

Substantial but spatially heterogeneous progress in male circumcision for HIV prevention in South Africa

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26 Abstract

27 Voluntary medical male circumcision (VMMC) reduces male HIV acquisition risk by 60% and has
28 become a priority HIV prevention intervention in eastern and southern Africa. Traditional circumcision
29 is also a long-standing male coming-of-age ritual, but practices vary by ethnic groups and geographies.
30 We developed a Bayesian spatio-temporal model to synthesise five national household surveys and HIV
31 prevention programme data for region-age-time-type circumcision probabilities across 52 districts of
32 South Africa. Nationally, in 2008, 24.1% (95%CI: 23.4–24.8%) of men 15–49 years were traditionally
33 circumcised and 19.4% (18.9–20.0%) were medically circumcised. Between 2010 and 2019, 4.25 million
34 VMMCs were conducted and coverage increased to 64.0% (63.2–64.9%), with medical circumcision
35 coverage increasing to 42% (41.3–43.0%). However, coverage varied widely across districts from 13.4%
36 to 86.3%. Overall, South Africa has made substantial, but heterogeneous, progress towards increasing
37 medical circumcision coverage. Detailed subnational information on practices will guide programmes
38 to identify unmet need and achieve national targets.

39 Introduction

40 Preventing HIV infection continues to be a major public health priority, particularly in southern and
41 eastern Africa. Despite considerable progress combatting the epidemic, new HIV infections remain well
42 above national and international targets [1]. Voluntary medical male circumcision (VMMC), defined
43 as the complete surgical removal of the foreskin, reduces the risk of female-to-male HIV acquisition by
44 60% [2–6]. Some evidence indicates that VMMC may also reduce the risk of HIV acquisition among
45 men who have sex with men [7] and may decrease the risk of other sexually transmitted infections,
46 such as syphilis, herpes simplex virus type 2, and human papillomavirus [8].

47 VMMC is appealing as an HIV prevention intervention because it is a one-time, efficient, safe, and cost-
48 effective method. The World Health Organization (WHO) and the Joint United Nations Programme
49 on HIV/AIDS (UNAIDS) identify fifteen African countries with high HIV prevalence and low male
50 circumcision (MC) prevalence as priority countries to scale-up VMMC for HIV prevention [9–11]. In
51 2010, ambitious targets were set to achieve 80% circumcision coverage among men aged 15–49 years by
52 2015. In 2016 new complementary targets were established to reach 90% circumcision coverage among
53 adolescent boys and young men aged 10–29 years by 2021 [12]. In South Africa, the *South African*
54 *National Strategic Plan for HIV, TB, and STIs 2017–2022* set a target to provide 2.5 million VMMC
55 over the five years as part of a comprehensive combination HIV prevention package [13].

56 While large-scale provision of medical male circumcision (MMC) for HIV prevention is relatively recent,
57 male circumcision has traditionally been practiced in many African countries as part of traditional male
58 initiation ceremonies (TMIC). Circumcisions during TMIC are typically conducted among adolescent
59 boys and young men, but its provision, typical age at circumcision, and what it entails differ consider-
60 ably between and within countries, influenced by community-established values, and religious, ethnic
61 and cultural identities. In South Africa, there is substantial heterogeneity in traditional circumcision
62 practices across ethnic groups, ranging from rarely conducted to nearly universal [14, 15]. Traditional
63 male circumcision (TMC) conducted during TMIC is often performed using non-medical methods in
64 non-clinical settings by a traditional practitioner with no formal medical training [16–18]. Whether
65 TMC involves complete or only partial removal of the foreskin varies by practicing groups. In some
66 cases, TMC may involve partial circumcision or only a simple incision in the prepuce and is not thought
67 to confer the same HIV prevention benefits as medical circumcision [19–21]. Due to incomplete HIV
68 prevention efficacy and safety considerations, VMMC programmes are increasingly working with tra-
69 ditional leaders for MMCs to be conducted as part of TMICs by medical service providers (hereafter
70 referred to as MMC-T for medical male circumcisions conducted in traditional settings). Replacing
71 TMC with MMC-T ensures men circumcised through TMIC have the same protection against HIV

infection, as well as safe and sanitary surgical procedures [19].

In light of this heterogeneity, planning and delivering VMMC services to meet programmatic targets requires detailed information about the coverage of circumcision by age group and type of circumcision (traditional or medical) at subnational levels. Information about male circumcision coverage is available from two sources: (i) household surveys collecting self-reported circumcision status, and (ii) health system programme data on the number of VMMC conducted for HIV prevention. National household surveys, conducted roughly every five years, collect data on current HIV status and other risk factors including self-reported circumcision status, age at circumcision, and type of circumcision from nationally-representative samples. Household survey estimates of circumcision coverage are relatively precise at the national level, but have large statistical uncertainty at subnational levels and within fine age groups due to small sample sizes. In South Africa, the numbers of VMMC conducted by HIV prevention services are reported to the National Department of Health (NDoH) by VMMC programme implementers, but this does not reflect men circumcised traditionally or medical circumcisions conducted before the start of the national VMMC programme in 2010.

Previous approaches to estimate district-level circumcision coverage have considered both data sources, but often not together. Cork *et al.* analysed household survey data using a Bayesian small area estimation model producing annual estimates of total circumcision coverage in men aged 15–49 years in sub-Saharan Africa at multiple spatial resolutions between 2000 and 2017 [22]. The *Decision Makers’ Program Planning Toolkit, Version 2* (DMPPT2) is a model to support planning VMMC scale-up in sub-Saharan Africa that allows national HIV programme users to enter reported number of VMMCs and generate VMMC targets, coverage estimates, and impact projections. DMPPT2 combines estimates of circumcision coverage prior to VMMC scale-up with the reported numbers of VMMCs from various programmes to estimate coverage and unmet need at a subnational level over time. This approach is limited as it does not incorporate data from more recent household surveys and does not provide statistical uncertainty associated with the circumcision coverage estimates [23, 24]. Combining information from both sources of data is vital for estimating the circumcision coverage required for target setting, as household surveys are only conducted infrequently and do not reflect recent programmatic progress.

We developed a model to synthesise both survey and VMMC programme data for estimates of the probabilities and coverage of MMC and TMC by subnational area, single-year age, and time with probabilistic uncertainty. We applied the model to estimate annual probabilities and coverage of circumcision by district in South Africa between 2008 and 2019, and quantify gaps in attainment of VMMC targets within priority age groups.

Results

National circumcision coverage

Nationally, between 350,000 and 650,000 VMMC were conducted in South Africa each year from 2010 to 2019 (Figure 1). Circumcision coverage among men aged 15–49 years was 64.0% (95% CI: 63.2–64.9%) in 2019, an increase of 20.5% (20.0–21.0%) since 2008. Traditional circumcision was more common in 2008 with a TMC coverage of 24.1% (23.4–24.8%) among men 15–49 years compared with MMC coverage of 19.4% (18.9–20.0%). This reversed by 2019 when MMC coverage was 42.0% (41.3–42.7%) compared with a decrease in TMC coverage to 22.0% (21.3–22.7%).

Circumcision coverage increased most among men aged 10–24 years (Figure 2), priority ages targeted by the South African VMMC programme. Coverage peaked at 74.2% (72.3–76.5%) in men aged 21 years in 2019, an increase of 32.2% (30.3–34.4%) since 2008. The large change was attributable due to increases in medical circumcision. The highest MMC coverage in 2019 was 61.3% (59.2–63.6%) in men aged 19 years, an increase of 44.9% (42.6–47.3%) between 2008 and 2019. Conversely, TMC coverage among men aged 10–24 years decreased. In 2019, TMC coverage in men aged 19 was 11.0% (10.6–11.5%), a decrease of 9.4% (9.0–9.9%) since 2008.

Subnational circumcision coverage

Coverage varied considerably across districts of South Africa (Figure 3). In 2008, prior to the scale-up of VMMC, male circumcision coverage was highest in Vhembe, Buffalo City, and Sekhukhune districts among men aged 15–49 years with 86.3% (81.4–89.8%), 84.6% (77.6–90.7%), and 80.6% (76.8–83.6%) coverage, respectively. Namakwa, Umkhanyakude, and Zululand districts had the lowest coverage, at 13.4% (9.4–18.9%), 16.9% (11.7–21.7%), and 17.4% (12.1–24.1%). This large range in the total circumcision coverage was due to considerably different traditional circumcision practices across South Africa. Districts in Eastern Cape, Limpopo, and Mpumalanga provinces had high levels of traditional circumcision, reaching over 90% coverage among men by age 30 years in Buffalo City district (Figure 5). These districts have large populations of Ndebele, Xhosa, Pedi, Venda, and Tsonga people, who all typically perform TMC as part of ritual transition to male adulthood. The lowest levels of traditional circumcision were in KwaZulu-Natal, where less than 10% of men were traditionally circumcised. In 2008, before VMMC programme scale-up medical circumcision coverage was relatively low in most districts, ranging between 3.5% (1.6–5.5%) among men aged 15–49 years in Chris Hani District and 34.7% (29.7–41.2%) in Capricorn District.

