0.99	1.02	0.90	0.63	0.74	0.73	0.76	1.27	1.10	0.79	0.63	0.42	0.61	0.47	0.42	0.24–0.72	$P=0.001$
Men																			
15–24 years	0.79	0.81	1.25	0.51	0.51	1.05	1.22	1.24	0.38	0.69	0.64	0.90	0.52	0.21	0.25	0.24	0.28	0.16–0.47	$P<0.001$
25–34 years	1.46	1.90	3.27	1.11	1.69	0.97	1.48	1.80	1.72	1.50	1.96	1.07	1.36	1.06	0.77	0.57	0.40	0.26–0.60	$P<0.001$
35–49 years	0.49	1.74	1.35	0.62	0.00	1.98	0.66	0.45	0.86	0.81	1.14	0.92	0.45	0.28	0.34	0.28	0.26	0.14–0.47	$P<0.001$
Women																			
15–24 years	1.74	0.72	2.71	0.85	1.62	1.56	1.39	0.91	1.42	1.50	1.05	1.39	0.97	1.29	1.23	0.16	0.48	0.32–0.73	$P<0.001$
25–34 years	1.50	2.14	0.76	1.31	0.96	1.08	1.15	1.62	1.15	1.46	1.34	1.35	0.79	0.80	1.03	0.60	0.54	0.35–0.82	$P=0.004$
35–49 years	2.31	0.76	1.12	0.82	0.67	1.04	0.81	0.72	0.75	0.85	1.00	0.73	0.96	0.44	0.41	0.49	0.40	0.23–0.67	$P=0.001$

Tests for trend assess the effect of time/round on HIV incidence and considers all survey rounds. Tests were performed using Poisson models with generalized estimating equations with exchangeable correlation structure. *N* is the number of individuals with household data on SES and included in incidence analyses. *N* averaged 4754 individuals per round and 21 143 unique individuals over all rounds. Model based IRR is for R18 (round 18) versus R02 (round 2).

Table 4. Household socioeconomic status and HIV incidence, men and women aged 15–49 years, Rakai, 1994–2018.

	Women and men Model 1			Women Model 2			Men Model 3		
Observations	76 071			42 581			33 490		
Number of unique individuals	21 143			11 431			9712		
	IRR	95% CI	*P* value *P* < 0.001	IRR	95% CI	*P* < 0.001	IRR	95% CI	*P*-value *P* < 0.001
SES category									
Lowest	Ref		–	Ref		–	Ref		–
Low-middle	1.047	0.871–1.257	0.625	1.062	0.829–1.362	0.633	1.033	0.787–1.355	0.815
High-middle	0.802	0.668–0.962	0.018	0.868	0.680–1.108	0.255	0.723	0.548–0.955	0.022
Highest	0.545	0.447–0.664	<0.001	0.601	0.462–0.781	<0.001	0.478	0.353–0.647	<0.001
Round	0.947	0.929–0.965	<0.001	0.97	0.953–0.987	0.001	0.95	0.932–0.969	<0.001
Age group			*P* < 0.001			*P* < 0.001			*P* < 0.001
15–24	Ref		–	ref		–	ref		–
25-34	2.207	1.769–2.754	<0.001	0.968	0.814–1.152	0.716	2.211	1.772–2.759	<0.001
35-49	1.101	0.841–1.441	0.483	0.622	0.507–0.764	<0.001	1.099	0.839–1.438	0.494
Sex									
Men	Ref		–						
Women	1.42	1.003–2.015	0.048						
Interaction: age group × sex			*P* < 0.001						
25–34 × women	0.439	0.331–0.582	<0.001						
35–49 × women	0.563	0.401–0.789	0.001						
Interaction: round × sex	1.027	1.002–1.053	0.032						

Changes in HIV incidence were estimated with a Poisson regression model with generalized estimating equations and an exchangeable correlation structure. Incident rate ratio (IRR) and corresponding 95% confidence intervals (CIs) are reported.

Data analysis

We examined the association between HIV incidence and household SES, sex, and age-group over time in 28 RCCS communities followed continuously from rounds 1–18. We stratified HIV incidence by SES, sex, survey-round, and age-group and tested trends over time in each stratum using GEE Poisson regression (Table 3). Finally, we explored the independent association of SES and HIV infection over time, adjusting for sex and age (Table 4). We also tested for interactions using multivariable GEE Poisson regression with robust standard errors and exchangeable correlation structure to account for clustering. Given significant interactions between sex and age-group, and between sex and time, we also stratified regression models by sex (Table 4).

