Supplementary material for "Projected prevalence and incidence of HIV among female sex workers and sex clients in Rwanda: a Markov model examining intervention effects"

Description of algorithm

1. *Initialization*: starting with a perceived present state distribution of the different sub-populations (FSWs, sex clients and general public) and the states described in the *Model description* section across the Rwandan population. Initial values for average number of partners and number of acts per partner for the different populations were chosen to match estimated HIV incidence at present time.
2. *Progression*: for each year between 2017 and 2027, the following steps are repeated –
    i. Update transmission probabilities according to Equations (1) - (4) in the "Rwanda FSW HIV model - Supplementary material - HIV Transmission Probabilities - v2.1" attachment, and the subsequent transition probabilities between states.
    ii. Re-distribute the three sub-populations across the different states, according to the updated transition probabilities.
    iii. Update the number of different male partners each FSW encounters annually, to match the updated male partners population.
    iv. Calculate the number of newborns, to match Rwanda's population growth rate statistics.
    v. Draw a random sample of retired FSWs (to be joining the general public), whose number is derived from the life expectancy in Rwanda, to reflect retirement on reaching a certain age, and another random sample of newly recruited FSWs from the general public, using similar principles.
    vi. Similarly, swap individuals between the general public and the sex clients group.
    vii. Update population groups:
        - FSWs = FSWs* - FSW retirement + FSW recruitment
        - SCs = SCs* - SCs retirement + SCs recruitment
        - GP = GP* - FSWs recruitment + FSWs recruitment – SCs recruitment + SCs retirement

    where we use SCs and GP for sex clients and general public, respectively, and the * superscript denotes the re-distributed population according to the calculated transition probabilities.

HIV transmission probabilities

We consider three populations: female sex workers (FSWs), their male sex clients, and the general population, which is divided into the subgroups male and female. For each underlying population, a Markov chain, depicted in (1), is considered with the state space consisting of the following six states:

- HIV negative (HIV-)
- HIV positive (HIV+) undiagnosed
- HIV+ diagnosed pre-ART
- HIV+ diagnosed on ART with viral suppression
- HIV+ diagnosed on ART with virological failure. This includes both cases of the failure of an alternative treatment, as well as the failure due to not adhering to the treatment.
- Death

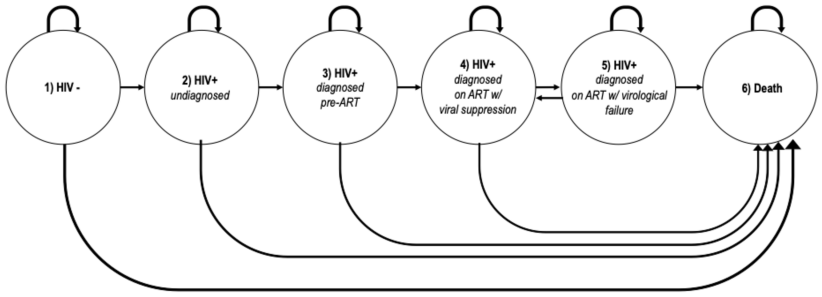


Figure 1: HIV Transmission Markov Model
Acronyms: HIV, *human immunodeficiency virus*; ART, *antiretroviral therapy*; "+", *positive*, and "-", *negative*.

Transition probabilities among the states is computed using the mortality rate, incidence rate, HIV testing rate, percentage of people selecting to start ART, ART failure rate, mortality rate for the ART patients with non-suppressed viral load, percentage of people starting an alternative ART, and the failure rate for the alternative ART, which we derived from the data set that was available to us (see Supplementary Table 1).

Let A_i be the event that an individual (male or female) does not become infected with HIV over the period, he (or she) is having intercourse with partner number i. We denote the number of intimate partners for each individual, over his (or her) lifetime, with $n \geq 1$. For simplicity, a fixed number of sex acts per partner is assumed for each individual, and is denoted by l. Assuming $A_1, A_2, \ldots, A_n$ are independent, we can therefore compute the probability (p) of HIV transmission through intercourse for each individual, within a specific population group, as follows:

$$\begin{aligned} p \triangleq P(\bigcup_{i=1}^{n} A_i^c) &= 1 - P(\bigcap_{i=1}^{n} A_i) \\ &= 1 - \prod_{i=1}^{n} P(A_i) \\ &= 1 - (P(A_1))^n. \end{aligned} \tag{1}$$

Given the states in our Markov chain model, a healthy individual could become infected with HIV through having intercourse with a HIV positive partner pre-ART, or with a HIV positive partner virally suppressed on ART, or with a HIV positive partner not virally suppressed on ART.

Let B be the event that the healthy individual becomes infected with HIV in a single sex act, C_0 be the event that his (or her) partner is HIV negative, C_1 be the event that his (or her) partner is HIV positive pre-ART, C_2 be the event that his (or her) partner is HIV positive virally suppressed on ART, and C_3 be the event that his (or her) partner is HIV positive virally unsuppressed on ART. Therefore,

$$P(A_1) = P(C_0) + \Big(1 - P(B|C_1)\Big)^l P(C_1) + \Big(1 - P(B|C_2)\Big)^l P(C_2) + \Big(1 - P(B|C_3)\Big)^l P(C_3). \tag{2}$$

Let D_1 be the event that the HIV transmission is through vaginal sex, and D_2 be the event that the HIV transmission is through anal sex. We denote the event that a preventative measure such as condom or PrEP is used in the sex act by E. The efficacy of such preventative measure is then denoted by e. For all $j = 1, 2, 3$, we compute $P(B|C_j)$ as follows:

$$P(B|C_j) = (1 - e)P(E)\Big[P(B|C_j, D_1)P(D_1) + P(B|C_j, D_2)P(D_2)\Big]. \tag{3}$$

Let E_1 be the event that only condom has been used as the preventative measure during the sex act, and E_2 be the event that only PrEP has been used as the preventative measure during the sex act.

$$\begin{aligned} P(E) &= P(E_1 \cup E_2) \\ &= P(E_1) + P(E_2) - P(E_1 \cap E_2). \end{aligned} \tag{4}$$

Supplementary tables

Supplementary Table 1. Demographic parameters for the study Markov model

Parameter	Estimate type	Base value	Lower bound	Upper bound	Source	Comments
All population						
Total size	N	11,809,264	--	--	NISR 2015[1]	Census data
HIV-	N	11,467,068	11,395,940	11,502,223	NISR 2015[1]; UNAIDS 2016[2]	Calculated using estimated HIV prevalence: 3.1% (2.6-3.5%)
HIV+	N	342,196	307,041	413,324	UNAIDS 2016[2]	Calculated using estimated HIV prevalence: 3.1% (2.6-3.5%)
Diagnosed HIV	N	317,859	233,351	392,658	UNAIDS 2016[2]	Number of people living with HIV who know their status (87%, 76%-95%)
Undiagnosed HIV	N	24,337	--	179,973	UNAIDS 2016[2]	Difference between HIV+ and diagnosed.
ART coverage in Rwanda	%	80%	69%	89%	UNAIDS 2016[2]	Reported % of adults and children receiving ART
HIV+ on ART	N	305,985	161,012	349,466	UNAIDS 2016[2]	Calculated using % of ART coverage – 80% (95% CI: 69-89%)
HIV+ with viral suppression on ART	N	156,679	112,499	244,172	UNAIDS 2016[2]; Nsanzimana 2015[3]	Calculated using % of patients who achieve viral suppression on ART (82.2%), assuming 85% adherence.
HIV+ with failed or discontinued ART	N	161,180	--	236,966	UNAIDS 2016[2]; Nsanzimana 2015[3]	Difference between ART and ART with viral suppression.
HIV+ pre-ART	N	11,874	--	231,646	UNAIDS 2016[2]	Calculated subtracting the number of HIV+ on ART from the HIV diagnosed
FSW population						
Total size	N	47,750	25,000	111,000	ESPHS Rwanda 2011[4]	Household survey data: 45000 (25000-111000)
HIV-	N	25,964	14,500	49,395	BBSS SW Rwanda 2016[5]	Calculated by subtracting number of HIV+

