



# Investigating the Associations between Drought, Poverty, High-Risk Sexual Behaviours, and HIV Incidence in Sub-Saharan Africa: A Cross-Sectional Study

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## Abstract

Climate change is increasing the likelihood of drought in sub-Saharan Africa, where HIV prevalence is high. Drought could increase HIV transmission through various mediating mechanisms; we investigated these associations. We used data on people aged 15–59 from Population-Based HIV Impact Assessment surveys from 2016 in Eswatini, Lesotho, Tanzania, Uganda, and Zambia. Survey data were geospatially linked to precipitation data for 2014–2016, with local droughts defined as cumulative rainfall between 2014 and 2016 being in < 15th percentile of all 2-year periods over 1981–2016. Using multivariable logistic regression, stratified by sex and rural/urban residence, we examined associations between (a) drought and poverty, (b) wealth quintiles and sexual behaviours (transactional, high-risk, and intergenerational sex), (c) sexual behaviours and recently acquiring HIV, and (d) drought and recent HIV. Among 102,081 people, 31.5% resided in areas affected by drought during 2014–2016. Experiencing drought was positively associated with poverty for women and men in rural, but not urban, areas. For each group, increasing wealth was negatively associated with transactional sex. For rural women, intergenerational sex was positively associated with wealth. Women reporting each sexual behaviour had higher odds of recent HIV, with strong associations seen for high-risk sex, and, for urban women, intergenerational sex, with weaker associations among men. Women in rural areas who had been exposed to drought had higher odds of having recently acquired HIV (2.10 [95%CI: 1.17–3.77]), but not women in urban areas, or men. Droughts could potentially increase HIV transmission through increasing poverty and then sexual risk behaviours, particularly among women in rural areas.

**Keywords** Incidence · AIDS · Rainfall · Climate · Serosurvey · Structural factors

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## Abbreviations

aOR	Adjusted odds ratio
ART	Antiretroviral therapy
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station Data
DBS	Dried blood spots
DHS	Demographic health survey
HIV	Human immunodeficiency virus
OR	Odds ratio
PHIA	Population-Based HIV Impact Assessment
RNA	Ribonucleic acid
SSA	Sub-Saharan Africa
UNAIDS	Joint United Nations Programme on HIV/AIDS

## Background

Climate change is hypothesised to be impacting the HIV epidemic in settings where Human immunodeficiency virus (HIV) prevalence is high [1]. Climate change is increasing severe weather events, including heatwaves, flooding and cyclones, as well as meteorological droughts [2, 3], defined as an exceptional lack of water compared to normal circumstances [4]. In turn, these weather events are impacting on health through various mechanisms. These include heat-related illnesses [5], and altered patterns of vector-borne and water-borne diseases linked to drought [6–9]. Sub-Saharan Africa (SSA) contains the majority of the world's HIV burden [10]. SSA will also be one of the regions most affected by climate change, with increasing risks of drought caused by changes in precipitation and limited water storage, as well as limited capacity and resources to support adaptation. Drought is an ongoing and worsening trend [3], with the fraction of SSA experiencing severe drought increasing from <5% to ~15% since 1901 [11].

The hypothesised impact of climate change on HIV occurs through various intermediary mechanisms. Extreme weather events, such as droughts, cause decreased food yields [12], which impact negatively on human health, increasing poverty and food insecurity, and exacerbating the structural problems underlying HIV transmission, particularly among women [10, 13–18]. This can be through changes in sexual behaviours driven by poverty, such as increased transactional sex [19], which is also linked to intergenerational sex - particularly where young women partner with older men who have more resources and higher HIV prevalence [13, 14, 20, 21]. Women in these circumstances may have less say in the use of contraception, increasing condomless sex with casual partners [22]. Additionally, drought has been hypothesised to affect HIV acquisition through an increase in gender-based violence and worsening mental health,

which can impact sexual behaviours and access to HIV prevention services [18, 23]. There are other links between climate change and HIV. Migration due to severe weather events could also bring new population groups together, increasing transmission of viruses [24], and potentially disrupting the provision of antiretroviral therapy (ART) due to a lack of access or competing priorities. For some regimens, ART absorption can also decrease in the absence of food [25, 26].

The Joint United Nations Programme on HIV/AIDS (UNAIDS) warned in 2008 that global warming could have a detrimental effect on HIV transmission, yet at the time there had been little research on these effects [1]. Since that warning, epidemiological analyses have found that rural areas of sub-Saharan Africa with increased droughts or flooding events have elevated HIV prevalence [16, 27]. Meanwhile, modelling has estimated that climate change may result in 11.6–16.0 million additional cases of HIV by 2050 without action to reduce emissions [28]. Other analyses have shown associations between droughts and reduced HIV testing in the prior year as well as heightened HIV prevalence and sexual behaviours [29–31]. Otherwise, research on the association between poverty and HIV in the SSA context has usually not considered drought and climate change [23, 32]. The relationships between poverty and HIV in SSA are nuanced and debated; at a global level HIV is thought to disproportionately affect poorer individuals [33], whilst in SSA the relationship between poverty and HIV differs between urban and rural areas [34]. More research is required on the mechanisms by which poverty affects HIV, and, additionally, on the associations connecting drought with HIV via poverty.

