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Article

The rise and fall of mortality inequality in South Africa in the HIV era

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ABSTRACT

Post-apartheid South Africa has seen an unprecedented rise and fall of mortality in less than two decades as a result of the HIV/AIDS epidemic and the subsequent rollout of free antiretroviral therapy (ART). Since the incidence of both was not equal for rich and poor, it is likely to also have affected disparities in health and survival chances by income. We use large nationwide surveys for 2001, 2007 and 2011 to obtain estimates of average income and mortality at the aggregate level of a municipality, and then to examine changes in mortality – and in inequality in mortality by income — over time. Using concentration indices to measure health inequality, we demonstrate that both the mean mortality level and absolute inequality in mortality by income rose rapidly until 2006, and declined again sharply since the rollout of free ART. Relative inequalities in mortality by income, however, remained fairly stable over the 2001–2011 period. The analysis of age-sex-specific mortality rates shows that it was in particular for adults aged 18–59 years that mortality and absolute inequality increased substantially between 2001 and 2006, followed by a rapid drop thereafter. These trends were far more pronounced for males than females. This means that the HIV/AIDS epidemic has taken a serious death toll, which was concentrated disproportionately among the poorest segments of the population and especially affected (older) males. While South Africa has been very successful in curbing the overall mortality trend since 2006, large disparities in survival prospects by income, race and gender continue to exist. Targeted efforts are required if it wants to further reduce the very unequal chances of living to old age for richer and poorer population groups of all ages.

1. Introduction

In spite of substantial socio-economic progress, two decades of structural reforms and a relatively high level of health spending, South Africa's health outcomes remain relatively weak. Compared to other middle-income countries, it performs worse in terms of age-adjusted death rates, years of life lost by premature death, and life expectancy at birth (Mayosi & Benatar, 2014). Wide inequalities also persist in South Africa's social determinants of health. Income inequality remains among the highest in the world (World Bank, 2017), unemployment rates have not improved, and limited progress has been made in reducing gender inequality (UNDP, 2014). Large disparities also continue in access to healthcare. Per capita expenditure on healthcare is approximately $1400 in the private sector compared to $140 in the public sector (Mayosi and Benatar, 2014). Likewise, although only 16 percent of the population have private health insurance, it accounts for 44 percent of South Africa's total health-care financing (Mills et al., 2012).

During the transition from apartheid to democracy, efforts to reduce health disparities were hampered by the emergence of the HIV/AIDS and tuberculosis (TB) epidemics. According to surveys conducted among first-time pregnant women who visited public clinics, HIV prevalence grew exponentially from 0.8% in 1990 to 10.4% in 1995 (Gouws, Abdool & Karim, 2005) and to 29.5% by 2011 (NDOH, 2013). Similarly, driven by the emergence of HIV, the incidence of TB almost tripled from 269 cases per 100,000 population in 1996, to 802 per 100,000 in 2009 and 843 per 100,000 in 2015 (NDOH, 2007; NDOH, 2012; NDOH, 2017). Largely due to a disproportional exposure to the risk of HIV acquisition, the effect of HIV/AIDS and TB has been greatest among black Africans (Oni & Mayosi, 2016), who make up 80.6% of the population (Stats SA, 2017). South Africa is estimated to account for 19.0% of the global burden of HIV in 2015 (UNAIDS, 2016), and is estimated to have the world's highest incidence of TB (WHO, 2016).

Encouragingly, the recently published Second National Burden of Disease study show signs of improvement (Pillay-van Wyk et al. 2016). HIV/AIDS and TB mortality trends appear to have reversed since 2006.

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This can be largely attributed to the success of the country's HIV/AIDS and TB programmes. Almost 1.8 million people received antiretroviral therapy (ART) in 2011 compared to an estimated 47,500 in 2004 (Johnson, 2012). The decline in HIV/AIDS and TB mortality since 2006, observed in various studies (Bradshaw et al., 2016; Johnson, 2014; Pillay-van Wyk et al., 2016) has been attributed to the intensified ART rollout (Larson, O'Bra, Brown, Mbengashe, & Klausner, 2012; Pillay-van Wyk et al., 2016). Furthermore, the percentage of undiagnosed HIV-positive adults decreased from over 80.0% in the early 2000s to 23.7% in 2012 (Johnson, Rehle, Jooste, & Bekker, 2015). Churchyard et al. (2014) state that the National Tuberculosis Programmes have contributed to a decline in TB case notifications since 2009, as well as improved treatment success rates of new infectious TB cases, which increased from 63.0% in 2000 to 77.1% in 2011 (NDOH, 2012). Similarly, 'Findings from Death Notifications', published annually by Statistics South Africa, suggests that the number of deaths caused by TB increased between 2001 and 2006, and decreased between 2006 and 2011 (Stats SA, 2005; Stats SA, 2008; Stats SA, 2014).

The reduction of inequality in health is important as this may translate into inequality in mortality, thereby perpetuating a cycle of poverty and vulnerability for these households. Ardington and Gasealahwe (2014) confirm the existence of a socio-economic mortality gradient (by asset index and education, not income per se) and demonstrate that it is associated with self-reported health differentials. More specifically related to HIV, Probst, Parry, and Rehm (2016) find that individuals of a lower socio-economic status (SES) (income, employment status and asset scores) have a higher risk of mortality due to HIV.

Whilst changes in South Africa's overall disease burden have been widely documented, far less information is available on progress with South Africa's post-apartheid objective of reducing overall health disparities. The majority of health inequality studies have focused on a specific set of diseases at a single time point (Cockburn et al., 2012; Doolan, Ehrlich, & Myer, 2007; Harling, Ehrlich, & Myer, 2008; Myer, Stein, Grimsrud, Seedat, & Williams, 2008; Nkonki, Chopra, Doherty, Jackson, & Robberstad, 2011; Zere & McIntyre, 2003); considered only part of the population (e.g. adults or females) (Ataguba, Akazili, & McIntyre, 2011; Wabiri et al. 2016); and mostly relied on self-assessed measures of health status (Ataguba, Day, & McIntyre, 2015; Wabiri et al. 2013). The one study that has considered changes in absolute and relative inequality in mortality did so for a relatively small sample limited to one geographic area (Kabudula et al., 2017). No nationally representative evidence is available on the evolution over time of disparities in mortality by income or other socio-economic indicators.

