OPEN

# Modelling the impact of HIV and hepatitis C virus prevention and treatment interventions among people who inject drugs in Kenya

Jack Stone[a], Hannah Fraser[a], Josephine G. Walker[a], Nyashadzaishe Mafirakureva[b], Bernard Mundia[c], Charles Cleland[d], Kigen Bartilol[e], Helgar Musyoki[e], Wanjiru Waruiru[f], Allan Ragi[c], Parinita Bhattacharjee[g], Nok Chhun[h], John Lizcano[h], Matthew J. Akiyama[i], Peter Cherutich[e], Ernst Wisse[j], Ann Kurth[h], Niklas Luhmann[k] and Peter Vickerman[a,l]

**Objectives:** People who inject drugs (PWID) in Kenya have high HIV (range across settings: 14–26%) and hepatitis C virus (HCV; 11–36%) prevalence. We evaluated the impact of existing and scaled-up interventions on HIV and HCV incidence among PWID in Kenya.

**Design:** HIV and HCV transmission model among PWID, calibrated to Nairobi and Kenya's Coastal region.

**Methods:** For each setting, we projected the impact (percent of HIV/HCV infections averted in 2020) of existing coverages of antiretroviral therapy (ART; 63–79%), opioid agonist therapy (OAT; 8–13%) and needle and syringe programmes (NSP; 45–61%). We then projected the impact (reduction in HIV/HCV incidence over 2021–2030), of scaling-up harm reduction [Full harm reduction ('Full HR'): 50% OAT, 75% NSP] and/or HIV (UNAIDS 90–90–90) and HCV treatment (1000 PWID over 2021–2025) and reducing sexual risk (by 25/50/75%). We estimated HCV treatment levels needed to reduce HCV incidence by 90% by 2030.

**Results:** In 2020, OAT and NSP averted 46.0–50.8% (range of medians) of HIV infections and 50.0–66.1% of HCV infections, mostly because of NSP. ART only averted 12.9–39.8% of HIV infections because of suboptimal viral suppression (28–48%). Full HR and ART could reduce HIV incidence by 51.5–64% and HCV incidence by 84.6–86.6% by 2030. Also halving sexual risk could reduce HIV incidence by 68.0–74.1%. Alongside full HR, treating 2244 PWID over 2021–2025 could reduce HCV incidence by 90% by 2030.

**Conclusion:** Existing interventions are having substantial impact on HIV and HCV transmission in Kenya. However, to eliminate HIV and HCV, further scale-up is needed with reductions in sexual risk and HCV treatment.



*AIDS* 2022, **36**:2191–2201

[a]Population Health Sciences, Bristol Medical School, University of Bristol, Bristol, [b]School of Health and Related Research, University of Sheffield, Sheffield, UK, [c]Kenya AIDS NGO Consortium, Kenya, [d]School of Global Public Health, New York University, USA, [e]Ministry of Health, Kenya, [f]Global Programs for Research and Training, Surveillance Department, University of California San Francisco, San Francisco, California, USA, [g]Institute for Global Public Health, University of Manitoba, Winnipeg, Manitoba, Canada, [h]Yale University School of Nursing, New Haven, Connecticut, [i]Department of Medicine, Montefiore Medical Center, Albert Einstein College of Medicine, Bronx, New York, USA, [j]Médecins du Monde, Paris, France, [k]Global HIV, Hepatitis and Sexually Transmitted Infections Programmes, World Health Organization, Geneva, Switzerland, and [l]NIHR Health Protection Research Unit in Behavioural Science and Evaluation at University of Bristol, Bristol, UK.

Correspondence to Jack Stone, Population Health Sciences, Bristol Medical School, University of Bristol, Bristol, UK.

E-mail: jack.stone@bristol.ac.uk

Received: 3 November 2021; revised: 11 April 2022; accepted: 19 April 2022.

DOI:10.1097/QAD.0000000000003382

**Keywords: hepatitis C virus, HIV, Kenya, mathematical modelling, people who inject drugs**

## Introduction

Kenya has high HIV prevalence (4.9% in 2018) among adults [1]. However, HIV prevalence (14–20%) among people who inject drugs (PWID) far exceeds this [2,3], particularly among female individuals (29–61%). In contrast, hepatitis C virus (HCV) prevalence among PWID in Kenya is relatively low (11–36% [4]) compared with other global settings [5], likely reflecting the recency of injecting drug use (IDU) in sub-Saharan Africa (SSA) [6] and a substantial sexual component to HIV transmission among PWID in Kenya. Indeed, condom use is low-to-moderate among PWID in Kenya [2,7] and over one-third (39%) of female PWID engage in transactional/commercial sex [7].

Opioid agonist therapy (OAT) and needle and syringe programmes (NSP) are effective at reducing HIV and HCV acquisition risk [8–10] but coverage typically remains low in SSA [11]. Kenya initiated NSP in 2013, with approximately half of PWID accessing NSP in 2017. OAT initiated in 2014, with coverage remaining low (<5%) by 2017 [11]. Both OAT and NSP have scaled-up further since 2017, with this not being adversely affected by the COVID-19 pandemic. Antiretroviral therapy (ART) for people with HIV (PWH) effectively reduces HIV transmission [12–14]. ART has scaled-up in Kenya, with 86% of PWH on ART in 2020 [15] and 64–68% among PWID in 2015 [4]. Although access to HCV diagnosis and treatment has been negligible in Kenya, recent pilot programmes among PWID have demonstrated the feasibility of such strategies [16]. The Kenyan government has recently secured direct-acting antiviral (DAA) treatments for 1000 people, with their national HCV guidelines recognizing PWID as a priority population [17].

The WHO and UNAIDS have set goals for eliminating HCV and HIV by 2030 [18,19]. Although modelling can help guide intervention planning for reaching these goals, through evaluating the long-term impact of implementing different strategies, only our study in Dar es Salaam [20] has considered the IDU-related epidemics in SSA. To aid policymaking in Kenya and SSA, we used modelling to evaluate the impact of existing and scaled-up prevention and treatment interventions on HIV and HCV transmission among PWID in Kenya and considered what is needed to reach elimination.

## Methods

### Model description

We developed a dynamic HIV and HCV transmission model amongst PWID for two sites in Kenya: Nairobi and Coastal region (specifically Mombasa, Kilifi and Kwale). These sites are where IDU is concentrated in Kenya [21] and have best available data. The modelled population is stratified by gender, HIV infection and treatment status, HCV infection, OAT and NSP status (Fig. 1). Model equations are in the Supplemental Appendix, http://links.lww.com/QAD/C640.

Individuals enter the model through initiating IDU, susceptible to HCV, and not accessing OAT/NSP. Some enter HIV-infected, with some on ART. Entry balances cessation of IDU and non-HIV related death.

Susceptible PWID become HIV and HCV infected through injecting-related transmission, with HIV also being sexually transmitted. We assume that injecting-related transmission does not differ by gender because male and female PWID have similar injecting behaviour and HCV prevalence (Appendix Table 1, http://links.lww.com/QAD/C640). For sexual HIV transmission, we just model heterosexual transmission because few male PWID report sex with men (<2.2% last month) [2]. Differences in HIV prevalence and sexual risk behaviours (Table 1 and Appendix, http://links.lww.com/QAD/C640) suggest female PWID have higher sexual HIV transmission risk than male PWIDs, which we incorporate. We assume PWID have sexual partners with other PWID and the general population. We do not explicitly model the general population; instead, transmission from the general population occurs as a function of their HIV prevalence (by gender) and ART coverage.

