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Increasing age and duration of sex work among female sex workers in South Africa and implications for HIV incidence estimation: Bayesian evidence synthesis and simulation exercise

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ABSTRACT

Introduction: In sub-Saharan Africa, accurate estimates of the HIV epidemic in female sex workers are crucial for effective prevention and care strategies. These estimates are typically derived from mathematical models that assume certain demographic and behavioural characteristics like age and duration of sex work to remain constant over time. We reviewed this assumption for female sex workers in South Africa.

Methods: We reviewed studies that reported estimates on either the age or the duration of sex work among female sex workers in South Africa. We used Bayesian hierarchical models to synthesize reported estimates and to study time trends. In a simulation exercise, we also investigated the potential impact of the "constant age and sex work duration"-assumption on estimates of HIV incidence.

Results: We included 24 different studies, conducted between 1996 and 2019, contributing 42 estimates on female sex worker age and 27 estimates on sex work duration. There was evidence suggesting an increase in both the duration of sex work and the age of female sex workers over time. According to the fitted models, over each decade the expected duration of sex work increased by 55.6% (95%-credible interval [CrI]: 23.5%–93.9%) and the expected age of female sex workers increased by 14.3% (95%-CrI: 9.1%–19.1%). Over the 23-year period, the predicted mean duration of sex work increased from 2.7 years in 1996 to 7.4 years in 2019, while the predicted mean age increased from 26.4 years to 32.3 years. Allowing for these time trends in the simulation exercise resulted in a notable decline in estimated HIV incidence rate among sex workers over time. This decline was significantly more pronounced than when assuming a constant age and duration of sex work.

Conclusions: In South Africa, age and duration of sex work in female sex workers increased over time. While this trend might be influenced by factors like expanding community mobilization and improved rights advocacy, the ongoing criminalisation, stigmatisation of sex work and lack of alternative employment opportunities could also be contributing. It is important to account for these changes when estimating HIV indicators in female sex workers.

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1. Introduction

In sub-Saharan Africa, female sex workers represent a marginalized and hard-to-reach population (Scorgie et al., 2012). They face numerous challenges, including social stigma, discrimination, gender-based violence, and human rights violations due to the nature and criminalisation of their work (Jewkes, Milovanovic, et al., 2021; Jewkes, Otwombe, et al., 2021; Scorgie et al., 2011; Shannon et al., 2018; UNAIDS, 2022). At the same time, female sex workers are disproportionately affected by HIV. According to a recent report by the Joint United Nations Programme on HIV/AIDS (UNAIDS), the median HIV prevalence among sex workers across countries in eastern and southern Africa between 2017 and 2021 was 33.4%, exceeding UNAIDS' estimate of the region's adult HIV prevalence of 6.2% by over fivefold (UNAIDS, 2022). Some modelling studies suggest a changing role of sex work in the historical course of the HIV epidemic in the region. For example, models of the South African HIV epidemic suggest transmission between sex workers and clients contributed more to HIV transmission in the early stages of the HIV epidemic than in the period after 2010 (Bekker et al., 2015; Stone et al., 2021). For the entire eastern and southern African region, UNAIDS estimated that in 2022, sex workers accounted for 5.4% of the region's new HIV infections, while clients of female sex workers contributed 11%, highlighting the persistent and critical role of sex work in the epidemic's transmission dynamics (Korenromp et al., 2024). Despite substantial declines in HIV incidence in much of southern and eastern Africa in the past decade (Garnett, 2021), concerns persist about HIV becoming increasingly concentrated in female sex workers and other key populations (Barr et al., 2021), particularly if they lack access to essential services, such as HIV prevention and care programmes (Lancaster et al., 2016; Tokar et al., 2018).

Accurate estimates of the HIV epidemic, particularly among key populations like female sex workers, are vital for UNAIDS' assessment of key populations' contributions towards new HIV infections and the development of effective prevention and care strategies. Transmission-dynamic mathematical models, such as the AIDS Epidemic Model (AEM) (for countries with concentrated HIV epidemics, primarily outside sub-Saharan Africa), the Estimation and Projection Package (EPP), the Goals model, the Optima model, and the Thembisa model (tailored to the South African HIV epidemic), have been instrumental in generating these estimates (Brown et al., 2006; Brown & Peerapatanapokin, 2004; Johnson et al., 2017; Kerr et al., 2015; Stone et al., 2021; Stover et al., 2021). These models rely on various data inputs and assumptions to model the HIV epidemic. For female sex workers, the inputs not only concern HIV prevalence rates, but also several behavioural and demographic characteristics, such as condom use, client contact rates, age, and the duration of sex work. Most models assume the latter two characteristics remain constant over time, which may potentially impact the generated HIV figures. Estimates of HIV incidence in female sex workers for example may be sensitive to assumptions about their 'turnover' and pre-entry HIV prevalence levels, which are tied to the average duration of sex work and the average age, respectively.

As in many other countries, the landscape of sex work in South Africa has undergone significant changes since the early 1990s, driven by shifting social attitudes, human rights considerations, and public health programmes. Over time, numerous initiatives have emerged with the aim of decriminalising sex work (Human Rights Watch, 2019; Matlala & Odeku, 2021). Simultaneously, multiple HIV prevention and treatment programmes for female sex workers have been implemented as part of the South African National Sex Workers Plan (SANAC, 2019) and South Africa's National Strategic Plan for HIV, TB and STIs (SANAC, 2023). Alongside potential shifts in socioeconomic conditions and migration patterns, these developments may have influenced the profiles of female sex workers in South Africa. Consequently, it is uncertain whether the assumption of constant age and sex work duration is valid. This study aims to assess whether there is evidence of changes in these characteristics over time and to explore the implications of changes for model-based estimates of HIV incidence in female sex workers.

2. Methods

2.1. Literature search, data extraction and definitions

To gather all published data on age and duration of sex work among female sex workers in South Africa, we conducted a comprehensive review of studies and data sources cited in the latest Thembisa model report (Johnson et al., 2017). Using these references as a starting point, we searched multiple bibliographic databases (PubMed, Web of Science, Google Scholar) for additional relevant studies on South African female sex workers. We included studies published since 1995 focusing on women engaged in commercial sex work and did not consider studies who reported on transactional sex only. For each identified study, we extracted information on female sex worker age and sex work duration, as well as the number of participants, exclusion criteria, study location, and the study year. If the study year was not reported, we assumed it was conducted three years prior to publication. If the study presented data stratified by location, we extracted the data separately for each location.

2.2. Statistical framework

2.2.1. Distributional assumptions

To align with the Thembisa model (Johnson et al., 2017), we made the following assumptions about the sex worker populations contributing data to the studies.

- For study j, the durations of sex work d_{ji} for individuals $i = 1,\ldots,n_j$, are independent and follow an Exponential distribution with rate λ_j:

$$d_{ji} \overset{iid}{\sim} \mathrm{Exp}(\lambda_j) \tag{1}$$

- For study j, the ages a_{ji} of individuals $i = 1,\ldots,n_j$, are independent and follow a Gamma distribution with shape α_j, rate β_j and an offset of 10 years (to avoid ages below 10 years):

$$a_{ji} - 10 \overset{iid}{\sim} \mathrm{Gamma}(\alpha_j, \beta_j) \tag{2}$$

2.2.2. Adjustment of data

Studies typically provided summary statistics (e.g., mean, or median) of sex work duration and female sex worker age instead of the individual-level data d_{ji} and a_{ji}. There were two challenges with the reported data. First, different studies reported different summary statistics (means, medians, or other quantiles). Second, many studies excluded individuals below a certain age, leading to truncation-induced bias in reported figures concerning age of female sex workers. To address these issues, we conducted data adjustment, transforming medians and other quantiles into means and correcting for potential truncation-induced bias, guided by distributional assumptions (1) and (2). The detailed adjustment approach can be found in the **supplementary appendix**.