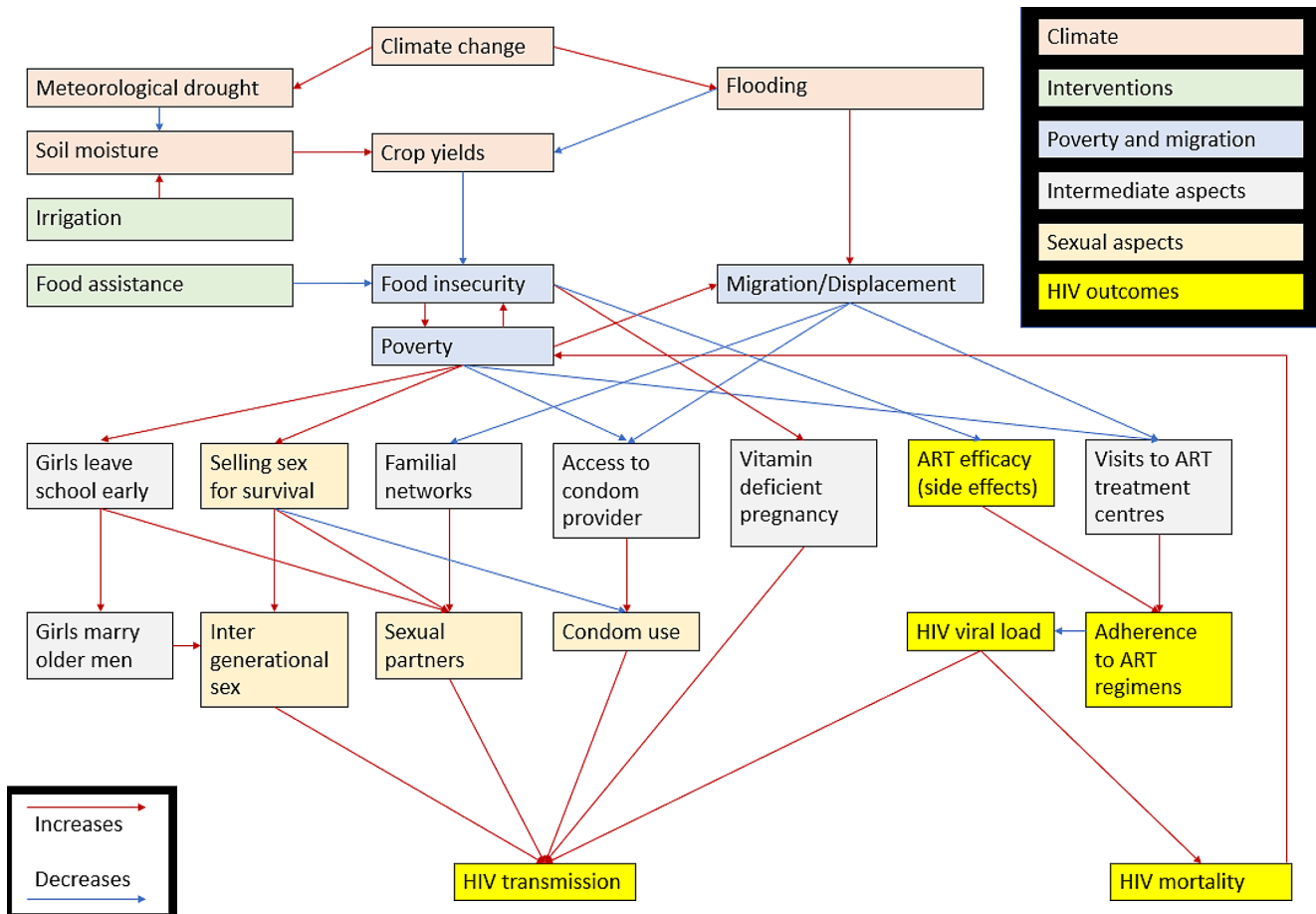
We aimed to address this research gap by investigating a potential pathway by which drought may affect HIV transmission through examining associations between drought and poverty, poverty and sexual behaviours, and sexual behaviours and HIV incidence, as well as associations between drought and HIV incidence.

## Methods

A diagram of the theorised connections between climate change and HIV is shown in Fig. 1.

## Data and Procedures

Data were taken from five nationally representative Population-Based HIV Impact Assessment (PHIA) cross-sectional surveys where data collection started in 2016 (Eswatini, Lesotho, Tanzania, Uganda, and Zambia). People were surveyed using a two-stage sampling design, stratified by urban



**Fig. 1** Theoretical framework linking climate change and drought with HIV transmission

and rural areas, as described previously [35, 36]. Consent was indicated by signing or making a mark on the consent form on a tablet computer and on a printed copy, which was retained by the participant. Further details on sampling, eligibility, consent procedures, staff and training, data collection and cleaning, and response rates are provided in the individual country final reports. Links to these reports are given on page 3 and in supplementary Tables 1–5 of the appendix and include the questionnaires used. In each survey people aged 0–59 years (or greater) were sampled, however, in this analysis we only include those aged 15–59 years old, so that adults of the same age were analysed across all surveys. We also excluded individuals with missing data on wealth quintile or education. Missing data were not imputed as they were rare (< 1% for most variables) and this would have added considerable complexity to the analyses and limited the outputs that could be produced.

The household questionnaire captured data from the household head on assets and receipt of social support in the past 3 months, whilst the adult questionnaire was administered to all consenting eligible participants aged  $\geq 15$  years during face-to-face interviews. The adult questionnaire

included questions on demographics, lifetime and recent (over the past 12 months) sexual behaviours, and on characteristics of their three most recent sexual partners. Further details on survey questions are provided in the online supplemental appendix.

Participants were tested for HIV by survey staff using the national testing algorithm. Among adults that tested positive for HIV, real-time polymerase chain reaction was used to measure HIV ribonucleic acid (RNA) in plasma and dried blood spots (DBS), and qualitative screening was done on DBS specimens to detect the most common antiretroviral drugs with long half-lives. To classify recent infections among adults, staff used HIV-1 limited antigen avidity immunoassays. Samples were considered a recent infection if there was a normalised optical density < 1.5 and the individual did not have a suppressed viral load (HIV-1 RNA < 1000 copies/mL) or detectable antiretroviral drugs.

Data on precipitation estimates from the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) at 0.05° resolution were used to create a variable comparing current and historical rainfall that was used to define drought [37]. This was a dataset prepared by the Vulnerability

Analysis and Mapping Geospatial Analysis Team at the Analysis and Trends Service of the World Food Programme. The dataset summed the 2-year total rainfall from June 2014 to May 2016 for each gridded location, which was then ranked compared to all 2-year rainfall amounts in the same gridded location over the period 1981–2016 to give an empirical percentile. Further data on the climatic context preceding the surveys are given in the appendix. This 2-year period was chosen to align with Southern Africa having experienced a severe drought from late-2014 to mid-2016, including two separate rainfall seasons, October 2014–May 2015 and October 2015–May 2016. The previous and following seasons registered abundant rainfall and good levels of crop production, hence this 2014–2016 can be seen as an episodic but very intense drought period (supplementary Fig. 1, supplementary Table 6).

Each participant's household location was included within an enumeration area based on the most recent census from each country. These enumeration areas are geographic areas that differ in size depending on population density. They are the smallest statistical sample unit in a national census and are usually defined by the number of households they contain, which is usually the number of households that a single staff member can visit and interview during the census period. As it is quicker to move between households when they are closer together, urban enumeration areas usually have more households than rural enumeration areas. Enumeration areas are normally smaller than the grids in each dataset, although very rural areas with small populations could be quite large.

We combined the PHIA survey data with the gridded data on drought using latitude and longitude data from the centroid of each primary sampling (enumeration area) unit in the surveys, to define whether that area had experienced drought.

## Variables

Drought was defined if the rainfall during the 2-year period (June 2014 to May 2016) was less than the 15th percentile compared with historical 2-year periods from 1981 to 2016 for the same location. This binary variable approximates the level below which rainfall deficits are particularly harmful to gross domestic product and maize yields [16]. We also performed sensitivity analyses, defining drought using the 10th percentiles.

