Socioeconomic differences in mortality in the antiretroviral therapy era in Agincourt, rural South Africa, 2001–13: a population surveillance analysis

Chodziwadziwa W Kabudula, Brian Houle, Mark A Collinson, Kathleen Kahn, Francesc Xavier Gómez-Olivé, Stephen Tollman, Samuel J Clark

Summary

Background Understanding the effects of socioeconomic disparities in health outcomes is important to implement specific preventive actions. We assessed socioeconomic disparities in mortality indicators in a rural South African population over the period 2001–13.

Methods We used data from 21 villages of the Agincourt Health and socio-Demographic Surveillance System (HDSS). We calculated the probabilities of death from birth to age 5 years and from age 15 to 60 years, life expectancy at birth, and cause-specific and age-specific mortality by sex (not in children <5 years), time period, and socioeconomic status (household wealth) quintile for HIV/AIDS and tuberculosis, other communicable diseases (excluding HIV/AIDS and tuberculosis) and maternal, perinatal, and nutritional causes, non-communicable diseases, and injury. We also quantified differences with relative risk ratios and relative and slope indices of inequality.

Findings Between 2001 and 2013, 10 414 deaths were registered over 1 058 538 person-years of follow-up, meaning the overall crude mortality was 9·8 deaths per 1000 person-years. We found significant socioecomonic status gradients for mortality and life expectancy at birth, with outcomes improving with increasing socioeconomic status. An inverse relation was seen for HIV/AIDS and tuberculosis mortality and socioeconomic status that persisted from 2001 to 2013. Deaths from non-communicable diseases increased over time in both sexes, and injury was an important cause of death in men and boys. Neither of these causes of death, however, showed consistent significant associations with household socioeconomic status.

Interpretation The poorest people in the population continue to bear a high burden of HIV/AIDS and tuberculosis mortality, despite free antiretroviral therapy being made available from public health facilities. Associations between socioeconomic status and increasing burden of mortality from non-communicable diseases is likely to become prominent. Integrated strategies are needed to improve access to and uptake of HIV testing, care, and treatment, and management of non-communicable diseases in the poorest populations.

Funding Wellcome Trust, South African Medical Research Council, and University of the Witwatersrand, South Africa.

Lancet Glob Health 2017; 5: e924–35

See Comment page e851

MRC/Wits Rural Public Health and Health Transitions Research Unit (Agincourt), School of Public Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa (C W Kabudula MSc, B Houle PhD, M A Collinson PhD, Prof K Kahn PhD, F X Gómez-Olivé PhD, Prof S Tollman PhD, Prof S J Clark, PhD); **School of Demography, Australian National University, Canberra, ACT, Australia** (B Houle); **CU Population Center, Institute of Behavioral Science, University of Colorado at Boulder, Boulder, CO, USA** (B Houle, Prof S J Clark); **INDEPTH Network, Accra, Ghana** (M A Collinson, Prof K Kahn, F X Gómez-Olivé, Prof S Tollman, Prof S J Clark); **Umeå Centre for Global Health Research, Division of Epidemiology and Global Health, Department of Public Health and Clinical Medicine, Umeå University, Umeå, Sweden** (Prof K Kahn, Prof S Tollman); **Department of Science and Technology/ Medical Research Council, South African Population Research Infrastructure Network (SAPRIN), Acornhoek, South Africa** (M A Collinson); **and Department of Sociology, The Ohio State University, Columbus, OH, USA** (Prof S J Clark)

Correspondence to: Mr Chodziwadziwa W Kabudula, MRC/Wits Rural Public Health and Health Transitions Research Unit (Agincourt), University of the Witwatersrand, PO Box 2, Acornhoek 1360, South Africa **chodziwadziwa.kabudula@wits.ac.za**

Introduction

The distribution of health outcomes varies by social factors, such as marital status, ethnic origin, and socioeconomic status.[1,2] For example, a review by Link and Phelan[3] showed that socioeconomic status has a positive association with life expectancy and a negative association with overall, infant, and perinatal mortality. McKinnon and colleagues[4] also reported a negative association between household socioeconomic status and neonatal mortality in many low-income and middle-income countries, through use of data from demographic and health surveys done between 1997 and 2012. Social disparities in population health outcomes are sustained because social conditions, such as knowledge, money, power, prestige, and beneficial social connections, allow individuals to avoid health-related risks, adopt protective strategies, and access medical facilities and services.[3,5–7] Understanding the magnitude of social disparities in health outcomes is important to implement specific actions to reduce them. In many sub-Saharan African settings, however, evidence of socioeconomic differences in health is limited because of the requirement for complex information systems, longitudinal studies with sufficiently large samples, and detailed information on health outcomes and social characteristics.