Parameter	Estimate type	Base value	Lower bound	Upper bound	Source	Comments
HIV prevalence	%	46%	42%	55%	BBSS SW Rwanda 2016[5]	National prevalence of HIV: 46%, HIV prevalence in Kigali (55%) and other provinces (42%) taken for upper and lower ranges
HIV+	N	21,786	10,500	61,605	BBSS SW Rwanda 2016[5]	Calculated using HIV prevalence rate of FSWs: 46% (42-55.5%)
Diagnosed HIV	N	20,803	7,980	58,525	BBSS SW Rwanda 2016[5]	Calculated using % of those who are HIV+ and diagnosed (87%; 95% CI: 76 - 95%)
Undiagnosed HIV	N	983	--	53,625	BBSS SW Rwanda 2016[5]	Calculated by subtracting number of diagnosed HIV
ART coverage for FSW in Rwanda	%	78.4%	74.2%	82.3%	BBSS SW Rwanda 2016[5]	Reported % of FSWs on ART at diagnosis: 74.8% (74.2-82.3%)
HIV+ on ART	N	20,032	7791	50,701	BBSS SW Rwanda 2016[5]	Calculated using % of ART coverage for FSW: 78.4% (74.2-82.3%)
HIV+ with viral suppression on ART	N	9,940	5,444	35,425	BBSS SW Rwanda 2016[5]	Calculated using % of patients who achieve viral suppression on ART (82.2%), assuming 85% adherence.
HIV+ with failed or discontinued ART	N	10,092	--	45,257	BBSS SW Rwanda 2016[5]	Calculated by subtracting number of FSWs without viral suppression on ART
HIV+ pre-ART	N	771	--	50,734	BBSS SW Rwanda 2016[5]	Calculated by subtracting number of FSWs with diagnosed HIV on ART
Sex client population						
Total size	N	156,611	42,300	177,000	ESPHS Rwanda 2011[4]	Estimated from Household survey data; used the highest number for base case
HIV-	N	133,808	38,916	141,600	BBSS SW Rwanda 2016[5]	Calculated by subtracting number of HIV+
HIV prevalence	%	15%	8%	20%	BBSS SW Rwanda 2016[5]	Assumed

Parameter	Estimate type	Base value	Lower bound	Upper bound	Source	Comments
HIV+	N	22,803	3,384	35,400	BBSS SW Rwanda 2016[5]	Calculated using assumed HIV prevalence
Diagnosed HIV	N	18,637	2,572	33,630	BBSS SW Rwanda 2016[5]	Calculated using % of those who are HIV+ and diagnosed (87%; 95% CI: 76 - 95%)
Undiagnosed HIV	N	4,166	--	32,828	BBSS SW Rwanda 2016[5]	Calculated by subtracting number of diagnosed HIV
HIV+ on ART	N	16,778	2,057	26,904	UNAIDS 2016[2]	Calculated using 80% of ART coverage
HIV+ with viral suppression on ART	N	9,815	1,438	18,798	UNAIDS 2016[2]; Nsanzimana 2015[3]	Calculated using % of patients who achieve viral suppression on ART (82.2%), assuming 85% adherence.
HIV+ with failed or discontinued ART	N	6,963	--	25,466	UNAIDS 2016[2]; Nsanzimana 2015[3]	Calculated subtracting patients with suppressed viral load from the overall ART numbers.
HIV+ pre-ART	N	1,859	--	31,573	UNAIDS 2016[2]	Calculated by subtracting Diagnosed HIV with HIV+ on ART

The base values used for the 2017-2027 model run were the output values for the 2010-2017 validation period.

Supplementary Table 2. Transition probabilities between health states, population growth and mortality rates, and HIV transmission probabilities

Parameter	Estimate type	Base value	Lower bound	Upper bound	Source	Comments
Transition probabilities between HIV health states						
Probability of being tested for HIV among FSWs	%	71.0%	70.6%	74.4%	BBSS SW Rwanda 2016[5]	70.6 - 74.4% reported being tested for HIV; took the lower bound as the base case as this is likely over-reported
Probability of being tested for HIV among general population	%	46.0%	44.5%	47.3%	RAIHIS 2013-14[6]	Assumed to be the same for male partners
Probability of being on ART among FSWs	%	80.0%	74.2%	82.3%	BBSS SW Rwanda 2016[5]	Percentage of those reporting yes to being enrolled on ART at HIV diagnosis
Probability of being on ART among general population	%	80.0%	69.0%	89.0%	UNAIDS, 2016[2]	Assumed to be the same for male partners
Probability of viral suppression given ART	%	82.2%	--	--	Nsanizimana 2015[7]	Estimated from Electronic medical records; Assumed to be the same for all groups
Probability of adhering to ART	%	90.0%	85.1%	97.3%	Elul 2013[8]; BBSS SW Rwanda 2015[5]	BBSS SW Rwanda 2015 (88.9%, 95% CI: 85.1 - 92.2%)
Probability of switching to second line ART	%	4.0%	3.8%	4.2%	Nsanizimana 2015[7]	Assumed to be the same who came back to care after being lost to follow-up at pre-ART
Probability of failing first line ART	%	17.8%	--	--	Nsanizimana 2015[7]	Calculated using 100 – probability of viral suppression given ART (82.2%)
Probability of switching to second line given failure of first line	%	22.5%	21.3%	23.6%	Nsanizimana 2015[7]	Calculated using probability of switching divided by probability of failing first line ART (17.8%)
Probability of going on ART given initial no ART	%	15.0%	25.1%	27.5%	Nsanizimana 2015[7]	% of those returning to ART
Parameters related to population growth, demographics, and changes						
Proportion of females among Rwanda general population	%	51.0%	--	--	World Bank 2016	100 to 196.17
Annual growth rate	%	2.5%	--	--	World Bank 2016	
Annual mortality rate for HIV- individuals	%	0.6%	--	--	World Bank 2016	General mortality rate (assumed to be equivalent for FSWs and male partners)
Annual mortality rate for virally suppressed HIV+ individuals	%	1.0%	0.9%	1.1%	Nsanizimana 2015[7]	Estimated mortality rate for those HIV positive on ART (assumed to be equivalent for FSWs and male partners)

Parameter	Estimate type	Base value	Lower bound	Upper bound	Source	Comments
Annual mortality rate for HIV+ not virally suppressed or undiagnosed	%	2.0%	2.0%	2.2%	Nsanizimana 2015[7]	Assumed to equivalent to those with virological failure (assumed to be equivalent for FSWs and male partners)
Parameters related to sexual intercourse						
Average number of sexual acts per sex client for FSWs	N	2.5	3.00	10.00	Assumed	Calibrated to present time incidence (Range assumed)
Average number of sex clients for FSWs (12 months)	N	52.00	26.00	104.00	Assumed	Calculated assuming one partner per week for base case (0.5/week for lower bound, and 2/week for upper bound)
Average number of sexual acts per partner for general population (12 months)	N	52	52.00	104.00	Rwanda DHS[1]	Calculated assuming 1.5 intercourse per week with one partner for base value (1 intercourse per week for lower bound and 2 intercourse per week for upper bound)
Average number of sexual partners for general population (12 months)	N	1.2	1.50	2.70	Rwanda DHS[1]	Assuming same as number of life time sexual partners (Range 1.5 - 2.7)
Condom efficacy	%	100%	60%	100%	Weller 2002[9], Jin 2009[10], Remis 2014[11]	Base case assumed 100% if reported consistent condom use, the lower bound was determined by the estimates reported from different studies
ART efficacy	%	82.2%	60.0%	95.0%	Nsanzimana 2015[7]	
PrEP efficacy	%	93.0%	60.0%	99.0%	Donnell 2014[12]	93% (95% CI: 60 - 99%)
Probability of condom use for sex workers	%	25.0%	16.4%	28.3%	BBSS SW Rwanda 2016[5]	Consistent condom use reported for last 30 days: 21.9% (95% CI: 16.4, 28.3%)
Probability of condom use for general public	%	12.5%	13.0%	55.7%	Rwanda DHS[1]	Calibrated to present time incidence assuming over-reporting of condom use; % reporting yes to using condom during last sexual intercourse in the past 12 months: Women: 48.4% (95% CI: 41.3 - 55.7%) and men: 28.0% (95% CI: 25.3 - 30.8%)
Probability of having vaginal sex	%	91.4%	90.1%	92.6%	BBSS SW Rwanda 2016[5]	Survey data, assumed complement of probability of anal sex
Probability of having anal sex	%	8.6%	7.4%	9.9%	BBSS SW Rwanda 2016[5]	Survey data (95% CI: 7.4% - 9.9%)
Probability of HIV infection through *receptive vaginal sex (unprotected)*	% per act	0.82%	0.39%	1.5%	Wawer 2005[13]	0.82/coital act (95% CI: 0.39%-1.5%)
Probability of HIV infection through *receptive anal sex,*	% per act	1.40%	0.48%	2.85%	Jin 2010[14]	95% CI: 0.48 - 2.85%