All analyses were stratified by sex and rural/urban location to account for a higher prevalence of subsistence farming in rural areas [16] and differences in sexual behaviours between men and women. Variables used for adjustment were survey country, age, having received a secondary-level education or higher, whether they had ever been married,

whether they had reported receiving a pay check in the last 2 months, whether they had experienced severe food insecurity (defined as having no food more than 3 times in the last 4 weeks [38]), and whether they had received economic support in the previous 3 months (no support, food support, or other economic support). This support could include cash transfers, assistance for school fees, education, or shelter, social pensions, or other.

Relative poverty, henceforth referred to as poverty, was defined as being in the lowest two wealth quintiles for each country's survey. These wealth quintiles (described in detail on supplementary materials page 17) were also included as a continuous variable in the analyses with sexual behaviours as the outcome. Where age and wealth quintile were included as continuous variables, sensitivity analyses were also performed in which these were included as categorical variables.

The recent sexual behaviours considered were transactional sex, high-risk sex, and intergenerational sex. Each sexual behaviour could overlap with the others but we do not explicitly include transactional sex or intergenerational sex in high-risk sex. Transactional sex was defined as having bought/sold sex (unavailable for Zambia) or entered into a relationship to either supply or receive food, money, or support. Transactional sex was defined the same for both men and women in our analysis, but in practice most men engaging in transactional sex are supplying money/food/support, and most women engaging in transactional sex are receiving this [39]. High-risk sex was defined as condomless sex with a partner who was HIV+ or had unknown HIV status, who they did not live with and were not married to. Intergenerational sex was defined for women as sex with a partner who was older by  $\geq 10$  years, and for men as sex with a partner that who was younger by  $\geq 10$  years. Intergenerational sex was defined differently for men and women because it mostly occurs between young women and older men [21]. Due to the imbalanced power dynamics, the women in these age-disparate relationships are less able to negotiate safe-sex practices [40], leading to high HIV incidence [41]. Additionally, there is literature from the Southern African region that shows a strong link between age-disparate relationships and partner concurrency [42, 43].

Regional viraemia was defined as the percentage of adults in the enumeration area with unsuppressed HIV-1 viral loads.

## Statistical Analyses

The analyses investigating the associations between drought and poverty were adjusted for demographic variables and variables regarding economic support, age, secondary education or higher, having ever been married, having received

a paycheck in the last 12 months, receipt of food support or other economic support, and survey country. Univariable and multivariable odds ratios (ORs) were calculated using logistic regression, with household-level survey weights. All survey weighting was done using Taylor-series weights, accounting for clustering by sampling units [44].

For the analyses examining the associations between wealth quintiles and sexual behaviours (transactional sex, high-risk sex, and intergenerational sex), logistic regression was used with the individual-level survey weights. To assess the effect of variables that could impact household wealth, analyses were unadjusted, adjusted for age and survey country, and then fully adjusted for demographic variables, age, survey country, receipt of food or other economic support, secondary education or higher, and having received a paycheck in the previous 12 months, ever having been married.

In analyses of the associations between the sexual behaviours and recent HIV, logistic regression was used with the survey weighting for blood testing. The regression models contained each sexual behaviour (transactional sex, high-risk sex, and intergenerational sex) and were also adjusted for age, and an interaction term between survey country and regional HIV viraemia levels.

To investigate the associations between drought and recent HIV, we used logistic regression with the survey weighting for blood testing. We first used unadjusted models and then adjusted for potential mediators: age and an interaction term between survey country and regional HIV viraemia levels. We then further adjusted for demographic and sexual behaviour variables that could mediate the relationship between drought and recent HIV, age, an interaction term between survey country and regional viraemia, secondary education or higher, having received a paycheck in the previous 12 months, ever having been married, receipt of food or other economic support, severe food insecurity, wealth quintile, transactional sex, high-risk sex, and intergenerational sex. Sensitivity analyses were performed without the survey weighting.

People with missing data on HIV testing were excluded from the analyses with recent HIV as the outcome. People with missing data on a binary variable, e.g. having ever been married or reporting a sexual behaviour were assumed unexposed.

## Ethical Approval

All PHIA survey protocols, consent forms, screening forms, refusal forms, referral forms, recruitment materials, and questionnaires were reviewed and approved by in-country ethics and regulatory bodies and the institutional review boards of Columbia University Medical Center, Westat, and the United States Centers for Disease Control.

## Results

Across the five country surveys, response rates varied from 84.5% in Eswatini ( $N=11673$ ), 89.4% in Zambia ( $N=21280$ ), 93.0% in Lesotho ( $N=12887$ ), 94.8% in Tanzania ( $N=33004$ ), to 96.7% in Uganda ( $N=29383$ ). We excluded persons aged  $\geq 60$  years; 1437 in Eswatini, 3361 in Tanzania, and 997 in Uganda. We also excluded persons with missing data on wealth quintile or education level; 15 in Eswatini, 42 in Lesotho, 22 in Tanzania, 159 in Uganda, and 113 in Zambia. In total, 102,081 respondents aged 15–59 were included; 12,845 (12.6%) from Lesotho, 29,621 (29.0%) from Tanzania, 28,227 (27.7%) from Uganda, 10,221 (10.0%) from Eswatini, and 21,167 (20.7%) from Zambia. Further information on survey response rates, exclusions, and missing data are given on supplementary materials page 13. The unweighted percentage of people from each country who had experienced a drought varied from 357 (1.3%) in Uganda and 1,187 (4.0%) in Tanzania, to 12,455 (58.8%) in Zambia, 6,740 (65.4%) in Eswatini, and 12,061 (93.9%) in Lesotho; 32,800 (32.1%) in total. Of the 102,081 respondents included, 58,341 (57.2%) were female and 34,388 (33.7%) lived in urban areas.

## Drought and poverty

Table 1 shows the weighted demographic characteristics of women and men stratified by wealth quintiles. Wealth quintiles were positively correlated with having received a secondary education. The percentage of people living in urban areas increased with each wealth quintile, whilst a decreasing trend was seen for ever having been married, having received food support, or other economic support, and experiencing severe food insecurity. The percentage of participants who were female or had experienced drought was similar across the wealth quintiles.

Table 2 shows the unadjusted and adjusted odds ratios of experiencing poverty. For women in rural areas, those who had experienced a recent drought had higher odds of being in poverty than those who had not (adjusted odds ratio [aOR] 1.28 [95% confidence interval: 1.02–1.61]). There was not strong evidence of a positive association for women in urban areas (1.24 [0.68–2.26]). Similarly, men in rural areas who had experienced a drought had higher odds of poverty (1.31 [1.04–1.66]), but not in urban areas (1.03 [0.46–2.27]).