Over the past two decades, complex and rapidly evolving health transitions have occurred in South Africa. Most important has been the steady and substantial increase in overall mortality due to communicable diseases from the mid-1990s to the mid-2000s, peaking around 2005–07 owing to the HIV/AIDS epidemic.[8–14] After the widespread introduction of free antiretroviral therapy (ART) available from public health facilities, AIDS-related mortality declined.[11,15,16] At the same time, however, modernisation and changes in social and economic development (eg, increases in the proportion of households that owned wealth-associated assets, such as stoves, fridges, and televisions[17]) have resulted in the adoption of lifestyle

Research in context

Evidence before this study

We searched PubMed and Google Scholar for studies on mortality and associated differences in socioeconomic status in South Africa, using the search terms "mortality", "death", "socioeconomic", "wealth", and "South Africa" without any language or date restrictions. Several studies showed that the emergence of the HIV/AIDS epidemic substantially increased overall mortality and the contribution of communicable diseases to the overall mortality burden and reduction in life expectancy from the mid-1990s to the mid-2000s. Later studies have shown that HIV/AIDS-related mortality has been declining since antiretroviral therapy (ART) became widely available through public health services, but limited information was available on the distribution of mortality by socioeconomic status, particularly in resource-poor rural areas.

Added value of this study

Our evidence describes the distribution of mortality in a resource-poor rural area of northeast South Africa by household socioeconomic status before and after free ART became available. HIV/AIDS-related mortality reduced and life expectancy at birth improved, but individuals from the poorest households continue to bear the greatest burden of HIV/AIDS and tuberculosis mortality. Additionally, the mortality burden from non-communicable diseases is rising, and associations with household socioeconomic status are likely to become prominent. These findings might reflect the situation in other resource-poor rural settings with high HIV/AIDS disease burdens and increasing risk of non-communicable diseases in South Africa and southern Africa.

Implications of all the available evidence

Integrated health-care planning and programme delivery strategies are needed to increase access to and uptake of HIV testing, linkage to care and ART, and prevention and treatment of non-communicable diseases among the poorest individuals in resource-poor settings with high burdens of HIV/AIDS and rising burdens of non-communicable disease risk factors. The aim should be to reduce socioeconomic inequalities in mortality where disease burden is high, and to achieve further reductions in overall mortality.

For more on **Agincourt HDSS data** see http://www.agincourt.co.za

For more on **INDEPTH Network Data Repository** see http://www.indepth-ishare.org/

practices that expose South Africans to risk factors for non-communicable diseases and injury. The mortality profile in South Africa over the past two decades has been dominated by communicable diseases, maternal, perinatal, and nutritional causes, non-communicable diseases, and injury.[11,15,16,18–27] Information on how mortality patterns are changing in relation to socioeconomic status, however, has been limited, particularly in rural areas. We used a high-quality and methodologically consistent longitudinal dataset that provides detailed information on health outcomes by indicators of socioeconomic status to assess changes in mortality in a poor rural South African population over the period 2001–13.

Methods

Setting and data sources

We used data from the ongoing Agincourt Health and socio-Demographic Surveillance System (HDSS), which was established in 1992.[28,29] Agincourt is located in a resource-poor rural setting in Bushbuckridge Municipality in northeast South Africa, close to the Mozambique border. The Agincourt HDSS has generated detailed longitudinal data on births, deaths, and migration and complementary data covering health and socioeconomic indicators. The study area included 21 villages spread over 402 km² until 2006,[22] and was extended to 26 villages in 2007 and to 31 villages from 2010 to 2012.[17] Most people speak Shangaan. About a third of the population is made up of immigrants from Mozambique, who arrived in the area in the early to mid-1980s, and their descendants. Data have been collected annually since 1999. Detailed documentation describing the Agincourt HDSS data and an anonymised database containing data from 10% of the surveillance households are available for public access. The Agincourt HDSS core demographic data are also routinely deposited for public access in the INDEPTH Network Data Repository. In this study we have used only data from the original 21 villages to maximise the duration of follow-up at the village level. These customised data are available on request to interested researchers.