Parameter	Estimate type	Base value	Lower bound	Upper bound	Source	Comments
while not on ART (unprotected)						
Probability of HIV infection through *insertive vaginal sex*, while not on ART (unprotected)	% per act	0.040%	0.080%	2.0%	Baggaley 2010[15]	95% CI: 0.08 - 2.0%
Probability of HIV infection through *insertive anal sex*, while not on ART (unprotected)	% per act	0.34%	0.060%	0.62%	Jin 2010[14]	95% CI: 0.06 - 0.62%

The base values used for the 2017-2027 model run were the output values for the 2010-2017 validation period.

Supplementary Table 3. Probability transition matrix for the HIV transmission Markov model

	1. HIV-	**2. HIV+ undiagnosed**	**3. HIV+ diagnosed pre-ART**	**4. HIV+ ART suppressed VL**	**5. HIV+ ART non-uppressed VL**	**6. Death**
State 1. HIV-	[1-(1)]x[1-(2)]	[1-(1)]x(2)				(1)
State 2. HIV+ undiagnosed		[1-(3)]x[1-(4)]	[1-(3)]x(4)			(3)
State 3. HIV+ diagnosed pre-ART			[1-(5)]x[1-(6)]	[1-(5)]x(6)		(5)
State 4. HIV+ ART suppressed VL				[1-(7)]x(8)x[1-(9)]	[1-(7)]x[1-(8)+(8)x(9)]	(7)
State 5. HIV+ ART non-suppressed VL				[1-(10)]x(11)x[1-(12)]	[1-(10)]x[1-(11)x{1-(12)}]	(10)
State 6. Death						1

State 1: (1) GP mortality rate; (2) = Incidence;
State 2: (3) = HIV+ undiagnosed mortality rate; (4) = Testing rate;
State 3: (5) = Mortality rate pre-ART; (6) = % choosing to start ART
State 4: (7) = Mortality rate of ART suppressed with suppressed viral load; (8) = % adhering to ART; (9) = ART failure rate
State 5: (10) = Mortality rate for ART patients with non-supressed viral load; (11) = % starting alternative ART

Supplementary Table 4. Different scenario analyses of ART, condom, and PrEP, and changes in the number of FSWs on HIV prevalence

Description	Input			Output: Prevalence (%) at Year 2027								
				Female sex workers (FSWs)			Sex clients			General population		
	Base case	Worst case	Best case	Base case	Worst case	Best case	Base case	Worst case	Best case	Base case	Worst case	Best case
Scenario 1: Changes in testing and treatment for ART												
A) Probability of HIV test for FSW	0.71	0.50	0.90	37.37	37.36	37.38	17.87	18	17.8	2.32	2.32	2.32
B) Probability of HIV test for general population	0.46	0.30	0.80	37.37	37.75	36.92	17.87	17.84	17.91	2.32	2.32	2.31
C) % of national coverage of ART	0.80	0.60	0.90	37.37	37.59	37.28	17.87	17.97	17.84	2.32	2.32	2.32
D) % of consistent adherence to ART	0.90	0.74	0.95	37.37	38.42	36.99	17.87	18.86	17.5	2.32	2.35	2.3
E) Parameters above combined	--	--	--	37.37	38.94	36.4	17.87	19.02	17.42	2.32	2.36	2.29
Scenario 2: Changes in condom and PrEP use												
A) % of consistent condom use for FSWs*	0.45-0.55	0.30-0.40	0.75-0.85	37.37	41.96	29.51	17.87	21.27	11.9	2.32	2.32	2.3
B) % of consistent condom use for General population	0.30	0.2	0.45	37.37	37.4	37.32	17.87	17.91	17.85	2.32	2.44	2.15
C) % of consistent PrEP use for FSWs*	0.25-0.65	0.05-0.40	0.35-0.75	37.37	38.64	36.09	17.87	17.99	17.76	2.32	2.32	2.32
D) Parameters above combined	--	--	--	37.37	43.74	29.07	17.87	21.49	11.85	2.32	2.45	2.13
Scenario 3: Changes in number of FSWs												
A) Probability of women entering as a sex worker	0.0004	0.0008**	0.0002***	37.37	24.45	46.63	17.87	16.19	18.95	2.32	2.31	2.32
Combined scenarios												
A) Scenarios 1 and 2 combined	--	--	--	37.37	46.52	28.99	17.87	23.31	11.81	2.32	2.52	2.12
B) Scenarios 1, 2, and 3 combined	--	--	--	37.37	30.72	36.45	17.87	20.6	12.18	2.32	2.51	2.12

The probabilities of sex workers and clients disengaging from paid sex (i.e., transitioning back to the general population) are provided in the supplementary table 2
Prevalence (%) at year 2017: FSW = 45.4%; MP = 15.3%; Overall population = 2.9%
** Intervals represent starting point (2017) and end point (2027) assuming a linear increase over 10 years*
***2x times more young girls choosing to enter sex work assumed as the worse case*
****50% fewer young girls choosing to enter sex work assumed as the best case.*

Supplementary Table 5. Different scenario analyses of ART, condom, and PrEP, and changes in the number of FSWs on HIV incidence

Description	Input			Output: Incidence (Cases/1000 person-years) at Year 2027								
				Female sex workers (FSWs)			Sex clients			General population		
	Base case	Worst case	Best case	Base case	Worst case	Best case	Base case	Worst case	Best case	Base case	Worst case	Best case
Scenario 1: Changes in testing and treatment for ART												
A) Probability of HIV test for FSW	0.71	0.50	0.90	15.84	15.95	15.75	12.45	12.57	12.36	0.88	0.88	0.88
B) Probability of HIV test for general population	0.46	0.30	0.80	15.84	16.38	15.36	12.45	12.56	12.3	0.88	0.91	0.86
C) % of national coverage of ART	0.80	0.60	0.90	15.84	16.17	15.71	12.45	12.61	12.38	0.88	0.89	0.88
D) % of consistent adherence to ART	0.90	0.74	0.95	15.84	19.02	14.64	12.45	14.63	11.59	0.88	1.02	0.83
E) Parameters above combined	--	--	--	15.84	19.89	13.95	12.45	15.02	11.29	0.88	1.05	0.8
Scenario 2: Changes in condom and PrEP use												
A) % of consistent condom use for FSWs*	0.45-0.55	0.30-0.40	0.75-0.85	15.84	24.99	3.59	12.45	18.45	3.39	0.88	0.89	0.88
B) % of consistent condom use for General population	0.30	0.2	0.45	15.84	15.86	15.8	12.45	12.45	12.43	0.88	1.06	0.64
C) % of consistent PrEP use for FSWs*	0.25-0.65	0.05-0.45	0.35-0.75	15.84	20.23	11.49	12.45	12.86	12.03	0.88	0.88	0.88
D) Parameters above combined	--	--	--	15.84	32.01	2.61	12.45	19.22	3.34	0.88	1.07	0.64
Scenario 3: Changes in number of FSWs												
A) Probability of women entering as a sex worker	0.0004	0.0008**	0.0002***	15.84	8.94	21.47	12.45	8.24	15.42	0.88	0.88	0.88
Combined scenarios												
A) Scenarios 1 and 2 combined	--	--	--	15.84	41.1	2.4	12.45	23.72	3.12	0.88	1.28	0.59
B) Scenarios 1, 2, and 3 combined	--	--	--	15.84	22.68	3.15	12.45	15.9	3.91	0.88	1.28	0.59