In sensitivity analyses using a more stringent definition of drought ( $< 10$ th percentile of rainfall instead of  $< 15$ th percentile), the association between drought and poverty for women and men in rural areas remained (aORs 1.42 [1.17–1.73] and 1.43 [1.15–1.76], respectively), whilst it was attenuated for women and men in urban areas (1.50

**Table 1** Weighted\* demographic characteristics by wealth quintile, stratified by gender

Variable	Wealth quintile 1	Wealth quintile 2	Wealth quintile 3	Wealth quintile 4	Wealth quintile 5	Total
N women	10,261 (19%)	10,538 (19%)	11,259 (20%)	11,259 (20%)	12,202 (22%)	55,464 (100%)
Mean age (95% confidence interval)	30.6 (30.3–30.9)	30.9 (30.6–31.2)	30.8 (30.5–31.1)	29.9 (29.6–30.1)	28.7 (28.5–29.0)	30.1 (30.0–30.3)
Urban	471 (5%)	693 (7%)	2501 (22%)	6300 (56%)	10,608 (87%)	20,544 (37%)
Secondary education (or higher)	889 (9%)	1682 (16%)	2855 (25%)	4536 (40%)	7363 (60%)	17,305 (31%)
Received paycheck last 12 months	3040 (30%)	3342 (32%)	3728 (33%)	4230 (38%)	5176 (42%)	19,496 (35%)
Ever married	8470 (83%)	8340 (79%)	8492 (75%)	7958 (71%)	7469 (61%)	40,688 (73%)
Tested HIV + in survey	660 (6%)	751 (7%)	1107 (10%)	1295 (12%)	1088 (9%)	4897 (9%)
Food support	207 (2%)	157 (1%)	116 (1%)	111 (1%)	70 (1%)	660 (1%)
Other economic support	813 (8%)	728 (7%)	637 (6%)	498 (4%)	400 (3%)	3073 (6%)
Severe food insecurity	1802 (18%)	1520 (14%)	1215 (11%)	858 (8%)	526 (4%)	5912 (11%)
Drought	1305 (13%)	1408 (13%)	1451 (13%)	1297 (12%)	1390 (11%)	6844 (12%)
Transactional sex	1308 (13%)	1164 (11%)	1297 (12%)	1208 (11%)	1026 (8%)	6001 (11%)
High-risk sex	358 (3%)	429 (4%)	466 (4%)	446 (4%)	458 (4%)	2158 (4%)
Intergenerational sex	1730 (17%)	1729 (16%)	1910 (17%)	1602 (14%)	1624 (13%)	8586 (15%)
N men	10,538 (19%)	11,315 (20%)	11,315 (20%)	10,926 (20%)	11,370 (21%)	55,464 (100%)
Mean age (95% confidence interval)	29.9 (29.5–30.2)	30.4 (30.0–30.7)	30.4 (30.0–30.8)	29.6 (29.3–29.9)	29.5 (29.2–29.8)	30.0 (29.8–30.1)
Urban	424 (4%)	708 (6%)	2280 (20%)	5872 (54%)	9833 (86%)	19,113 (34%)
Secondary education (or higher)	1719 (16%)	2454 (22%)	3557 (31%)	5399 (49%)	7835 (69%)	20,960 (38%)
Received paycheck last 12 months	4997 (47%)	5834 (52%)	6295 (56%)	6865 (63%)	7587 (67%)	31,576 (57%)
Ever married	6889 (65%)	7055 (62%)	6783 (60%)	6102 (56%)	5901 (52%)	32,729 (59%)
Tested HIV + in survey	453 (4%)	540 (5%)	673 (6%)	696 (6%)	534 (5%)	2895 (5%)
Food support	192 (2%)	140 (1%)	140 (1%)	106 (1%)	69 (1%)	649 (1%)
Other economic support	720 (7%)	651 (6%)	494 (4%)	397 (4%)	351 (3%)	2612 (5%)
Severe food insecurity	1679 (16%)	1427 (13%)	1108 (10%)	740 (7%)	421 (4%)	5374 (10%)
Drought	1233 (12%)	1504 (13%)	1495 (13%)	1283 (12%)	1393 (12%)	6905 (12%)
Transactional sex	408 (4%)	428 (4%)	413 (4%)	358 (3%)	299 (3%)	1908 (3%)
High-risk sex	625 (6%)	815 (7%)	824 (7%)	857 (8%)	661 (6%)	3783 (7%)
Intergenerational sex	1778 (17%)	1862 (16%)	2026 (18%)	1652 (15%)	1608 (14%)	8924 (16%)

\*Household survey weighting

[0.69–2.31] and 1.43 [0.86–1.36], respectively). In sensitivity analyses treating age as a categorical variable (supplementary Table 7), results were similar.

### Poverty and Sexual Behaviours

Table 3 shows unadjusted and adjusted odds ratios for each sexual behaviour in the last year by wealth quintile stratified by sex and urban/rural location. In each group there was a negative association between increasing wealth quintile and transactional sex; aORs 0.92 (0.88–0.97), 0.88 (0.81–0.94), 0.92 (0.85–1.00), and 0.84 (0.74–0.95) for rural women, urban women, rural men, and urban men, respectively.

The associations between wealth quintile and high-risk sex were less clear. Among women in rural areas, there was a positive association between wealth and high-risk sex; OR 1.09 (1.02–1.17). However, this association attenuated somewhat upon adjustment; aOR 1.04 (0.98–1.10). For women in urban areas there was a negative association in unadjusted analyses; OR 0.91 (0.82–1.01) that attenuated

after adjustment; aOR 0.98 (0.90–1.06). For men in rural areas there was a positive association between wealth and high-risk sex; aOR 1.08 (1.02–1.13) and there was a negative association in urban areas; aOR 0.90 (0.83–0.98).

For women in rural areas there was a positive association between increasing wealth quintile and intergenerational sex; aOR 1.04 (1.01–1.08). There was no evidence of such an association for women in urban areas; aOR 1.01 (0.95–1.07), men in rural areas; aOR 0.99 (0.94–1.04), or men in urban areas; 1.03 (0.94–1.12).