Using two rounds of the national Census (Stats SA 2001, 2011), and the nationally representative 2007 Community Survey (CS) (Stats SA, 2007) (all three publicly available from https://www.datafirst.uct.ac.za/), we aim to fill this evidence gap by considering inequality in mortality by income at the geographical level. Using nationally representative, individual-level data on both mortality and income aggregated at the municipal level, we are able to assess changes in mortality rates by income across three points in time. As such, we are able to provide new evidence on trends in South Africa's income-related disparities in mortality in an era characterised by the rise and fall of the HIV/AIDS and TB epidemics.

2. Methods

Our approach is inspired by Currie and Schwandt (2016) who examined the distribution of life expectancy and mortality in the United States (US). Rather than considering differences in mortality by education or income, they ranked groups of counties by their poverty rates. Their main reason for pursuing a geographical approach was a lack of individual-level data on income and health status. Aggregating at the geographical level allowed them to overcome this challenge, by generating county-level observations on average mortality and poverty rates. A similar geographical approach was used by Chetty et al. (2016), for example, to show that low-income individuals in the US tend to live longest in cities with highly educated populations, high incomes, and high government expenditures. Our approach is inspired by this research, but due to differences in data availability between the US and South Africa, we adopt a somewhat different approach, as described below.

2.1. Data

The only sources of individual-level data on both mortality and income in South Africa that are consistent across time are the decadal censuses. We use the 10.0% public use sample data of the 2001 and 2011 Census household surveys (Stats SA 2001, 2011), in combination with the full (100%) sample of the 2007 Community Survey (CS), also referred to as the Mini-Census (Stats SA 2007), to assess changes in mortality inequality by income. Only individuals living in housing units (and converted hostels in 2011) are included. The institutionalised population was excluded as no mortality questions were asked in institutions. A high proportion of missing values for the Census 2001 sample in key indicators such as gender (1.3%), education (6.6%) and income (15.6%) were imputed by Barnes, Gutierrez-Romero, and Noble (2006) using a sequential multiple-imputation procedure.

2.2. Variables

2.2.1. Health indicator: mortality rates

While there was some variation in scope across the three surveys, our main variables of interest were collected fairly consistently. Information on mortality was obtained from the question: 'Has any member of this household passed away in the last 12 months? (i.e. between 10 October 2000 and 10 October 2001, February 2006 and March 2007, 10 October 2010 and 9 October 2011)'. As the majority of deaths (88.9%) in the 2007 CS occurred in 2006, we refer to 2006 mortality rates from this point onward. Unlike in 2001, mortality and other household information was not derived from the *same* 10.0% random sample as in 2011. As these were two random but separately drawn 10.0% samples in 2011, it was not possible to conduct an individual-level analysis, and this forced us to perform an analysis at the municipal level. We assumed that the 10.0% mortality sample in 2010 was a random sample of deaths in each municipality. As a reliability check, we examined how the Census/CS death rates compared to the mortality rates obtained from death notifications adjusted for completeness, which are available only at the province level. The results, presented in Online Appendix A, suggest that at the province level we would derive similar conclusions if we used death registrations rather than census mortality rates, as they show similar levels and patterns over time for most age groups (except 60+).

Municipal mortality rates were computed for four age groups: 0–5, 19–39, 40–59 and 60+ (Table 1). This categorisation was chosen for two reasons. First, we drop age group 6–18 because it has too few deaths to compute reliable mortality rates. All other municipality-age-sex groups consist of a sufficient number of deaths to calculate reliable mortality rates. Second, the categorisation is chosen to reflect the differential impact that HIV/AIDS and TB have had on the various age-sex groups (Bradshaw et al., 2016). The results of mortality rates (and inequality in mortality rates) for age groups 0–5, 19–39, 40–59 and 60+ are presented in the results section. Results for age groups 6–18 are not presented but for completeness the results are made available in Online Appendix B.

2.2.2. SES indicator: Household equivalent income

Our main SES ranking indicator is household income per adult equivalent computed as follows. In the 2001 Census, each person was asked: 'What is the income category that best describes the gross income of (this person) before tax?'. Although the income intervals

Table 1
Descriptive statistics for three surveys.

Domain	10% Census 2001	CS 2007	10% Census 2011
General:			
Households surveyed	905,748	246,618	1,171,116[a]
Persons surveyed	3,725,665	949,100	4,337,697
% of persons surveyed living in institutions	3.37%	0%	1.7%
Local Municipalities	262	262	234
Demographics:			
Population group (%)			
Black African	79.74%	79.82%	80.18%
Coloured	9.03%	10.48%	8.75%
Indian or Asian	2.57%	2.18%	2.48%
White	8.67%	7.52%	8.19%
Other	NA	NA	0.41%
Age group (%)			
0–5	12.4%	12.3%	13.3%
6–18	30.0%	30.0%	24.9%
19–39	33.6%	33.4%	35.1%
40–59	16.8%	18.4%	18.6%
60+	7.5%	7.8%	8.2%
Mean age	26.6	27.4	27.9
Males / Females (%)	46.9% / 53.1%	47.4% / 52.6%	47.9% / 52.1%
Households:			
Mean household income (in ZAR) [b]	R 43,687	R 73,735	R 112,045
Median household income (In ZAR) [b]	R 13,576	R 23,976	R 27,176
Number of household with zero income	12.2%	7.3%	7.9%
% of missing household income	(imputed)	1.15%	1.45%
Average household size	5.62	5.48	5.11
Deaths			
Number of deaths (12-month period)	36,267	14,969	40,303
Minimum # of deaths per municipal-age-sex group* [c]	144	53	72
Median # of deaths per municipal-age-sex group [c]	447	172	489
Maximum # of deaths per municipal-age-sex group [c]	759	359	828