We conducted two sensitivity analyses. First, we examined HIV incidence using round-specific ABM of SES, instead of the ABM over all rounds. Second, we examined the association of HIV incidence with education attainment – as educational attainment is commonly used as measure of SES.

Results

Household assets

Frequency data on household ownership of each asset by round are reported in Table 1. In round 1 (1994), the most commonly owned assets were a latrine (92%) and modern roofing material (81%) and the least commonly owned were a car (2%) and electricity (3%). By round 18 (2016–2018), asset ownership increased for eight of nine assets but declined for bicycle ownership; increases were largest for modern construction of walls (ranged from 36 to 93%), floors (ranged from 28–75%), electricity (ranged from 3–48%), and radios (ranged from 50–73%). By R18, almost complete ownership was found for two assets: modern construction of roofs and access to a latrine (100 and 98%, respectively).

Asset-based measure of socioeconomic status

Table 5 shows the component weights for the ABM of SES. The assets with the highest weights were modern flooring (0.49), modern wall construction (0.49), electricity (0.35), modern roofing (0.34), and ownership of a radio (0.33). The asset with the lowest weights was

Table 5. Component weights from principal component analysis.

Radio	0.33
Bicycle	0.10
Motorcycle	0.21
Car	0.29
Latrine	0.21
Electricity	0.35
Modern roofing	0.34
Modern flooring	0.49
Modern wall construction	0.49
Proportion of variance explained	0.26
Eigenvalue	2.31

ownership of a bicycle (0.10). The weights in Table 5 are similar to round-specific weights (see Methodologic Appendix, http://links.lww.com/QAD/C209). PCA also estimates the proportion of overall variance explained by each asset, which varied from 0.21–0.26 with an overall score proportion of 0.26. Higher SES scores were modestly associated with higher educational attainment of heads of households (Spearman $r = 0.29$, $P < 0.001$) and with higher educational attainment of the most educated member of the household (Spearman $r = 0.32$, $P < 0.001$).

Table 2 shows the distribution of ABM scores for SES over time. SES rose considerably over time. At round 1, 39% of households were in the lowest SES group and 14% were in the highest SES group. By round 18, only 4% of households were in the lowest SES group and 50% were in the highest SES group. For certain later analyses, we combined the lowest and low-middle SES groups given the small proportion of households in the lowest SES group in the most recent survey rounds; in round 18, this combined group was 17% of the sample.

HIV incidence

Table 3 shows HIV incidence rates by round, SES, sex, and age-group. In general, similar declines in HIV incidence by round were found by sex and age group. From round 2 (1995) to round 18 (2018), HIV incidence declined from 1.45 to 0.40 per 100 person-years (IRR = 0.39 for round 18 versus round 2; 95% CI = 0.32–0.47; $P < 0.001$).

HIV incidence was similar by SES in the initial rounds of the RCCS (1994–1997) but greater declines in incidence occurred in higher SES groups leading to increasing HIV disparities over time. The three higher SES groups showed the greatest declines in HIV incidence from rounds 2 to 18 with greatest change in the highest SES group (IRR = 0.36, in the highest SES group; 95% CI = 0.23–0.54; $P < 0.001$); no significant change was found among those in the lowest SES group (IRR = 0.70; 95% CI = 0.43–1.13; $P = 0.148$). HIV incidence declined for men (IRR = 0.31; 95% CI = 0.24–0.42; $P < 0.001$) and women (IRR = 0.46; 95% CI = 0.36–0.59; $P < 0.001$) and in each age group.

Multivariable models (Table 4) demonstrated an independent association between SES and HIV incidence, for the highest SES category ($P < 0.001$) in models 1 (women and men), 2 (women), and 3 (men) and for the high-middle SES category for models 1 and 3. The three models demonstrated similar associations between SES and HIV incidence in the highest SES category; there were no differences between low and low-middle SES across all three models, with IRRs for the low-middle SES category varying between 1.03 and 1.06 (all nonsignificant). The IRRs for high-middle SES varied between 0.72 and 0.87; these were significant in model 1 (women and men) and 3 (men only) but not model 2 (women only). As the reference category (lowest SES) became quite small by round 18 (4% of the sample), we created a new reference category by combining the lowest and low-middle category; models using this three-way SES index were virtually identical to those with the four-way SES index (data not shown).