2.2.3. Trend estimation

We developed two Bayesian hierarchical meta-regression models to estimate time trends in the mean duration of sex work (the "Duration-model") and the mean age of female sex workers (the "Age-model"). In summary:

1) **Duration-model:** Input data included adjusted mean sex work durations $\overline{d}_j$, study sizes n_j and study years t_j from all studies j that provided information on sex work duration. The likelihood of the observed data was specified based on assumption (1). We assumed a log-linear relationship between the expected duration of sex work $E[d_{ji}] = 1/\lambda_j$ and the study year t_j: $1/\lambda_j = \exp(\theta_j + \gamma \cdot t_j)$ (accounting for study-population heterogeneity with random intercepts θ_j while assuming a common slope γ over time).
2) **Age-model:** Input data consisted of adjusted mean ages $\overline{a}_j$, adjusted age standard deviations s_j (if available), study sizes n_j and study years t_j from all relevant studies. We used assumption (2) to build the likelihood of the observed data and assumed a log-linear relationship between the expected age of female sex workers $E[a_{ji} - 10] = \alpha_j/\beta_j$ and the study year t_j: $\alpha_j/\beta_j = \exp(\eta_j + \omega \cdot t_j)$ (accounting for study-population heterogeneity with random intercepts η_j while assuming a common slope ω over time). Additionally, we assumed a constant coefficient of variation $c_{vj} = 1/\sqrt{\alpha_j} = c_v$ across studies.

For both models we assumed weakly informative prior distributions for parameters, except for c_v, where an informative prior distribution was used. More information about the model structure and prior distributions can be found in the **supplementary appendix**.

2.2.4. Sensitivity analyses

We did four sensitivity analyses. The first one addressed the fact that studies typically reported "current" age of female sex workers rather than their age at entry into sex work. Consequently, when applying the Age-model as previously described, it captures age trends *during sex work*. An observed increase does not necessarily imply a higher age at the onset of sex work; it could also be due to a simultaneous increase in the duration of sex work. To address this, we conducted a sensitivity analysis examining trends in the ages *at entry into sex work*. We included only studies providing both the adjusted mean age and the mean duration of sex work. We defined the mean age at entry into sex work by subtracting the adjusted mean duration of sex work from the adjusted mean age. Similarly, we determined the year of starting sex work by subtracting the adjusted mean duration of sex work from the study year. We then fitted the Age-model using these variables as input data. In the second sensitivity analysis, we explored how much results changed if we excluded the study by Milovanovic et al., which contributed the most estimates on female sex worker age and sex work duration. In the third sensitivity analysis, we addressed the fact that there were five studies included which have used RDS as recruitment approach and have reported both crude and RDS-weighted proportions for quantiles of female sex worker ages and sex work duration (Lafort et al., 2016, 2018; Schwartz et al., 2017; The Aurum Institute, Anova Health Institute, & UCSF, 2020; UCSF, Anova Health Institute, & WRHI, 2015). The main analysis used adjusted means derived from crude proportions, given the absence of weight incorporation in the other studies. In this sensitivity analysis, we assessed differences in results when substituting adjusted means derived from RDS-weighted proportions for the five studies. Lastly, we investigated the impact of the 10-year offset in the assumed gamma distribution for individual sex worker ages, a choice made to align with the Thembisa model. It is worth noting that several other HIV transmission models opt for a 15-year offset instead. The fourth sensitivity analysis thus involved exploring the differences in estimated time trends between employing a 10-year offset, as in the main analysis, and a 15-year offset.

2.2.5. Simulation exercise

We conducted a simulation exercise to examine the potential impact of estimated time trends on HIV incidence estimates in female sex workers. The detailed approach can be found in the **supplementary appendix**. In brief, the HIV incidence rate in female sex workers $\rho(t)$ at time t can - under simplifying assumptions - be expressed in terms of the overall HIV prevalence in female sex workers $P(t)$, the prevalence at entry into sex work $P_0(t)$ and the rate of leaving sex work $\lambda(t)$ as:

$$\rho(t) = (dP(t)\,/\,dt + \lambda(t) \cdot (P(t) - P_0(t)))\,/\,(1 - P(t)) \tag{3}$$

We used the following input data and assumptions in (3) to estimate $\rho(t)$:

i) For $P(t)$ and $dP(t)/dt$ we used Thembisa's annual HIV prevalence estimates in female sex workers, which are based on calibration to sex worker survey data (Johnson et al., 2017).
ii) For $\lambda(t)$ we drew samples from the posterior predictive distribution of expected sex work duration from the Duration-model fit. $\lambda(t)$ was calculated as the inverse of the estimated expected duration.
iii) For $P_0(t)$, the prevalence at entry into sex work, we assumed it was equal to the HIV prevalence of the general female population *in the same age group* at that time $P_{\text{female}}(t)$ multiplied by a factor r: $P_0(t) = r \cdot P_{\text{female}}(t)$. We used draws from the posterior predictive distribution of the expected age of female sex workers from the Age-model fit and matched them with Thembisa's *age-specific* annual HIV prevalence estimates in females (Johnson et al., 2017). We allowed r to range between 1 (HIV prevalence at entry into sex work equals the prevalence of the general female population of the same age) and 2 (HIV prevalence at entry into sex work is twice the prevalence in the general female population of the same age). The r parameter was included to reflect uncertainty regarding the relative risk of HIV prior to entry into sex work.

We then compared trends in the resulting estimated HIV incidence rate in female sex workers to those assuming constant sex work duration and age over time. For the latter, we estimated mean sex work duration and mean age of female sex workers by fitting the Duration- and Age-model, allowing for random intercepts but no slope over time, and used the obtained results in steps ii) and iii) above.

All analyses were conducted in a Bayesian framework with the *rstan* package in *R* (version 4.3.0) (Carpenter et al., 2017). We summarize estimated posterior (predictive) distributions with medians and 95% credible intervals (CrI). A research replication archive - including the summary data used for analysis, Stan-models and R-Code - is accessible at https://github.com/naninatamar/FSW_profiles_SA.

3. Results

We included a total of 24 studies (Black et al., 2015; Coetzee et al., 2017; Delva et al., 2011; DIFFER Project, 2018; Dunkle et al., 2005; Eakle et al., 2017; Gould and Fick, 2008; Lafort et al., 2016, 2018; Luseno & Wechsberg, 2009; Milovanovic et al., 2021; Peltzer et al., 2004; Poliah & Paruk, 2017; Ramjee et al., 2005; Richter et al., 2013; Schwartz et al., 2017; Slabbert et al., 2017; Slabbert & Radebe, 2016; The Aurum Institute, Anova Health Institute, & UCSF, 2020; UCSF, Anova Health Institute, & WRHI, 2015; van Loggerenberg et al., 2008; Varga, 2001; Williams et al., 2000; Williams et al., 2003; Yeo et al., 2022), conducted between 1996 and 2019, covering all 9 South African provinces (Table 1). Studies have recruited women from various settings such as female sex worker programmes, clinics, HIV counselling services, and outreach in known hotspots. The sex work settings in most studies were diverse, including both outdoor-based (e.g., street-based) and indoor-based venues (e.g., brothels, bars, nightclubs). While all studies provided information on female sex worker ages, only 12 reported data on sex work duration. Among the 24 studies, 18 were conducted in single locations, while 6 reported data for

Table 1
Included studies and reported summary statistics.