Notes:
[a] In addition to the housing units, 23,006 converted hostels were considered in the 2011 census. According to Stats SA, a converted hostel is defined as: 'Hostels where the accommodation has been converted into self-contained units for households' (Stats SA, 2011).
[b] Not adjusted for inflation.
[c] Excluding age group 6–18.

remained the same over the years, the wording of the income question changed slightly in 2007 and 2011 to:'What is the income category that best describes the gross monthly or annual income of (this person) before deductions *and* including all sources of income?', resulting in a possible underestimation of income in 2001. Annual household incomes were then calculated by adding up the midpoints of income categories for all household members. Allocation rules suggested by Stats SA were used (Stats SA, 2011). Following Leibbrandt, Woolard, Finn, and Argent (2010), we computed equivalent adult household income by dividing the annual household income by the square root of household size (of people still alive).

2.3. Aggregation to approximate decile groups of municipalities

We use municipalities as our geographical unit, the lowest level that is available in all three surveys. In the 2001 Census and 2007 CS, South Africa consisted of 262 municipalities, which was reduced to 234 in the 2011 Census. Because we aggregate municipalities into large decile-like categories (see below), this reduction had no impact on our results. For individuals reported as deceased during the preceding year, the municipality of household residence was selected as their main municipality in the 2001 Census and 2007 CS. Due to data restrictions, however, the municipality where the person had died (rather than residential municipality) was selected in the 2011 Census.

In each year, we rank municipalities by their average household income per adult equivalent into ten similar-sized groups, each representing (approximately) 10 per cent of the surveyed population. For the graphs, we computed age-gender-specific one-year mortality rates (by dividing the total number of deaths in the preceding 12-month period by the sum of the population surveyed plus the reported deaths).

The municipality groups do not represent exact deciles of 10% of the population due to the presence of five larger (and, on average, richer) municipalities: Johannesburg, Cape Town, eThekwini, Ekurhuleni and Tshwane (see Online Appendix C). As a result, some of these larger municipalities dominate their group's mortality experience. For example, in 2011, 98.0% of 'Municipality Group 9' consists of respondents living in the City of Cape Town (see Online Appendix C).

Before examining age-gender specific mortality changes, we conducted a full population analysis for 2001–2011 showing indirectly age-sex-standardised mortality rates per year per municipality group (as in O'Donnell, van Doorslaer, Wagstaff, & Lindelow, 2008). Because we know (from Pillay-van Wyk et al., 2016; see their figures 2, 3, 4) that most, if not all, of the mortality variation observed over the first decade of this century is related to changes in HIV and TB risks faced by subgroups, we examine the mortality experience of specific demographic subgroups separately using the same measures as for the total population.

2.4. Measuring inequality in mortality

Like Currie and Schwandt (2016), we present graphs showing the slope of a simple bivariate regression line through the 10 mortality rates associated with the (fractional) income ranks of 10 municipality groupings to visualise changes in absolute inequality in mortality by income. As these municipality groupings are constructed by ranking all municipalities by average income and then dividing these into approximate (i.e. not exactly 10%) deciles, the (cumulative) rank on the x-axis reflects the (slightly) varying size of the 10 approximate decile groups. To quantify the degree of health inequality we use the absolute and the relative concentration index (CI) (Wagstaff, Paci, & Van Doorslaer, 1991). We used the convenient regression based methods (O'Donnell et al., 2008) to obtain point estimates and standard errors of two indices: (i) the standard CI measures relative inequality in mortality by income (and is therefore invariant to equiproportionate changes in mortality), and (ii) the generalised CI, which is a measure of absolute inequality in mortality by income (and thus invariant to equal additions or subtractions of mortality) (cf Van Doorslaer & van Ourti, 2011). Estimates of the indices and their standard errors can easily be obtained from a simple bivariate regression of a 'convenient' transformation of the dependent health variable (here individual mortality) on relative rank of the income decile (cf. Wagstaff et al., 1991) as implemented in the CONINDEX Stata routines developed by O'Donnell, O'Neill, van Ourti, and Walsh (2016). Standard errors were adjusted for clustering at the income group level.

We test for differences between indices using t-tests to generate p-values. For both indices, a negative value indicates a higher concentration of mortality among the lower income ranks, a positive value indicates the opposite and a zero value indicates an equal distribution of mortality across income groups. The relative CI has the advantage that it is theoretically bounded between –1 and 1, while the absolute CI is bounded by plus or minus the mean mortality rate. The generalized index has the advantage that it satisfies the so-called mirror

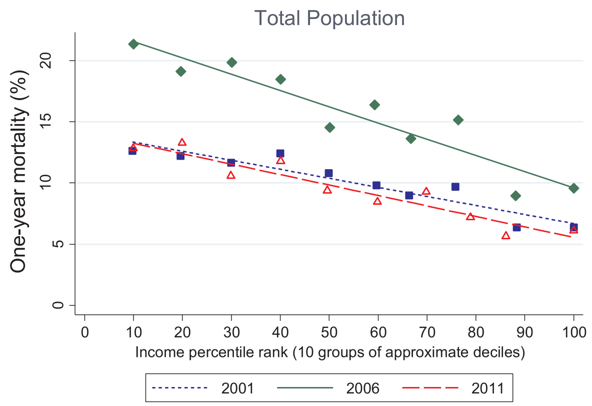

Fig. 1. Age-sex standardised mortality rates by income, total population. Note to Fig. 1: X axis shows 10 (approximate) income decile groups, ranked by average adult equivalent (AAE) income. Actual municipality group sizes close to but not exactly 10% because of municipalities overlapping 10% ranking thresholds. Bivariate regression lines of mortality on (fractional) income rank.

property (Erreygers, 2009): whether health is measured as a shortfall (e.g. deaths) or an attainment (e.g. deaths avoided) does not change the index value, only its sign (positive versus negative). We show both index values to highlight the differences in findings depending on whether the main concern is with inequality in a relative or absolute sense, and the value judgements that underlie the different measures (Kjellson, Gerdtham, & Petrie, 2015).