Circumcision coverage increased in all districts in South Africa since the implementation of VMMC national campaigns in 2010 (Figure 4). Increases have not been uniform across districts as VMMCs

have typically been prioritised in areas where HIV incidence and prevalence are high and where there is higher acceptance of VMMC as HIV prevention [11]. Over half of the VMMCs performed were conducted in the three provinces with the highest HIV prevalence among 15–49 year-olds: KwaZulu-Natal, Mpumalanga, and Free State [25]. Consequently, the districts with the largest changes in circumcision coverage between 2008 and 2019 were also located in these provinces, with increases of 47.2% (44.9–49.6%), 46.0% (43.4–48.1%) and 42.9% (40.4–45.2%) in uMgungundlovu, Umzinyathi, and Uthukela districts, respectively. In 2019, Vhembe, Mopani, and Sekhukune districts had the highest circumcision coverage among men aged 15–49 years with 94.2% (90.1–96.7%), 91.6% (88.0–94.6%) and 91.6% (88.9–93.9%) coverage. Namakwa, ZF Mgcawu, and West Coast district had the lowest coverage in 2019 at 18.7% (15.2–23.3%), 28.0% (25.3–31.0%) and 32.9% (27.6–39.6%) coverage. Medical circumcision coverage among men aged 15–49 years ranged considerably in 2019 from 11.6% (10.1–13.0%) in Chris Hani to 64.5% (62.2–66.9%) in Umzinyathi. TMC coverage decreased between 2008 and 2019, with the largest decreases in Sekhukhune, Alfred Nzo, and Oliver Tambo of 8.6% (7.6–9.6%), 8.0% (6.2–10.0%), and 7.6% (6.4–8.7%), respectively.

Subnational variation in practice of and age at circumcision

The distribution of age at circumcision varied by circumcision type and geography (Figure 6). Nationally, for circumcisions conducted in 2018, the average age of medical circumcision was 18.4 (95% CI: 17.4–19.5) years and for traditional circumcisions was 17.4 (17.2–17.8) years. The average age of traditional circumcision was the lowest in Limpopo province for both traditional (12.2 years; 11.9–12.8) and medical circumcision (14.7 years; 13.8–15.8). Mpumalanga province also had a lower average of traditional circumcision (15.2 years; 14.6–16.1) than the national average. In other provinces, traditional circumcision typically occurred around age 18. Western Cape also had a substantially lower average age of medical circumcision (15.6 years; 13.7–17.4) due to the considerable number of circumcisions at birth, which are not related to VMMC programme circumcisions.

Progress to national and international targets

By 2019, only six districts (Vhembe, Mopani, Sekhukhune, Capricorn, Nkangala and Buffalo City) out of 52 were estimated to have achieved the 80% circumcision coverage target in men aged 15–49 years (Table 1) and no districts reached the new ambitious targets of 90% coverage in adolescent boys and young men aged 10–29 years. However, twelve districts achieved 80% coverage in the 15–24 years age group (Mopani, Vhembe, Nkangala, Capricorn, Sekhukhune, Umzinyathi, uMgungundlovu, Uthukela, Ehlanzeni, King Cetshwayo, Waterberg, T Mofutsanyana, Johannesburg and Sedibeng). Between 2017 and 2019, over 1.7 million VMMCs were delivered. Meeting the South African Government’s

169 2.5 million VMMC target would require a further 800,000 VMMCs by the end of 2022. In 2019,
170 there were estimated to be 5.43 million (4.83–5.67 million) uncircumcised men aged 15–49 years, with
171 the largest number located in metropolitan areas of Cape Town (623,000; 95% CI: 562,000–659,000),
172 Johannesburg (554,000; 451,000–614,000), and eThekweni (480,000; 360,000–528,000).

173 **Effect of jointly synthesising multiple data sources**

174 The model presented here utilised both household survey and VMMC programme data to produce
175 timely estimates of male circumcision coverage, particularly where survey data is limited or no longer
176 available. Models with and without the programme data included produced similar coverage estimates
177 in most provinces, but estimates were much more precise in the version with programme data included
178 (Figure 7). The exception was KwaZulu-Natal province, where coverage was substantially higher by
179 2019 when including programme data (58.6%; 95% CI: 57.1–60.3%) than excluding programme data
180 (46.0%; 41.8–52.2%). Nationally, when excluding programme data, circumcision coverage in 2019 was
181 62.4% (59.3–66.5%), 1.6% lower and with a four-fold wider uncertainty range than in the primary
182 results with program data included in the model (64.0%; 63.2–64.9%). This correspondence indicated
183 a high level of agreement in the estimated number of MMCs conducted from the survey data with the
184 number of MMCs conducted by VMMC program providers in South Africa.

185 **Discussion**

186 Estimates of male circumcision coverage by age and type of circumcision (traditional or medical) over
187 time at subnational levels are essential for planning and delivering VMMC programmes. These data
188 support attaining HIV prevention programme targets and evaluating the impact of VMMC campaigns
189 on HIV incidence. In this paper, we developed a model to produce region-age-time-type specific
190 probabilities and coverage of male circumcision, along with associated measures of uncertainty. The
191 model extends a competing risks time-to-event model to integrate both survey data and VMMC
192 programme data, building on previous approaches from Kripke *et al.* [24] and Cork *et al.* [22], which
193 did not model both data sources formally.

194 Our results highlight considerable heterogeneity in circumcision coverage across the 52 districts of South
195 Africa and in the changes between 2008 and 2019. Circumcision coverage increased in all districts in
196 South Africa. The largest increases were in KwaZulu-Natal province, which has the highest HIV
197 prevalence in South Africa and lowest practice of traditional circumcision. Traditional circumcision
198 coverage decreased over the period due to the replacement of traditional circumcisions with medical
199 circumcisions conducted in traditional male initiation settings and men circumcised through VMMC

200 interventions before or instead of through TMIC. While circumcision has increased dramatically, over
201 5 million men aged 15–49 years remained uncircumcised and there were significant gaps to reaching
202 80% coverage among men aged 15–49 years in many districts. However, 12 districts achieved greater
203 than 80% coverage of medical circumcision in the 15–24 years age group among whom intervention
204 circumcisions focused. Continuing to provide VMMC services on this scale and focusing programmes
205 in specific areas will ensure more districts will achieve these targets in the near future.

206 The granular results can be used to identify locations and key age groups in which either circumci-
207 sion coverage is low or there are large numbers of uncircumcised men. Stratifying by circumcision
208 type enables VMMC programmes to make programmatic decisions about how to intervene in areas
209 where traditional circumcision is common. For HIV prevention purposes, it may be beneficial to offer
210 “recircumcision” if TMCs are only partial circumcisions that do not involve complete removal of the
211 foreskin. Furthermore, when assessing the impact of the VMMC programmes on HIV incidence, our
212 estimates stratified by circumcision type enable models to account for different protective effects of
213 full medical circumcision versus traditional circumcision.

214 This model can be applied by circumcision programmes in other countries with household surveys and
215 VMMC programmes for HIV prevention. The estimated numbers of MMCs conducted were largely
216 similar in models with and without the inclusion of programme data, however, the difference was no-
217 table in KwaZulu-Natal. It is therefore important to consider and reconcile both data sources when
218 estimating circumcision coverage. Interpreting VMMC programme data required detailed knowledge of
219 the chronology of the South Africa VMMC programme and incorporating them into the model involved
220 specific model features to account for local nuances, such as when integration of medical circumcision
221 into traditional male initiation ceremonies occurred, migration for circumcision, and changing policies
222 around circumcision age. This bespoke data review and model development process for VMMC pro-
223 gramme data will likely be similarly time intensive for applications to other settings. However, as a first
224 step, we recommend applying the model with survey data only to furnish district/age/type stratified
225 estimates, which can be triangulated with VMMC programme data and other local information.

226 The typical age at circumcision varied across provinces for both traditional and medical circumcisions.
227 In Limpopo and Mpumalanga provinces, where the majority of the circumcising population were
228 Ndebele, Pedi, Venda, and Tsonga, circumcision was traditionally between age 12 to 15 years old. In
229 Eastern Cape, Western Cape, Free State, and North West, most of the circumcised population were
230 Xhosa, Sotho, and Tswana, and typical age at circumcision was 18 to 19 years. Since 2016, the U.S.
231 President’s Emergency Plan for AIDS Relief (PEPFAR), the major funder of VMMC programmes in
232 South Africa and other countries in the region, has prioritised circumcising men age 15–29 due to
233 delayed epidemiological impact of circumcising boys below age 15 [10]. Since 2020, PEPFAR have

234 discontinued reimbursement for MMCs among boys below age 15 years following some evidence of
235 increased rate of medical complications among this age group [26]. Through domestic co-funding
236 arrangements, South Africa has continued providing VMMC to boys age 10–14 years to reach them
237 coinciding with preferred traditional circumcision ages. Other countries may also need to reconsider
238 circumcision age restrictions, and locally tailor target age ranges, to reach men with safe and effective
239 VMMC that aligns with local practices and preferences.

240 Several circumcision dynamics are anecdotally known, but have limited data to quantify and required
241 strong modelling assumptions. The first was the proportion of traditional circumcisions conducted
242 using medical methods (MMC-T) in recent years. Ensuring safe and complete circumcisions for young
243 men has been a major initiative for the VMMC programme. We made prior assumptions about
244 this proportion based on expert knowledge of programme managers and evidence of large number of
245 MMCs reported in districts that have high levels of traditional circumcision. In 2020, the national
246 health information system began explicitly recording the number of MMC-T, so quantitative data on
247 this will be available for future analyses. The second uncertainty was about re-circumcision of men who
248 were previously traditionally circumcised. We assumed that rates of re-circumcision were sufficiently
249 low that it was not important to incorporate into the model. Future household surveys in South Africa
250 plan to separately capture data on medical and traditional circumcision, which will substantiate or
251 guide revision of this assumption. However, re-circumcision of those who previously underwent only
252 partial circumcision could be important for maximising the HIV prevention impact of VMMC.

253 Estimates presented here end in 2019 due to data availability for this analysis. The COVID-19 pan-
254 demic created significant short-term disruption to VMMC provision in South Africa [27] and temporary
255 suspension of traditional male initiation ceremonies in several provinces [28]. Nationally, the reported
256 number of VMMCs conducted declined from 464,000 in 2019 to 144,000 in 2020 and 388,000 in 2021.
257 District-level data on changes in numbers of VMMCs since 2019 could be directly incorporated into
258 an extension of this model, but, to capture the full dynamics of the circumcision programme during
259 the COVID-19 period, the model will also need to be updated to replace the assumption of stable tra-
260 ditional circumcision practices with time-location specific information about suspension of traditional
261 male initiation ceremonies during COVID-19.