The probabilities of sex workers and clients disengaging from paid sex (i.e., transitioning back to the general population) are provided in the supplementary table 2

Incidence (cases/1000 PY) at year 2017: FSW = 43.5.; MP = 18.2; Overall population = 1.4

** Intervals represent starting point (2017) and end point (2027) assuming a linear increase over 10 years*

***2x times more young girls choosing to enter sex work assumed as the worse case*

****1/2 times less young girls choosing to enter sex work assumed as the best case*

Supplementary Table 6. Overall number of people living with HIV in Rwanda from 2017 to 2027, with and without PrEP

Time	Overall number of people living with HIV, without PrEP			Overall number of people living with HIV, with PrEP		
	Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2017-01-01	344,769	344,971	345,183	344,757	344,971	345,182
2017-04-01	346,118	346,360	346,616	346,078	346,350	346,629
2017-07-01	347,466	347,742	348,072	347,438	347,743	348,035
2017-10-01	348,793	349,137	349,495	348,797	349,123	349,463
2018-01-01	350,148	350,527	350,908	350,154	350,514	350,888
2018-04-01	351,502	351,913	352,354	351,517	351,912	352,318
2018-07-01	352,876	353,306	353,748	352,867	353,300	353,746
2018-10-01	354,253	354,701	355,190	354,155	354,617	355,071
2019-01-01	355,614	356,097	356,590	355,447	355,920	356,399
2019-04-01	356,991	357,494	358,008	356,710	357,215	357,728
2019-07-01	358,351	358,887	359,450	358,020	358,510	359,062
2019-10-01	359,749	360,293	360,861	359,296	359,805	360,399
2020-01-01	361,108	361,691	362,263	360,557	361,094	361,694
2020-04-01	362,496	363,099	363,684	361,802	362,367	362,986
2020-07-01	363,887	364,496	365,094	363,069	363,658	364,303
2020-10-01	365,271	365,898	366,543	364,309	364,932	365,570
2021-01-01	366,701	367,316	367,955	365,562	366,212	366,866
2021-04-01	368,055	368,717	369,385	366,837	367,473	368,139
2021-07-01	369,434	370,123	370,793	368,079	368,732	369,410
2021-10-01	370,839	371,538	372,237	369,302	369,996	370,672
2022-01-01	372,235	372,954	373,679	370,540	371,261	371,969
2022-04-01	373,616	374,371	375,110	371,774	372,510	373,256
2022-07-01	375,023	375,780	376,494	372,994	373,755	374,525
2022-10-01	376,438	377,193	377,978	374,246	375,003	375,773
2023-01-01	377,829	378,626	379,410	375,469	376,248	377,007
2023-04-01	379,254	380,043	380,824	376,695	377,493	378,304
2023-07-01	380,648	381,465	382,240	377,876	378,707	379,539
2023-10-01	382,063	382,900	383,669	379,102	379,940	380,783
2024-01-01	383,466	384,317	385,105	380,359	381,169	382,024
2024-04-01	384,865	385,735	386,572	381,560	382,374	383,271
2024-07-01	386,290	387,164	388,007	382,742	383,583	384,501
2024-10-01	387,688	388,589	389,499	383,968	384,770	385,706
2025-01-01	389,109	390,014	390,964	385,147	385,978	386,915
2025-04-01	390,531	391,436	392,412	386,348	387,186	388,153
2025-07-01	391,940	392,867	393,813	387,484	388,395	389,373
2025-10-01	393,365	394,293	395,223	388,657	389,587	390,560
2026-01-01	394,741	395,714	396,680	389,807	390,772	391,764
2026-04-01	396,167	397,144	398,123	390,971	391,946	392,925
2026-07-01	397,584	398,570	399,574	392,141	393,125	394,107
2026-10-01	399,000	400,013	401,022	393,333	394,306	395,289

Time	Overall number of people living with HIV, without PrEP			Overall number of people living with HIV, with PrEP		
	Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2027-01-01	400,438	401,443	402,451	394,491	395,453	396,487

Supplementary Table 7. Overall incidence of HIV in Rwanda from 2017 to 2027, with and without PrEP (per 100 years)

	Overall HIV incidence (per 1000 person-years) without PrEP			Overall HIV incidence (per 1000 person-years) with PrEP		
Time	Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2017-01-01	1.358	1.360	1.362	1.358	1.360	1.362
2017-04-01	1.353	1.356	1.358	1.353	1.356	1.358
2017-07-01	1.349	1.352	1.355	1.349	1.352	1.355
2017-10-01	1.345	1.349	1.352	1.345	1.348	1.352
2018-01-01	1.342	1.345	1.349	1.342	1.345	1.348
2018-04-01	1.338	1.342	1.346	1.338	1.342	1.346
2018-07-01	1.335	1.339	1.342	1.335	1.339	1.342
2018-10-01	1.331	1.335	1.339	1.282	1.286	1.290
2019-01-01	1.328	1.332	1.336	1.276	1.280	1.283
2019-04-01	1.325	1.329	1.333	1.269	1.273	1.276
2019-07-01	1.322	1.325	1.330	1.262	1.266	1.270
2019-10-01	1.318	1.322	1.326	1.255	1.259	1.263
2020-01-01	1.314	1.318	1.323	1.248	1.252	1.256
2020-04-01	1.311	1.315	1.319	1.242	1.246	1.250
2020-07-01	1.307	1.311	1.315	1.235	1.239	1.243
2020-10-01	1.303	1.307	1.312	1.228	1.232	1.236
2021-01-01	1.300	1.304	1.308	1.222	1.226	1.230
2021-04-01	1.296	1.300	1.304	1.215	1.219	1.223
2021-07-01	1.292	1.296	1.300	1.208	1.212	1.216
2021-10-01	1.288	1.292	1.296	1.201	1.206	1.210
2022-01-01	1.284	1.288	1.292	1.195	1.199	1.203
2022-04-01	1.280	1.284	1.288	1.188	1.192	1.196
2022-07-01	1.276	1.280	1.284	1.181	1.185	1.189
2022-10-01	1.272	1.276	1.280	1.174	1.178	1.182
2023-01-01	1.268	1.272	1.276	1.168	1.171	1.175
2023-04-01	1.264	1.268	1.272	1.161	1.164	1.168
2023-07-01	1.259	1.263	1.268	1.154	1.158	1.161
2023-10-01	1.255	1.259	1.263	1.147	1.151	1.154
2024-01-01	1.251	1.255	1.259	1.140	1.144	1.147
2024-04-01	1.246	1.251	1.255	1.133	1.137	1.141
2024-07-01	1.242	1.246	1.251	1.127	1.130	1.134
2024-10-01	1.238	1.242	1.246	1.120	1.123	1.127
2025-01-01	1.233	1.238	1.242	1.113	1.116	1.120
2025-04-01	1.229	1.233	1.238	1.106	1.109	1.113
2025-07-01	1.225	1.229	1.233	1.099	1.103	1.106
2025-10-01	1.220	1.224	1.229	1.092	1.096	1.100
2026-01-01	1.215	1.220	1.224	1.085	1.089	1.093
2026-04-01	1.211	1.216	1.220	1.079	1.082	1.086
2026-07-01	1.207	1.211	1.216	1.072	1.076	1.079
2026-10-01	1.202	1.207	1.211	1.065	1.069	1.073