HIV transmission risk is dependent upon the HIV prevalence and ART coverage [12] in their sexual and injecting partners. Injecting HIV transmission risk is decreased for PWID on OAT and/or NSP [8,9]. We assume that a proportion of PWID's sexual partners also inject, which differs by gender. Due to limited data, we assume that PWID mix randomly to form potential transmission contacts (sexual or injecting) with other PWID.

Following HIV infection, individuals progress through the acute, chronic, pre-AIDS and AIDS phases of infection. Individuals in the acute and pre-AIDS phases of infection have heightened infectivity [22]. Individuals with AIDS experience HIV-related mortality and only engage in risk behaviours if on ART. PLHIV (except acute) can be enrolled onto ART, which reduces HIV disease progression and infectivity (depends on levels of viral suppression [12]). PWID receiving ART can be lost to care (LTC) and then re-enrolled at the same rate as ART-naive PWID. Being on OAT improves ART outcomes (initiation, retention and viral suppression) [23].

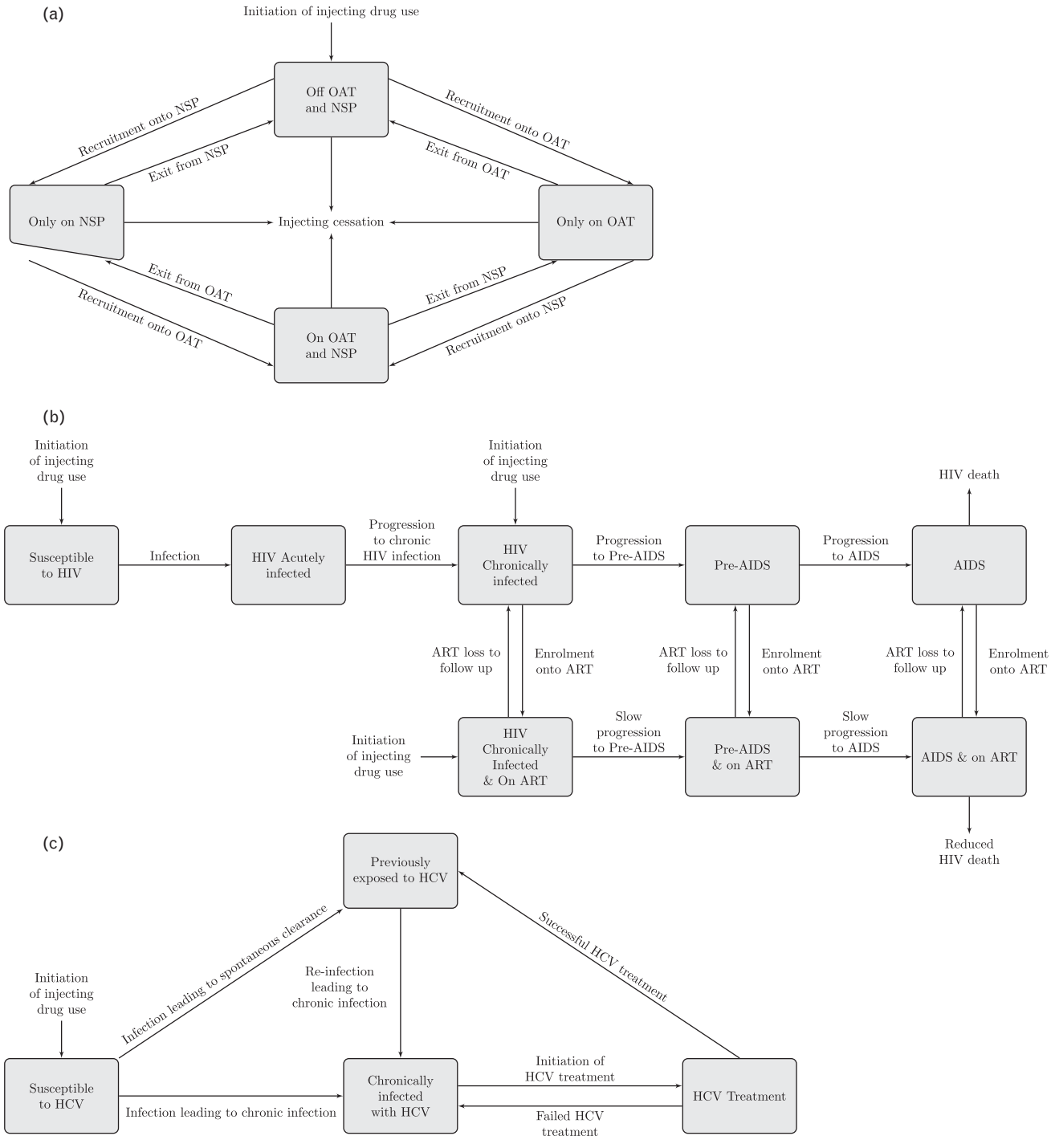


**Fig. 1. Model schematic of (a) harm reduction interventions; (b) HIV transmission and treatment; (c) hepatitis C virus transmission and treatment.** HCV, hepatitis C virus; NSP, needle and syringe programme; OAT, opioid agonist therapy.

**Table 1. Summary of main prior parameter ranges and calibration data (most recent estimates) used for Nairobi and Coastal region.**

| | Nairobi | Coastal region | Data source |
|---|---|---|---|
| Demographics | | | |
| PWID population size* | 9750–17 150 | 5700–13 100 | [44] |
| Proportion of PWID that are female* | 13.1–16.4% | 9.2–11.9% | TLC-IDU [4] |
| Average duration of injecting (years) | 1.75–7.0 | 2.05–8.2 | TLC-IDU [4] |
| HIV/HCV prevalence | | | |
| HIV prevalence amongst male PWID (2015)* | 8.2–11% | 10.3–17.4% | TLC-IDU [4] |
| HIV prevalence amongst female PWID (2015)* | 19.8–38.4% | 31.2–65% | TLC-IDU [4] |
| HIV prevalence amongst new male PWID in 2012 | 3.4–6.4% | 3.1–5.4% | TLC-IDU [4] |
| HIV prevalence amongst male adults in 2012 | 2.4–5.2% | 1.1–4% | KAIS 2012 [24] |
| HIV prevalence amongst new female PWID in 2012 | 12.2–26.1% | 27.9–50.1% | TLC-IDU [4] |
| HIV prevalence amongst female adults in 2012 | 4.2–8% | 4.1–8.1% | KAIS 2012 [25] |
| HCV antibody prevalence amongst PWID (2015)* | 8.4–13.3% | 19.5–40.7% | TLC-IDU [4] and [26] |
| ART coverage/viral suppression | | | |
| ART coverage amongst HIV-positive PWID (2015)* | 60.3–71% | 50.1–78.4% | TLC-IDU [4] |
| Proportion of PWID on ART that are virally supressed | 28–40% | 35–48% | TLC-IDU [4] |
| Mean log HIV viral load if on ART and virally suppressed | 2.70–2.74 | 2.66–2.70 | TLC-IDU [4] |
| Mean log HIV viral load if on ART and not virally suppressed | 3.71–4.00 | 3.81–4.05 | TLC-IDU [4] |
| Mean log HIV viral load if not on ART | 4.22–4.42 | 4.09–4.32 | TLC-IDU [4] |
| Efficacy of ART for reducing HIV transmission | 25.9–68.9% | 21.7–64.8% | Based on above parameters – see Appendix, http://links.lww.com/QAD/C640 for details |
| Harm reduction | | | |
| Number of PWID on NSP (2020)* | 8537 | 9191 | Programme data |
| Number of PWID ever enrolled onto OAT (2021)* | 2245 | 3411 | Programme data |
| Number currently enrolled on OAT (2021)* | 1137 | 2651 | Programme data |
| Sexual risk | | | |
| Average years of sexual risk before males start injecting | 14.3–15.3 | 15.3–16.0 | TLC-IDU [4] |
| Average years of sexual risk before females start injecting | 12.8–14.7 | 11.0–13.9 | TLC-IDU [4] |
| Proportion of male PWID's sexual partners that are PWID | 0.11–0.17 | 0.12–0.19 | TLC-IDU [4] |
| Proportion of female PWID's sexual partners that are PWID | 0.34–0.50 | 0.24–0.38 | TLC-IDU [4] |

Calibration data are marked by an asterisk; all other entries are model parameters. Full parameter tables and calibration data are in the Appendix, http://links.lww.com/QAD/C640.PWID, people who inject drugs.