262 A further national household survey, SABSSM VI, is currently underway in South Africa, with full
263 results anticipated in late 2023. This survey will provide new data, which can be incorporated into
264 this model, about the scale-up of VMMC during the 2017–2022 National Strategic Plan and how both
265 medical and traditional circumcision practices changed among young men over the COVID-19 period.
266 This survey will also collect information about the extent of replacement of traditional circumcision
267 by medical circumcision and VMMC re-circumcision of men previously partially circumcised through

268 TMIC.

269 The models presented here have several limitations and opportunities for further development. First,
270 surveys typically record self-reported circumcision status, which may be susceptible to misreporting
271 as a result of social desirability bias. Many cultures that promote male circumcision as a rite of
272 passage into manhood and some studies using physical examinations have shown that there is some
273 misreporting in circumcision status [29, 30]. Second, the classification of circumcision type is based
274 on self-reported questions from surveys, which may be subject to similar misreporting errors due to
275 confusion between medical and traditional circumcision practices. Third, a complete-case analysis was
276 used, that did not adjust for non-response bias in the self-reported circumcision status. Fourth, we
277 relied on a self-reported age at circumcision which may be subject to recall bias and age-heaping.
278 Fifth, the models used did not make use of any covariates that are predictive of circumcision coverage,
279 such as ethnicity, culture, or religion, to improve precision of the estimates. Extending the models in
280 this way could allow for further targeting of VMMC services for specific population groups. Sixth,
281 the model did not account for any uncertainty about the male population sizes by age and district.
282 Small area population estimates are uncertain in many countries where the most recent census was
283 long ago (in South Africa the last census was in 2011, with results of the 2022 census expected in
284 mid-2023). Finally, the model did not explicitly represent migration between districts and its impact
285 on district probabilities of circumcision and the corresponding coverage over time. It is suspected that
286 many young men in South Africa move away from rural homes for work and return for their traditional
287 male initiation ceremony. This is particularly the case with Xhosa men from Eastern Cape who move
288 to Western Cape for work. When compiling the programme dataset used in the case study in this
289 paper, we redistributed MMC-T conducted in the Eastern Cape to Xhosa populations residing in the
290 Western Cape and Gauteng under the assumption that this is the normal place of residence for some
291 men circumcised in the Eastern Cape, but future work should more explicitly model these migration
292 dynamics and how they have changed over age and time.

293 South Africa has made considerable progress over the past decade towards increasing coverage of medi-
294 cal male circumcision for HIV prevention, with the largest increases among districts in KwaZulu-Natal
295 province which have the lowest coverage of traditional circumcision and the highest HIV burden. How-
296 ever, progress has been unequal across the country, and, as of end 2019, over 5.4 million adult men aged
297 15–49 years remained uncircumcised. Estimating rates of both medical and traditional circumcision by
298 age over time elucidated large heterogeneity across districts in both practice of traditional circumcision
299 and the age at which it occurs. This underscores the need for VMMC programmes to be tailored at the
300 subnational level to effectively reach young men in line with local norms and practices. The analytical
301 methods proposed here for combining analysis of multiple household surveys with up-to-date VMMC

programme data provide a new tool which programmes can use to identify and target unmet need more precisely as margins start to diminish in certain regions. Future household survey data will allow us to address key uncertainties about how circumcision practices have changed as VMMC programmes have scaled-up, including (i) the extent to which traditional circumcision has been replaced by medical circumcision, (ii) levels of re-circumcision for HIV prevention in men who have been previously traditionally circumcised, and (iii) how both traditional and medical circumcision practices changed during the COVID-19 pandemic.

309 Methods

310 We created a Bayesian hierarchical model using small area estimation methods for probabilities of
311 circumcision stratified by district, age, and time for two types of circumcision: (1) circumcisions that
312 occurred in traditional male initiation ceremonies or other religious or cultural reasons (TMIC) and (2)
313 circumcisions for non-traditional reasons and/or HIV prevention that take place in a clinical setting
314 using medical methods (MMC-nT). Reflecting recent efforts to encourage adoption of medical circum-
315 cision methods in TMICs, TMICs were sub-categorised into: (1) traditional circumcisions conducted
316 using non-medical methods (TMC) and (2) circumcisions conducted as part of TMIC but using medical
317 methods (MMC-T), determined by a district- and year-specific probability that TMIC circumcisions
318 were performed as MMC-Ts.

319 Likelihood functions were specified for the two data sources to inform parameter calibration: (1)
320 the probability of individual-level observations of circumcision age, type, and year reported by men in
321 national household surveys in a time-to-event framework, and (2) the reported number of medical male
322 circumcisions conducted in each district for HIV prevention among males 10 years and older using a
323 Poisson count model. We refer to the following types of circumcision throughout (Figure 8):

- 324 • **MMC-nT:** Medical male circumcisions conducted outside of traditional male initiation cere-
325 monies, representing the large majority of MMC conducted.
- 326 • **TMC:** Traditional male circumcisions, assumed to be conducted outside a medical setting for
327 traditional male initiation purposes.
- 328 • **MMC-T:** Medical male circumcisions conducted as part of traditional male initiation cere-
329 monies, typically in place of circumcisions that previously would have been conducted as TMC.

330 Useful aggregates of these circumcision types are referred to as:

- 331 • **MMC:** All medical male circumcisions ($[MMC-nT] + [MMC-T]$), assumed to be consistent with
332 circumcisions reported through VMMC programme data reporting.
- 333 • **TMIC:** All male circumcisions conducted as part of traditional male initiation practices ($[TMC]$
334 $+ [MMC-T]$).
- 335 • **MC:** All male circumcisions of any type ($[MMC-nT] + [TMC] + [MMC-T]$).

336 Model

337 Probabilities of circumcision were modelled using a competing risk discrete time-to-event model [31].
338 The probability of TMIC was modelled by a logit-linear function with random effects for age, district,

and an age-district interaction, allowing for different age patterns of circumcision across districts. We assumed that the probability of TMIC was constant over time as TMIC practices have been relatively stable. The probability of MMC-nT was separated into two processes: (i) paediatric circumcision (for boys aged 0–9 years) and (ii) adolescent and adult circumcision (for those aged 10 years and over). VMMC programmes only provide MMCs for HIV prevention to those aged 10 and over, while infant and paediatric medical circumcision tends to occur through cultural or religious practices unrelated to scale-up of VMMC for HIV prevention. The probability of paediatric MMC-nT was also modelled using a logit-linear function with random effects for age, district, an age-district interaction, for different patterns of paediatric circumcision across districts. We assumed that the probability of paediatric MMC-nT was constant over time. The probability of adolescent and adult MMC-nT was modelled using logit-linear function with random effects for age, time, and district, and interactions for district-time, age-time, and age-district interactions, to allow for inter-district/time/age variation in circumcision rates. To ensure the probability of any circumcision (i.e. the sum of the probabilities of MMC-nT and TMIC) was bounded by one, we applied the probability of TMIC before MMC-nT in each time step.

The probabilities of MMC-T and TMC were determined by specifying a proportion of TMICs believed to be conducted as MMC-Ts in each year and district. Prior to VMMC programmes, all circumcisions conducted in TMIC were assumed to be TMC. The proportion of TMICs conducted as MMC-Ts may not be identifiable from the survey data, particularly for years since the most recent survey. Thus non-zero proportions of TMICs conducted as MMC-Ts were only specified in districts where there was knowledge among programme implementers that MMC-Ts were implemented in TMIC settings.

Estimates of circumcision coverage by type within each cohort was calculated using the cumulative incidence function, which defines the marginal probability (or proportion/coverage of) individuals who were circumcised by type (MMC-nT, MMC-T, TMC, TMIC or MMC) by district, age and time, accounting for the competing risk of other circumcision type.

Utilising data on the number of VMMCs reported, we further informed the probabilities of becoming circumcised by district and year. VMMCs conducted by public health programmes consisted of the total number of MMCs (both MMC-nT and MMC-T) conducted. We modelled number of district-age-time MMCs using a Poisson likelihood. To calculate the predicted number of circumcisions conducted per year, we multiplied the male population size with the probability of remaining uncircumcised and the probability of having a MMC-T or MMC-nT.

Prior distributions were specified on all model parameters. We assigned district random effects intrinsic conditional autoregressive (ICAR) priors [32]. Temporal random effects were assigned autoregressive

process of order 1 (AR1) priors. Age random effects were modelled using penalised B-spline functions. The age-space, age-time, and space-time interaction terms were modelled as Type IV separable interactions as defined by Knorr-Held and Leonard [33], where the precision matrices were constructed using Kronecker products. Diffuse Gaussian priors were assigned to each of the intercepts, and exponential priors were applied to standard deviation parameters. Gaussian priors were specified for all correlation parameters on the logit scale, such that *a priori* there was 95% probability that the autocorrelation parameters on AR1 processes were between 0.48 and 0.99 on the real scale. The proportion of TMICs performed as MMC-Ts were assigned independent Gaussian distributions on the logit scale, if there was knowledge of the VMMC programmes to suggest MMC-Ts are taking place. Otherwise, the proportions of TMICs performed as MMC-Ts were fixed at zero.

Technical details of the model are in Supplementary Text S1.