Time	Overall HIV incidence (per 1000 person-years) without PrEP			Overall HIV incidence (per 1000 person-years) with PrEP		
	Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2027-01-01	1.198	1.202	1.206	1.058	1.062	1.066

Supplementary Table 8. Number of FSWs and sex clients living with HIV in Rwanda from 2017 to 2027, with and without PrEP

Time	Population group	Number of people living with HIV, without PrEP			Number of people living with HIV, with PrEP		
		Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2017-01-01	Female sex workers	21,764	21,824	21,887	21,763	21,823	21,884
2017-04-01	Female sex workers	21,772	21,847	21,922	21,765	21,846	21,919
2017-07-01	Female sex workers	21,783	21,869	21,957	21,783	21,869	21,952
2017-10-01	Female sex workers	21,805	21,895	21,994	21,792	21,898	21,989
2018-01-01	Female sex workers	21,830	21,925	22,028	21,818	21,926	22,026
2018-04-01	Female sex workers	21,852	21,957	22,066	21,841	21,958	22,065
2018-07-01	Female sex workers	21,879	21,991	22,107	21,875	21,993	22,103
2018-10-01	Female sex workers	21,911	22,027	22,149	21,827	21,945	22,064
2019-01-01	Female sex workers	21,941	22,066	22,191	21,777	21,897	22,023
2019-04-01	Female sex workers	21,969	22,108	22,238	21,723	21,851	21,978
2019-07-01	Female sex workers	22,010	22,144	22,290	21,673	21,802	21,933
2019-10-01	Female sex workers	22,046	22,189	22,336	21,618	21,751	21,892
2020-01-01	Female sex workers	22,082	22,233	22,379	21,559	21,702	21,844
2020-04-01	Female sex workers	22,125	22,279	22,427	21,508	21,651	21,795
2020-07-01	Female sex workers	22,171	22,323	22,480	21,448	21,599	21,745
2020-10-01	Female sex workers	22,218	22,369	22,533	21,383	21,550	21,689
2021-01-01	Female sex workers	22,256	22,416	22,596	21,336	21,493	21,634
2021-04-01	Female sex workers	22,303	22,464	22,633	21,264	21,433	21,587
2021-07-01	Female sex workers	22,354	22,514	22,684	21,201	21,373	21,527
2021-10-01	Female sex workers	22,404	22,564	22,736	21,148	21,314	21,471
2022-01-01	Female sex workers	22,452	22,615	22,795	21,076	21,252	21,410
2022-04-01	Female sex workers	22,502	22,668	22,848	21,007	21,189	21,352
2022-07-01	Female sex workers	22,560	22,721	22,914	20,945	21,120	21,281
2022-10-01	Female sex workers	22,604	22,774	22,958	20,866	21,052	21,218
2023-01-01	Female sex workers	22,653	22,828	23,011	20,792	20,976	21,146
2023-04-01	Female sex workers	22,703	22,879	23,064	20,719	20,904	21,075
2023-07-01	Female sex workers	22,747	22,934	23,122	20,642	20,827	21,001
2023-10-01	Female sex workers	22,809	22,985	23,188	20,560	20,751	20,917
2024-01-01	Female sex workers	22,857	23,040	23,235	20,481	20,666	20,845
2024-04-01	Female sex workers	22,901	23,092	23,293	20,396	20,584	20,758
2024-07-01	Female sex workers	22,952	23,146	23,353	20,309	20,498	20,680
2024-10-01	Female sex workers	23,001	23,197	23,408	20,227	20,409	20,590
2025-01-01	Female sex workers	23,049	23,251	23,455	20,137	20,322	20,505
2025-04-01	Female sex workers	23,094	23,302	23,507	20,046	20,230	20,411
2025-07-01	Female sex workers	23,143	23,353	23,560	19,950	20,133	20,319
2025-10-01	Female sex workers	23,185	23,400	23,614	19,851	20,035	20,230
2026-01-01	Female sex workers	23,233	23,453	23,665	19,749	19,934	20,130
2026-04-01	Female sex workers	23,282	23,502	23,713	19,649	19,831	20,026
2026-07-01	Female sex workers	23,324	23,549	23,766	19,540	19,724	19,920
2026-10-01	Female sex workers	23,365	23,599	23,811	19,428	19,620	19,815
2027-01-01	Female sex workers	23,419	23,646	23,861	19,318	19,512	19,702
2017-01-01	Sex clients	23,458	23,544	23,633	23,456	23,541	23,628
2017-04-01	Sex clients	23,796	23,903	24,008	23,793	23,898	24,000

Time	Population group	Number of people living with HIV, without PrEP			Number of people living with HIV, with PrEP		
		Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2017-07-01	Sex clients	24,136	24,252	24,373	24,126	24,247	24,359
2017-10-01	Sex clients	24,460	24,595	24,729	24,460	24,589	24,713
2018-01-01	Sex clients	24,785	24,925	25,076	24,791	24,924	25,066
2018-04-01	Sex clients	25,103	25,258	25,421	25,108	25,254	25,406
2018-07-01	Sex clients	25,418	25,579	25,749	25,421	25,574	25,729
2018-10-01	Sex clients	25,726	25,895	26,060	25,717	25,892	26,055
2019-01-01	Sex clients	26,022	26,202	26,388	26,009	26,193	26,366
2019-04-01	Sex clients	26,321	26,505	26,691	26,296	26,488	26,678
2019-07-01	Sex clients	26,607	26,800	26,988	26,583	26,775	26,971
2019-10-01	Sex clients	26,902	27,094	27,289	26,848	27,055	27,260
2020-01-01	Sex clients	27,177	27,379	27,574	27,112	27,322	27,541
2020-04-01	Sex clients	27,447	27,659	27,859	27,380	27,583	27,798
2020-07-01	Sex clients	27,716	27,936	28,144	27,612	27,840	28,056
2020-10-01	Sex clients	27,980	28,207	28,419	27,860	28,092	28,312
2021-01-01	Sex clients	28,237	28,468	28,701	28,083	28,322	28,562
2021-04-01	Sex clients	28,484	28,731	28,967	28,311	28,552	28,791
2021-07-01	Sex clients	28,738	28,983	29,235	28,529	28,777	29,021
2021-10-01	Sex clients	28,982	29,233	29,475	28,739	29,000	29,241
2022-01-01	Sex clients	29,225	29,477	29,715	28,955	29,213	29,465
2022-04-01	Sex clients	29,469	29,713	29,952	29,164	29,414	29,666
2022-07-01	Sex clients	29,693	29,946	30,195	29,362	29,613	29,859
2022-10-01	Sex clients	29,916	30,175	30,429	29,540	29,804	30,064
2023-01-01	Sex clients	30,139	30,399	30,644	29,731	29,992	30,247
2023-04-01	Sex clients	30,354	30,619	30,882	29,903	30,167	30,435
2023-07-01	Sex clients	30,563	30,837	31,096	30,072	30,340	30,620
2023-10-01	Sex clients	30,760	31,046	31,310	30,236	30,510	30,781
2024-01-01	Sex clients	30,961	31,258	31,526	30,400	30,666	30,952
2024-04-01	Sex clients	31,157	31,460	31,725	30,536	30,819	31,115
2024-07-01	Sex clients	31,359	31,659	31,935	30,684	30,968	31,262
2024-10-01	Sex clients	31,552	31,856	32,133	30,813	31,108	31,398
2025-01-01	Sex clients	31,741	32,050	32,325	30,955	31,242	31,528
2025-04-01	Sex clients	31,933	32,237	32,515	31,082	31,371	31,659
2025-07-01	Sex clients	32,100	32,418	32,706	31,192	31,492	31,796
2025-10-01	Sex clients	32,281	32,597	32,874	31,303	31,608	31,917
2026-01-01	Sex clients	32,439	32,772	33,059	31,407	31,721	32,031
2026-04-01	Sex clients	32,607	32,943	33,227	31,505	31,826	32,117
2026-07-01	Sex clients	32,789	33,112	33,400	31,608	31,925	32,225
2026-10-01	Sex clients	32,946	33,272	33,560	31,690	32,017	32,337
2027-01-01	Sex clients	33,108	33,439	33,729	31,774	32,107	32,430