Ethics approval was obtained from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg, South Africa, for surveillance activities in the Agincourt HDSS (protocols M960720 and M110138) and for the analyses reported in this study (protocol M120488). Informed verbal consent was obtained at every surveillance visit from the head of the household or another eligible adult in the household. The person giving consent was noted in the household roster, and the details and date of the process were recorded by the responsible fieldworker.

Causes of death

For every death recorded from 2001 to 2013, we used the InterVA-4 probabilistic model (version 4.03) to assign the most probable cause, rather than the more traditional, clinically oriented underlying cause. This model enables a standardised, automated assignment of cause of death that is much quicker and more consistent than physician assessment, and is particularly useful for assessing changes over time and across settings. It assigns each death to a maximum of three likely causes, with associated likelihoods based on information about signs and symptoms of illness or injury collected through verbal autopsy interviews.[30] In the annual surveillance updates of the Agincourt HDSS, caregivers of individuals who had died since the previous visit were interviewed with a questionnaire in Shangaan that had been locally validated.[29,31] Thus, timing of the interviews ranged from 1 to 11 months after death. The cause of death was categorised as indeterminate when inadequate information was obtained for the model to assign a cause of death. The causes of death generated by the InterVA-4 model are based on the WHO 2012 verbal autopsy standards and correspond to the International Classification of Diseases, tenth edition.[30]

We categorised the most probable causes of death into five broad groups: HIV/AIDS and tuberculosis; other communicable diseases (excluding HIV/AIDS and tuberculosis) and maternal, perinatal, and nutritional causes; non-communicable diseases; injury; and indeterminate. The first four categories are consistent with the burden of disease classification system used in South Africa.[27] We combined HIV/AIDS and tuberculosis because HIV is an underlying cause in most tuberculosis deaths and distinguishing those that are HIV related from those that are not is difficult with the verbal autopsy method.[23]

Socioeconomic status

We measured socioeconomic status with an absolute household wealth index computed from a list of household asset indicators that were grouped in the following categories: construction materials in the main dwelling; type of toilet facilities and sources of water; sources of energy; ownership of modern assets; and livestock.[17,23,32] For each household, after categorisation, asset indicators were assigned weights, with higher values corresponding to higher socioeconomic status. The value assigned to each item was divided by the highest value for all households to obtain normalised values that fell in the range of 0–1. The normalised values within each category were summed to obtain category-specific values, normalised by the same method, then summed to produce an overall household wealth index value that fell in the range 0–5. Once constructed, the wealth index was divided into household wealth quintiles, in which the first quintile represented the poorest households and the fifth the richest households. Data on household asset indicators were collected in 2001, 2003, 2005, 2007, 2009, 2011, and 2013.

Statistical analysis

For each individual we organised data into a person-year file that contained one record for each full year lived, similar to the methods of Houle and colleagues[23,33,34] and Kabudula and colleagues.[26] We included only records for completely observed person-years plus the year in which the individual died irrespective of whether the person-year was complete. Covariates recorded were sex, age (<5, 5–14, 15–49, 50–64, or ≥65 years), time period (2001–03, 2004–07, 2008–10, and 2011–13), date of death, likely cause of death, and household wealth quintile. For covariates that change over time, such as age and household wealth quintile, we used the value at the beginning of the relevant person-year. For completed person-years the death indicator was set to 0, and it was set to 1 in records where there was a death during the year. Time periods were split across years to contextualise the dynamics of the HIV/AIDS epidemic and the roll-out of services for prevention of mother-to-child transmission and ART.