The risk of HCV transmission is dependent on the chronic HCV prevalence among PWID. HCV transmission risk is decreased for PWID on OAT and/or NSP [10]. Following HCV infection, some PWID spontaneously clear infection (differs by HIV infection), with the remainder progressing to chronic infection. Chronically infected PWID can receive HCV treatment, with most (90.1% [16]) achieving a sustained virologic response (SVR). Those not achieving SVR return to the chronically infected compartment and are eligible for re-treatment. HIV–HCV co-infected PWID are more infectious than HCV mono-infected PWID [24].

## Model parameterization and calibration

The model was calibrated using data from the 2012 Kenya AIDS indicator survey (KAIS) [25], 2015 and 2016 national polling booth surveys among PWID [7], 2011 integrated bio-behavioural assessment among PWID in Nairobi [3], OAT and NSP programme data, a 2015 HCV prevalence study of PWID in Coastal region [26], and the Testing and Linkage to Care study among PWID (TLC-IDU; NCT01557998) [2,4]. Most data came from TLC-IDU, which consisted of six rounds (2012–2015) of cross-sectional surveys of PWID in Nairobi and Coastal Kenya (total $n = 4871$). Participants were tested for HIV infection and viral load at each round and for HCV antibody in round 6. We assume that IDU initiated between 1997 and 2001 [6], sampling the year of initiation uniformly from this range. OAT, NSP and ART were scaled-up in line with available data (Fig. 2) using different recruitment rates over specific time periods wherever necessary (Appendix Tables 2, http://links.lww.com/QAD/C640 and 3, http://links.lww.com/QAD/C640), and assuming constant recruitment rates after the last available estimate. Programmatic data shows that OAT, NSP and ART coverages were not affected by the COVID-19 pandemic (https://www.unaids.org/en/resources/presscentre/featurestories/2020/october/20201016_covid-impact-on-hiv-treatment-less-severe-than-feared).

For each site, the model was calibrated using an approximate Bayesian computation methods (ABC) [27] to data on: PWID population size in 2011, the proportion of PWID that are female over 2011–2015, HIV prevalence amongst male and female PWID over 2011–2015, HCV seroprevalence amongst all PWID in 2015, ART coverage amongst HIV positive PWID over 2012–2015, the number of PWID currently and ever enrolled onto OAT over 2015–2021, and the number of PWID currently in contact with NSP over 2014–2021. Table 1 summarizes prior ranges for key parameters and calibration data, with full details in Appendix Tables 2–5, http://links.lww.com/QAD/C640.

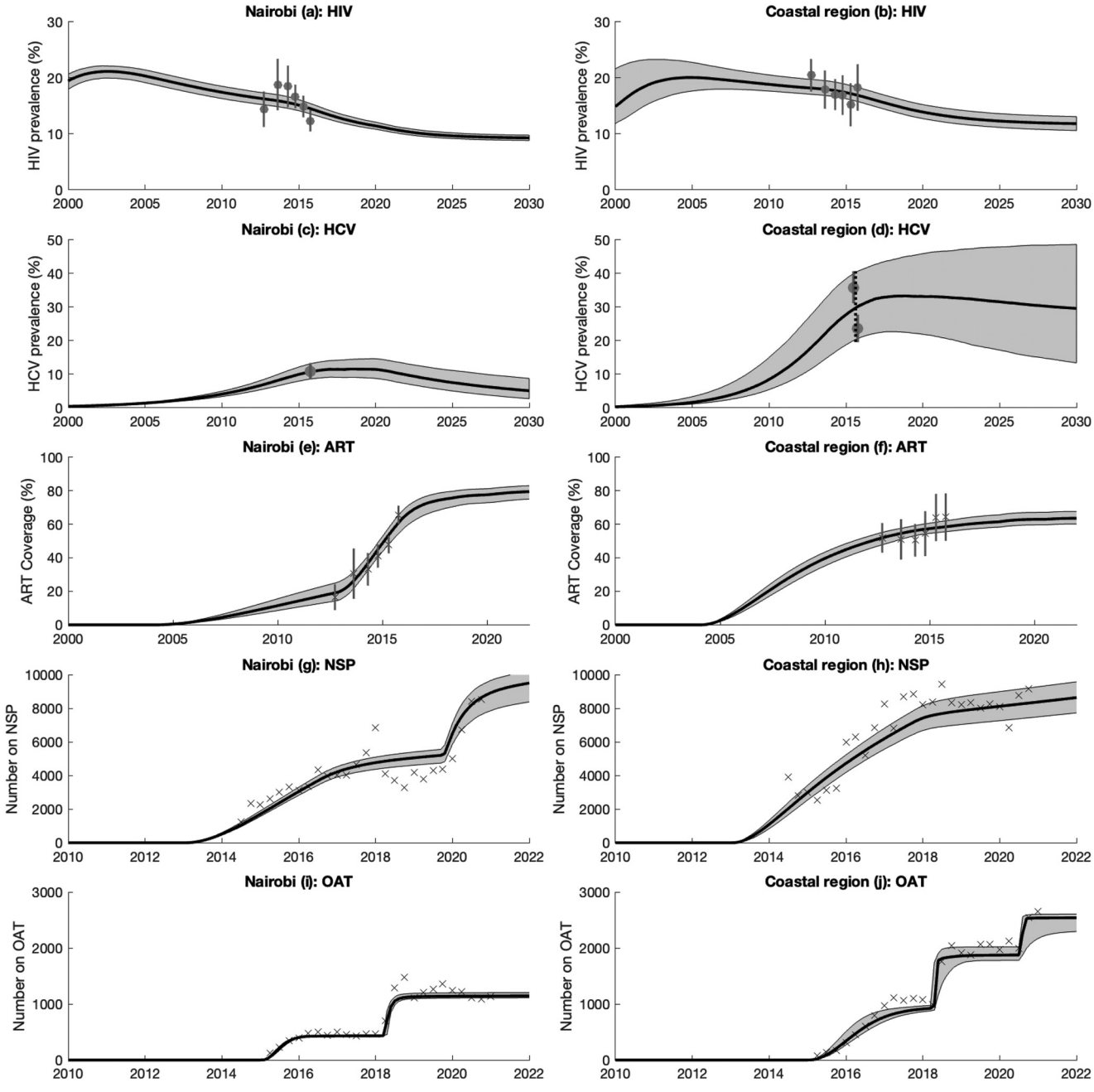


**Fig. 2. Model projections of: HIV prevalence among PWID in Nairobi and Coastal region (a and b); HCV antibody prevalence among PWID in Nairobi and Coastal region (c and d); ART coverage among HIV-positive PWID in Nairobi and Coastal region (e and f); number of PWID currently on NSP in Nairobi and Coastal region (g and h); number of PWID currently on OAT in Nairobi and Coastal region (i and j).** Black lines show the median model projections whilst the shaded area shows the 95% CrI for the baseline projections. Data points with their 95% CI (wherever appropriate) are shown for comparison. Green dotted lines show the calibration range used for HCV prevalence in Coastal region. CrI, credibility interval; NSP, needle and syringe programme; OAT, opioid agonist therapy; PWID, people who inject drugs.