In sensitivity analyses treating wealth quintile as a categorical variable (supplementary Table 8), the point estimates for the associations between wealth and transactional sex generally followed a linear pattern consistent with the odds ratios when treating wealth quintile as a continuous variable. However, for high-risk sex, the directions of the odds ratios for men and women in urban areas (aORs above 1) differed from when treating wealth quintile as a continuous variable (aORs below 1). For men and women in rural areas, the same direction of ORs was observed (aORs above

**Table 2** Weighted odds ratios of poverty\*

		Outcome: Poverty			
		Rural		Urban	
		Univariable	Multivariable	Univariable	Multivariable
<b>Women</b>	Drought	1.34 (1.14–1.58)	1.28 (1.02–1.61)	0.56 (0.38–0.83)	1.24 (0.68–2.26)
	Age (per 10-year increase)	1.02 (0.99–1.04)	0.86 (0.83–0.89)	1.18 (1.11–1.26)	1.00 (0.94–1.06)
	Secondary education or higher	0.27 (0.24–0.30)	0.25 (0.23–0.28)	0.17 (0.13–0.23)	0.14 (0.11–0.19)
	Ever married	1.57 (1.44–1.70)	1.37 (1.22–1.53)	1.79 (1.47–2.16)	1.21 (0.99–1.49)
	Received paycheck in last 12 months	0.76 (0.71–0.82)	0.82 (0.76–0.88)	0.91 (0.76–1.10)	0.74 (0.61–0.90)
	Food support (vs. no support)	1.78 (1.21–2.62)	1.71 (1.42–2.05)	1.24 (0.60–2.53)	0.83 (0.39–1.78)
	Other economic support (vs. no support)	1.55 (1.28–1.87)	1.97 (1.32–2.92)	3.35 (2.40–4.68)	2.95 (2.03–4.29)
	Eswatini	1	1	1	1
	Lesotho	1.41 (1.16–1.72)	1.16 (0.94–1.43)	0.20 (0.13–0.31)	0.12 (0.08–0.20)
	Tanzania	1.49 (1.20–1.85)	1.00 (0.77–1.29)	0.20 (0.12–0.32)	0.08 (0.05–0.15)
	Uganda	1.05 (0.89–1.24)	0.80 (0.62–1.04)	0.56 (0.37–0.85)	0.33 (0.19–0.57)
Zambia	1.65 (1.40–1.95)	1.17 (0.95–1.43)	0.07 (0.04–0.12)	0.04 (0.02–0.07)	
<b>Men</b>	Drought	1.24 (1.05–1.47)	1.31 (1.04–1.66)	0.46 (0.30–0.69)	1.03 (0.46–2.27)
	Age (per 10-year increase)	0.99 (0.97–1.02)	0.84 (0.81–0.87)	1.10 (1.02–1.18)	1.08 (0.96–1.21)
	Secondary education or higher	0.35 (0.32–0.38)	0.34 (0.31–0.37)	0.26 (0.19–0.35)	0.21 (0.16–0.29)
	Received paycheck in last 12 months	0.71 (0.66–0.76)	0.70 (0.65–0.76)	0.76 (0.58–1.01)	0.61 (0.45–0.83)
	Ever married	1.25 (1.18–1.33)	1.56 (1.43–1.71)	1.22 (0.97–1.52)	0.87 (0.60–1.25)
	Food support (vs. no support)	1.44 (0.94–2.18)	1.63 (1.06–2.52)	0.69 (0.28–1.72)	0.55 (0.22–1.38)
	Other economic support (vs. no support)	1.57 (1.27–1.93)	1.77 (1.44–2.19)	2.93 (2.05–4.17)	2.71 (1.81–4.06)
	Eswatini	1	1	1	1
	Lesotho	1.54 (1.27–1.88)	1.14 (0.92–1.41)	0.18 (0.11–0.28)	0.13 (0.08–0.23)
	Tanzania	1.58 (1.27–1.97)	1.32 (1.03–1.70)	0.20 (0.12–0.33)	0.12 (0.07–0.23)
	Uganda	1.17 (0.98–1.39)	1.15 (0.89–1.48)	0.61 (0.41–0.92)	0.52 (0.29–0.93)
Zambia	1.53 (1.28–1.81)	1.38 (1.13–1.68)	0.05 (0.03–0.08)	0.05 (0.03–0.08)	

\*Poverty defined as being in the lowest two wealth quintiles

**Table 3** Weighted odds ratios of sexual behaviours for increasing wealth (per quintile)

Outcome	Population	Odds ratios (95% confidence intervals)		
		Univariable	Adjusted for country and age	Fully adjusted*
Transactional sex	Rural women	0.94 (0.89–0.99)	0.92 (0.88–0.96)	0.92 (0.88–0.97)
	Urban women	0.84 (0.79–0.90)	0.84 (0.79–0.90)	0.88 (0.81–0.94)
	Rural men	0.95 (0.87–1.02)	0.92 (0.85–0.99)	0.92 (0.85–1.00)
	Urban men	0.84 (0.75–0.94)	0.85 (0.76–0.95)	0.84 (0.74–0.95)
High-risk sex	Rural women	1.09 (1.02–1.17)	1.03 (0.98–1.09)	1.04 (0.98–1.10)
	Urban women	0.91 (0.82–1.01)	0.94 (0.87–1.02)	0.98 (0.90–1.06)
	Rural men	1.14 (1.07–1.21)	1.08 (1.02–1.13)	1.08 (1.02–1.13)
	Urban men	0.86 (0.78–0.95)	0.89 (0.82–0.97)	0.90 (0.83–0.98)
Intergenerational sex	Rural women	0.97 (0.94–1.01)	0.97 (0.94–1.01)	1.04 (1.01–1.08)
	Urban women	0.91 (0.86–0.97)	0.94 (0.89–1.00)	1.01 (0.95–1.07)
	Rural men	1.00 (0.96–1.04)	0.99 (0.95–1.04)	0.99 (0.94–1.04)
	Urban men	0.92 (0.86–0.98)	1.00 (0.92–1.09)	1.03 (0.94–1.12)

\* Analyses were adjusted for receipt of food or other economic support, secondary education or higher, having received a paycheck in the previous 12 months, ever having been married, age, and survey country

1), but the trend did not appear linear, although confidence intervals were wide. For intergenerational sex, there was little evidence of associations with wealth quintile among urban women and men, and rural men, which was also seen in the categorised analysis. For rural women, the association of more intergenerational sex with higher wealth, was mostly reflected through higher odds in the highest wealth quintile.

### Sexual Behaviours and Recent HIV

The unadjusted and adjusted odds ratios of having recently acquired HIV for each sexual behaviour are shown in Table 4, with full model results shown in supplementary Table 7. Testing information was unavailable for 5667 (5.6%) of individuals who were excluded from the analysis with recent HIV as the outcome. For women in both rural and urban areas, the percentage who had recently acquired HIV was higher for those reporting each individual sexual behaviour than those who did not. In multivariable analyses among women in rural areas, there were positive

associations between high-risk sex and recent HIV; aOR 3.40 (1.34–8.59). However, evidence was much weaker for transactional sex; aOR 1.73 (0.71–4.18) and intergenerational sex 1.66 (0.81–3.41). For women in urban areas, there was an association with high-risk sex; aOR 2.86 (1.30–6.32), and also intergenerational sex; aOR 2.60 (1.22–5.58), but not for transactional sex; 1.61 (0.63–4.10). For men in both rural and urban areas there was no evidence of any associations between sexual behaviours and having recently acquired HIV. For women and men in both rural and urban areas there was a positive association between having recently acquired HIV and regional HIV viraemia levels (supplementary Table 9).