We used the person-year file to calculate the probabilities of death from birth to age 5 years and from age 15 to 60 years, life expectancy at birth, and age-specific and cause-specific mortality by sex (excluding children <5 years), time period, and household wealth quintile. Thereafter, we estimated relative and absolute socioeconomic differences in the mortality indicators with the relative index of inequality (RII) and the slope index of inequality (SII), respectively (appendix).[35] These measures take into account the whole socioeconomic distribution and the effects on mortality indicators of a person moving from the lowest to the highest quintile.[35,36] RII=1 and SII=0 imply no difference between the lower and higher ends of the socioeconomic continuum. RII values greater than 1 and positive SII values imply greater mortality at the lower end of the continuum, and RII values less than 1 and negative SII values imply greater mortality at the higher end. We fitted separate models for each time period and sex (except for children <5 years) to calculate RIIs and SIIs for mortality in children and adults and life expectancy at birth, with the modified ridit score (appendix)[37,38] as the independent variable. To calculate RIIs and SIIs for cause-specific mortality, we fitted separate models for each cause-of-death category, time period, and sex, with the modified ridit score and age group as independent variables. We also fitted models with two-way interaction terms between the modified ridit score and time period to assess trends in socioeconomic differences in the mortality indicators over time.

See Online for appendix

We also calculated relative risk ratios and 95% CIs to investigate associations between relative inequalities and household wealth quintile, which we obtained from multinomial logistic regression models,[39–43] with cause of death as an indicator of mortality used as the dependent variable and household wealth quintiles, sex, age group, and time period as independent variables.

Although socioeconomic status can be measured at the individual level with factors such as education and occupation,[44] samples are necessarily restricted to people who have reached a certain age to make the indicators meaningful (eg, age beyond which individuals are unlikely to advance their eduction further or working age). Instead, we used unadjusted household socioeconomic