TLC-IDU data was analysed to estimate the HIV prevalence in 2013 among male PWID when they initiate injecting. This was sampled in the ABC and estimated over time by assuming the same ratio between the HIV prevalence among new male PWID and male general population over time. The sampled HIV prevalence among new male PWID in 2013 was also used to estimate a range for the average level of sexual HIV transmission risk experienced by male individuals over the duration of sexual risk before initiating IDU. The same level of sexual HIV transmission risk was assumed after initiating IDU, with this range being calibrated in the ABC. The same method was used for female individuals.

We performed multiple iterations of the ABC, each consisting of 5000 parameter sets, until the main results from the combined parameter sets converged (Appendix Figures 1, http://links.lww.com/QAD/C640 and 2, http://links.lww.com/QAD/C640). These combined parameter sets were sampled, weighted by their likelihood, to give a final group of model fits consisting of 10% of the combined parameter sets (4000 for Nairobi and 3000 for Coastal region); these were used in subsequent analysis.

### Model analyses

We projected the baseline HIV and HCV epidemics among PWID until 2021 and estimated the percentage of new HIV infections in 2020 that were acquired sexually. We then projected the proportion of infections prevented by OAT, NSP and/or ART in 2020.

We then projected the impact, in terms of reduction in HIV/HCV incidence (over 2021–2030), of scaling-up harm reduction interventions and/or HIV and HCV treatment from 2021 (modelled as an increase in treatment recruitment rates). Specifically, we modelled the following scenarios:

(1) Full harm reduction (HR): scale-up OAT and NSP to 50 and 75% coverage, respectively (modelled as an increase in OAT/NSP recruitment rates). These coverages represent what some high-income countries have achieved [28,29] and align with WHO and UNAIDS targets
(2) Full ART: scale-up ART to meet UNAIDS 90–90–90 targets among PWID, that is, 81% ART coverage and 90% viral suppression
(3) Full HR+Full ART
(4) Treat HCV: treat 1000 HCV-positive PWID over next 5 years, based on the Kenyan government having secured 1000 DAAs for use over 5 years
(5) Full HR+Treat HCV

We also estimated the additional impact of reducing HIV sexual transmission risk by 25, 50 or 75% alongside Full HR+Full ART from 2021. These reductions in sexual risk are in line with what has been achieved through sexual risk reduction interventions among people who use drugs [30] and other male or high-risk populations [31,32]. Lastly, we estimated the HCV treatments needed to decrease HCV incidence by 90% over 2021–2030 (WHO elimination target).

To determine which parameter uncertainties are important for contributing to the variability in our model projections, a linear regression analysis of covariance was performed on the relative reduction in HIV and HCV incidence achieved over 2021–2030 from Full HR+Full ART.

## Results

### Baseline model projections

The calibrated model fit the data well (Fig. 2), suggesting a slowly decreasing HIV epidemic among PWID in both settings, a decreasing HCV epidemic in Nairobi and a stable HCV epidemic in Coastal region. HIV prevalence is projected to be 2.8 times [95% credibility interval (CrI): 2.6–3.0] and 4.2 times (95% CrI: 3.5–4.8) higher among female PWID than male PWID in Nairobi and Coastal region, respectively.

The model projects HIV and HCV incidences of 1.0 (95% CrI: 0.9–1.2) and 3.4 (95% CrI: 2.3–4.9) per 100 person-years (py) in 2021 in Nairobi, respectively, and 1.8 (95% CrI: 1.3–2.3) and 13.3 (95% CrI: 7.3–23.1) per 100 py in Coastal region. Despite similar injecting risks, a much higher HCV incidence is projected in Coastal region because of a longer duration of injecting (posterior: 4.7 years, 95% CrI 3.0–6.7) than in Nairobi (3.4 years; 95% CrI: 3.0–3.8), which results in a greater HCV prevalence and so incidence (Fig. 2). In both settings, sexual HIV transmission contributes majorly to HIV transmission, with 25.6% (95% CrI: 21.3–30.1) and 52.1% (95% CrI: 46.0–57.9) of new HIV infections among male and female PWID being sexually transmitted in Nairobi (30.4% (95% CrI: 25.6–35.5) among all PWID), respectively, compared with 15.4% (95% CrI: 9.9–22.0) and 63.6% (95% CrI: 54.0–70.5) in Coastal region [22.7% (95% CrI: 16.3–30.3] among all PWID). Overall, HIV incidence among female PWID is greater than among male PWID in both Nairobi (IRR: 1.6, 95%]: 1.4–1.7) and Coastal region (IRR: 2.3, 95% CrI: 1.9–2.7), with the incidence of sexually acquired HIV infection being three times higher among female PWID than male PWID in Nairobi (IRR: 3.2, 95% CrI: 2.8–3.5) and 10 times higher in Coastal region (IRR: 9.7, 95% CrI; 7.5–12.7).

### Impact of existing interventions

In 2021, for Nairobi and Coastal region, the model projects NSP coverages of 60.8% (95% CrI: 52.5–67.4) and 45.2% (95% CrI: 32.1–4.7), OAT coverages of 7.8%

(95% CrI: 7.2–8.4) and 13.4% (95% CrI: 8.8–16.6), and ART coverages of 78.7% (95% CrI: 74.0–82.2) and 63.2% (95% CrI: 59.9–67.4), respectively. In general, these interventions have had greatest impact in Nairobi and more impact on HCV (Fig. 3 and Appendix Figure 3, http://links.lww.com/QAD/C640). For instance, in 2020 existing harm reduction interventions averted 50.8% (95% CrI: 43.5–56.5) and 66.1% (95% CrI: 58.7–71.6) of new HIV and HCV infections in Nairobi and 46.0% (95% CrI: 32.6–54.8) and 50.0% (95% CrI: 29.5–64.2) in Coastal region. The impact of NSP and OAT on HIV is less than for HCV because of the high levels of sexual HIV transmission among PWID, while NSP had more (3–10-times) impact than OAT (Fig. 3) because of its much higher coverage.

ART (among PWID) has had greater impact in Nairobi than Coastal region, averting 39.8% (95% CrI: 34.8–44.2) and 12.9% (95% CrI: 6.8–19.8) of HIV infections in 2020, respectively. Impact is lower in Coastal region because they have lower ART coverage than in Nairobi and smaller reductions in viral load when on ART (Table 1; likely because of differences in adherence to ART) reducing its prevention efficacy.

Without existing interventions, HIV and HCV prevalence would have been much higher in both settings (Appendix Figure 3, http://links.lww.com/QAD/C640). HIV prevalence still declines without these interventions because of ongoing reductions in HIV prevalence among the general population.