Study	Population ID	Province	Location	Setting	Year[a]	Study size[b]	Mean SW duration	Quantile (cumulative probability) SW duration	Mean (SD) FSW age	Quantile (cumulative probability) FSW age	Max FSW age	Exclusion
Dunkle et al., 2005	I	GP	Johannesburg	street, bars	1996	295	2.12	1.2 (0.50)	25.10 (–)	21 (0.25); 24 (0.50); 28 (0.75)	43	<16 years
Ramjee et al., 2005	II	GP, KZN	5 truck stops between Johannesburg and Durban	5 truck stops	1998	412	2.44	–	24.92 (–)	–	–	no
Varga, 2001	III	KZN	Durban	bars, street, nightclubs	1998[a]	100	–	–	25.50 (–)	20 (0.13)	–	no
Williams et al., 2000	IV	GP	Carletonville	unspecified, probably street	1998	121	–	–	32.50 (–)	25 (0.12); 40 (0.83)	–	no
Williams et al., 2003	V	GP	Carletonville	unspecified, probably street	2000	93	–	–	31.50 (–)	25 (0.16); 40 (0.89)	–	no
Peltzer et al., 2004	VI	LP	Tzaneen and Phalaborwa	unspecified, probably street ("mobile sex worker")	2001[a]	70	5.70	–	26.60 (5.50)	–	45	no
van Loggerenberg et al., 2008	VII	KZN	Durban	unspecified	2004	245/775[b]	–	3 (0.50)	31.30 (–)	–	58	<18 years
Luseno & Wechsberg, 2009	VIII	GP	Pretoria	unspecified, probably street	2005.5	425	–	–	28.00 (7.50)	24 (0.39); 44 (0.83)	–	<18 years
Gould and Fick, 2008	IX	WC	Cape Town, brothel-based	brothel	2006.5	83	4.60	–	29.00 (–)	–	46	no
	X	WC	Cape Town, street-based	street	2006.5	35	6.50	–	29.00 (–)	–	47	no
Delva et al., 2011	XI	KZN, WC, GP	Women advertising services online or in one of 3 local newspapers (Durban, Cape Town, Johannesburg)	unspecified (women advertised SW online or in newspaper)	2010	210	–	–	28.60 (–)	–	55	no
Richter et al., 2013	XII	GP, WC	Sandton, Hillbrow, Rustenburg, Cape Town	mix (indoors/outdoors)	2010	1503/1653[b]	–	1 (0.16); 5 (0.56)	29.70 (6.50)	–	–	<18 years
Lafort et al., 2016/DIFFER Project, 2018	XIII	KZN	Durban	mix (indoor/outdoor)	2012.5	400	–	–	–	21 (0.07); 26 (0.42); 31 (0.73); 36 (0.90)	–	<18 years
Slabbert & Radebe, 2016	XIV	GP	Johannesburg brothels	inner city brothels	2013[a]	124	–	–	32.08 (6.56)	–	–	<18 years
	XV	GP	Pretoria brothels	inner city brothels	2013[a]	50	–	–	31.52 (5.21)	–	–	<18 years
UCSF, Anova Health Institute, & WRHI, 2015	XVI	GP	Johannesburg	mix (mostly street, some brothel)	2013.5	763	–	–	–	25 (0.25); 30 (0.53); 35 (0.81)	–	<16 years
	XVII	WC	Cape Town	mix (mostly street, some brothel)	2013.5	648	–	–	–	25 (0.25); 30 (0.55); 35 (0.76)	–	<16 years
	XVIII	KZN	Durban	mix (mostly street, some brothel)	2013.5	765	–	–	–	25 (0.31); 30 (0.58); 35 (0.76)	–	<16 years
Black et al., 2015	XIX	GP	Johannesburg	unspecified, probably mix	2014	249	4.90	–	31.50 (–)	27 (0.25); 35 (0.75)	–	no
Schwartz et al., 2017	XX	EC	Port Elizabeth	unspecified	2014.5	410	–	2 (0.20)	–	25 (0.30); 35 (0.80)	–	<18 years
Slabbert et al., 2017	XXI	GP	Pretoria	mix (street, brothel)	2014.5	407/404[b]	–	2 (0.73); 5 (0.91)	33.20 (9.90)	25 (0.11); 30 (0.33); 35 (0.64)	–	no
	XXII	GP	Johannesburg	mix (street, brothel)	2014.5	939/1422[b]	–	2 (0.53); 5 (0.86)	28.60 (5.35)	25 (0.24); 30 (0.60); 35 (0.86)	–	no

(*continued on next page*)

Table 1 (*continued*)