In model 1, factors associated with HIV incidence included highest SES (IRR = 0.545; 95% CI = 0.45–0.66; $P < 0.001$), high-middle SES (IRR = 0.80; 95% CI = 0.67–0.96; $P = 0.018$), survey round (i.e. time, IRR = 0.95; 95% CI = 0.93–0.97; $P < 0.001$), sex (IRR for women compared with men = 1.42; 95% CI = 1.0–2.02; $P = 0.048$), and age group. Interaction terms demonstrate significant interactions for sex and age-group ($P < 0.001$), and for time and sex ($P = 0.032$). The latter suggests that although HIV incidence declined in both men and women over time, men experienced greater improvement time compared with women. This is the same pattern by sex demonstrated in Table 3.

The interaction term with age group (model 1) suggests that age-related risk of HIV infection is different for men and women; thus, we created two additional models stratified by sex. For women, HIV incidence was similar between 15–24-year-olds and 25–34-year-olds; but women who were 35–49 years old had lower incidence (IRR = 0.62; 95% CI = 0.51–0.76; $P < 0.001$). For men, HIV incidence was highest among 25–34-year-olds (IRR = 2.21; 95% CI = 1.77–2.76; $P < 0.001$), compared with younger and older men. These stratified models have significant effects of SES and time and the associations of SES with incidence were similar to model 1.

We conducted two sensitivity analyses with alternative ways of measuring SES (data not shown, available from first author). We examined HIV incidence using round-specific ABM of SES, instead of the ABM over all rounds. That analysis showed similar patterns of association between SES and HIV incidence. Second, we examined the association of HIV incidence with education attainment of the individuals. The association of educational attainment and HIV incidence over time was similar to the association between ABM of SES and HIV incidence.

Discussion

These analyses demonstrate that higher SES was generally associated with lower HIV incidence and the SES gradients widened over time. The three higher SES group showed the greatest declines in HIV incidence; no change over time was found among those in the lowest SES group. Thus, SES disparities in HIV incidence widened over time and as such, these disparities have implications for HIV prevention and treatment efforts.

As noted above, HIV incidence better reflects the influence of SES on the risk for new HIV infection. Our results are generally consistent with research on HIV prevalence and SES in the period before ART [3,4,6,7]. In the current period, HIV incidence is a better measure of the impact of prevention programs.

These findings are consistent with social determinants' research showing higher SES increases access to resources, such as knowledge, money, social connections [1,2], and suggesting that SES may protect against HIV infection [3,4,6,7]. Hargreaves *et al.* [6] suggested that the relationship between SES and HIV prevalence in SSA changed after 1996. Consistent with Hargreaves and our hypothesis, we found HIV incidence did not differ by SES earlier in the epidemic (1994–1997) but SES disparities increased over time and higher SES emerged as a protective factor. Research from the pre-ART period suggests that SES was having an impact on access to information and individual sexual behaviors [6,9].

We also found that a single ABM of SES could be useful over time, despite considerable increases in SES and changes in the importance of specific household assets. This measure allows one to track changes in SES over time. Asset weights changed over time in ways that make sense intuitively, for example, the declining importance to SES of bicycle ownership and the increasing importance of motorcycle and car ownership. Our asset-based measure of household wealth is consistent with other indicators of SES used in low-income and middle-income country studies of wealth [12,13,15].

Limitations

We would note several limitations of our analyses. Household assets were measured by interview of the head of household and by direct observation by research staff; however, over time subtle changes may have occurred in reporting of individual assets. Although, HIV incidence reflects access to information, prevention services, ART, and male circumcision available after 2004, in these analyses, we did not assess use of prevention and treatment services.

The use of PCA to measure household wealth represents one of several ways to quantify household SES [12–13,15–17]; other measures of household SES include household income and consumption measures. Although commonly used in population surveys [12,15], it is not clear if PCA is superior to other methods, such as simple counts of household assets [16]. Further, there is a paucity of methodological research demonstrating the superiority and/or relative value of specific methods [16]. Moreover, household assets inherently ignore interhousehold redistributions (such as assets or funds from the households of adult brothers, sisters, and cousins), which may be common when families face crises, such as HIV infection [17]. For example, HIV-infected persons in a household may pull resources from the households of other family members.

Implication for HIV prevention

The trends in HIV incidence may also be influenced by complicated changes in social context including rising educational access, greater access to health online, prevention and treatment programs, such as male medical circumcision and ART, changing social and gender norms, and changing HIV risk behaviors. The influence of SES, in face of these other changes, needs further exploration.

Our findings are consistent with previous research on social inequities that suggests wealth reduces disease burden by increasing access to information and resources, including prevention and treatment services. As such SES disparities should be addressed by HIV prevention programs – prioritizing prevention and treatment among those living in the poorest households. The poor, like other key populations, should be targeted for prevention and treatment.

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Conflicts of interest

There are no conflicts of interest.

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