3. Results

3.1. Total Population analysis

Differences in overall age-sex standardised mortality inequality are presented in Fig. 1. In this graph, and Fig. 2.1a-2.4b, municipality groups are ranked by their average adult equivalent income on the horizontal axis. The vertical axis shows one-year mortality rates (per 1000) per municipality group, for 2001, 2006 and 2011 respectively. The lines represent the fitted bivariate linear-regression lines through these points for each year. When the slope of the line becomes steeper over time (as in 2006), it implies that mortality rates have increased more (in absolute numbers) in poorer than in richer municipalities, and vice versa. Hence, a steeper slope indicates an increase in absolute inequality. It is clear in Fig. 1 that in 2006 the line has not only shifted upward, its slope has also become steeper in 2006, while the opposite pattern is observed between 2006 and 2011: a falling slope and intercept.

Table 2 presents estimates of annual mortality rates, as well as relative and absolute CIs, with standard errors adjusted for clustering at the group level, and p-values of t-tests for differences between years. It is clear that both mean mortality and its absolute inequality by income increased sharply from 2001 to 2006, and then dropped again between 2006 and 2011. Relative inequality in mortality between income groups, however, as measured with the CI, remained fairly constant. As a result, the average mortality risk of South Africans, which was about 10% in 2001 bounced back to that rate in 2011, but it was 50% higher (i.e. 15%) in 2006. Similarly, absolute inequality between rich and poor rose in 2006 and fell again in 2011, while relative inequality remained fairly stable over this period, and only increased slightly. In other words: after a decade, overall average mortality was back to where it was in 2001, but had become a little more concentrated among the poor.

3.2. Age-sex stratified analysis

Patterns of change do, however, differ very much by age and sex. Showing all graphs combined in Fig. 2.1a-2.4b clearly visualises the differences and facilitates comparisons across age, sex, income and year. For children between 0 and 5, mortality rates increased at all income levels between 2001 and 2006, for both boys and girls. Since the reduction in mortality rates during the 2006–2011 period exceeded the increase before 2006, mortality rates in 2011 were lower than in 2001. The negative slope signals that, in all years, and for both girls and boys, under-five child mortality was higher in poorer than in richer municipalities. However, as indicated in Table 2, none of the CI differences between years are statistically significant, neither for boys, nor for girls: absolute and relative inequality did not change between 2001 and 2011.

For the young adult age group 19–39, for both sexes, we see that average mortality rose and fell rapidly in this relatively short period of ten years. Young women, for example, were twice as likely to die in 2006 than they were in 2001 or in 2011. Likewise, the much steeper slopes observed in 2006 in Fig. 2 clearly show that also absolute inequality rose rapidly in the 2001–2006 period, and dropped again after 2011. The significant differences in absolute CIs in Table 2 confirm this. Interestingly, the picture is quite different for relative inequality: none of the differences in the relative CI between years are significant (Table 2). This means that – while those on lower incomes in absolute terms obviously enjoyed greater survival gains in the post-2006 period that coincided with the rollout of free ART – they did not significantly gain more in relative terms, and relative inequality (in mortality inequality by income) remained fairly stable in this age group.

Results presented in Fig. 2.3a-b for male and female older adults aged 40–59 show that, as for the 19–39 age group, both average mortality and its absolute inequality by income increased for both males and females between 2001 and 2006, and decreased again after 2006. Also in this older adult age group, relative inequality remained almost constant across the entire period: for both sexes, the relative concentration indices do not differ significantly across years (Tables 2 and 3). Also in this age group we conclude that – while absolute gains and losses were clearly different – in relative terms richer and poorer segments seem to have suffered and benefited relatively equally from mortality losses and gains.

Results for the oldest age group (60 +) are presented in Fig. 2.4a-b. Male mortality shows a very similar pattern over time as for the older adult age group: rising and falling average mortality and absolute inequality, but no change in relative inequality, as measured by the CIs. The most striking observation is that not only is female mortality much lower than male mortality, but also that an income gradient in mortality is completely absent: richer and poorer older females are equally likely to die. We address potential explanations for this finding in the Discussion.

4. Conclusion and discussion

We have documented the large changes in mortality risk that occurred in the recent history of South Africa in relation to SES, in particular to position in the income ranking of municipalities. The mortality and income data collected in the (Mini-) Census surveys allowed us to paint a moving picture of the changing relationship between death and income in the first decade of this century, a decade that was characterised by a spectacular rise and fall of the HIV/AIDS epidemic which did not affect rich and poor equally.

Our findings quantify the rise and fall in levels of mortality, as well as in the absolute and relative inequality in its distribution by income. Throughout the decade, overall population mortality was more concentrated among poorer municipalities. However, both mean mortality and the absolute gap between rich and poor increased in the first five years of the new millennium, but then returned to levels similar to those in 2001 in the next five years. Relative inequality, however, remained largely stable during this period.