Household survey likelihood and accounting for survey weights

The likelihood function consisted of the product of the likelihoods for two independent data sources: (1) household survey data on individual male respondents' age at circumcision and circumcision type, and (2) VMMC programme data about the number of circumcisions conducted for HIV prevention in each district. Survey data consists of individual observations of self-reported age at circumcision, month of birth, and circumcision type (medical or traditional) for male survey respondents. Each respondent contributed an episode from their year of birth until their year of circumcision (classified as either medical or traditional) or censoring, if they remained uncircumcised at the time of the survey. Observations were right censored if the respondent reported not being circumcised at the time of the survey or left censored if the individual reported being circumcised at the time of survey but did not report their age at circumcision. For circumcised individuals, the year of circumcision was calculated as the year of birth plus the age at circumcision. It was assumed that no circumcisions occurred after age 59, so for uncircumcised individuals, censoring occurred either in the survey year or when they were 59. Individuals who self-reported they were circumcised but have a missing age at circumcision were included in the analysis through left censoring.

Survey data were collected through a complex two-stage cluster sampling design with unequal sampling probabilities. To account for these survey designs, the probabilities of circumcision were estimated using a weighted pseudo-likelihood in which we replaced the observed counts with weighted counts, calculated using survey weights. Individuals sampling weight were normalised using the Kish effective sample size [34].

403 Implementation, inference, and outputs

404 Models were implemented and fitted in R [35] using Template Model Builder (TMB) [36], which uses
405 automatic differentiation and Laplace approximations to estimate posterior distributions for model
406 parameters. Models were optimised using the quasi-newton L-BFGS-B optimisation method [37].
407 Predictions of the district-age-time probabilities of circumcision and other quantities of interest were
408 estimated using Monte Carlo sampling, drawn from the joint posterior distribution, conditional on
409 the optimised hyper-parameters [38]. Marginal predictive distributions of any quantity of interest, for
410 example, circumcision coverage aggregated to any geographical unit and/or age groups, can then be
411 made by summarising the joint samples generated.

412 The model produced annual probabilities of becoming circumcised and the corresponding circumcision
413 coverage in South Africa between 2008 and 2019, by circumcision type, single-year age group, and
414 district. Results were aggregated: (1) from district level to coarser administrative boundaries (province,
415 national), (2) from single-year age groups to five-year age group (0–4, 5–9, etc.) and coarser priority
416 age groups (15–49, 15–29, etc.) and (3) from individual types of circumcision (MMC-nT, MMC-T and
417 TMC) to produce combinations including MMC, TMIC and MC. For each output, the posterior mean,
418 median, standard deviation, and quantile-based 95% credible intervals (CI) were computed.

419 Data

420 South Africa is composed of 52 districts at the second administrative level (admin-2) situated in nine
421 provinces (admin-1). Estimates for the male population size by district and five-year age group from
422 2008 through 2019 were sourced from Statistics South Africa Mid-Year Population Estimates 2020 [39].
423 District population estimates were scaled to align with provincial population estimates by five-year age
424 group from the Thembisa version 4.4 HIV and demographic model, and distributed to single-year of
425 age according to the proportion of population within each single-year age group from Thembisa v4.4
426 [40].

427 Household surveys

428 Data on self-reported circumcision status were included from five nationally-representative household
429 surveys conducted in South Africa between 2002 and 2017: the South African National HIV Prevalence,
430 HIV Incidence, Behaviour and Communication Survey (SABSSM) from 2002, 2008, 2012 and 2017
431 [41–44] and the South Africa Demographic and Health Survey (DHS) 2016 [45]. Information was
432 extracted for 51,261 male respondents across all surveys related to age, district of residence, self-
433 reported circumcision status, age at circumcision, who performed the circumcision and where the
434 circumcision took place, and survey sampling weight. Survey respondents were located to district of

residence using survey cluster centroid latitude and longitude.

The specific questions about circumcision status in each survey are in Supplementary Material Table B.1. Circumcisions were classified as either *medical male circumcisions conducted in non-traditional settings* (MMC-nT) or traditional male initiation ceremony circumcisions (TMIC) based on responses to both ‘Who performed the circumcision?’ and ‘Where did the circumcision take place?’ using the criteria described in Supplementary Material Table B.2.

VMMC programme data

We obtained data on the number of VMMCs performed annually among men aged 10 years and older from South Africa NDoH District Health Information System (DHIS) for South African government fiscal years (April to March) from 2013 through 2019. These were supplemented for the years 2009 through 2012 by district-level data on number of circumcisions recorded in the DMPPT2 model applications [23, 24]. For 2018 through 2019, the number of VMMCs conducted in districts in the Eastern Cape province were sourced from data reported to PEPFAR via the Monitoring, Evaluation, and Reporting (MER) Indicator framework instead of NDoH DHIS due to known incomplete reporting of VMMC conducted in traditional male initiation ceremonies (MMC-T) to the NDoH DHIS. The total number of VMMCs performed in each district by data source is shown in Supplementary Material Figure B.4.

Assumptions about MMC in traditional settings (MMC-T) and migration for circumcision

Direct data about MMCs conducted in traditional male initiation contexts (MMC-T) were not available. Consequently, strong prior assumptions were required about the proportion of circumcisions conducted in TMIC which were MMC-T, informed by expert knowledge of the national circumcision programme. Within the model, it was assumed that all TMICs were TMC prior to 2013, after which a proportion of TMIC circumcisions conducted were assumed to be MMC-Ts as follows:

- In Nkangala District in Mpumalanga Province, we assumed that around 90% of the TMICs were MMC-Ts each year from 2013 to 2019.
- In Waterberg, Capricorn, Vhembe, Sekhukune, Mopani, Ehlanzeni and Gert Sibande districts (Limpopo and Mpumalanga Provinces), we assumed that an increasing proportion of TMICs were done in a medical context between 2015–2019. Around 20% (in 2015), 40% (in 2016), 60% (in 2017), 80% (in 2018), 90% (in 2019) TMICs are assumed to be MMC-Ts each year.
- For districts in Eastern Cape province and the City of Cape Town district, we assumed that 99%

of men receiving TMICs were MMC-Ts in 2018 and 2019. The majority of men residing in City of Cape Town who received TMIC were Xhosa men who returned to traditional male initiation ceremonies conducted in Eastern Cape province.

- In all other districts, we assumed that there were no TMICs done in a medical context.

Many young men who migrate for work return to their family home for traditional male initiation, for example Xhosa men from the Eastern Cape province to Cape Town and other parts of the Western Cape. Such men appear in household surveys in their district of residence, and the model estimates the probabilities of circumcision among men in their district of residence, not where the circumcision occurred. However, MMC-T provided to these men during TMIC would be recorded in the district where the ceremony occurred. To account for this, the number of VMMCs reported in Eastern Cape province in 2018 and 2019 were re-allocated to all districts in South Africa proportionally to the distribution of men reporting isiXhosa as their primary language in the South Africa 2011 census. The number of re-allocated circumcisions was small in most districts, with most reallocated to larger metropolitan areas such as Cape Town and Johannesburg (Supplementary Material Figure B.4).

Author contributions

MLT, JWE, LFJ, and GM-R conceived the study. KZ, DL, BD, SEP, and TS collated data sources. MLT led the data management, developed the statistical model, and conducted the analysis. DL, BD, PV, SEP, KK, TS, GM-R, and LFJ gave expert input on the South Africa VMMC programme and interpretation of data. MLT wrote the first draft of the manuscript with input from JWE. All authors revised the manuscript for content and approved the final version for submission.

Competing interests

All authors declare that they have no competing interests.

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501 For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY)
502 license to any Author Accepted Manuscript version arising.

503 Data Availability

504 Household survey data are available by request to the South Africa Human Science Research Council
505 (HSRC; <http://datacuration.hsrc.ac.za/content/view/access-to-data>) and The Demographic
506 and Health Survey (DHS) Program (<https://dhsprogram.com/methodology/survey/survey-display-390.cfm>). Information on the number of VMMC's performed were obtained from DMPPT2 and South Africa
507 National Department of Health (NDoH) DHIS are by data request to the South Africa NDoH. Data on
508 VMMC's conducted from PEPFAR MER are available from [https://data.pepfar.gov/datasets#](https://data.pepfar.gov/datasets#PDD)
509 [PDD](https://data.pepfar.gov/datasets#PDD). Estimates of population were obtained from Thembeisa and Statistics South Africa, which
510 are available from <https://thembeisa.org/downloads> and [http://www.statssa.gov.za/?page_id=](http://www.statssa.gov.za/?page_id=1854&PPN=P0302&SCH=72634)
511 [1854&PPN=P0302&SCH=72634](http://www.statssa.gov.za/?page_id=1854&PPN=P0302&SCH=72634), respectively. Estimates of the proportions of men by primary language
512 group in South Africa were obtained from the South Africa 2011 census, which is available from
513 <https://www.datafirst.uct.ac.za/dataportal/index.php/catalog/485>.

515 Code Availability

516 The code used to implement the models and produce results presented in this manuscript is avail-
517 able from <https://github.com/mrc-ide/zaf-circumcision-rates>. An R package implementing
518 the model is available from <https://github.com/mrc-ide/threemc>.

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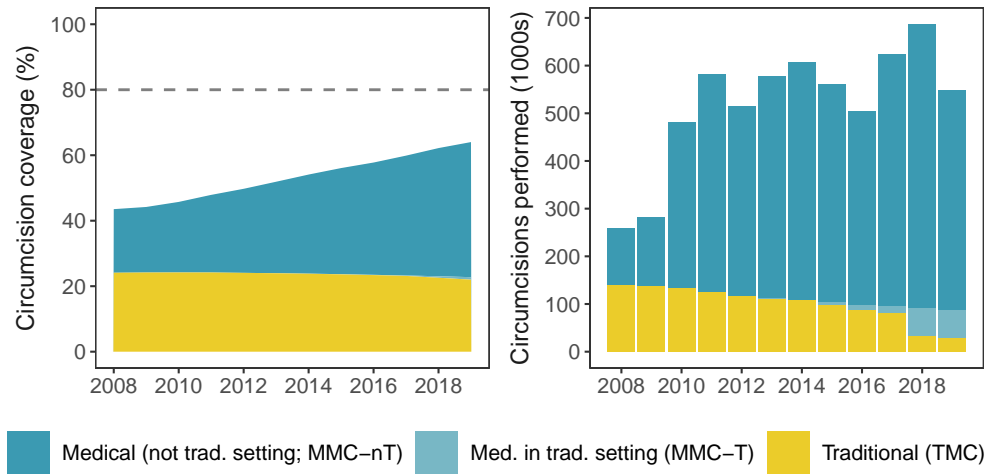


Figure 1: **Circumcision coverage among men 15–49 years, 2008–2019.** (Left) National male circumcision (MC) coverage among men aged 15–49 years between 2008 and 2019, stratified by circumcision type. Shaded areas represent the posterior mean. Horizontal dashed line denote the target circumcision coverage of 80%. (Right) Estimated number of circumcisions performed annually between 2010 and 2019 stratified by type. Bars represent the posterior mean.