## Impact of scaling-up interventions

Without intervention scale-up, HIV incidence is projected to decrease by 16.0% (95% CrI: 12.9–19.2) in Nairobi and 9.1% (95% CrI: 6.7–15.6) in Coastal region over 2021–2030. Scaling-up harm reduction interventions and ART could reduce HIV incidence by 51.5% (95% CrI: 45.4–57.7) in Nairobi and 64% (95% CrI: 54.4–75.6) in Coastal region over 2021–2030 (Fig. 4; Appendix Figure 4, http://links.lww.com/QAD/C640). Just scaling-up ART or harm reduction has less impact; in Nairobi, for example, HIV incidence reduces by 45.1% (95% CrI: 38.5–51.8) through just scaling-up of

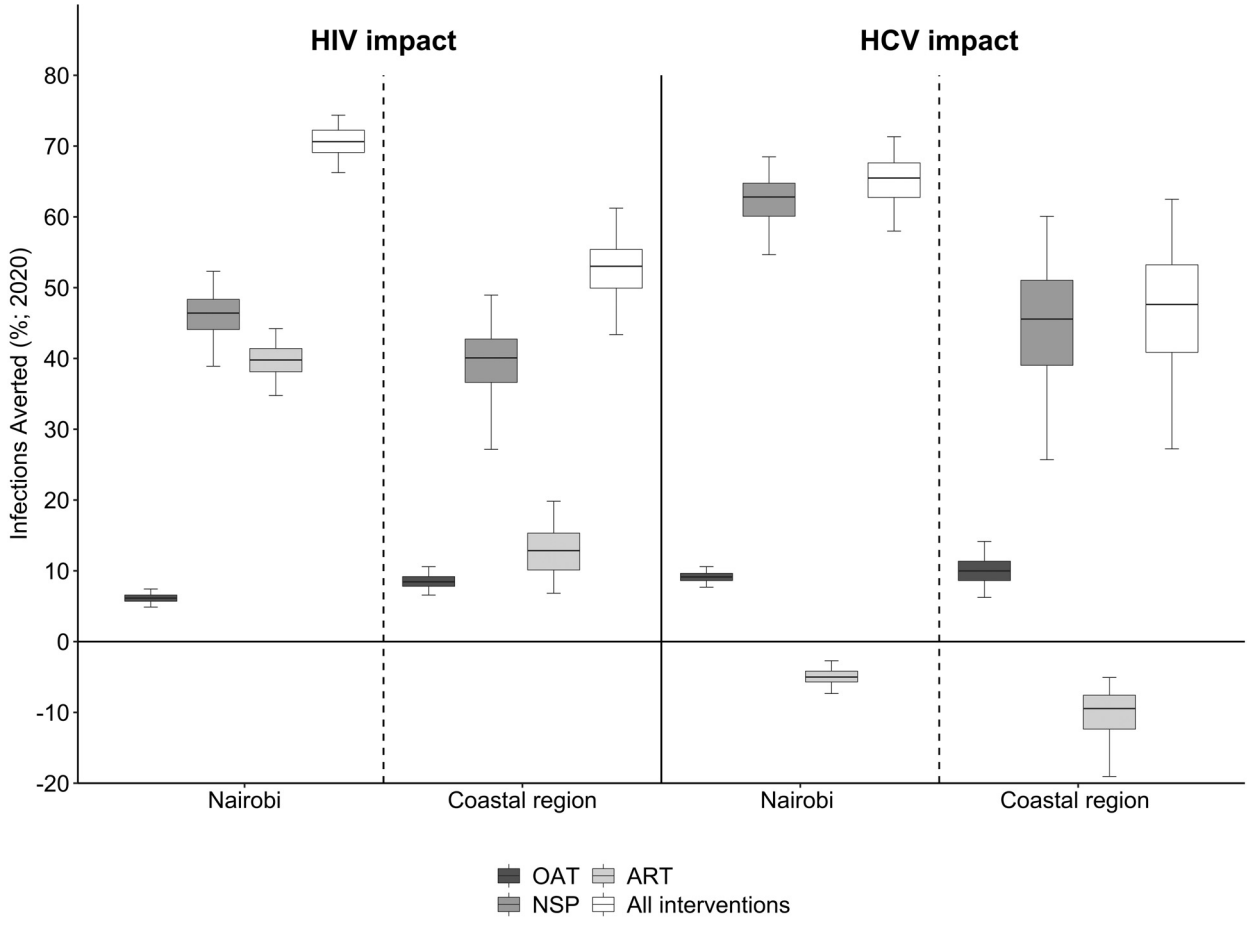


**Fig. 3. Proportion of new HIV and hepatitis C virus infections averted among PWID in Nairobi and Coastal region by existing interventions in 2020** Boxes indicate the interquartile range, with the lines inside indicating the median impact, with whiskers representing 95% credibility intervals for the simulations. NSP, needle and syringe programme; OAT, opioid agonist therapy; PWID, people who inject drugs.