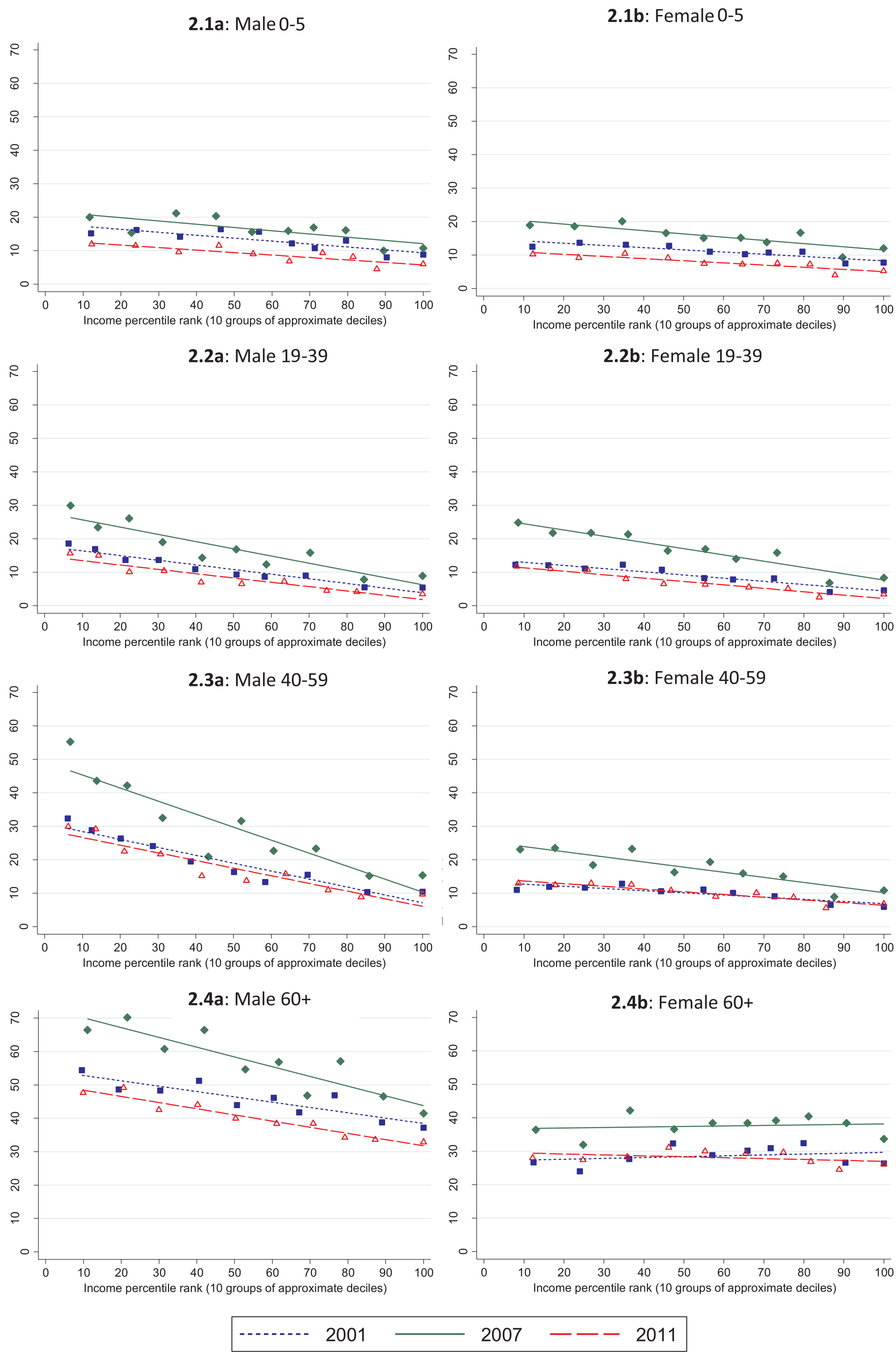

Fig. 2. One-year mortality for population groups aged 0–5, 19–39, 40–59 and 60+ by income: a) males, b) females. Figure 2.1: One-year mortality for population aged 0–5 by income: (a) males, (b) females. Note: Cf Fig. 1. Figure 2.2: One-year mortality for population aged 19–39 by income: (a) males, (b) females. Note: Cf Fig. 1. Figure 2.3: One-year mortality for population aged 40–59 by income: (a) males, (b) females. Note: Cf Fig. 1. Figure 2.4: One-year mortality for population aged 60+ by income: (a) males, (b) females. Note: Cf Fig. 1.

Table 2
Mean mortality rates, and relative and absolute concentration indices, for total population, and for age-sex specific groups, (2001, 2006 and 2011).