Study	Population ID	Province	Location	Setting	Year[a]	Study size[b]	Mean SW duration	Quantile (cumulative probability) SW duration	Mean (SD) FSW age	Quantile (cumulative probability) FSW age	Max FSW age	Exclusion
Lafort et al., 2018/ DIFFER Project, 2018	XXIII	KZN	Durban	mix (indoor/outdoor)	2015	400	–	–	–	21 (0.02); 26 (0.28); 31 (0.59); 36 (0.79)	–	<18 years
Poliah & Paruk, 2017	XXIV	KZN	4 sites in KZN. SWs were attending "support groups".	unspecified	2015	153	–	–	–	31 (0.61); 41 (0.95); 51 (0.99); 61 (0.99)	–	<18 years
Eakle et al., 2017	XXV	GP	Johannesburg and Pretoria	mix (mostly brothels, some streets, bars)	2015.5	692	–	–	30.62 (6.09)	21 (0.01); 31 (0.51); 41 (0.92); 51 (0.99)	55.4	<18 years
Coetzee et al., 2017	XXVI	GP	Soweto	mix (street, taverns, hotels, brothels)	2016	508	–	3 (0.34); 8 (0.80)	–	25 (0.24); 30 (0.47)	59	<18 years
The Aurum Institute, Anova Health Institute, & UCSF, 2020	XXVII	GP	Johannesburg	mix (bars, street, nightclubs, brothels)	2018	546	–	2 (0.05); 4 (0.34); 6 (0.58); 11 (0.81)	–	25 (0.15); 30 (0.36); 35 (0.62)	–	<16 years
	XXVIII	WC	Cape Town	mix (bars, street, nightclubs, brothels)	2018	781	–	2 (0.07); 4 (0.31); 6 (0.53); 11 (0.73)	–	25 (0.13); 30 (0.38); 35 (0.65)	–	<16 years
	XXIX	KZN	Durban	mix (bars, street, nightclubs, brothels)	2018	600	–	2 (0.07); 4 (0.31); 6 (0.48); 11 (0.81)	–	25 (0.18); 30 (0.51); 35 (0.70)	–	<16 years
Yeo et al., 2022	XXX	NW	Klerksdorp	unspecified, probably mix	2018	156	–	–	–	25 (0.25); 32 (0.50); 36 (0.75)	–	<18 years
Milovanovic et al., 2021	XXXI	NW	Bojanala	mix (indoor/outdoor)	2019	272	7.03	5 (0.50)	34.00 (6.85)	29 (0.25); 33 (0.50); 39 (0.75)	53	<18 years
	XXXII	EC	Buffalo City	mix (indoor/outdoor)	2019	261	8.50	5 (0.50)	35.00 (8.96)	28 (0.25); 34 (0.50); 41 (0.75)	60	<18 years
	XXXIII	WC	Cape Town	mix (indoor/outdoor)	2019	376/ 377[b]	8.93	7 (0.50)	33.10 (7.32)	28 (0.25); 33 (0.50); 37 (0.75)	59	<18 years
	XXXIV	MP	Ehlanzeni	mix (indoor/outdoor)	2019	265/ 267[b]	7.20	5 (0.50)	31.70 (7.70)	26 (0.25); 30 (0.50); 36 (0.75)	59	<18 years
	XXXV	GP	Ekurhuleni	mix (indoor/outdoor)	2019	168	5.54	4 (0.50)	32.80 (5.97)	28 (0.25); 32.5 (0.50); 36.2 (0.75)	55	<18 years
	XXXVI	KZN	Ethekwini	mix (indoor/outdoor)	2019	348/ 351[b]	10.10	8 (0.50)	33.80 (7.92)	28 (0.25); 33 (0.50); 39 (0.75)	64	<18 years
	XXXVII	NC	Francis Baard	mix (indoor/outdoor)	2019	81/ 82[b]	6.17	5 (0.50)	31.00 (7.28)	26 (0.25); 31 (0.50); 35 (0.75)	60	<18 years
	XXXVIII	GP	Johannesburg	mix (indoor/outdoor)	2019	540	7.62	5 (0.50)	33.80 (8.13)	28 (0.25); 33 (0.50); 39 (0.75)	59	<18 years
	XXXIX	FS	Thabo Mofutsanyane	mix (indoor/outdoor)	2019	190	7.24	5 (0.50)	31.30 (7.88)	25 (0.25); 31 (0.50); 35 (0.75)	57	<18 years
	XL	GP	Tshwane	mix (indoor/outdoor)	2019	157	11.50	9 (0.50)	37.00 (8.98)	30 (0.25); 36 (0.50); 42 (0.75)	62	<18 years
	XLI	KZN	Ugu	mix (indoor/outdoor)	2019	78/ 80[b]	6.94	5 (0.50)	30.20 (6.91)	25 (0.25); 29 (0.50); 34.2 (0.75)	48	<18 years
	XLII	LP	Vhembe	mix (indoor/outdoor)	2019	259/ 260[b]	7.78	5 (0.50)	32.00 (8.32)	25 (0.25); 31 (0.50); 38 (0.75)	54	<18 years

[a] For studies that did not report the year, year was defined as 3 years prior to publication.
[b] For some studies the sizes differed for summary statistics on SW duration and FSW age. For those "size SW duration/size SW age" is reported.

multiple locations, resulting in 27 distinct study populations with information on sex work duration and 42 with information on age. Notably, one of the most recent studies presented data for 12 different locations (Milovanovic et al., 2021).

The 27 study populations with sex work duration data included a total of 10078 individuals, with varying sample sizes (ranging from 35 to 1503 women, Table 1). In 5 instances, the mean sex work duration was reported, 9 reported quantiles (most commonly the median) and 13 studies reported both mean and median duration. After transforming quantiles to means, the adjusted mean sex work duration ranged from 1.6 years to 11.5 years (Table 2).

The 42 study populations with data on female sex worker age comprised 16348 individuals, again with varying sample sizes (ranging from 35 to 1653 women, Table 1). For half (21, 50.0%) of study populations, both mean age and quantiles were reported, while 9 reported the mean only and a further 12 reported quantiles only. Furthermore, 12 studies excluded women under 18, 3 excluded those under 16, and only 9 studies did not report any age exclusion criteria (Table 1). After transforming quantiles to means and correcting for truncation, the adjusted mean age of female sex workers ranged from 24.6 years to 37.0 years. The standard deviation of age was reported for 20 study populations and ranged from 5.2 years to 9.9 years after adjustment (Table 2). The estimated bias resulting from truncation was small, with mean ages decreasing on average by 0.2 years and standard deviations increasing on average by 0.1 years after correction (Table 2).

3.1. Time trends

3.1.1. Trends in sex work duration and age of female sex workers

There was evidence suggesting an increase over time in both the duration of sex work and the age of female sex workers. According to the fitted models, a 10-year increase in calendar time was associated with a 55.6% increase in the expected sex work duration (95%-CrI: 23.5%–93.9%) and a 14.3% increase in the expected age of female sex workers (95%-CrI: 9.1%–19.1%) (Supplementary Fig. S1). Although the increase in sex work duration was larger in magnitude, the evidence was less certain, indicated by the large credible interval. Furthermore, there was heterogeneity among study populations, particularly for the Duration-model fit, as reflected by substantial variability in estimated random intercepts (Supplementary Fig. S2).

Fig. 1 shows predicted time trends in the expected sex work duration between 1996 and 2019, along with the corresponding rate parameter estimate of the assumed underlying Exponential distribution. Over the 23-year period, the predicted mean duration of sex work increased from 2.7 years in 1996 (95%-CrI: 1.1–6.9 years) to 7.4 years in 2019 (95%-CrI: 3.2–17.1 years). Fig. 2 presents the corresponding results from the Age-model, which demonstrated a good fit to the data in terms of both mean ages and standard deviations. In 2019, the predicted mean age among female sex workers was 32.3 years (95%-CrI: 28.3–37.2 years); reflecting a 5.9-year increase compared to 1996, when the predicted mean age was 26.4 years (95%-CrI: 23.3–30.2 years). Using distributional assumption (1) and (2) to generate posterior predictions at the individual level revealed substantial variability: In 2019, individual sex work durations were estimated to range between 2.0 months and 32.5 years (with 95% probability) and individual ages of female sex workers between 19.4 years and 51.1 years (Supplementary Fig. S3). Omitting the study conducted by Milovanovic et al., which contributed 12 estimates on the age and duration of sex work among female sex workers, had limited impact on estimated age trends. However, it did result in a less pronounced increase in the expected duration of sex work over time (Supplementary Fig. S4). Using RDS-weighted proportions instead of crude ones for the five RDS-studies, did result in little change in estimated time trends (Supplementary Fig. S5), as did choosing an offset of 15 years instead of 10 years for the assumed underlying gamma distribution of individual sex worker ages (Supplementary Fig. S6).

3.1.2. Sensitivity analysis: trends in age at entry into sex work

In contrast to the main analysis focusing on age during sex work, the sensitivity analysis examining age at entry into sex work was based on only the 27 out of 42 unique study populations with information on sex work duration. Additionally, by using the year of starting sex work instead of the study year, a different time period was covered, spanning from 1993.9 to 2013.5. Over this period, the estimated common slope was very similar to the one observed in the main analysis with an estimated 14.8% increase (95%-CrI: 4.0%–26.8%) in the expected age at entry into sex work for a 10-year increase in calendar time (Supplementary Fig. S1). The random intercepts were smaller in magnitude (Supplementary Fig. S2). The resulting predicted mean age at entry into sex work was 22.3 years in 1996 (95%-CrI: 19.0–26.9 years) and, when extrapolated to 2019, 26.9 years (95%-CrI: 22.4–33.2 years, Fig. 3).