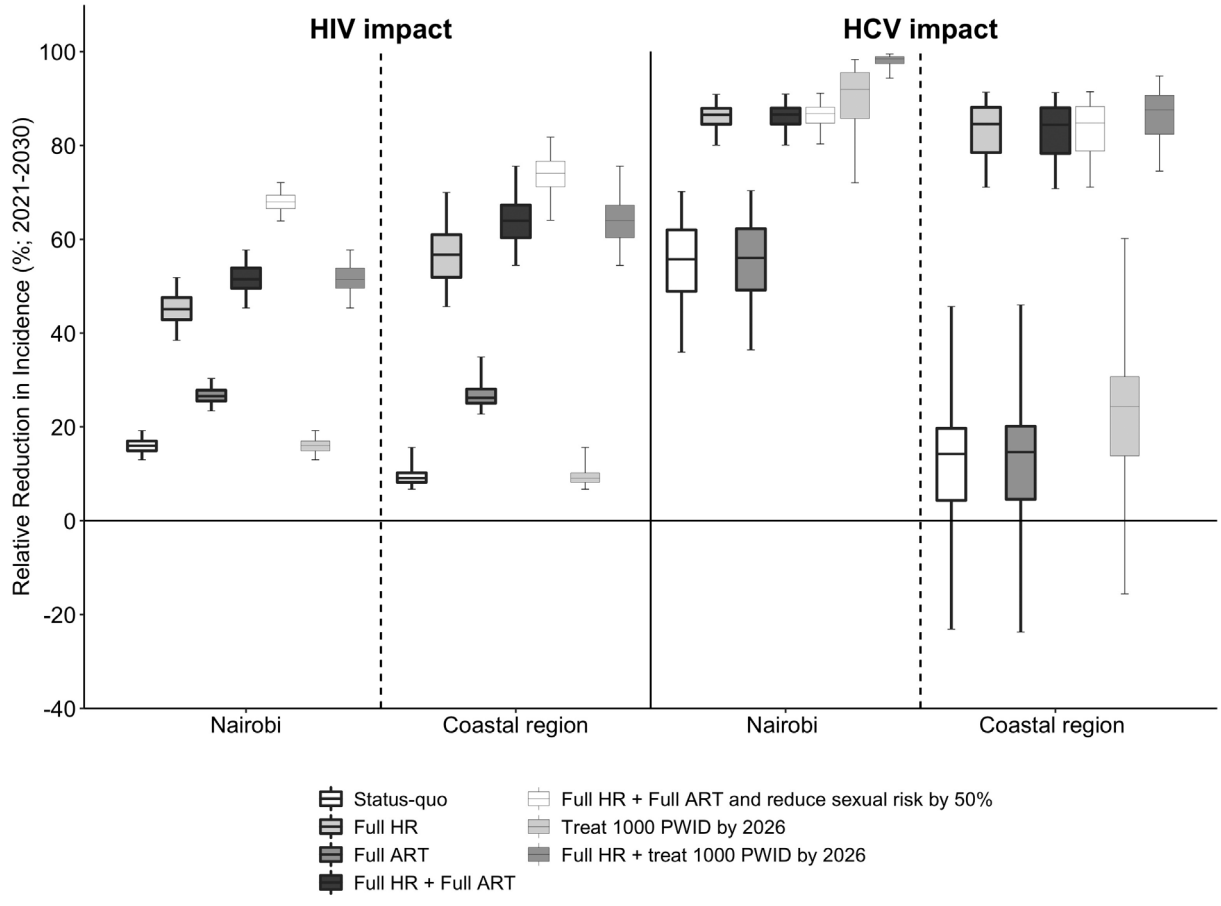


**Fig. 4. Relative reduction in HIV and hepatitis C virus incidence over 2021–2030 among people who inject drugs in Nairobi and Coastal region for different intervention scale-up scenarios** Boxes indicate the interquartile range, with the lines inside indicating the median impact, with whiskers representing 95% credibility intervals for the simulations.

harm reduction (Full HR) or 26.6% (95% CrI: 23.4–30.3) through just scaling-up ART (Full ART). In Nairobi, 69.1% (95% CrI: 61.0–79.7) of the impact of scaling-up harm reduction is achieved through scaling-up OAT, whereas 48.6% (95% CrI: 31.3–62.6) is achieved if only NSP is scaled up. In contrast, scaling-up OAT and NSP individually have similar impact in Coastal region (Appendix Figure 5, http://links.lww.com/QAD/C640). In both settings, improving levels of viral suppression achieves much of the impact of scaling-up ART (92.2%; 95% CrI: 67.1–100.0 in Nairobi and 49.6%; 95% CrI: 38.3–61.6 in Coastal region).

Further reductions in HIV incidence can be achieved in both settings through reducing sexual risk (Fig. 4). Halving sexual risk alongside scaling-up harm reduction interventions and ART (Full HR+Full ART) reduces HIV incidence by 68.0% (95% CrI: 63.9–72.1) in Nairobi and 74.1% (95% CrI: 64.1–81.8) in Coastal region. For Nairobi, this changes to HIV incidence decreasing by 60.3% (95% CrI: 55.5–65.3) or 74.6% (95% CrI: 71.2–77.8) if sexual risk is reduced by 25 or 75%, while in Coastal region the decrease in HIV incidence becomes 69.1% (95% CrI: 59.4–78.8) or 78.6% (95% CrI: 68.4–84.8) (Appendix Figure 6, http://links.lww.com/QAD/C640).

Without intervention scale-up, HCV incidence is projected to decrease by 55.8% (95% CrI: 35.9–70.2) in Nairobi over 2021–2030, and by 14.2% (95% CrI: −23.1 to 45.7) in Coastal region; both with considerable uncertainty. Scaling-up OAT and NSP (Full HR) could reduce HCV incidence by 86.6% (95% CrI: 80.0–90.9) in Nairobi and 84.6% (95% CrI: 71.1–91.4) in Coastal region (Fig. 4). Conversely, treating 1000 PWID in each setting over the next 5 years could reduce HCV incidence by 92.0% (95% CrI: 72.1–98.3) in Nairobi but only 24.3% (95% CrI: −15.6 to 60.2) in Coastal region, while combining this with Full HR could nearly eliminate HCV. Treating 1000 PWID has much greater impact in Nairobi than Coastal region because there are substantially fewer chronically infected PWID in Nairobi (1242 in 2021; 95% CrI: 904–1713) than in Coastal region (4952; 95% CrI: 2777–9521). A 90% reduction in HCV incidence is achieved by 2030 if alongside scaling-up harm reduction, 301 (95% CrI: 0–716) PWID are treated

by 2026 in Nairobi and 1943 (95% CrI: 0–5998) are treated in Coastal region, with this increasing to 948 (550–1524) and 6,190 (2609–16 738) without Full HR.

### Uncertainty analysis

Uncertainty in the levels of sexual transmission (37.5 and 51.3% of uncertainty in Nairobi and Coastal region, respectively) and NSP coverage (Nairobi: 31.6%, Coastal region: 11.8%) contributed most to the variability in the impact of scaling-up harm reduction interventions and ART on HIV incidence (Appendix Table 6, http://links.lww.com/QAD/C640). Conversely, uncertainty in the duration of injecting (Nairobi: 51.6%, Coastal region: 38.1%), NSP coverage (Nairobi: 14.6%, Coastal region: 5.2%) and NSP effectiveness (Nairobi: 14.6%, Coastal region: 29.0%) contributed most to the variability in the impact on HCV incidence (Appendix Table 7, http://links.lww.com/QAD/C640).

## Discussion

### Main findings

Our projections show that NSP has resulted in substantial impact, because of its rapid expansion to 45–61% coverage, preventing 40–46% of HIV infections and 46–63% of HCV infections in 2020. In contrast, OAT has averted less than 10% of HIV/HCV infections because of low coverage levels. The impact of ART (13–40% infections averted) has been limited by sub-optimal viral suppression. To increase impact, harm reduction interventions (particularly OAT in Nairobi) and ART (particularly viral suppression) need to be scaled-up and optimized, with HIV incidence decreasing by 51–66% and HCV incidence by about 85% if NSP is increased to 75% coverage, OAT to 50% coverage and the 90/90/90 targets for ART are reached. HIV incidence can be reduced further through implementing interventions that reduce sexual risk, whereas HCV incidence can be reduced by more than 90% through scaling-up HCV treatment alongside harm reduction.

### Strengths and limitations

Strengths of our analyses include the use of detailed epidemiological, behavioural and programmatic data from multiple sources to calibrate our model within a Bayesian framework; increasing the rigour of our analyses. We also modelled the two settings where IDU is concentrated in Kenya [21] and where data enabled detailed modelling. Although, data is limited for other regions, initial data suggests Western Kenya may be at an earlier stage of their HCV and IDU epidemics [4], and so our findings may not be fully generalizable across all regions. Whilst we had detailed data on trends in HIV prevalence among PWID, HCV prevalence data were limited, as for much of SSA [33], with no HIV/HCV prevalence estimates being available after 2016. Better data on HCV prevalence trends among PWID will improve the accuracy of our impact projections. The last decade has seen significant improvements in the availability of HIV and HCV prevalence estimates for PWID in SSA [5]; the move to increase HCV testing and treatment in low-income and middle-income countries should also produce better data for HCV in SSA. We used global systematic reviews to parameterize the effectiveness of OAT and NSP in reducing HIV and HCV transmission risk [10]. However, these reviews are largely based on studies from Europe, Australia and North America and so it is uncertain whether these interventions would have similar effectiveness in SSA. As harm reduction interventions are scaled-up, it is important to investigate whether these interventions have a similar effectiveness in SSA. When modelling the sexual transmission of HIV among PWID, we were limited by available sexual behaviour data. Consequently, we modelled the level of sexual risk indirectly and, although sexual and injecting networks may overlap, the model assumed that PWID mix randomly to form potential sexual and injecting transmission contacts with other PWID. Despite these limitations, the calibrated models accurately captured observed differences in HIV prevalence between male and female PWID, which is largely thought to be because of differences in sexual risk. This results in a high proportion of new HIV infections being acquired sexually, particularly among female PWID, similar to those previously estimated for Tanzania [20].