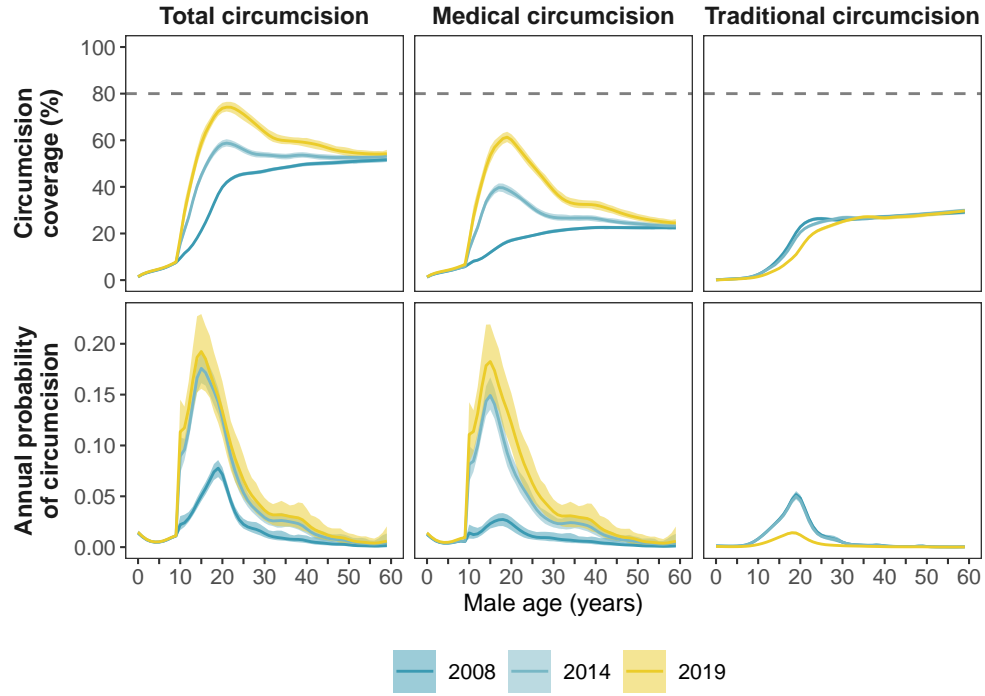


Figure 2: **Circumcision coverage and annual circumcision probability by age in 2008, 2014, and 2019.** (Top) Estimated Total (MC), Medical (MMC) and Traditional (TMC) coverage nationally by age in 2008, 2014 and 2019. (Bottom) Estimated probability of Total (MC), Medical (MMC) and Traditional (TMC) circumcision nationally by age in 2008, 2014 and 2019. Lines denote the posterior mean with shaded regions denoting the 95% CI. Dashed line denotes the target circumcision coverage of 80%.

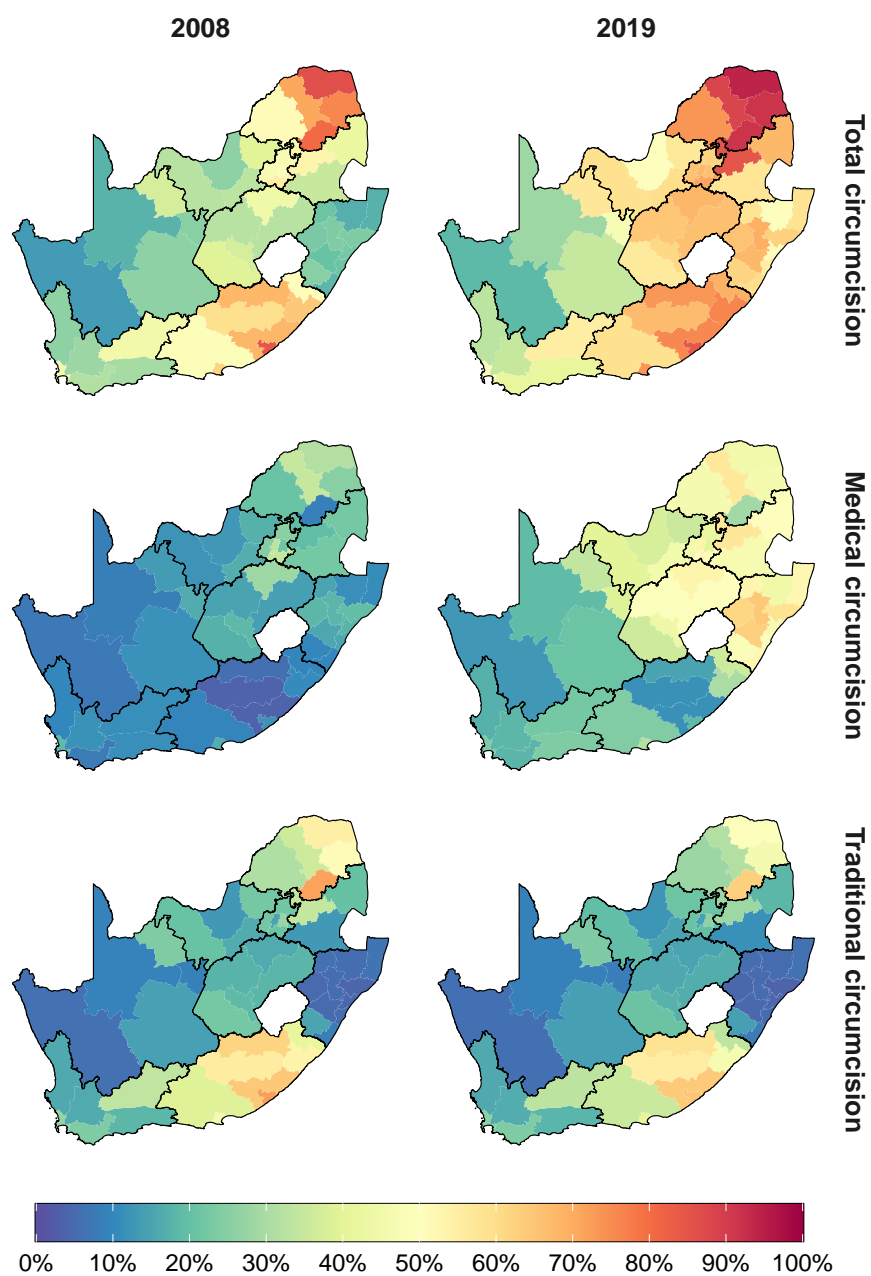


Figure 3: **Circumcision coverage by district among men 15–49 years, 2008 and 2019.** Estimated Total (MC), Medical (MMC) and Traditional (TMC) circumcision coverage for men aged 15–49 in each district in 2008 and 2019. Colours denote the posterior mean.