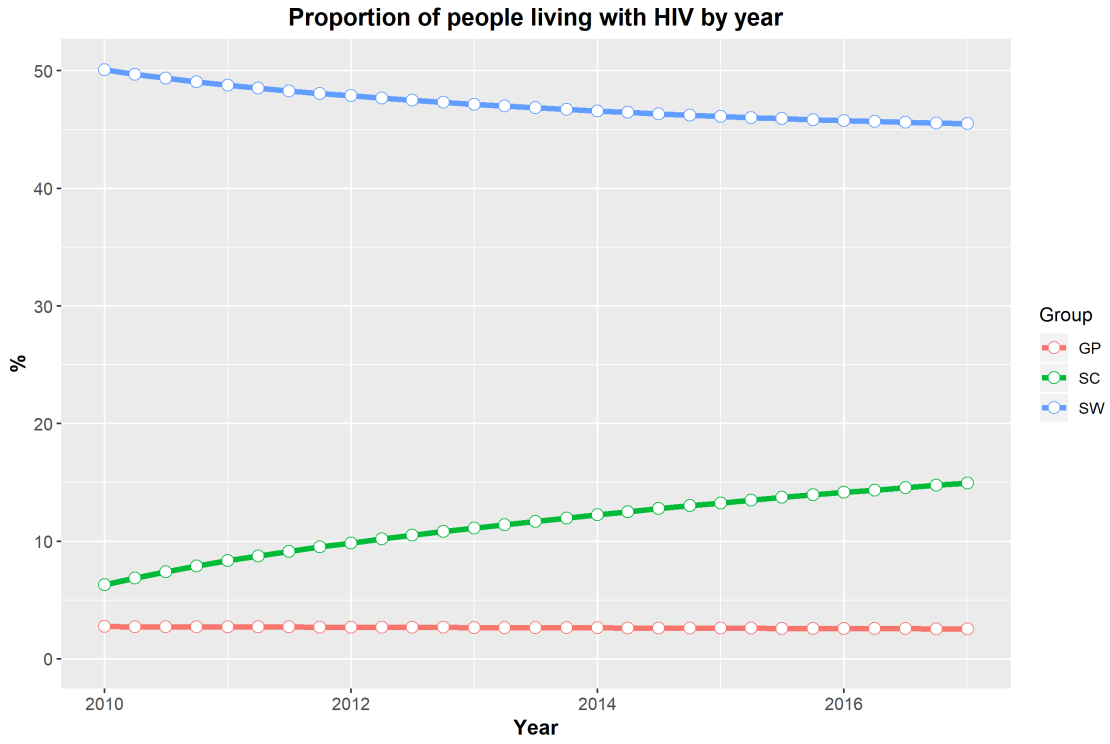
Supplementary Table 9. Incidence of HIV among FSWs and sex clients in Rwanda from 2017 to 2027, with and without PrEP (per 1000 person-years)

Time	Population group	HIV incidence (per 1000 person-years) without PrEP			HIV incidence (per 1000 person-years) with PrEP		
		Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2017-01-01	Female sex workers	42.38	42.60	42.82	42.38	42.59	42.83
2017-04-01	Female sex workers	42.53	42.84	43.16	42.55	42.83	43.13
2017-07-01	Female sex workers	42.74	43.10	43.42	42.76	43.09	43.46
2017-10-01	Female sex workers	42.98	43.35	43.71	42.95	43.34	43.72
2018-01-01	Female sex workers	43.18	43.60	44.02	43.18	43.58	44.01
2018-04-01	Female sex workers	43.40	43.84	44.27	43.42	43.83	44.30
2018-07-01	Female sex workers	43.60	44.07	44.54	43.65	44.05	44.52
2018-10-01	Female sex workers	43.81	44.29	44.78	31.82	32.13	32.48
2019-01-01	Female sex workers	44.02	44.50	44.96	31.44	31.76	32.12
2019-04-01	Female sex workers	44.21	44.69	45.14	31.08	31.38	31.74
2019-07-01	Female sex workers	44.40	44.87	45.35	30.66	30.99	31.32
2019-10-01	Female sex workers	44.57	45.02	45.51	30.25	30.57	30.91
2020-01-01	Female sex workers	44.68	45.18	45.65	29.80	30.13	30.46
2020-04-01	Female sex workers	44.83	45.33	45.82	29.35	29.67	30.00
2020-07-01	Female sex workers	44.96	45.46	45.94	28.88	29.21	29.54
2020-10-01	Female sex workers	45.07	45.58	46.07	28.41	28.73	29.05
2021-01-01	Female sex workers	45.17	45.67	46.19	27.91	28.25	28.55
2021-04-01	Female sex workers	45.25	45.78	46.33	27.40	27.73	28.04
2021-07-01	Female sex workers	45.33	45.85	46.38	26.90	27.22	27.54
2021-10-01	Female sex workers	45.40	45.92	46.46	26.39	26.70	27.03
2022-01-01	Female sex workers	45.45	45.98	46.49	25.87	26.17	26.49
2022-04-01	Female sex workers	45.49	46.02	46.55	25.34	25.63	25.94
2022-07-01	Female sex workers	45.54	46.05	46.58	24.80	25.09	25.38
2022-10-01	Female sex workers	45.54	46.07	46.57	24.25	24.53	24.82
2023-01-01	Female sex workers	45.59	46.07	46.59	23.69	23.97	24.25
2023-04-01	Female sex workers	45.55	46.06	46.60	23.12	23.41	23.68
2023-07-01	Female sex workers	45.56	46.05	46.56	22.55	22.85	23.12
2023-10-01	Female sex workers	45.52	46.01	46.60	22.00	22.28	22.54
2024-01-01	Female sex workers	45.47	45.99	46.52	21.44	21.70	21.95
2024-04-01	Female sex workers	45.43	45.94	46.48	20.86	21.11	21.37
2024-07-01	Female sex workers	45.33	45.90	46.44	20.31	20.53	20.78
2024-10-01	Female sex workers	45.28	45.84	46.41	19.71	19.95	20.19
2025-01-01	Female sex workers	45.20	45.77	46.32	19.14	19.36	19.60
2025-04-01	Female sex workers	45.11	45.69	46.24	18.55	18.77	19.00
2025-07-01	Female sex workers	45.05	45.61	46.14	17.97	18.18	18.40
2025-10-01	Female sex workers	44.91	45.53	46.05	17.38	17.60	17.82
2026-01-01	Female sex workers	44.84	45.42	45.91	16.81	17.01	17.22
2026-04-01	Female sex workers	44.72	45.31	45.85	16.23	16.42	16.62
2026-07-01	Female sex workers	44.60	45.19	45.72	15.64	15.83	16.02
2026-10-01	Female sex workers	44.53	45.07	45.63	15.06	15.25	15.43
2027-01-01	Female sex workers	44.40	44.94	45.50	14.48	14.66	14.85
2017-01-01	Sex clients	18.21	18.30	18.39	18.21	18.30	18.39
2017-04-01	Sex clients	18.05	18.17	18.29	18.06	18.17	18.29