	Mean mortality rates and Concentration indices			P values of differences between years		
Total Population	**2001**	**2006**	**2011**	**2001 vs. 2006**	**2006 vs. 2011**	**2001 vs. 2011**
Per 1.000 Mortality	9.97 (0.052)	15.53(0.125)	9.45 (0.046)	< 0.001	< 0.001	< 0.001
Relative CI	-0.13 (0.015)	-0.14 (0.015)	-0.15 (0.013)	0.304	0.555	0.104
Absolute CI	-1.25 (0.148)	-2.24 (0.236)	-1.39 (0.121)	0.001	0.018	0.186
Observations (N)	*3,636,239*	*964,069*	*4,264,392*			
Males						
Age 0–5	**2001**	**2006**	**2011**	**2001 vs. 2006**	**2006 vs. 2011**	**2001 vs. 2011**
Per 1.000 Mortality	13.27 (0.241)	16.35 (0.519)	9.11 (0.178)	< 0.001	< 0.001	< 0.001
Relative CI	-0.1 (0.023)	-0.1 (0.028)	-0.13 (0.016)	0.846	0.346	0.399
Absolute CI	-1.39 (0.302)	-1.6 (0.459)	-1.17 (0.143)	0.706	0.370	0.502
Observations (N)	*225,644*	*59,708*	*284,555*			
Age 19–39						
Per 1.000 Mortality	10.08 (0.133)	15.91 (0.32)	7.64 (0.102)	< 0.001	< 0.001	< 0.001
Relative CI	-0.23 (0.024)	-0.22 (0.032)	-0.27 (0.038)	0.912	0.343	0.344
Absolute CI	-2.27 (0.245)	-3.52 (0.509)	-2.05 (0.291)	0.028	0.012	0.561
Observations (N)	*567,144*	*152,835*	*729,386*			
Age 40–59						
Per 1.000 Mortality	17.7 (0.250)	27.38 (0.571)	16.28 (0.211)	< 0.001	< 0.001	< 0.001
Relative CI	-0.22 (0.025)	-0.22 (0.036)	-0.22 (0.032)	0.855	0.935	0.920
Absolute CI	-3.82 (0.448)	-6.13 (0.977)	-3.58 (0.517)	0.032	0.021	0.725
Observations (N)	*277,397*	*81,804*	*360,020*			
Age 60+						
Per 1.000 Mortality	45.58 (0.639)	56.93 (1.327)	40.16 (0.523)	< 0.001	< 0.001	< 0.001
Relative CI	-0.06 (0.009)	-0.08 (0.011)	-0.08 (0.007)	0.070	0.518	0.113
Absolute CI	-2.67 (0.388)	-4.81 (0.648)	-3.05 (0.272)	0.005	0.012	0.429
Observations (N)	*106,637*	*30,511*	*141,151*			
Females						
Age 0–5	**2001**	**2006**	**2011**	**2001 vs. 2006**	**2006 vs. 2011**	**2001 vs. 2011**
Per 1.000 Mortality	11.18 (0.222)	15.83 (0.514)	8.13 (0.169)	< 0.001	< 0.001	< 0.001
Relative CI	-0.09 (0.02)	-0.1 (0.021)	-0.13 (0.014)	0.836	0.208	0.119
Absolute CI	-1.06 (0.223)	-1.6 (0.335)	-1.08 (0.116)	0.183	0.146	0.935
Observations (N)	224,475	58,885	280,734			
Age 19–39						
Per 1.000 Mortality	8.66 (0.115)	16.01 (0.305)	7.05 (0.096)	< 0.001	< 0.001	< 0.001
Relative CI	-0.19 (0.021)	-0.2 (0.021)	-0.25 (0.029)	0.791	0.150	0.096
Absolute CI	-1.66 (0.186)	-3.21 (0.344)	-1.78 (0.202)	< 0.001	< 0.001	0.683
Observations (N)	653,558	169,693	762,006			
Age 40–59						
Per 1.000 Mortality	9.72 (0.17)	16.93 (0.413)	10.19 (0.152)	< 0.001	< 0.001	0.039
Relative CI	-0.12 (0.022)	-0.15 (0.021)	-0.14 (0.017)	0.302	0.641	0.497
Absolute CI	-1.18 (0.216)	-2.59 (0.360)	-1.43 (0.174)	0.001	0.004	0.365
Observations (N)	335,020	97,353	435,933			
Age 60+						
Per 1.000 Mortality	28.32 (0.399)	37.42 (0.871)	28.13 (0.356)	< 0.001	< 0.001	0.714
Relative CI	0.01 (0.017)	0.01 (0.017)	-0.01 (0.012)	0.754	0.371	0.215
Absolute CI	0.42 (0.483)	0.28 (0.623)	-0.30 (0.328)	0.855	0.409	0.215
Observations (N)	172,933	47,437	216,158			

Notes: Standard errors in parentheses, adjusted for clustering. P values based on t-test of difference in means. Negative concentration index estimate implies greater concentration of mortality among low income groups.

4.1. Overall changes in mortality

Critical for the development of mortality and mortality inequality were the changes that occurred in the HIV/AIDS and TB epidemics and their treatment. Several studies based on notification of death statistics have shown that mortality changes in South Africa in the first decade of this century were almost entirely attributable to changes in deaths due to HIV/AIDS and TB. Pillay-van Wyk et al. (2016), for instance, demonstrate very clearly that only the mortality for these two causes rose and fell in the period 2000–2012, while hardly any change was detected in any other causes of death. Almost all of the change in mortality occurred among the Black African adult population. While we do not observe cause-of-death in the Census data, it is most likely that the great majority of mortality changes that we observed are related to HIV/AIDS and TB.

4.2. Overall changes in mortality inequality by income

Both average mortality and absolute mortality inequality by income first rose until 2006 and declined thereafter. In the first five years, the average mortality risk of South Africans increased by 50% (from about 10% in 2001 to 15% in 2006), but another five years later (in 2011) it had fallen back to its level of 2001. In absolute terms, poorer municipalities were more severely affected by HIV/AIDS and TB in the first five years. Probst et al. (2016) have found that individuals of a lower SES (income, employment status and asset scores) are at higher risk of dying of HIV. However, these (poorer) municipalities also seem to have benefited more from the rollout of the ART programme in the next five, in spite of reports of poorer provinces somewhat lagging behind in the ART rollout (Adam & Johnson, 2009). This did not lead to large changes in relative inequality: in proportional terms, losses and gains were fairly

Table 3
Male-female differences in mortality and concentration indices, 2001–2006–2011.

	Difference Male minus Female			P values		
Age 0–5	**2001**	**2006**	**2011**	**2001**	**2006**	**2011**
Per 1.000 Mortality	2.1 (0.328)	0.52 (0.731)	0.98 (0.246)	< 0.001	0.478	< 0.001
Relative CI	-0.01 (0.030)	0.00 (0.035)	0.01 (0.021)	0.747	0.926	0.808
Absolute CI	-0.33 (0.375)	0.00 (0.568)	-0.08 (0.184)	0.381	0.998	0.648
Age 19–39				2001	2006	2011
Per 1.000 Mortality	1.42 (0.175)	-0.1 (0.442)	0.59 (0.140)	< 0.001	0.823	< 0.001
Relative CI	-0.03 (0.032)	-0.02 (0.039)	-0.02 (0.048)	0.307	0.592	0.733
Absolute CI	-0.61 (0.307)	-0.31 (0.615)	-0.27 (0.354)	0.048	0.616	0.440
Age 40–59				2001	2006	2011
Per 1.000 Mortality	7.98 (0.302)	10.45 (0.705)	6.09 (0.26)	< 0.001	< 0.001	< 0.001
Relative CI	-0.09 (0.034)	-0.07 (0.042)	-0.08 (0.036)	0.005	0.090	0.028
Absolute CI	-2.64 (0.497)	-3.53 (1.042)	-2.15 (0.546)	< 0.001	0.001	< 0.001
Age 60+				2001	2006	2011
Per 1.000 Mortality	17.26 (0.753)	19.51 (1.587)	12.04 (0.632)	< 0.001	< 0.001	< 0.001
Relative CI	-0.07 (0.019)	-0.09 (0.020)	-0.07 (0.013)	< 0.001	< 0.001	< 0.001
Absolute CI	-3.09 (0.620)	-5.08 (0.899)	-2.74 (0.427)	< 0.001	< 0.001	< 0.001