3.1.3. Simulation exercise: impact on HIV incidence estimation

Using estimated time trends in sex work duration and female sex worker age in the simulation exercise, led to an estimated decrease in HIV incidence rate in female sex workers starting from the year 1999 or before, with the decline commencing earlier as the assumed prevalence ratio r increased (Fig. 4). Of note, when assuming $r = 2$, the prevalence at entry into sex work $P_0(t)$ exceeded the prevalence "during" sex work $P(t)$ at most times t, resulting in impossible negative estimates of HIV incidence, so these results are not displayed (the same can be observed for $r = 1.75$ between years 2017 and 2019, Fig. 4). When assuming stability, the Duration- and Age-model estimated expected sex work duration at 6.0 years (95%-CrI: 2.1–16.8 years) and female sex worker age at 30.5 years (95%-CrI: 25.6–37.0 years, Supplementary Fig. S7). When using

Table 2
Final input for statistical models after data adjustment.

Study	Population ID	Year[a]	Study size (SW duration)	Adjusted mean SW duration[b]	Study size (FSW age)	Adjusted mean FSW age[b]	Adjusted Standard deviation FSW age[b]	Truncation bias mean age[c]	Truncation bias standard deviation age[c]
Dunkle et al., 2005	I	1996	295	2.12	295	24.59[d,e]	–	0.51	–
Ramjee et al., 2005	II	1998	412	2.44	412	24.92	–	0 (no exclusion)	–
Varga, 2001	III	1998[a]	–	–	100	25.50	–	0 (no exclusion)	–
Williams et al., 2000	IV	1998	–	–	121	32.50	–	0 (no exclusion)	–
Williams et al., 2003	V	2000	–	–	93	31.50	–	0 (no exclusion)	–
Peltzer et al., 2004	VI	2001[a]	70	5.70	70	26.60	5.50	0 (no exclusion)	0 (no exclusion)
van Loggerenberg et al., 2008	VII	2004	245	4.33[d]	775	31.24[e]	–	0.06	–
Luseno & Wechsberg, 2009	VIII	2005.5	–	–	425	26.46[e]	8.09[e]	1.54	−0.59
Gould and Fick, 2008	IX	2006.5	83	4.60	83	29.00	–	0 (no exclusion)	–
	X	2006.5	35	6.50	35	29.00	–	0 (no exclusion)	–
Delva et al., 2011	XI	2010	–	–	210	28.60	–	0 (no exclusion)	–
Richter et al., 2013	XII	2010	1503	6.01[d]	1653	29.50[e]	6.64[e]	0.20	−0.14
Lafort et al., 2016/DIFFER Project, 2018	XIII	2012.5	–	–	400	27.70[d,e]	–	–	–
Slabbert & Radebe, 2016	XIV	2013[a]	–	–	124	32.04[e]	6.60[e]	0.04	−0.04
	XV	2013[a]	–	–	50	31.52[e]	5.22[e]	0.00	−0.01
UCSF, Anova Health Institute, & WRHI, 2015	XVI	2013.5	–	–	763	29.89[d,e]	–	–	–
	XVII	2013.5	–	–	648	30.16[d,e]	–	–	–
	XVIII	2013.5	–	–	765	29.56[d,e]	–	–	–
Black et al., 2015	XIX	2014	249	4.90	249	31.50	–	0 (no exclusion)	–
Schwartz et al., 2017	XX	2014.5	410	9.09[d]	410	29.07[d,e]	–	–	–
Slabbert et al., 2017	XXI	2014.5	407	1.60[d]	404	33.20	9.90	0 (no exclusion)	0 (no exclusion)
	XXII	2014.5	939	2.62[d]	1422	28.60	5.35	0 (no exclusion)	0 (no exclusion)
Lafort et al., 2018/DIFFER Project, 2018	XXIII	2015	–	–	400	30.37[d,e]	–	–	–
Poliah & Paruk, 2017	XXIV	2015	–	–	153	29.73[d,e]	–	–	–
Eakle et al., 2017	XXV	2015.5	–	–	692	30.56[e]	6.15[e]	0.06	−0.05
Coetzee et al., 2017	XXVI	2016	508	5.91[d]	508	31.71[d,e]	–	–	–
The Aurum Institute, Anova Health Institute, & UCSF, 2020	XXVII	2018	546	8.20[d]	546	33.57[d,e]	–	–	–
	XXVIII	2018	781	9.28[d]	781	32.83[d,e]	–	–	–
	XXIX	2018	600	9.03[d]	600	31.29[d,e]	–	–	–
Yeo et al., 2022	XXX	2018	–	–	156	31.73[d,e]	–	–	–
Milovanovic et al., 2021	XXXI	2019	272	7.03	272	33.99[e]	6.86[e]	0.01	−0.01
	XXXII	2019	261	8.50	261	34.89[e]	9.05[e]	0.11	−0.09
	XXXIII	2019	376	8.93	377	33.04[e]	7.37[e]	0.06	−0.05
	XXXIV	2019	265	7.20	267	31.49[e]	7.85[e]	0.21	−0.15
	XXXV	2019	168	5.54	168	32.79[e]	5.98[e]	0.01	−0.01
	XXXVI	2019	348	10.10	351	33.73[e]	7.98[e]	0.07	−0.06
	XXXVII	2019	81	6.17	82	30.79[e]	7.43[e]	0.21	−0.15
	XXXVIII	2019	540	7.62	540	33.71[e]	8.21[e]	0.09	−0.08
	XXXIX	2019	190	7.24	190	30.98[e]	8.08[e]	0.32	−0.20
	XL	2019	157	11.50	157	36.96[e]	9.01[e]	0.04	−0.03
	XLI	2019	78	6.94	80	29.97[e]	7.07[e]	0.23	−0.16
	XLII	2019	259	7.78	260	31.68[e]	8.52[e]	0.32	−0.20

[a] For studies that did not report the year, year was defined as 3 years prior to publication.
[b] Medians and other quantiles were transformed to means and (age) estimates were adjusted for potential truncation (see supplementary appendix).
[c] Estimated bias due to truncation (see supplementary appendix).
[d] Mean derived by transformation (study reported quantiles).
[e] Mean corrected for truncation (study excluded FSW below a certain age).

these constant values in the simulation exercise, the resulting HIV incidence rate remained relatively stable between 2005 and 2015, followed by a less notable decrease thereafter (Fig. 4).