### Drought and Recent HIV

Unadjusted and adjusted odds ratios for having recently acquired HIV, including exposure to drought, are shown in Table 5 for women and Table 6 for men. For women in rural areas, those exposed to drought had higher odds of having recently acquired HIV (2.26 [95%CI: 1.44–3.56]) in

**Table 4** Associations between having recently acquired HIV and sexual behaviours among HIV-negative women and men (weighted)

	% with recent HIV	Odds ratios (95% confidence intervals)	
		Univariable	Multivariable*
<b>Rural women (N: 31,647, 88 with recent HIV)</b>			
No transactional sex	0.2%	1	1
Transactional sex	0.4%	2.18 (0.99–4.76)	1.73 (0.71–4.18)
No high-risk sex	0.2%	1	1
High-risk sex	0.8%	4.16 (1.89–9.19)	3.40 (1.34–8.59)
No intergenerational sex	0.2%	1	1
Intergenerational sex	0.3%	1.78 (0.84–3.75)	1.66 (0.81–3.41)
<b>Urban women (N: 15,698, 63 with recent HIV)</b>			
No transactional sex	0.2%	1	1
Transactional sex	0.5%	2.05 (0.84–5.00)	1.61 (0.63–4.10)
No high-risk sex	0.2%	1	1
High-risk sex	1.2%	4.89 (2.27–10.53)	2.86 (1.30–6.32)
No intergenerational sex	0.2%	1	1
Intergenerational sex	0.6%	2.74 (1.31–5.75)	2.60 (1.22–5.58)
<b>Rural men (N: 25,812, 43 with recent HIV)</b>			
No transactional sex	0.1%	1	1
Transactional sex	0.1%	1.06 (0.24–4.75)	0.97 (0.20–4.66)
No high-risk sex	0.1%	1	1
High-risk sex	0.2%	1.41 (0.43–4.57)	1.39 (0.39–4.98)
No intergenerational sex	0.1%	1	1
Intergenerational sex	0.3%	3.39 (1.46–7.86)	1.84 (0.68–4.99)
<b>Urban men (N: 11,424, 20 with recent HIV)</b>			
No transactional sex	0.1%	1	1
Transactional sex	0.0%	0.47 (0.06–3.70)	0.35 (0.04–3.09)
No high-risk sex	0.1%	1	1
High-risk sex	0.4%	6.04 (1.19–30.64)	3.81 (0.85–17.12)
No intergenerational sex	0.1%	1	1
Intergenerational sex	0.2%	3.29 (0.81–13.33)	1.92 (0.47–7.83)

\*Adjusted for sexual risk behaviour variables, age, and an interaction between survey country and regional viraemia. Regional viraemia is defined as the percentage of individuals in the enumeration area with unsuppressed HIV-1 viral loads



**Table 5** Adjusted weighted odds ratios of having recently acquired HIV among women\*

	Rural			Urban		
	Unadjusted	Adjusted	Further adjusted	Unadjusted	Adjusted	Further adjusted
Drought	2.26 (1.44–3.56)	2.10 (1.23–3.60)	2.10 (1.17–3.77)	1.44 (0.75–2.75)	0.62 (0.25–1.52)	0.74 (0.29–1.88)
Age (per 10-year increase)	1.13 (0.89–1.43)	1.13 (0.90–1.43)	1.08 (0.76–1.54)	1.11 (0.88–1.39)	1.13 (0.90–1.41)	0.81 (0.57–1.16)
Eswatini and regional viraemia interaction	1.16 (1.11–1.21)	1.13 (1.07–1.18)	1.15 (1.09–1.21)	1.05 (0.96–1.16)	1.07 (0.97–1.17)	1.07 (0.97–1.18)
Lesotho and regional viraemia interaction	1.13 (1.08–1.18)	1.09 (1.04–1.14)	1.08 (1.03–1.14)	1.09 (1.04–1.14)	1.11 (1.05–1.18)	1.11 (1.04–1.18)
Tanzania and regional viraemia interaction	1.15 (1.05–1.27)	1.16 (1.06–1.26)	1.18 (1.08–1.28)	0.73 (0.56–0.96)	0.72 (0.54–0.94)	0.72 (0.55–0.94)
Uganda and regional viraemia interaction	1.22 (1.09–1.36)	1.23 (1.11–1.37)	1.20 (1.08–1.34)	1.05 (0.90–1.23)	1.04 (0.89–1.22)	0.98 (0.81–1.19)
Zambia and regional viraemia interaction	1.13 (1.06–1.20)	1.09 (1.02–1.17)	1.09 (1.01–1.17)	1.10 (1.03–1.18)	1.12 (1.05–1.21)	1.14 (1.07–1.22)
Secondary education or higher	1.19 (0.61–2.35)		1.55 (0.67–3.58)	0.72 (0.37–1.37)		0.71 (0.31–1.64)
Received paycheck in last 12 months	1.28 (0.69–2.38)		1.20 (0.58–2.45)	2.44 (1.47–4.05)		2.37 (1.38–4.09)
Ever married	1.89 (0.86–4.18)		1.93 (0.73–5.09)	2.80 (1.43–5.46)		2.66 (1.21–5.88)
No support	1		1	1		1
Food support (vs. no support)	0.64 (0.27–1.51)		0.54 (0.23–1.25)	2.55 (0.92–7.07)		2.83 (1.01–7.91)
Other economic support (vs. no support)	0.57 (0.20–1.67)		0.35 (0.13–0.94)	NA		NA
Severe food insecurity	2.24 (1.03–4.86)		2.14 (0.91–5.03)	1.60 (0.67–4.32)		1.40 (0.56–3.49)
Wealth quintile	0.91 (0.71–1.16)		0.88 (0.68–1.13)	0.84 (0.65–1.08)		0.95 (0.68–1.31)
Transactional sex	2.17 (0.99–4.76)		1.62 (0.64–4.06)	2.05 (0.84–5.00)		1.39 (0.53–3.59)
High-risk sex	4.16 (1.89–9.19)		3.42 (1.38–8.44)	4.89 (2.27–10.53)		2.83 (1.30–6.17)
Intergenerational sex	1.78 (0.84–3.75)		1.57 (0.72–3.39)	2.74 (1.31–5.75)		2.19 (1.02–4.71)