Time	Population group	HIV incidence (per 1000 person-years) without PrEP			HIV incidence (per 1000 person-years) with PrEP		
		Lower limit	Median	Upper limit	Lower limit	Median	Upper limit
2017-07-01	Sex clients	17.91	18.05	18.18	17.91	18.05	18.19
2017-10-01	Sex clients	17.78	17.93	18.09	17.79	17.93	18.07
2018-01-01	Sex clients	17.67	17.82	17.98	17.67	17.82	17.97
2018-04-01	Sex clients	17.55	17.72	17.88	17.55	17.71	17.88
2018-07-01	Sex clients	17.45	17.62	17.78	17.45	17.62	17.78
2018-10-01	Sex clients	17.35	17.51	17.68	17.35	17.52	17.68
2019-01-01	Sex clients	17.26	17.41	17.58	17.15	17.31	17.49
2019-04-01	Sex clients	17.16	17.32	17.49	16.95	17.11	17.29
2019-07-01	Sex clients	17.07	17.23	17.40	16.75	16.92	17.10
2019-10-01	Sex clients	16.97	17.14	17.30	16.57	16.74	16.92
2020-01-01	Sex clients	16.87	17.05	17.22	16.38	16.57	16.74
2020-04-01	Sex clients	16.80	16.96	17.13	16.22	16.40	16.57
2020-07-01	Sex clients	16.69	16.87	17.04	16.05	16.24	16.41
2020-10-01	Sex clients	16.62	16.78	16.96	15.90	16.08	16.26
2021-01-01	Sex clients	16.53	16.70	16.87	15.76	15.93	16.11
2021-04-01	Sex clients	16.43	16.61	16.78	15.60	15.78	15.95
2021-07-01	Sex clients	16.35	16.53	16.71	15.44	15.63	15.80
2021-10-01	Sex clients	16.27	16.44	16.62	15.30	15.48	15.64
2022-01-01	Sex clients	16.19	16.36	16.54	15.14	15.33	15.50
2022-04-01	Sex clients	16.10	16.27	16.45	15.00	15.17	15.34
2022-07-01	Sex clients	16.01	16.19	16.37	14.84	15.02	15.19
2022-10-01	Sex clients	15.93	16.11	16.29	14.70	14.86	15.03
2023-01-01	Sex clients	15.85	16.03	16.20	14.56	14.71	14.87
2023-04-01	Sex clients	15.78	15.94	16.11	14.39	14.55	14.72
2023-07-01	Sex clients	15.69	15.86	16.02	14.23	14.40	14.56
2023-10-01	Sex clients	15.60	15.78	15.95	14.07	14.23	14.39
2024-01-01	Sex clients	15.53	15.69	15.88	13.92	14.07	14.23
2024-04-01	Sex clients	15.44	15.61	15.80	13.76	13.92	14.06
2024-07-01	Sex clients	15.37	15.53	15.71	13.60	13.76	13.90
2024-10-01	Sex clients	15.28	15.45	15.62	13.44	13.59	13.74
2025-01-01	Sex clients	15.20	15.37	15.55	13.27	13.43	13.59
2025-04-01	Sex clients	15.10	15.28	15.46	13.10	13.27	13.41
2025-07-01	Sex clients	15.02	15.19	15.37	12.94	13.11	13.26
2025-10-01	Sex clients	14.94	15.11	15.29	12.78	12.94	13.10
2026-01-01	Sex clients	14.86	15.03	15.20	12.61	12.78	12.94
2026-04-01	Sex clients	14.77	14.94	15.12	12.45	12.61	12.77
2026-07-01	Sex clients	14.69	14.86	15.03	12.29	12.45	12.60
2026-10-01	Sex clients	14.59	14.77	14.94	12.12	12.28	12.43
2027-01-01	Sex clients	14.51	14.69	14.86	11.97	12.11	12.27

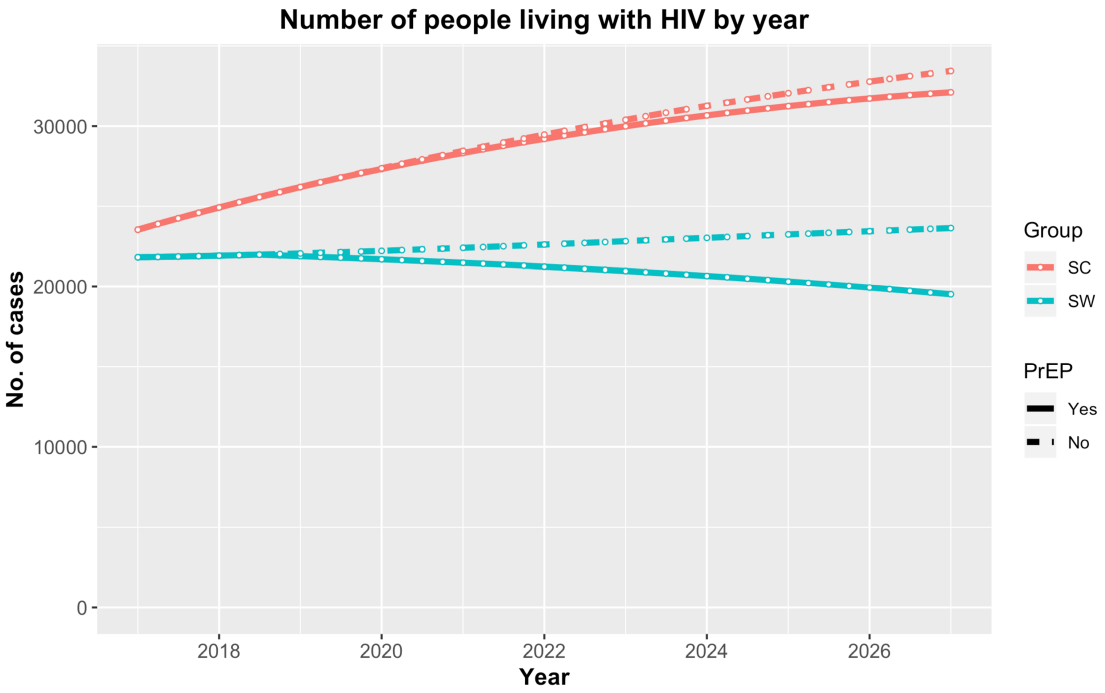
Supplementary figures

Supplementary Figure 1. HIV prevalence among FSWs and sex clients from 2010 to 2017 (calibration)



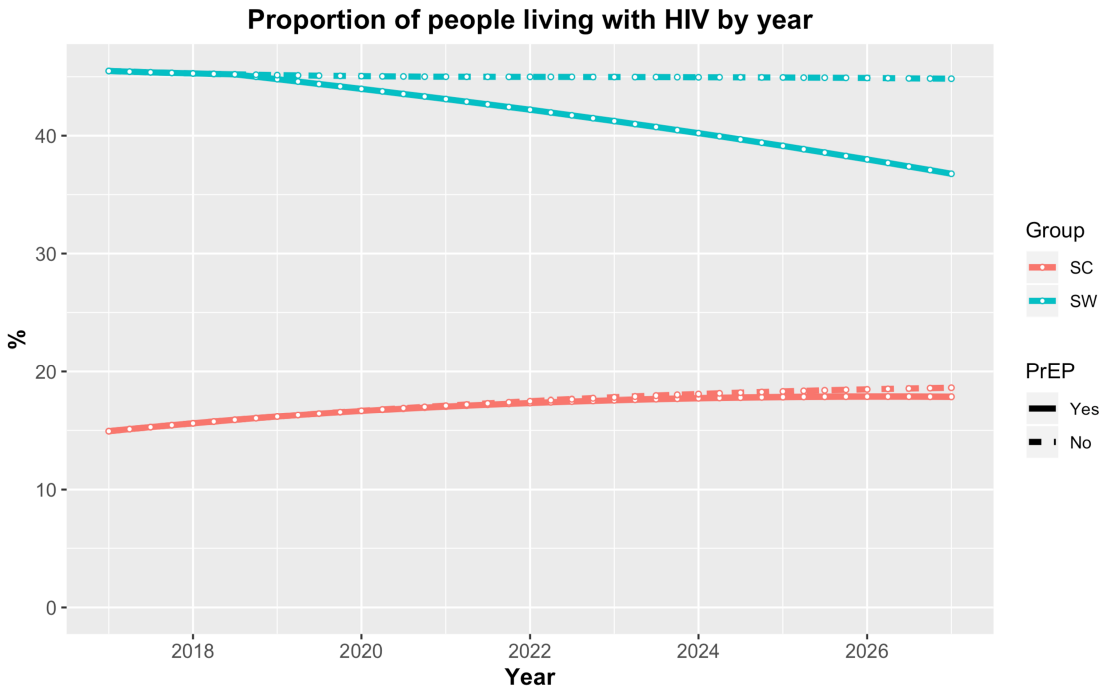
Acronyms: GP, general population; SC, sex clients; FSW, female sex workers