Notes: Standard errors in parentheses, adjusted for clustering. P values based on t-test of difference in means. Positive difference in mortality means higher (excess) male mortality. Negative differences in (absolute and relative) concentration indices means greater concentration of mortality among lower income deciles for males than females.

evenly spread across richer and poorer municipalities and relative inequality in mortality did not increase significantly over the whole period.

4.3. Age-sex specific mortality and mortality inequality changes

Mortality trends in the first decade of the millennium did, however, vary substantially across age and gender. For children under-five, for both sexes, we observe a 50% drop in average mortality between 2006 and 2011, after an earlier increase in 2001–2006. Trend estimates of under-five mortality in South Africa have shown similar patterns (WHO, 2017a; Kerber et al., 2013; UNICEF, 2014). While under-five mortality was more concentrated in poorer municipalities, we do not observe much change in inequality by income. While absolute inequality grew and fell again, relative inequality in under-five mortality remained fairly stable between 2001 and 2006, and increased somewhat after 2006. The effective prevention of mother-to-child transmission of HIV (PMTCT) programme and the increase in immunisation levels, both argued to be largely responsible for the reduction in under-five mortality (Mayosi & Benatar, 2014; Republic of South Africa, 2013), seem to have benefited richer municipalities relatively more than poorer municipalities.

As South Africa's burden of HIV/AIDS is predominantly driven by heterosexual transmission (Fraser-Hurt et al., 2011), adults in the reproductive age group (15–49) are obviously most at risk (Shisana et al. 2014; Bradshaw et al., 2016; Pillay-van Wyk et al., 2016). The mortality risk associated with HIV/AIDS and TB is therefore most visible in the adult population in their reproductive years. TB was responsible for 20.1% of all deaths in the age group 15–49 in 2006, compared to 2.3% in age group 0–14, and 3.2% in those aged 65+ (Stats SA, 2008). It is therefore not a surprise to observe most of the variation in mortality – and mortality inequality –over time in this age group.

For the young adult population aged 19–39, we saw a substantial increase in mortality for both sexes between 2001 and 2006. In absolute terms, the rise was even larger for females (mortality rate doubled from 8.7% to 16.0%) than for males (from 10.9% to 15.9%). This result is consistent with estimates from Bradshaw et al. (2016), for example, who analysed death notification statistics to show that over the 2000–2005 period, HIV/AIDS mortality for females aged 15–29 years increased faster than for males. After 2006, however, mortality also shows a sharper decline among females than males. It has now been documented that large-scale HIV programmes have been associated with a larger decrease in mortality for women compared to men (Bor et al. 2015). This may partly be explained by the fact that women were more affected by HIV/AIDS, but it has also been attributed to poorer HIV testing among males (Shisana et al., 2014), men initiating treatment at more advanced stages of HIV (Cornell, Myer, Kaplan, Bekker, & Wood, 2009; Schneider et al. 2012), and females showing better adherence to treatment (Kranzer et al., 2010). Better healthcare-seeking behaviour among females who experience TB symptoms (Smith et al. 2016), and poorer TB treatment outcomes among males (Ershova et al. 2014) may have also played some part in the larger mortality decline among females. Absolute mortality inequality in this age group grew and fell, for both sexes, in line with the average mortality rates. Relative inequality, on the other hand, grew over the entire period but not significantly so, signaling that in relative terms the poor did not disproportionately benefit from the mortality reduction due to ART.

Larger differences between males and females were observed among the two highest age groups (40–59 and 60+). Not only average mortality, but also absolute inequality in mortality by income, is much higher among men than women. Strikingly, however, and for both sexes, relative inequality is lower than for the younger adult group, it is higher for males than females, and it did not rise significantly. Again, these gender disparities are consistent with findings from Bradshaw et al. (2016), who show that for the age group 45–59, HIV/AIDS mortality was significantly higher in the 2001–2010 period for males than females. As indicated above, these differences are probably related to gender differences in healthcare-seeking behaviour and adherence to treatment for HIV/AIDS and TB.

Also pulmonary smear-positive TB cases were twice as prevalent among males as females for this age group (WHO, 2017b). Further research is needed to understand gender differences in care-seeking behaviour and adherence, in order to fully realise the benefits of free mass ART and TB treatment provision.

Finally, we find that significant mortality disparities by income exist for males aged 60+, but also that old-age mortality was equally distributed across municipalities among older females. These findings are very much in line with results from Bradshaw et al. (2016) who reported an increasing HIV mortality rate for 60+ males, but not for females. Again, the gender differences in mortality are most likely to be caused by variation in health-seeking behaviour (including testing), treatment adherence, and age-discordant sexual relationships between older men and younger women (Shisana et al., 2014). Also, apart from the impact of HIV, there has traditionally (and not limited to South Africa) been a higher mortality rate for men than women in the age group older than 60. In the case of South Africa, the higher inequality of mortality at this age, if the impact of HIV is excluded, may also be partly due to greater participation in more strenuous and hazardous labour market activities.