Regional viraemia is defined as the percentage of individuals in the enumeration area with unsuppressed HIV-1 viral loads (the odds ratio is per percentage increase)

\*Among women testing negative for HIV antibodies or testing positive with evidence of recent HIV infection

unadjusted analyses, attenuating to 2.10 (95%CI: 1.23–3.60) in analyses adjusted for age and an interaction between survey country and regional viraemia. In analyses also adjusted for demographic variables and sexual behaviours, the association held (2.10 [1.17–3.77]). This fully adjusted association also held when using a more stringent cut-off to define drought (2.46 [1.38–4.42]) and when not using survey weighting (2.20 [1.29–3.74]) (supplementary Table 8). For women in urban areas (0.74 [0.29–1.88]), and men in both rural (0.52 [0.19–1.45]) and urban areas (1.47 [0.40–5.45]), there was no evidence of an association between having been exposed to drought and having recently acquired HIV (Tables 5 and 6). For these groups, there was also no evidence of an association in sensitivity analyses using a more stringent cut-off to define drought and when not using survey weighting (supplementary Table 10). When treating age and wealth quintile as categorical variables, analyses produced similar results when the model was able to converge (supplementary Table 11).

## Discussion

We found that women in rural areas who had recently experienced drought had increased odds of having recently acquired HIV. We also examined the individual links in the hypothesised chain linking drought and HIV. Women and men in rural areas, but not urban areas, that had been exposed to drought had increased odds of being in poverty. Behavioural patterns differed by levels of poverty, with associations identified between poverty and various self-reported recent sexual behaviours. For women and men in both rural and urban areas, there was a negative association between increasing wealth and transactional sex, whilst there was a positive association between increasing wealth and intergenerational sex for women in rural areas. There was weak evidence of a positive association between increasing wealth and high-risk sex among women in rural areas, whilst there was stronger evidence of a positive association among rural men, but the opposite pattern among urban men. Finally, there were increased odds of having recently acquired HIV among women in rural areas reporting high-risk sex, and women in urban areas reporting high-risk sex or intergenerational sex, with no strong associations observed among men. This provides some evidence that drought may be linked to increased HIV transmission risk through intermediary mechanisms as previously hypothesised [1], particularly among women in rural areas. This suggests that as the frequency and severity of droughts in SSA increases, progress towards HIV prevention targets in the region may be hindered.

## Comparison with other Literature

Few analyses have investigated the associations between drought and HIV incidence or prevalence. Burke et al. used Demographic Health Survey (DHS) data to examine the associations between local rainfall shocks and HIV prevalence, finding that infection rates in rural areas where HIV is endemic increase by 11% for every recent drought [16]. Using the Lesotho PHIA survey, Low et al. also found that drought in rural areas was associated with higher HIV prevalence and riskier sexual behaviour in young women [30]. Similarly, Treibich et al.'s analysis of Malawi's DHS data found that experiencing drought increased the likelihood that women employed in agriculture engaged in transactional sex, and that a single drought increased HIV prevalence by around 15% among men and women [31]. Austin et al. used structural equation modelling to demonstrate that droughts are indirect predictors, via factors such as food insecurity, of the percentage of a country's population living with HIV who are women [18]. Lastly, Epstein et al. used multi-country DHS data to show that experiencing droughts was associated with higher odds of condomless sex and lower odds of HIV testing in the prior year [29].

Studies in SSA have looked at the associations between related variables in the theoretical framework linking drought and HIV [1]. Droughts are associated with extreme poverty in SSA [45], whilst the World Bank has estimated that climate change, including droughts, will lead to millions of people in SSA falling into poverty [46], partially through reliance on subsistence agriculture [47]. The supplementary materials (page 21) contain an in-depth discussion of the literature on the relationships between poverty and sexual risk behaviours and these behaviours and HIV.

## Strengths and Limitations

Strengths of this analysis include the large sample taken from nationally representative bio-behavioural surveys across five countries, and our ability to look at multiple outcomes in the theorised pathway between drought and recent HIV, whilst adjusting for multiple confounders at each step. These results should be generalisable to other similar settings in the region. The biggest limitation is the cross-sectional nature of the surveys, which does not provide direct evidence of the causal relationships in the pathway. However, the period in which the data on rainfall/drought were gathered preceded the surveys, so it is likely that a period of extended drought caused subsequent poverty, although poorer people may have less resources than wealthier counterparts to migrate away from drought-affected areas. Rural areas are perhaps more affected by drought due to the high prevalence of subsistence farming. Unfortunately, we could

**Table 6** Adjusted weighted odds ratios of having recently acquired HIV among men\*

	Rural			Urban		
	Unadjusted	Adjusted	Further adjusted	Unadjusted	Adjusted	Further adjusted
Drought	0.67 (0.29–1.51)	0.52 (0.20–1.39)	0.52 (0.19–1.45)	1.70 (0.55–5.24)	1.23 (0.37–4.16)	1.47 (0.40–5.45)
Age (per 10-year increase)	1.64 (1.33–2.03)	1.67 (1.35–2.07)	1.17 (0.79–1.72)	1.45 (1.05–2.02)	1.49 (1.06–2.09)	1.01 (0.48–2.09)
Eswatini and regional viraemia interaction	1.08 (0.97–1.20)	1.12 (1.02–1.22)	1.12 (1.00–1.25)	1.17 (1.08–1.27)	1.16 (1.06–1.27)	1.16 (1.05–1.28)
Lesotho and regional viraemia interaction	1.14 (1.08–1.20)	1.18 (1.12–1.23)	1.17 (1.10–1.25)	1.08 (1.01–1.16)	1.07 (1.00–1.14)	1.08 (1.00–1.16)
Tanzania and regional viraemia interaction	1.15 (0.97–1.36)	1.14 (0.96–1.35)	1.14 (0.97–1.34)	0.61 (0.27–1.39)	0.61 (0.27–1.40)	0.65 (0.29–1.45)
Uganda and regional viraemia interaction	1.24 (1.09–1.41)	1.24 (1.09–1.41)	1.21 (1.05–1.39)	1.21 (0.96–1.52)	1.22 (0.97–1.53)	1.18 (0.92–1.51)
Zambia and regional viraemia interaction	1.05 (0.92–1.19)	1.08 (0.95–1.23)	1.08 (0.95–1.23)	1.01 (0.89–1.15)	1.01 (0.89–1.14)	1.01 (0.90–1.14)
Secondary education or higher	0.97 (0.44–2.16)	1.08 (0.95–1.23)	1.44 (0.63–3.27)	0.81 (0.24–2.74)	1.01 (0.89–1.14)	0.83 (0.18–3.92)
Received paycheck in last 12 months	2.21 (1.01–4.84)	1.58 (0.74–3.39)	1.58 (0.74–3.39)	14.41 (3.60–57.75)	9.45 (2.39–37.29)	9.45 (2.39–37.29)
Ever married	16.03 (4.11–62.49)	10.92 (2.26–52.76)	10.92 (2.26–52.76)	4.98 (1.25–19.83)	3.38 (0.55–20.87)	3.38 (0.55–20.87)
No support	1	1	1	1	1	1
Food support (vs. no support)	1.15 (0.25–5.35)	1.09 (0.23–5.20)	1.09 (0.23–5.20)	NA	NA	NA
Other economic support (vs. no support)	4.09 (0.59–28.48)	3.81 (0.52–27.89)	3.81 (0.52–27.89)	3.37 (0.41–27.63)	2.42 (0.26–22.84)	2.42 (0.26–22.84)
Severe food insecurity	1.56 (0.56–4.36)	1.54 (0.56–4.23)	1.54 (0.56–4.23)	1.86 (0.42–8.15)	1.70 (0.39–7.42)	1.70 (0.39–7.42)
Wealth quintile	0.98 (0.73–1.30)	0.93 (0.70–1.24)	0.93 (0.70–1.24)	0.94 (0.61–1.46)	0.99 (0.57–1.70)	0.99 (0.57–1.70)
Transactional sex	1.06 (0.24–4.75)	0.84 (0.18–3.99)	0.84 (0.18–3.99)	0.47 (0.06–3.70)	0.37 (0.04–3.10)	0.37 (0.04–3.10)
High-risk sex	1.41 (0.43–4.57)	1.47 (0.41–5.27)	1.47 (0.41–5.27)	6.04 (1.19–30.64)	3.30 (0.76–14.36)	3.30 (0.76–14.36)
Intergenerational sex	3.39 (1.46–7.86)	1.71 (0.67–4.36)	1.71 (0.67–4.36)	3.29 (0.81–13.33)	1.73 (0.47–6.45)	1.73 (0.47–6.45)