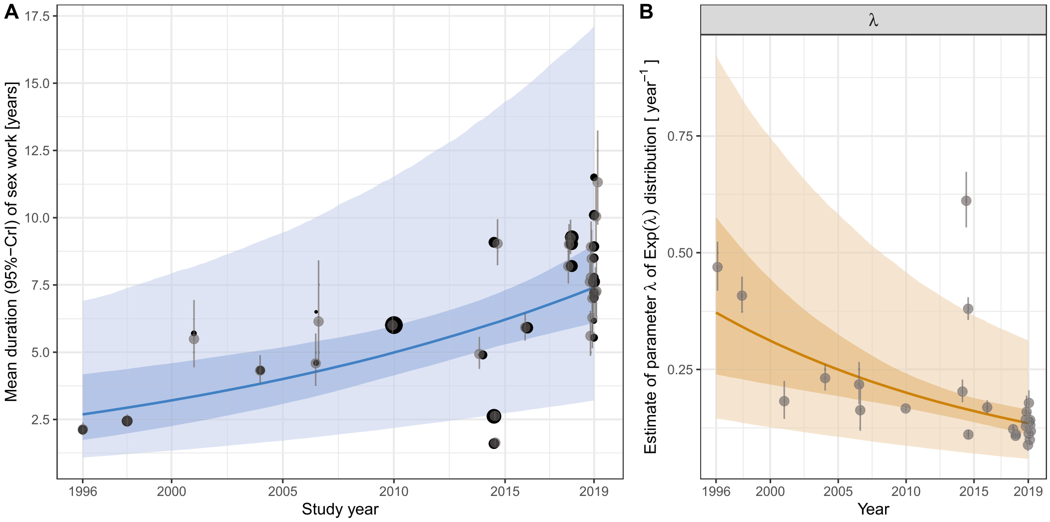

Fig. 1. (A) Estimated time trends in the expected duration of sex work (SW) from 1996 to 2019 and (B) corresponding time trends in the rate parameter λ of the underlying exponential distribution we assumed for individual durations of SW. The solid lines reflect medians of posterior predictive distributions, while shaded areas correspond to 95% credible intervals (less transparent ones exclude random-effect variability while more transparent ones include it). The estimates and 95% credible intervals for each unique study population are shown in gray. Black dots correspond to the input data (adjusted mean duration of SW) with areas proportional to the study population sizes.

4. Discussion

4.1. Main findings

This analysis, involving data from 24 studies comprising 42 distinct study populations, found a shifting profile of female sex workers in South Africa from 1996 to 2019. A 10-year increase in calendar time was associated with a 14.3% increase in the expected age of female sex workers and a 55.6% increase in the expected duration of sex work. Accounting for these time trends resulted in a significantly greater decrease in estimated HIV incidence among female sex workers compared to when assuming a constant age and duration of sex work over time.

4.2. Interpretation and implications

The increase in female sex worker age and sex work duration could be attributable to several factors. While general population ageing might account for some of the changes in the age distribution, improved access to healthcare and the advent of antiretroviral treatment (ART) have resulted in an increased life expectancy for individuals living with HIV (Makhakhe et al., 2019; Wandeler et al., 2016). As a result, older sex workers may be able to continue their work for longer periods of time. Additionally, in recent years, there has been a growing recognition of the importance of decriminalising sex work (Human Rights Watch, 2019; Matlala & Odeku, 2021). The evolving legal framework and support networks might provide safer environments for female sex workers, allowing them to engage in sex work for longer durations. This is supported by anecdotal community observations that initiatives such as Sisonke and SWEAT which advocate for sex workers' rights, not only enhance safety but also give hope for future recognition of sex work as a legitimate form of employment. On the other hand, factors like limited alternative employment opportunities, particularly among undocumented migrants who form a large portion of female sex workers, social isolation, and economic distress may force women to enter sex work later in life and remain in it for longer periods (Amnesty International, 2019; Anesu et al., 2019; Farley, 2019; Mutambara & Naidu, 2023; Walker & Oliveira, 2015; Yingwana et al., 2019). Changes in AIDS-related mortality among female sex workers may also have contributed to the observed trends in sex work duration, as ART programmes have substantially reduced AIDS mortality. However, Thembisa's estimates suggest relatively low AIDS-related mortality rates among female sex workers, peaking at 0.015 per annum in 2004 (Supplementary Fig. S8). This is likely due to the fact that female sex workers tend to be younger, which is associated with slower HIV disease progression, and they have a higher likelihood of recent HIV infection, reducing the chances of being in the advanced stages of HIV. Therefore, it is unlikely that changes in AIDS-related mortality over time (at most a 0.015 absolute change over the study period) can fully explain the change of 0.2 in the annual rate of exit from sex work.

While the simulation exercise did not aim to provide accurate estimates of HIV incidence in female sex workers, it demonstrated how different assumptions about demographic and behavioural characteristics can impact estimates of HIV indicators. Many existing models that provide HIV estimates for female sex workers, assume constant characteristics, and do

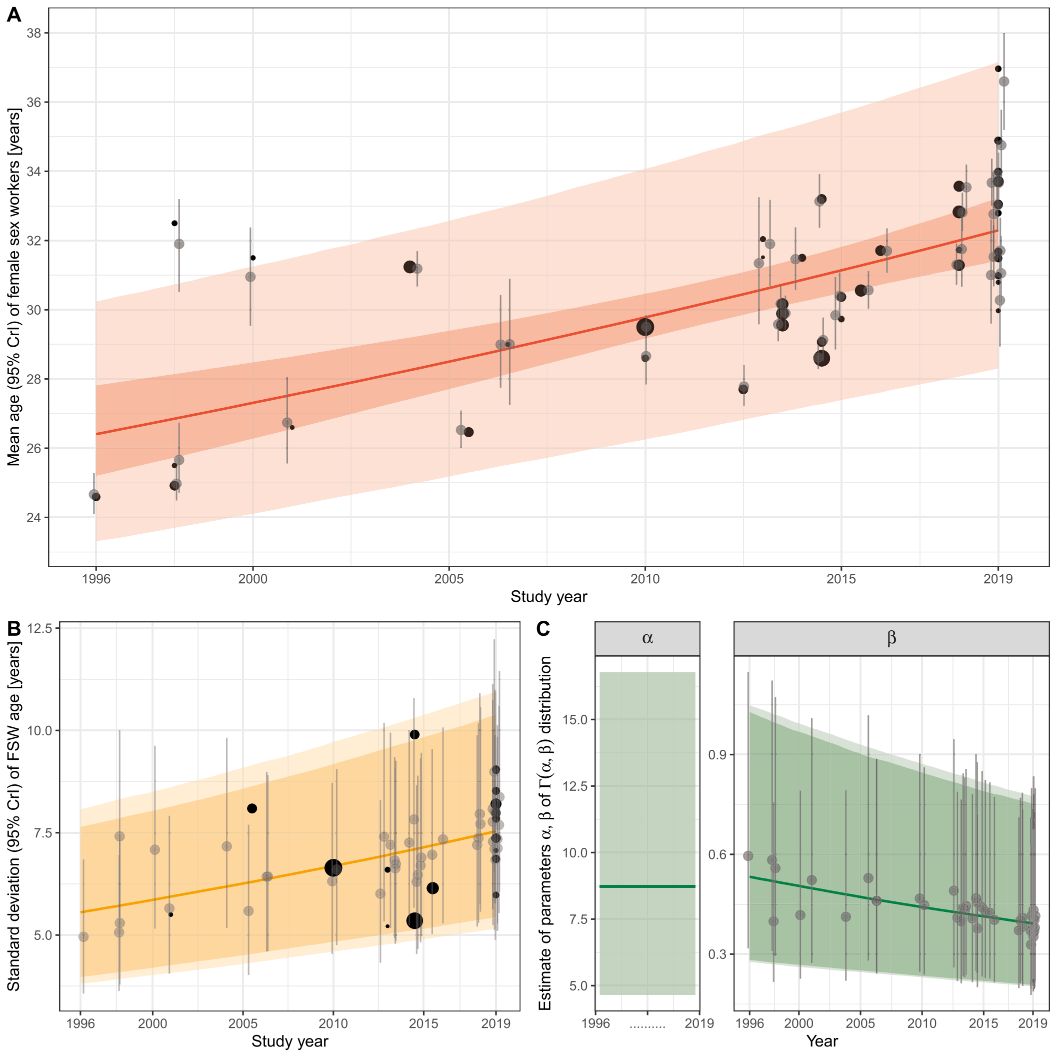

Fig. 2. Estimated time trends in the mean (A) and standard deviation (B) age of female sex workers (FSW) from 1996 to 2019, and (C) corresponding time trends in the shape parameter α and rate parameter β of the underlying Gamma distribution we assumed for individual ages of FSW. The solid lines reflect medians of posterior predictive distributions, while shaded areas correspond to 95% credible intervals (less transparent ones exclude random-effect variability while more transparent ones include it). Estimates and 95% credible intervals for each unique study population are shown in gray. Black dots correspond to the input data (adjusted mean and standard deviation of FSW ages) with areas proportional to the study population sizes.