### Comparisons with existing studies

To our knowledge, this study, along with an accompanying study in Dar es Salaam [20], Tanzania, represents the first dynamic modelling of ongoing HIV and HCV epidemics among PWID in SSA. Previous modelling for Nairobi suggested that scaling-up of OAT to 40% coverage in Kenya could reduce HIV incidence by a fifth over 10 years [34]. Adding to this, we show that OAT has had limited impact so far because coverage remains low, although large impact could be achieved if scaled-up. Other modelling for Kenya [35] and other settings [36] have shown that a combined approach of scaling-up harm reduction interventions alongside ART is needed to substantially reduce HIV transmission. Although our modelling agrees with this, through capturing sexual HIV transmission, we also show the importance of sexual risk reduction interventions for achieving substantial reductions in HIV incidence in Kenya. This will be relevant to other SSA settings. As for Tanzania [20,37] and other more established HCV epidemics [38], our modelling also suggests that scaling-up harm reduction alone cannot achieve HCV elimination, but that HCV treatment is also needed.

### Implications

To achieve HIV and HCV elimination targets among PWID, OAT, HCV treatment and ART (to a lesser extent) urgently need scaling-up among PWID in Kenya.

Mobile outreach models for OAT are being implemented to improve access [39] with similar models for ART being considered (P Bhattacharjee, Personal Communication, 1 February 2022). However, efforts are also required to improve and ensure treatment outcomes, including the integration and differentiation of OAT and HIV care that links community outreach and clinical efforts [40,41]. In addition, HCV testing needs expanding to allow HCV treatment scale-up; only 22% of PWID in 2015 reported being tested for HCV in last 3 months compared with 74% for HIV [7]. This testing could occur when HIV testing occurs through NSP or OAT clinics as demonstrated by two pilot HCV screening and treatment interventions in Kenya [16,42].

Interventions to reduce sexual risk among PWID, particularly female individuals, are also needed to reduce HIV transmission. This should firstly focus on promoting condom use, which could be achieved through individual-level counselling strategies based on the information–motivation–behavioural skills model [31]. HIV pre-exposure prophylaxis (PrEP) could also be introduced, which could be particularly important for the large portion of female PWID engaged in transactional/commercial sex [7]. However, knowledge of PrEP among female PWID needs improving [43] while PrEP interventions need to specifically target this group. Due to the high HIV prevalence among newly initiating PWID, harm reduction interventions should target all people who use drugs, not just PWID, and should focus on reducing both their injecting and sexual transmission risk.

## Acknowledgements

This study was funded by the Global Fund East Africa Harm Reduction Project and Medicins du Monde. J.S., P.V., and H.F. acknowledge support from the NIHR Health Protection Research Unit in Behavioural Science and Evaluation. P.V. acknowledges support from NAID/NIDA (R01AI147490). M.J.A. acknowledges support from NIDA (R00DA043011). Funding for study data provided from A.K. and P.C. was from NIDA 5R01DA032080.

Publication history: This manuscript was previously posted to medRxiv: doi: https://doi.org/10.1101/2021.02.02.21251008

Authors contributions: P.V. undertook the initial conceptualization with N.L. and B.M., which was refined with E.W.. J.S. developed the model with input from J.G.W., H.F. and P.V. J.S. performed the model analyses and wrote the first draft of the manuscript. P.V. supervised the project, which was coordinated in Kenya by B.M.. P.B., H.M., A.K., and J.G.W. provided data and/or undertook data analyses for the model. All authors contributed to data interpretation, writing the manuscript and approved the final version.

### Conflicts of interest

H.F. has received an honorarium from MSD unrelated to this research. P.V. and J.G.W. have received unrestricted research funding from Gilead unrelated to this work. All other authors have no disclosures.

## References

1. National AIDS and STI Control Programme (NASCOP), Preliminary KENPHIA 2018 Report. Nairobi: NASCOP; 2020.
2. Kurth AE, Cleland CM, Des Jarlais DC, Musyoki H, Lizcano JA, Chhun N, *et al*. **HIV prevalence, estimated incidence, and risk behaviors among people who inject drugs in Kenya.** *J Acquir Immune Defic Syndr* 2015; **70**:420–427.
3. Tun W, Sheehy M, Broz D, Okal J, Muraguri N, Raymond HF, *et al*. **HIV and STI prevalence and injection behaviors among people who inject drugs in Nairobi: results from a 2011 biobehavioral study using respondent-driven sampling.** *AIDS Behav* 2015; **19 Suppl 1**:S24–S35.
4. Akiyama MJ, Cleland CM, Lizcano JA, Cherutich P, Kurth AE. **Prevalence, estimated incidence, risk behaviours, and genotypic distribution of hepatitis C virus among people who inject drugs accessing harm-reduction services in Kenya: a retrospective cohort study.** *Lancet Infect Dis* 2019; **19**:1255–1263.
5. Degenhardt L, Peacock A, Colledge S, Leung J, Grebely J, Vickerman P, *et al*. **Global prevalence of injecting drug use and sociodemographic characteristics and prevalence of HIV, HBV, and HCV in people who inject drugs: a multistage systematic review.** *Lancet Glob Health* 2017; **5**:e1192–e1207.
6. Beckerleg S, Telfer M, Hundt GL. **The rise of injecting drug use in East Africa: a case study from Kenya.** *Harm Reduct J* 2005; **2**:12.
7. National AIDS & STI Control Programme, Ministry of Health, Kenya. *Second National Behavioural Assessment of Key Populations in Kenya: Polling Booth Survey Report*. Nairobi: NASCOP; 2016.
8. Aspinall EJ, Nambiar D, Goldberg DJ, Hickman M, Weir A, Van Velzen E, *et al*. **Are needle and syringe programmes associated with a reduction in HIV transmission among people who inject drugs: a systematic review and meta-analysis.** *Int J Epidemiol* 2014; **43**:235–248.
9. MacArthur GJ, Minozzi S, Martin N, Vickerman P, Deren S, Bruneau J, *et al*. **Opiate substitution treatment and HIV transmission in people who inject drugs: systematic review and meta-analysis.** *BMJ* 2012; **345 (oct03 3)**:e5945.
10. Platt L, Minozzi S, Reed J, Vickerman P, Hagan H, French C, *et al*. **Needle syringe programmes and opioid substitution therapy for preventing hepatitis C transmission in people who inject drugs.** *Cochrane Database Syst Rev* 2017; **9**:CD012021.
11. Larney S, Peacock A, Leung J, Colledge S, Hickman M, Vickerman P, *et al*. **Global, regional, and country-level coverage of interventions to prevent and manage HIV and hepatitis C among people who inject drugs: a systematic review.** *Lancet Global Health* 2017; **5**:e1208–e1220.
12. Quinn TC, Wawer MJ, Sewankambo N, Serwadda D, Li C, Wabwire-Mangen F, *et al*. **Viral load and heterosexual transmission of human immunodeficiency virus type 1. Rakai Project Study Group.** *N Engl J Med* 2000; **342**:921–929.
13. Rodger AJ, Cambiano V, Bruun T, Vernazza P, Collins S, Degen O, *et al*. **Risk of HIV transmission through condomless sex in serodifferent gay couples with the HIV-positive partner taking suppressive antiretroviral therapy (PARTNER): final results of a multicentre, prospective, observational study.** *Lancet* 2019; **393**:2428–2438.
14. Cohen MS, Chen YQ, McCauley M, Gamble T, Hosseinipour MC, Kumarasamy N, *et al*. **Prevention of HIV-1 infection with early antiretroviral therapy.** *N Engl J Med* 2011; **365**:493–505.