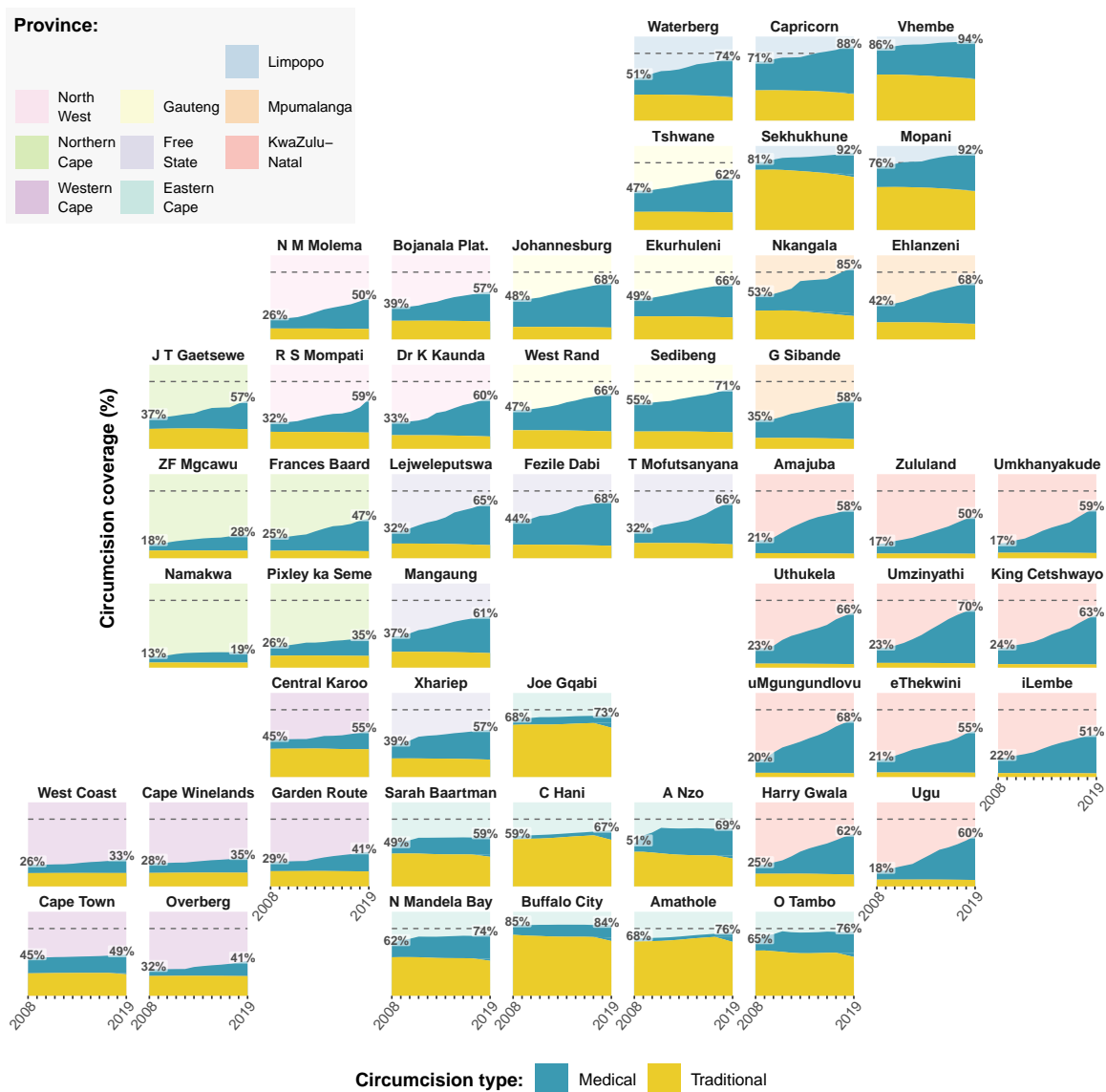


Figure 4: Circumcision coverage among men aged 15-49 by district, 2008 to 2019, stratified by circumcision type. Lines denote the posterior mean. Horizontal dashed lines denotes the 80% circumcision coverage target. Plots are organised by geography. Pastel panel background shading indicates the province within which each district is situated.

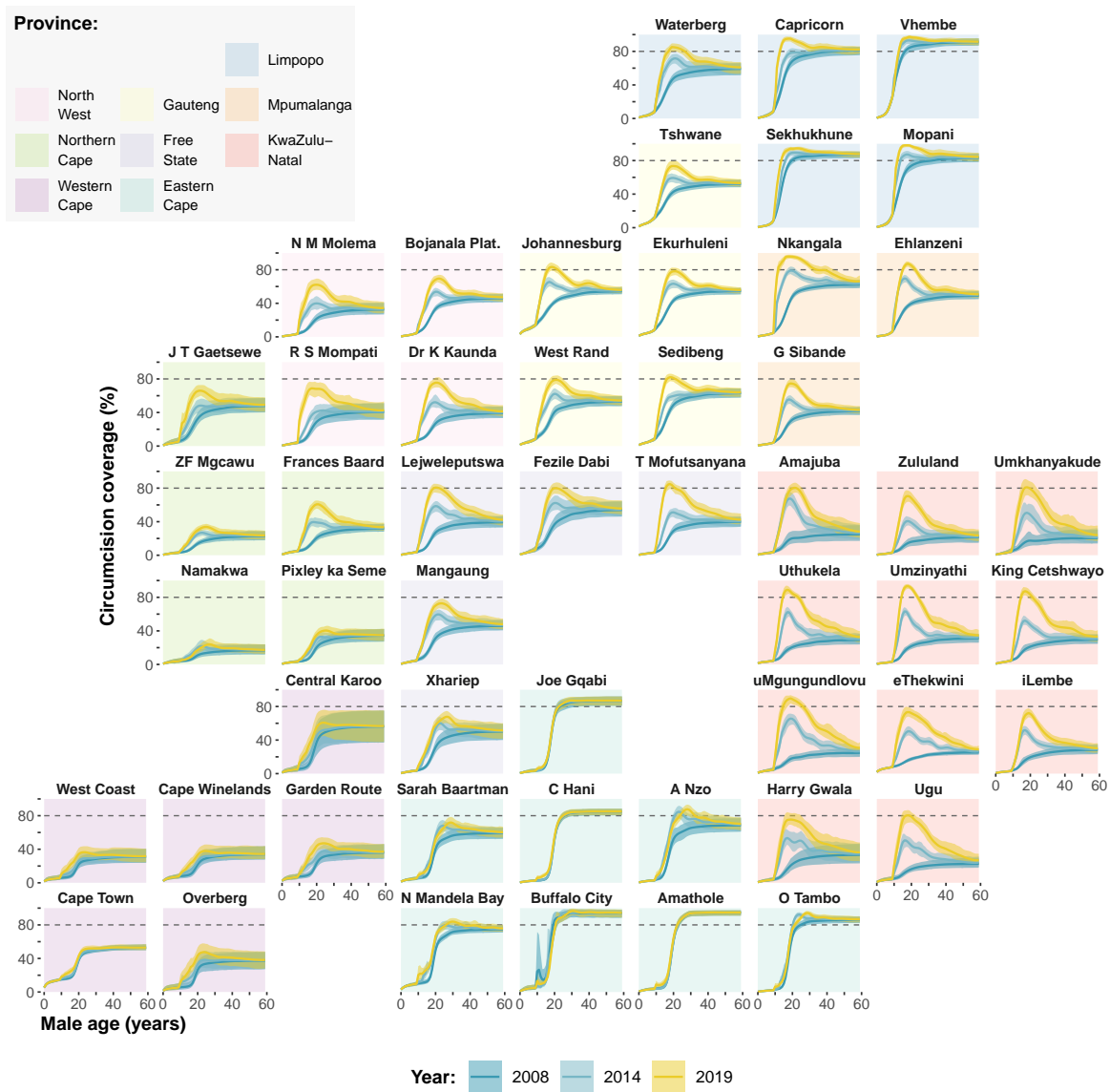


Figure 5: **Total circumcision coverage by age and district in 2008, 2014 and 2019.** Lines denote the posterior mean with shaded regions denoting the 95% CI. Horizontal dashed line denotes the target circumcision coverage of 80%. Pastel panel background shading indicates the province within which each district is situated.

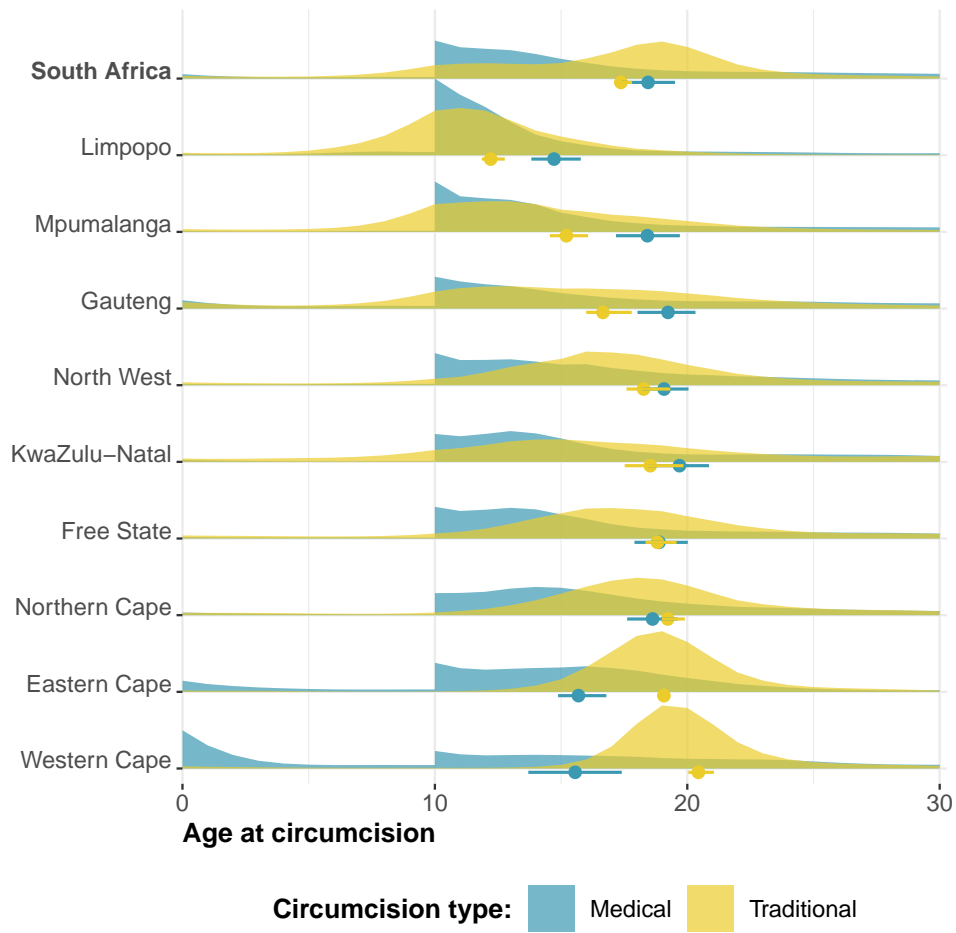


Figure 6: **Distribution of age at circumcision for medical (MMC-nT) and traditional (TMIC) circumcisions in 2019.** Results shown for South Africa overall and for each province. Dots below each density denote the average age of circumcision, with the bars denoting the 95% CI for the mean age of circumcision.