A recent publication (Kabudula et al., 2017) also examined changes in absolute and relative inequality in a rural surveillance population in Agincourt for a similar period (2001–2013). While much smaller and confined to one rural South African population, they do observe cause of death. Like us, they document a rise and fall in mortality over this same period, and strong absolute and relative gradients (by wealth, not income) in both overall and HIV/AIDS mortality using very similar indices (slope indices). However, because it is a cohort study, they document the mortality inequality evolution in the same rural population, and their estimates of changes over time are influenced by the stark gradients in mortality: inequality is bound to fall because the poor are more likely to attrite because of their greater death risk. This bias is not discussed in the paper but it is confirmed by their results: overall, both absolute and relative inequality in mortality by wealth falls, as one would expect, and in spite of the rise and fall in average mortality. When they test for changes over time in HIV/AIDS specific mortality, they do not find any significant differences in inequality, neither relative nor absolute. While these findings may accurately reflect the mortality experience of the Agincourt cohort, they are not really comparable to our nationwide representative estimates for 3 years in a decade.

Our study also has limitations. First and foremost, because for the 2011 Census the public release of Statistics South Africa's 10% mortality sample was different from the 10% person sample, we could not do all analysis at the individual level. Since the number of deaths was used as our numerator for calculating age-specific mortality rates (person sample), and while the sum of people surveyed plus those who died was used as our denominator (mortality sample), we had to assume that both 10% samples were randomly drawn from the same municipality populations. Encouragingly, a comparison in mortality trends and absolute levels by age group, gender and province, between mortality rates obtained from the Census/CS and from adjusted vital registrations showed that, except for age group 60 +, the mortality rates used in our study were fairly consistent with the rates from death notifications (see Online Appendix A). This suggests that, overall, our mortality rates are representative at the level of municipality groups ranked by income.

Second, as mortality questions were not asked to the population living in institutions this group was excluded from our analysis. This omission may have led to some bias in mortality and mortality inequality estimates. The White population, for example, has a higher proportion of people living in institutions such as old-age homes (Dorrington, Moultrie & Timæus, 2004). However, the bias is probably limited, due to the relatively small proportion of people living in institutions which Yu (2009) estimated as 1.4% of the population in 2007.

Third, all three surveys used had a high proportion of unspecified individual incomes (2001: 15.6%, 2006: 5.5%, 2011: 14%). Evidence suggests that particularly White respondents, as well as those living in the Western Cape and Gauteng, are more likely to have missing income values than other population groups and provinces (Ardington, Lam, Leibbrandt, & Welch, 2006). While this is, on average, the richer part of the population, ignoring missing values may have downwardly biased our income estimates. For the 2001 data, however, this issue was partially resolved by using imputed incomes. In addition, and despite the 2001 imputations, all surveys recorded a high proportion of zero household incomes (2001: 12.2%, 2006: 7.3%, 2011: 7.9%). However, as omitting them would also lead to biased results (Yu, 2009), we decided to retain these in the analysis. (See online Appendix D for a discussion on imputation in data sources.).

Finally, our research is restricted to the 2000–2011 period and we therefore cannot say anything about the impact of influential policy changes and developments since 2011. For example, the number of HIV-infected people in South Africa receiving ART has almost doubled between 2011 and 2014 (SANAC, 2016). In addition, the CD4 threshold for ART initiation was increased from 350 cells/μl initially to 500 cells/μl in 2014, and South Africa has formally adopted the 'Test and Treat' policy since 2016, which stipulates that all HIV-positive children, adolescents and adults are offered ART treatment regardless of CD4 count (NDOH, 2016). The resulting increases in ART provision are likely to further reduce health disparities. Another example is the introduction of the 'Fixed-Dose Combinations' drug regime in 2013 (SANAC, 2016). This reduces drug intake from three times a day to one tablet a day, and is known to improve treatment uptake and adherence. Better adherence may contribute to further reductions in mortality inequality, and to smaller disparities between males and females.

5. Conclusion

Our study provides insight into the South African nationwide mortality inequality experience by income. It demonstrates that South Africa's post-apartheid dedication to improving survival and reducing socio-economic disparities has been met with mixed success. After an initial period of rising mortality and inequalities, South Africa has managed to reverse mortality and absolute mortality inequality since 2006, but relative inequality has remained high and even increased slightly during the 2001–2011 period. This means that the slow response to the HIV/AIDS epidemic has taken a serious toll on average, but a relatively greater one among the poorest segments of the population. And while this trend has been reversed since 2006, large disparities in mortality by income continue to exist.

By identifying the most affected age-sex population groups, our study also provides actionable information. Traditionally, gender-targeted programming has sought to improve health outcomes for females. However, our results suggest that considerable gains could be made in reducing gender mortality disparities by implementing male-sensitive programmes. The South African government should focus on designing effective interventions that increase male uptake of HIV and TB services, as well as approaches to healthcare delivery which improve their treatment adherence. Furthermore, the observed reversal of adult absolute mortality inequality suggests that HIV/AIDS and TB treatment programmes have been successful in reaching also the poorer municipalities. The small rise in relative inequality mortality risk for young adults after 2006, however, implies that those groups in richer municipalities have benefitted relatively more from the ART and TB scale-up programmes. If they want to further reduce health disparities, South African policy makers must therefore make sure to target younger adults in the poorest municipalities. Focusing efforts in those areas in terms of improved access to a full range of social services, raised awareness, and better healthcare seeking and sexual behaviour could lead to further reductions in the unequal chances of surviving to old age.

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Conflicts of interest and financial interest statement

The authors have no financial or personal relationships that might bias this work, and no conflicts of interest in the manuscript. This paper is not under consideration for publication in whole or in part elsewhere.

Ethics approval statement

The study uses secondary, anonymised and publicly available (census and survey) data collected by the South African statistical agency, Stats SA. The agency obtained the necessary ethics approval before the collection of the data.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ssmph.2018.06.007.

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