Regional viraemia is defined as the percentage of individuals in the enumeration area with unsuppressed HIV-1 viral loads (the odds ratio is per percentage increase)

\*Among men testing negative for HIV antibodies or testing positive with evidence of recent HIV infection

not adjust for employment type such as farming because the employment questions could only capture formal, rather than casual employment. Instead, we had to use the rural/urban variable as a simple proxy for dominant types of employment. There will also likely be other confounders that we were unable to account for. Having received a pay check in the last 12 months is likely to exclude people who are in casual employment, but, nevertheless, it should act as a marker for more secure employment.

The cross-sectional survey limitation also applies to other outcomes we investigated. To minimise the effect of considering outcome variables that occurred before a predictor, we included sexual behaviours from the last year, whilst the recent HIV infections are likely to have occurred in the few months before the survey took place, although wealth is measured at the time of the survey. Much of the data was self-reported, which could be subject to recall bias, social desirability bias, and some difficulty in defining what could count as transactional sex in more long-term relationships. The sexual behaviour questions were those most affected by missingness, perhaps due to their sensitive nature. This missingness could explain why some of the sexual behaviours were not strongly associated with recent HIV. These various limitations regarding the order that variables may have occurred and the biases around them, may explain why the association between drought and recent HIV among women in rural areas did not attenuate upon adjustment for other variables such as wealth and sexual behaviours. Alternatively, this could be due to not including data on other potential mediating factors such as mental health or gender-based violence, which has been demonstrably under-reported in the PHIA surveys [48].

There could also have been some misclassification of drought severity, however, we believe that our results are reasonably robust due to the use of 2 years of data to define a drought period and using a relative rank rather than an absolute value for our drought indicator, to indicate a departure from normal weather. We also performed a sensitivity analysis using a more stringent cut-off to define drought. Finally, our definition of wealth/poverty was relative to others in that country, rather than absolute (e.g., the \$2.15 per day international poverty definition). An absolute measure was unavailable in the data, while purchasing power is usually justified relative to the setting, so the measure should be robust.

## Implications

The links between drought and HIV, highlighted in our study, could have effects that are particularly severe in countries in Southern Africa where the HIV prevalence is high, sometimes > 10% of adults [49], and the frequency and severity

of droughts is projected to increase due to climate change [2, 3]. Our results regarding the associations between poverty and HIV are also perhaps applicable to other causes of income shocks, such as the coronavirus disease pandemic [50] or rising food and commodity prices. With countries in SSA accounting for a very small percentage of the global emissions driving global warming, the interventions needed to stop this process would require a global response [2]. Alternatively, more localised responses may be appropriate. There is evidence that social protection cash transfer programs can be effective at reducing risky sexual behaviours, particularly among young women [51]. Additionally, further increasing ART coverage and viral suppression levels among people living with HIV could also help reduce HIV transmission even in the presence of increased risky sexual practices, as persons with undetectable viral loads have been shown to not transmit HIV [52]. However, adherence to ART can decrease in the presence of food insecurity [17, 25], which is strongly correlated to poverty and drought, highlighting the need for interventions to mitigate this problem.

## Conclusions

Our results provide increased evidence of the associations linking drought with increasing HIV transmission among women in rural areas of SSA via poverty and changing sexual behaviours. Interventions that could mitigate this effect of drought on HIV transmission should be considered. Future research should use longitudinal data to elucidate the temporal and causal associations for the pathway linking drought with increased HIV transmission.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s10461-024-04280-8>.

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**Author Contributions** AT, PV, and AL conceived and designed the study. AT and AL access and verified the combined dataset. RB provided the dataset on precipitation. AT performed the statistical analyses and wrote the original draft of the manuscript. All authors (AT, LJ, RB, AK, GH, SB, TW, AL, and PV) interpreted the data and critically revised the manuscript for important intellectual content. AT was responsible for the decision to submit the manuscript.

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**Data Availability** The PHIA datasets used in these analyses are available upon request on the PHIA website: <https://phia-data.icap.columbia.edu/>.

The data file designed by the World Food Programme's Vulnerability Analysis and Mapping Geospatial Analysis Team that compares historical rainfall patterns with rainfall between June 2014 to May 2016 is available on request - please contact the corresponding author for access as the datasets are very large.

## Declarations

**Ethical Approval and Consent to Participate** All PHIA survey protocols, consent forms, screening forms, refusal forms, referral forms, recruitment materials, and questionnaires were reviewed and approved by in-country ethics and regulatory bodies and the institutional review boards of Columbia University Medical Center, Westat, and the United States Centers for Disease Control.

**Consent for Publication** Not applicable.

**Competing interests** PV reports research grants from Gilead unrelated to this work. AT, AK, AL, GH, LJ, SB, RB, and TW report no transparency declarations.

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