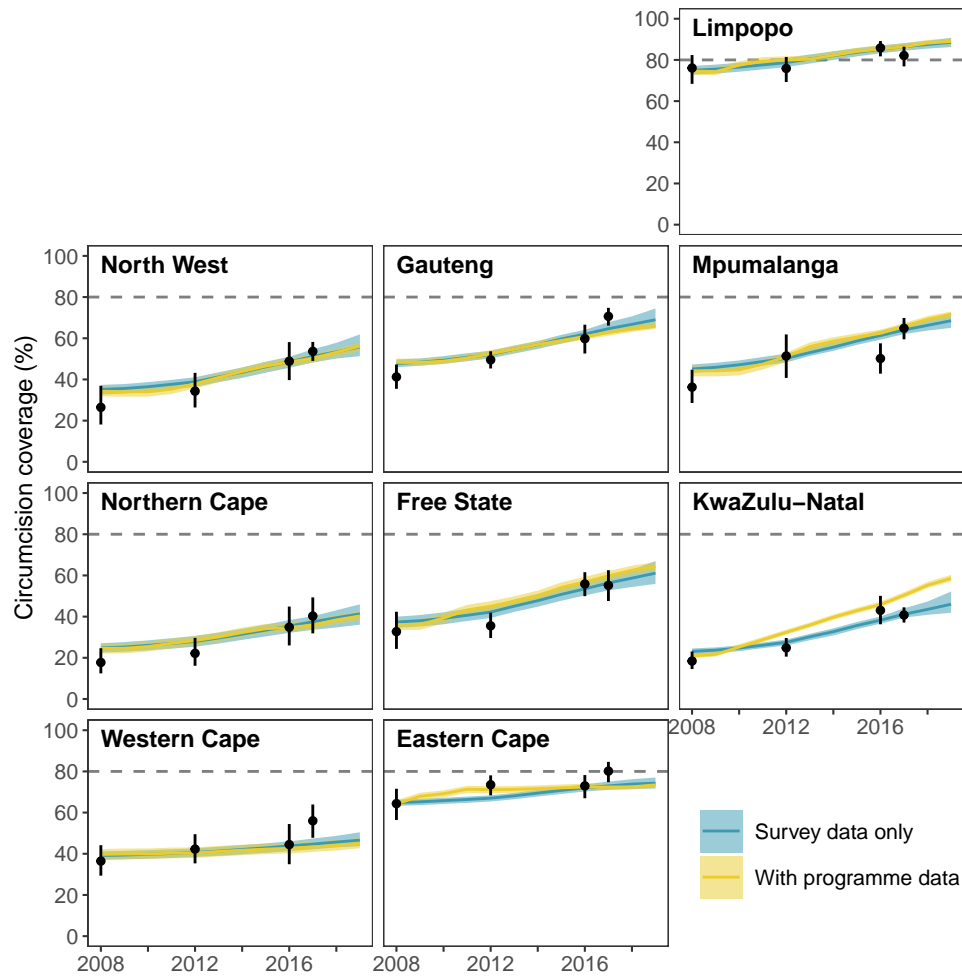


Figure 7: **Comparison of circumcision coverage estimates when analysing only survey data and including VMMC programme data.** Estimated male circumcision coverage in men aged 15–49 between 2008 and 2019 by province for models with only household survey data and including survey and VMMC programme data. Lines denote the model estimated mean prevalence, with the shaded regions denoting the 95% CI. Black dots denote the direct survey estimates for circumcision coverage from the 2008, 2012 and 2017 SABSSM surveys and the 2016 DHS survey with associated survey design-based 95% confidence intervals. Dashed horizontal line denotes 80% circumcision coverage target.

Region	Coverage			Change since 2008	Population (in 1000s)	
	Total	Medical	Traditional	Total	Circumcised	Uncircumcised
South Africa	65.7% (64.2–69.5%)	44.0% (42.4–47.8%)	21.6% (20.9–22.3%)	22.2% (20.8–26.0%)	10398 (10165–11003)	5432 (4827–5666)
Eastern Cape	74.2% (72.5–78.3%)	25.3% (23.3–29.5%)	48.9% (47.6–50.2%)	9.9% (8.3–13.4%)	1133 (1108–1196)	395 (332–420)
A Nzo	70.0% (64.3–77.0%)	37.2% (33.7–44.3%)	32.9% (28.1–38.0%)	19.3% (14.5–27.7%)	106 (97–116)	45 (35–54)
Amathole	75.9% (73.0–79.4%)	12.0% (10.1–15.6%)	63.9% (61.0–66.3%)	7.9% (6.6–11.3%)	135 (130–141)	43 (37–48)
Buffalo City	84.3% (78.8–88.8%)	19.7% (15.1–27.2%)	64.6% (59.7–68.0%)	-0.3% (-4.2–5.1%)	168 (157–177)	31 (22–42)
C Hani	67.2% (64.1–70.5%)	12.1% (10.1–15.1%)	55.2% (52.5–57.7%)	7.8% (6.6–10.5%)	105 (100–110)	51 (46–56)
Joe Gqabi	73.5% (68.4–78.1%)	15.2% (12.8–18.4%)	58.4% (52.7–63.7%)	5.7% (4.2–9.0%)	57 (53–61)	21 (17–25)
N Mandela Bay	75.1% (71.0–82.9%)	34.0% (29.6–41.3%)	41.1% (38.6–44.7%)	12.9% (10.2–20.0%)	222 (210–245)	74 (51–86)
O Tambo	76.8% (73.4–83.9%)	30.8% (28.2–37.3%)	46.0% (42.9–48.8%)	12.3% (10.0–18.1%)	265 (253–289)	80 (56–92)
Sarah Baartman	60.1% (55.1–65.1%)	25.2% (22.0–29.7%)	34.9% (30.3–40.9%)	11.5% (9.4–15.7%)	76 (69–82)	50 (44–56)
Free State	65.9% (63.2–69.6%)	49.9% (47.3–54.4%)	16.0% (14.2–18.7%)	29.8% (27.7–34.3%)	487 (467–514)	252 (225–272)
Fezile Dabi	69.4% (63.9–76.0%)	54.9% (50.2–61.2%)	14.5% (9.9–19.8%)	25.3% (21.5–30.1%)	91 (84–100)	40 (31–47)
Lejweleputswa	66.4% (61.5–71.3%)	51.2% (48.0–56.0%)	15.2% (12.0–20.1%)	34.3% (31.6–38.7%)	112 (104–120)	57 (48–65)
Mangaung	62.7% (58.0–67.6%)	45.8% (42.0–51.1%)	16.9% (13.6–20.7%)	25.3% (22.4–32.2%)	140 (129–151)	83 (72–94)
T Mofutsanyana	68.2% (64.0–72.6%)	52.3% (49.6–56.4%)	16.0% (12.5–19.7%)	36.1% (33.3–40.3%)	126 (119–134)	59 (51–67)
Xhariep	57.9% (50.8–64.9%)	37.5% (33.4–44.1%)	20.3% (15.1–27.8%)	18.6% (14.3–24.6%)	18 (16–20)	13 (11–15)
Gauteng	67.7% (65.5–72.3%)	48.3% (46.0–53.2%)	19.3% (17.9–21.3%)	19.4% (17.9–24.0%)	3202 (3101–3423)	1530 (1309–1632)
Ekurhuleni	67.6% (64.0–72.5%)	41.9% (38.2–46.2%)	25.8% (22.1–30.0%)	18.9% (17.2–22.8%)	835 (790–895)	399 (340–445)
Johannesburg	69.4% (66.1–75.1%)	55.5% (51.8–61.3%)	13.9% (11.4–16.3%)	21.5% (19.5–27.0%)	1256 (1196–1360)	554 (451–614)
Sedibeng	72.9% (68.5–78.7%)	53.6% (49.8–59.9%)	19.2% (16.1–23.3%)	17.9% (15.5–23.1%)	206 (194–223)	77 (60–89)
Tshwane	63.6% (59.3–68.3%)	42.9% (39.2–47.6%)	20.7% (17.7–24.8%)	16.8% (15.2–20.8%)	715 (666–768)	409 (356–457)
West Rand	67.7% (62.9–73.5%)	47.3% (42.7–53.0%)	20.4% (16.6–25.5%)	21.1% (18.7–24.5%)	190 (177–207)	91 (74–104)

Table 1: Estimated Total, Medical (MMC) and Traditional (TMC) circumcision coverage for 2019 among men aged 15-49, along with the absolute change in total circumcision coverage from 2008 to 2019 and the number of circumcised and uncircumcised men aged 15-49 in 2019.