Supplementary Figure 2. Number of FSWs and sex clients living with HIV over time with or without PrEP



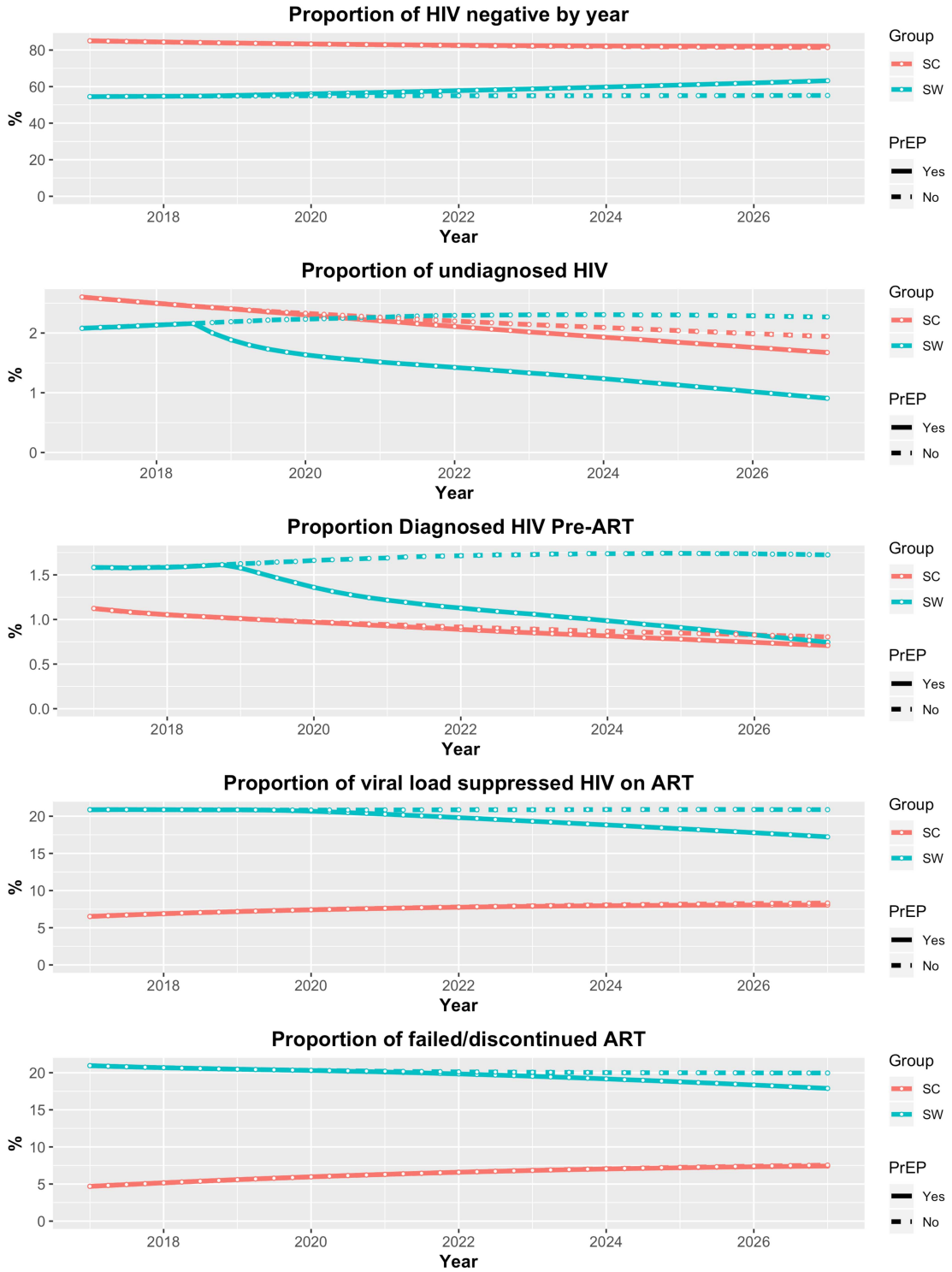
Acronyms: PrEP, pre-exposure prophylaxis; SC, sex clients; FSW, female sex workers

Supplementary Figure 3. Proportion of FSWs and sex clients living with HIV with or without PrEP

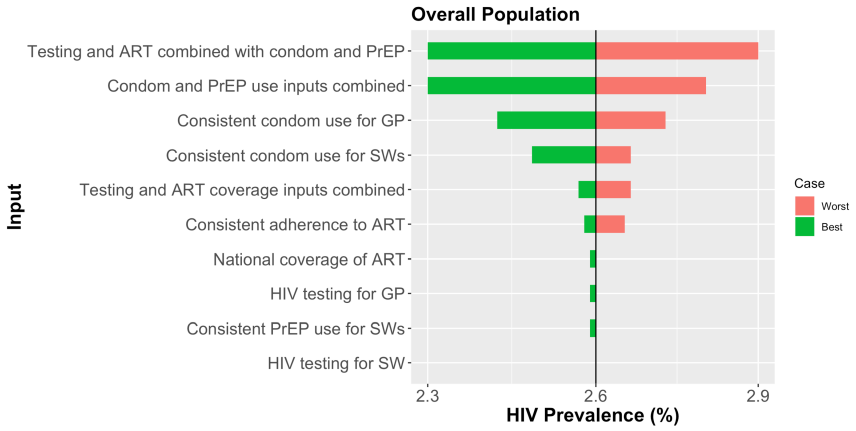


Acronyms: PrEP, pre-exposure prophylaxis; SC, sex clients; FSW, female sex workers

Supplementary Figure 4. Different Markov states of FSWs and sex clients

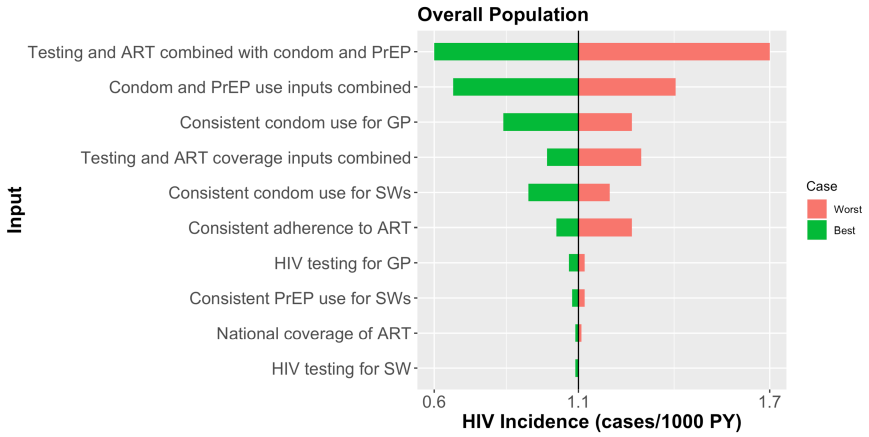


Supplementary Figure 5. Sensitivity analyses (tornado diagrams) of HIV prevalence for FSWs, clients, and overall population



Legend: Best-case and worst-case are shown in green and red color, respectively.
Acronyms: PrEP, pre-exposure prophylaxis; SW, female sex workers; GP, general population; ART, antiretroviral therapy.

Supplementary Figure 6. Sensitivity analyses (tornado diagrams) of HIV incidence for FSWs, clients, and overall population



Legend: Best-case and worst-case are shown in green and red color, respectively.
Acronyms: PrEP, pre-exposure prophylaxis; SW, female sex workers; GP, general population; ART, antiretroviral therapy.

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