not account for dynamic changes (Johnson et al., 2017; Kerr et al., 2015; Stone et al., 2021; Stover et al., 2021). Without allowing for changes in female sex worker age and sex work duration, the simulation exercise suggested a constant HIV incidence among female sex workers between 2005 and 2015, with only a slight decline thereafter. Such a finding might raise concerns about programmes failing to reach sex workers. However, when incorporating observed trends in age and sex work duration, estimated HIV incidence among female sex workers substantially decreased during that period. Accurate estimates of HIV incidence among female sex workers are crucial, particularly given concerns about the increasing role of key populations in sustaining HIV epidemics (Barr et al., 2021). Beyond HIV incidence, our results may also affect estimates of other HIV indicators. Longer average durations of sex work, for example, imply longer average duration of HIV infection and higher likelihood of HIV diagnosis and ART usage during sex work, impacting estimates related to the treatment cascade in female sex workers. Similarly, longer durations of sex work and older ages may be associated with lower rates of primary HIV infection, higher ART coverage and safer behaviour in HIV-positive female sex workers, influencing estimates on transmission to clients.

Different countries have different legal frameworks, economic conditions and societal contexts which all impact sex work (McCarthy et al., 2012; NSWP, 2023). Sex work communities likely differ across African countries and our findings may not be generalizable beyond South Africa. Moreover, studies in other African countries often employ broader definitions of sex work,

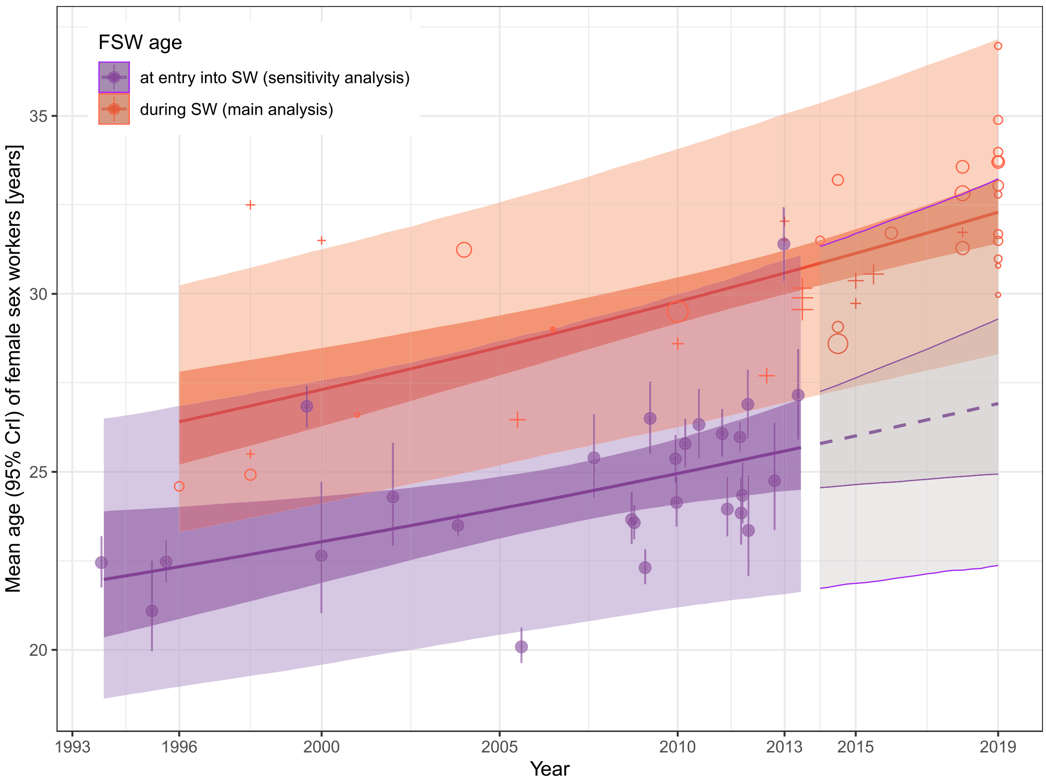

Fig. 3. Comparison of estimated time trends in the mean ages of female sex workers (FSW) during sex work (SW, main analysis) with estimated trends in the mean FSW ages at entry into SW (sensitivity analysis). Solid lines reflect the estimated medians of the posterior predictive distributions, while shaded areas correspond to 95% credible intervals (less transparent ones exclude random-effect variability while more transparent ones include it). For the gray area, no data was available and estimates were extrapolated. Estimates and 95% credible intervals for each unique study population obtained in the sensitivity analysis are shown in purple. The original data points (as used in the main analysis) are shown as red circles (data points included in sensitivity analyses) and crosses (data points not included in sensitivity analysis since the duration of SW was not reported for that study population).

including transactional sex. There is a need for similar studies in other sub-Saharan African countries, to assess whether profiles of female sex workers are changing in other settings as well.

4.3. Comparison with other studies

While there are no published studies specifically focusing on trends in sex worker profiles, some studies contain relevant information. One study from Rwanda examined shifts in sexual risk behaviours among female sex workers using data from three cross-sectional surveys (Mutagoma et al., 2018). They noted an increase in the median age of female sex workers from 24 years in 2006 to 26 years in 2015. While the age was thus lower than observed in our study, the magnitude of the increase over time was similar. Another study, comparing HIV prevention and care services among female sex workers in three sites in Zimbabwe between the year 2011 and the year 2015, found a similar median age among female sex workers in both years (Ndori-Mharadze et al., 2018). They observed that in two out of the three sites, the proportion of female sex workers that engaged in sex work for less than 2 years had doubled from 2011 to 2015, possibly indicating a declining trend in sex work duration. A cursory review of various rounds of Integrated Biological and Behavioural Surveillance (IBBS) surveys conducted by different Asian countries suggests a potential increase in the duration of sex work and the age of female sex workers in some regions. For example, in Malaysia, between 2014 and 2017, the median age among female sex workers increased from 34 to 37 years, and the median duration of sex work from 7 to 9 years (Ministry of Health Malaysia, 2014; Ministry of Health Malaysia, 2017). Similarly, in Vietnam, the mean age and mean duration of sex work among street-based female sex workers were higher in the IBBS 2013 survey compared to the IBBS 2005–2006 survey for all 5 cities/provinces included in both rounds (Ministry of Health Vietnam, 2006; Ministry of Health Vietnam, 2013). Thus it is difficult to draw conclusions about long-term trends in other settings, as most have only two surveys, and in many cases the surveys are only a few years apart.