Region	Coverage			Change since 2008	Population (in 1000s)	
	Total	Medical	Traditional	Total	Circumcised	Uncircumcised
KwaZulu-Natal	61.5% (58.8–68.3%)	56.1% (53.4–62.8%)	5.3% (4.6–6.0%)	40.5% (38.2–46.8%)	1810 (1731–2011)	1135 (935–1215)
Amajuba	60.0% (54.6–68.0%)	54.7% (50.4–61.6%)	5.3% (2.5–8.8%)	39.1% (34.9–45.9%)	87 (79–98)	58 (46–66)
eThekweni	58.2% (54.1–68.7%)	53.2% (49.0–63.5%)	5.1% (4.2–6.0%)	37.3% (34.4–46.9%)	669 (622–790)	480 (360–528)
Harry Gwala	64.8% (57.8–73.2%)	51.1% (46.5–59.3%)	13.7% (8.4–21.1%)	39.9% (35.4–45.7%)	74 (66–83)	40 (30–48)
iLembe	52.8% (49.3–60.2%)	48.5% (44.9–55.9%)	4.3% (2.6–6.2%)	30.5% (27.6–36.9%)	89 (83–101)	79 (67–85)
King Cetshwayo	66.0% (62.1–73.1%)	62.4% (58.8–69.8%)	3.7% (2.4–5.9%)	42.5% (38.6–51.3%)	151 (142–167)	78 (61–87)
Ugu	63.6% (59.3–73.5%)	56.1% (52.0–65.7%)	7.5% (4.8–11.2%)	45.5% (41.0–53.8%)	130 (122–151)	75 (54–83)
uMgungundlovu	70.1% (65.7–75.6%)	65.7% (61.5–71.5%)	4.4% (2.6–6.9%)	49.7% (46.6–54.9%)	214 (201–231)	91 (74–105)
Umkhanyakude	61.8% (55.8–69.6%)	55.8% (50.2–63.9%)	6.0% (2.9–11.6%)	44.5% (40.2–53.0%)	92 (83–103)	57 (45–66)
Umzinyathi	71.8% (68.5–80.2%)	67.0% (63.9–74.6%)	4.8% (3.4–6.9%)	48.3% (44.9–55.1%)	88 (84–98)	34 (24–39)
Uthukela	68.8% (65.1–75.5%)	64.7% (61.6–71.9%)	4.1% (2.7–6.0%)	45.8% (42.1–52.4%)	115 (109–126)	52 (41–58)
Zululand	52.8% (48.1–60.6%)	47.7% (43.8–56.3%)	5.2% (2.8–7.9%)	35.9% (32.1–46.4%)	101 (92–116)	91 (76–100)
Limpopo	89.6% (88.0–91.3%)	46.2% (44.4–48.8%)	43.4% (41.5–45.5%)	15.0% (14.0–16.5%)	1199 (1178–1222)	139 (116–160)
Capricorn	89.1% (84.9–92.3%)	58.8% (55.3–63.1%)	30.4% (26.3–34.9%)	18.4% (16.3–20.9%)	255 (243–263)	31 (22–43)
Mopani	92.3% (88.8–95.2%)	47.7% (44.0–52.2%)	44.6% (40.0–49.3%)	16.3% (13.6–18.7%)	244 (235–252)	21 (13–30)
Sekhukhune	92.2% (89.2–94.5%)	31.0% (28.2–33.9%)	61.2% (57.7–64.4%)	11.6% (10.1–13.5%)	257 (249–264)	22 (15–30)
Vhembe	94.4% (90.2–96.7%)	46.3% (41.6–50.9%)	48.1% (42.5–54.0%)	8.1% (6.6–10.4%)	301 (288–308)	18 (10–31)
Waterberg	74.8% (70.1–79.6%)	47.7% (44.3–51.5%)	27.1% (22.2–33.1%)	23.4% (21.4–26.5%)	142 (133–151)	48 (39–57)
Mpumalanga	73.1% (71.0–77.2%)	53.8% (51.9–57.5%)	19.3% (18.0–20.8%)	28.9% (27.2–33.1%)	929 (902–980)	341 (290–368)
Ehlanzeni	69.2% (66.2–75.0%)	51.6% (48.8–56.5%)	17.6% (15.0–20.0%)	26.8% (24.4–32.0%)	311 (297–336)	138 (112–152)
G Sibande	59.4% (55.6–64.2%)	48.2% (45.6–52.8%)	11.1% (9.3–13.0%)	24.3% (22.1–28.2%)	204 (192–221)	140 (123–153)
Nkangala	86.8% (83.9–89.7%)	59.9% (57.9–64.1%)	26.9% (24.3–29.5%)	33.4% (30.8–36.5%)	414 (401–428)	63 (49–77)

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Region	Coverage			Change since 2008	Population (in 1000s)	
	Total	Medical	Traditional	Total	Circumcised	Uncircumcised
Northern Cape	42.3% (39.0–47.5%)	30.2% (27.7–34.9%)	12.1% (10.2–14.3%)	17.7% (15.3–22.9%)	120 (111–135)	164 (149–173)
Frances Baard	49.5% (45.1–55.5%)	41.3% (38.0–48.2%)	8.2% (5.7–11.2%)	24.4% (21.2–32.5%)	45 (41–50)	46 (40–50)
J T Gaetsewe	59.9% (53.4–68.6%)	36.8% (31.7–44.9%)	23.1% (15.9–32.3%)	22.6% (18.6–30.1%)	35 (31–40)	23 (18–27)
Namakwa	19.1% (15.2–24.6%)	13.2% (10.4–17.5%)	6.0% (3.0–10.6%)	5.8% (3.9–9.5%)	5 (4–6)	20 (18–21)
Pixley ka Seme	35.9% (31.5–42.1%)	22.1% (19.4–28.7%)	13.8% (9.9–18.7%)	10.1% (7.4–17.0%)	16 (14–19)	28 (25–30)
ZF Mgcawu	29.7% (26.4–35.4%)	20.8% (18.2–26.3%)	9.0% (6.7–11.9%)	12.2% (9.6–17.4%)	20 (18–24)	47 (43–49)
North West	58.2% (55.6–61.3%)	40.4% (38.1–44.0%)	17.8% (15.7–19.8%)	23.9% (22.0–27.2%)	651 (622–686)	468 (434–497)
Bojanala Platinum	58.1% (54.7–62.2%)	37.1% (34.7–40.5%)	21.0% (18.3–23.9%)	18.8% (16.8–22.5%)	336 (316–360)	242 (219–262)
Dr K Kaunda	61.8% (57.3–66.4%)	47.5% (43.2–52.5%)	14.3% (10.7–18.5%)	28.9% (26.3–32.6%)	128 (119–138)	79 (70–89)
N M Molema	52.9% (47.3–60.6%)	40.7% (36.5–48.9%)	12.2% (8.6–16.7%)	27.1% (23.2–34.2%)	120 (108–138)	107 (90–120)
R S Mompoti	63.1% (55.9–72.1%)	44.3% (39.3–52.9%)	18.8% (12.9–26.5%)	30.7% (25.7–40.0%)	67 (59–76)	39 (29–46)
Western Cape	46.2% (43.8–50.9%)	23.3% (20.9–26.3%)	23.0% (20.9–25.2%)	6.5% (5.2–9.5%)	866 (821–954)	1008 (920–1054)
Cape Town	50.0% (47.1–54.9%)	24.5% (21.9–27.6%)	25.5% (22.9–28.2%)	4.6% (3.2–7.8%)	623 (587–684)	623 (562–659)
Cape Winelands	35.9% (29.4–43.9%)	19.6% (15.2–25.7%)	16.3% (12.0–23.1%)	8.2% (5.9–12.4%)	93 (76–113)	165 (145–182)
Central Karoo	56.8% (42.5–71.1%)	24.1% (18.5–30.8%)	32.7% (19.8–49.9%)	12.0% (8.4–16.7%)	10 (7–12)	7 (5–10)
Garden Route	42.8% (36.0–50.5%)	25.2% (21.3–31.2%)	17.6% (12.3–23.3%)	13.3% (10.9–17.5%)	63 (53–75)	85 (74–95)
Overberg	42.9% (34.9–52.7%)	19.6% (15.4–25.3%)	23.3% (15.2–33.3%)	11.4% (9.3–16.2%)	35 (28–43)	46 (38–53)
West Coast	34.6% (29.4–41.6%)	18.8% (14.5–26.4%)	15.8% (11.7–21.8%)	8.8% (5.4–14.6%)	43 (37–52)	81 (73–88)

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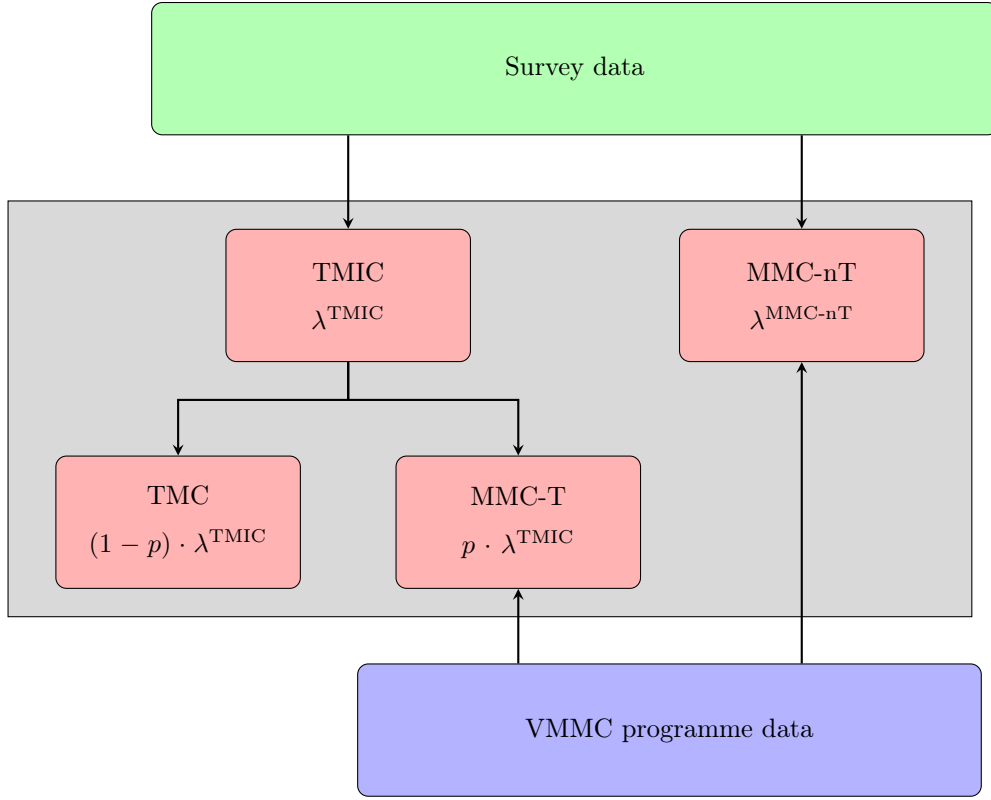


Figure 8: **Schematic representation of types of circumcision included in the model.** TMIC = circumcisions conducted as part of traditional male initiation ceremonies; TMC = traditional male circumcisions (conducted by a non-medical practitioner); MMC-T = medical male circumcision conducted as part of traditional male initiation practices; MMC-nT = medical male circumcision conducted outside the context of traditional male initiation (the majority of VMMC for HIV prevention and other routine medical male circumcision). The parameters $\lambda^{\text{MMC-nT}}$ and λ^{TMIC} represent the probabilities of having an MMC-nT and TMC respectively and p represent the proportion of TMICs conducted as medical methods.