15. UNAIDS. Kenya Country Factsheet. Available at: https://www.unaids.org/en/regionscountries/countries/kenya. [Accessed 17 January 2022]
16. Mafirakureva N, Stone J, Fraser H, Nzomukunda Y, Maina A, Thiong'o AW, *et al*. **An intensive model of care for hepatitis C virus screening and treatment with direct-acting antivirals in people who inject drugs in Nairobi, Kenya: a model-based cost-effectiveness analysis.** *Addiction* 2022; **117**:411–424.
17. National AIDS & STI Control Programme. National Guidelines for the Control and Management of Viral Hepatitis 2018. Available at: https://www.nascop.or.ke/key-populations-downloads/ [Accessed 11 February 2022]
18. World Health Organization. Global health sector strategy on viral hepatitis 2016–2021. Towards ending viral hepatitis. World Health Organization.2016.
19. UNAIDS. Fast-Track — ending the AIDS epidemic by 2030. Available at: https://www.unaids.org/en/resources/documents/2014/JC2686_WAD2014report [Accessed 17 January 2022]
20. Fraser H, Stone J, Wisse E, Sambu V, Mfisi P, Duran IJ, *et al*. **Modelling the impact of HIV and HCV prevention and treatment interventions for people who inject drugs in Dar es Salaam, Tanzania.** *J Int AIDS Soc* 2021; **24**:e25817.
21. NASCOP. Key population mapping and size estimation in selected counties in Kenya; Phase one, key findings, April 2019. Available at: https://hivpreventioncoalition.unaids.org/country-action/key-population-mapping-and-size-estimation-in-selected-counties-in-kenya-phase-one-key-findings-april-2019/.
22. Hollingsworth TD, Anderson RM, Fraser C. **HIV-1 transmission, by stage of infection.** *J Infect Dis* 2008; **198**:687–693.
23. Degenhardt L, Grebely J, Stone J, Hickman M, Vickerman P, Marshall BDL, *et al*. **Global patterns of opioid use and dependence: harms to populations, interventions, and future action.** *Lancet* 2019; **394**:1560–1579.
24. Fraser H, Mukandavire C, Martin NK, Hickman M, Cohen MS, Miller WC, *et al*. **HIV treatment as prevention among people who inject drugs - a re-evaluation of the evidence.** *Int J Epidemiol* 2017; **46**:466–478.
25. National AIDS and STI Control Programme (NASCOP), Kenya. Kenya AIDS Indicator Survey 2012: Final Report. Nairobi, NASCOP. June 2014.
26. Shah R, Boucheron P, Mandaliya K, Kattamaiyo A, Chevaliez S, Shimakawa Y, *et al*. **Hepatitis C virus infection in people who inject drugs in Africa.** *Lancet Infect Dis* 2020; **20**:282–283.
27. Toni T, Welch D, Strelkowa N, Ipsen A, Stumpf MP. **Approximate Bayesian computation scheme for parameter inference and model selection in dynamical systems.** *J R Soc Interface* 2009; **6**:187–202.
28. Platt L, Sweeney S, Ward Z, Guinness L, Hickman M, Hope V, *et al*. **Assessing the impact and cost-effectiveness of needle and syringe provision and opioid substitution therapy on hepatitis C transmission among people who inject drugs in the UK: an analysis of pooled data sets and economic modelling.** *Public Health Res* 2017; **5**:.
29. Fraser H, Mukandavire C, Martin NK, Goldberg D, Palmateer N, Munro A, *et al*. **Modelling the impact of a national scale-up of interventions on hepatitis C virus transmission among people who inject drugs in Scotland.** *Addiction* 2018; **113**:2118–2131.
30. Elkbuli A, Polcz V, Dowd B, McKenney M, Prado G. **HIV prevention intervention for substance users: a review of the literature.** *Subst Abuse Treat Prev Policy* 2019; **14**:1.
31. Townsend L, Mathews C, Zembe Y. **A systematic review of behavioral interventions to prevent HIV infection and transmission among heterosexual, adult men in low-and middle-income countries.** *Prev Sci* 2013; **14**:88–105.
32. Wariki WM, Ota E, Mori R, Koyanagi A, Hori N, Shibuya K. **Behavioral interventions to reduce the transmission of HIV infection among sex workers and their clients in low-and middle-income countries.** *Cochrane Database Syst Rev* **(2)**:2012:CD005272.
33. Sonderup MW, Afihene M, Ally R, Apica B, Awuku Y, Cunha L, *et al*. **Hepatitis C in sub-Saharan Africa: the current status and recommendations for achieving elimination by 2030.** *Lancet Gastroenterol Hepatol* 2017; **2**:910–919.
34. Rhodes T, Guise A, Ndimbii J, Strathdee S, Ngugi E, Platt L, *et al*. **Is the promise of methadone Kenya's solution to managing HIV and addiction? A mixed-method mathematical modelling and qualitative study.** *BMJ Open* 2015; **5**:e007198.
35. Strathdee SA, Hallett TB, Bobrova N, Rhodes T, Booth R, Abdool R, *et al*. **HIV and risk environment for injecting drug users: the past, present, and future.** *Lancet* 2010; **376**:268–284.
36. Degenhardt L, Mathers B, Vickerman P, Rhodes T, Latkin C, Hickman M. **Prevention of HIV infection for people who inject drugs: why individual, structural, and combination approaches are needed.** *Lancet* 2010; **376**:285–301.
37. Scott N, Mohamed Z, Rwegasha J, Mbwambo J, Lemoine M, Hellard M. **Upscaling prevention, testing and treatment to control hepatitis C as a public health threat in Dar es Salaam, Tanzania: a cost-effectiveness model.** *Int J Drug Policy* 2021; **88**:102634.
38. Fraser H, Martin NK, Brummer-Korvenkontio H, Carrieri P, Dalgard O, Dillon J, *et al*. **Model projections on the impact of HCV treatment in the prevention of HCV transmission among people who inject drugs in Europe.** *J Hepatol* 2018; **68**:402–411.
39. Kenya's Country Opetaional Plan 2020, Strategic Direction Summary. 2020. Available at: https://www.state.gov/wp-content/uploads/2020/08/Kenya-COP20-SDS-Final.pdf
40. Musyoki H, Bhattacharjee P, Sabin K, Ngoksin E, Wheeler T, Dallabetta G. **A decade and beyond: learnings from HIV programming with underserved and marginalized key populations in Kenya.** *J Int AIDS Soc* 2021; **24 (Suppl 3)**:e25729.
41. Guise A, Ndimbii J, Igonya EK, Owiti F, Strathdee SA, Rhodes T. **Integrated and differentiated methadone and HIV care for people who use drugs: a qualitative study in Kenya with implications for implementation science.** *Health Policy Plan* 2019; **34**:110–119.
42. Akiyama MJ, Riback LR, Nyakowa M, Musyoki H, Lizcano JA, Muller A, *et al*. **Hepatitis C treatment outcomes among people who inject drugs accessing harm reduction settings in Kenya.** *J Viral Hepat* 2022; **21**:691–694.
43. Bazzi AR, Yotebieng KA, Agot K, Rota G, Syvertsen JL. **Perspectives on biomedical HIV prevention options among women who inject drugs in Kenya.** *AIDS Care* 2018; **30**:343–346.
44. Kenya Ministry of Health. Kenya Most At Risk Populations Size Estimate Consensus report. 2013.