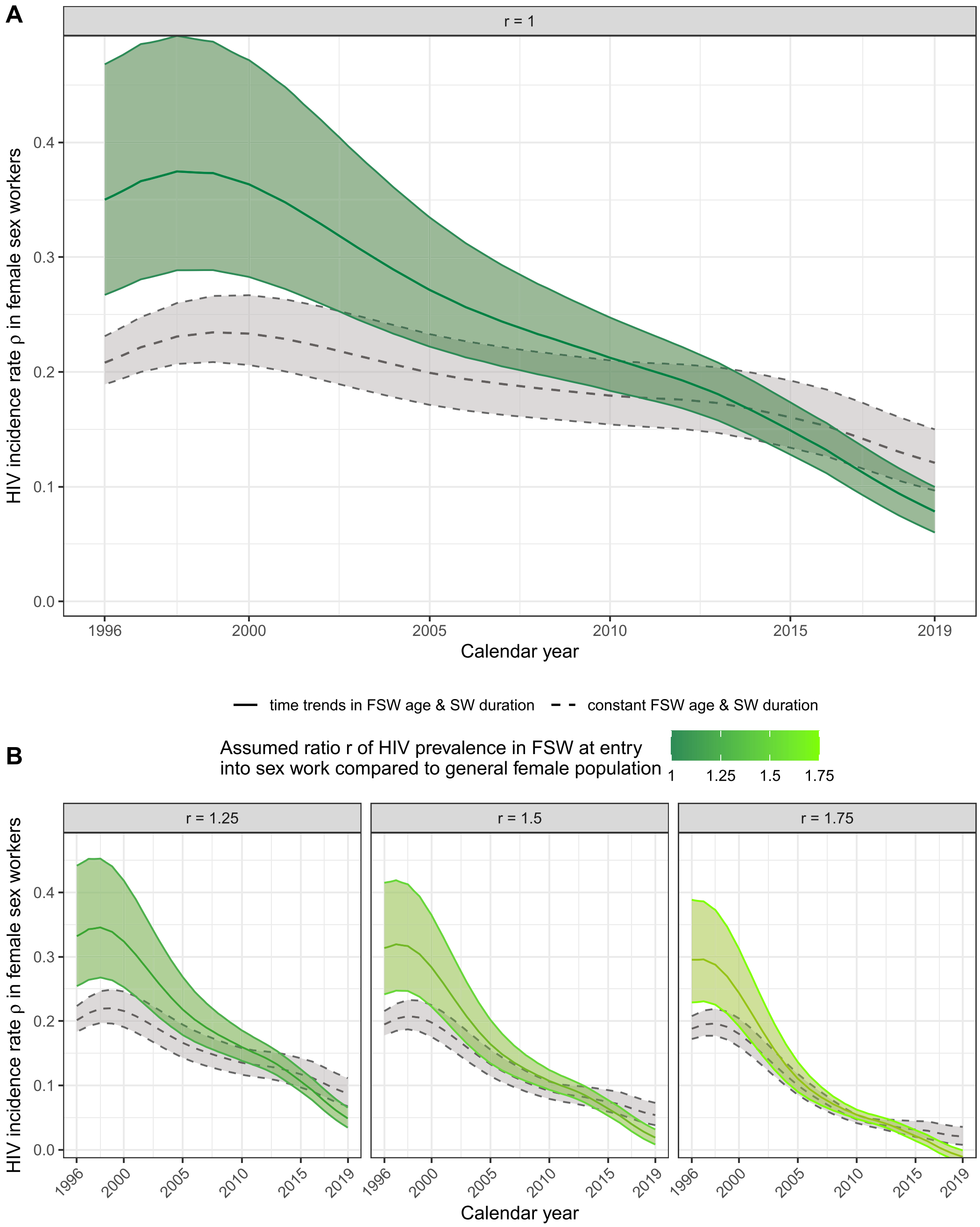

Fig. 4. Estimated time trends in the HIV incidence rate ρ from 1996 to 2019, assuming constant age of female sex workers (FSW) and duration of sex work (SW) (gray) or changing FSW age and duration of SW as estimated in the main analysis (color). (A) shows the results under the assumptions that the prevalence at entry into SW equals the prevalence of the general female population in the same age group. (B) shows results under the assumption that the prevalence at entry into SW is increased by a factor r ($r = 1.25, 1.5, 1.75$) compared to the general female population. Solid lines reflect medians of estimated posterior predictive distributions, while shaded areas correspond to 95% credible intervals (excluding random-effects variability).

4.4. Strengths and weaknesses

Our study has several strengths, contributing to its robustness and novelty. Unlike previous research that has primarily focused on trends in HIV indicators among female sex workers (Chemaitelly et al., 2019; Jones et al., 2022; Joshi et al., 2021), our study investigated changes in demographic and behavioural characteristics, making a unique contribution. We used a Bayesian approach, which is well suited due to the relatively small number of studies included, allowing for better integration of between study-population uncertainty (Williams et al., 2018). This approach accommodates flexible assumptions in line with the Thembisa model and enabled direct examination of parameters of assumed underlying distributions as well as inference at the individual level.

However, our study has notable weaknesses mainly resulting from the quality of the input data. First, significant heterogeneity exists among included study populations, such as differences in the recruitment of women and the settings of sex work. Due to limited information about these aspects in many studies, we could not account for setting differences in our analyses. While acknowledging the possibility of residual confounding and potential bias in our results, we believe that these differences are unlikely to fully explain the estimated time trends. This is supported by the observation that the variations in those aspects do not appear to follow a specific pattern over time. Second, many studies relied on non-random convenience samples of women from different sex worker programmes, introducing potential selection bias into the studies' reported summary statistics, and, subsequently, our estimated trends. For example, younger women engaging in sex work may opt to participate in programmes for adolescent girls and young women rather than sex worker programmes, possibly leading to an underrepresentation of younger women and an overestimation of female sex workers' mean age. However, since this underrepresentation likely remained consistent over time, it should not affect estimated temporal trends. Variations in sampling strategies may also contribute to differences in reported mean age or sex work duration. The observed reduction in the estimated trend in sex work duration, resulting from excluding the study by Milovanovic et al. - a study that employed a more rigorous sampling strategy than most other studies - may be partly explained by disparities in sampling approaches, for instance. Lastly, not all studies reported means as summary statistics and some of the reported figures were affected by truncation-induced bias, making data adjustment before model fit necessary.

4.5. Conclusions

Profiles of female sex workers in South Africa have changed over the last two decades, with women being older and staying in sex work longer in later years. While these trends might reflect an expanding community mobilization and a more supportive rights and advocacy environment, the ongoing criminalisation, stigmatisation and a lack of alternative employment opportunities could also be contributing. It is important to account for such changes when estimating HIV incidence and other indicators in female sex workers to get an accurate understanding of the epidemic in this population. More reliable data on female sex workers is needed and this would be greatly facilitated by further reducing stigma, advocating for female sex worker rights, and providing comprehensive support.

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Ethics approval and consent to participate

This study includes no individual-level data and uses only published information in the public domain. Therefore ethical approval was not requested.

CRediT authorship contribution statement

Nanina Anderegg: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Mariette Slabbert:** Writing – review & editing, Writing – original draft. **Kholi Buthelezi:** Writing – review & editing, Writing – original draft. **Leigh F. Johnson:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.idm.2024.01.006.

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