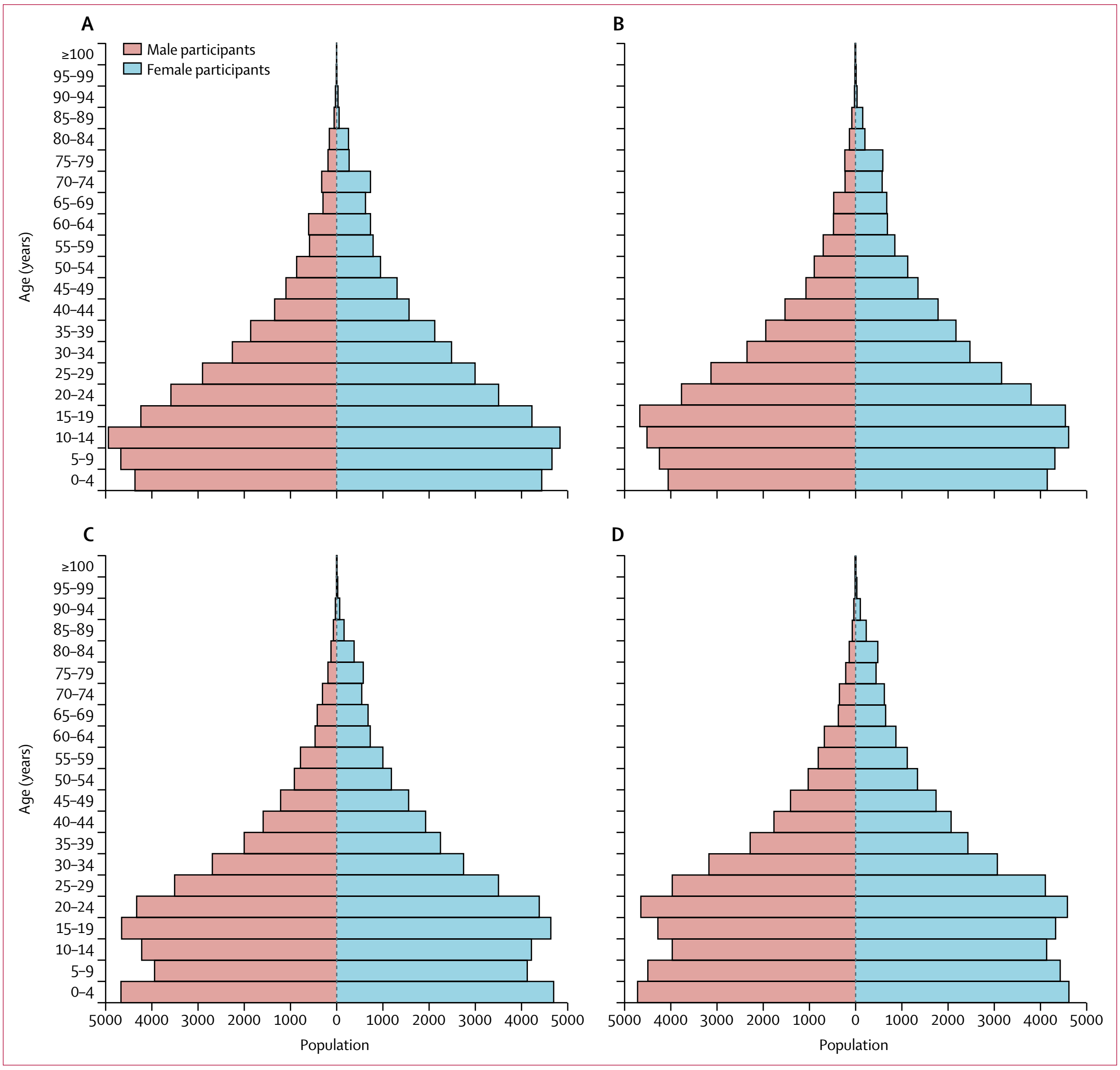

Figure 1: **Age distribution in the original 21 villages of the Agincourt Health and socio-Demographic Surveillance System**
(A) Population, July 1, 2001. (B) Population, July 1, 2005. (C) Population, July 1, 2009. (D) Population, July 1, 2013.

status to maximise the sample size because these data are collected more frequently than individual data and because all individuals in the household are affected by the household environment. Household socioeconomic status provides a good cumulative indicator of material living standards,[44,45] which strongly affect individual household members.

Data on household asset indicators used for calculating the household wealth index were collected in alternate years from 2001 onwards and, therefore, we used multiple imputation to minimise the loss of data due to missing values. We used partial mean matching (based on the nearest two neighbours) to generate five imputed datasets and derive parameter estimates and SEs by averaging across the imputations and adjusting for variance. As done by Houle and colleagues,[33] the imputations are generated from a household-year data set that includes counts of men, boys, women, and girls, Mozambicans and South Africans, individuals aged younger than 20 years, 20–59 years, and 60 years and older, and 1–2-year lags of household wealth index.

We did all analyses with Stata version 14.1. Estimates with p values less than 0·05 were taken to be significant.

Role of the funding source

The funders had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

In 2001, the population assessed by the Agincourt HDSS in the original 21 villages was 70 809 people in 11 818 households. The population had increased to 71 830 people in 12 302 households by 2005, 75 603 people in 13 460 households by 2009, and 79 912 in 14 692 households in 2013. The age structure of the population in selected years is shown in figure 1 and table 1. Changes in the distribution of education attainment and key asset indicators are shown in table 1. Between 2001 and 2013, 10 414 deaths were recorded in 1 058 538 person-years of follow-up in 2001–13 (table 2). Information from verbal autopsy interviews was available for 93·5% of these deaths, of which the InterVA-4 model classified 435 (4·5%) as indeterminate. The verbal autopsy information for the 672 (6·5%) remaining deaths was mainly missing due to inability to contact suitable respondents.

Overall mortality reduced steadily over the study period among children younger than 5 years and increased in adults from 2001 to 2007 but reduced steadily thereafter. Overall life expectancy at birth decreased from 2001 to 2007 but then increased until the end of the study (figure 2, appendix). Adult mortality and life expectancy from birth were consistently better for women than men (figure 2, appendix).

Except at the height of the HIV/AIDS epidemic in 2004–07 and in the early years after ART introduction in 2008–10, we found a strong inverse relation between mortality in children younger than 5 years and household socioeconomic status (figure 2, appendix). In 2001–03 the probability of death from birth to age 5 years was 90·95 (95% CI 73·23–108·66) per 1000 person-years in the poorest households, which was significantly higher than in the richest households (53·98, 40·53–67·43). In 2011–13, both values had substantially reduced (42·81, 32·57–53·05 *vs* 19·46, 12·26–26·67 per 1000 person-years), but the difference remained significant. An inverse relation with socioeconomic status was also seen for women and men, and was significant for women from 2001 to 2007 and for men throughout the study period (figure 2, appendix). Although overall adult mortality remained higher in women in the poorest households in 2008–10 (probability of death from age 15 to 60 years 440·31, 95% CI 350·56–530·05) and in 2011–13 (325·96, 266·43–385·48) than in the richest households (322·57, 266·50–378·64 and 265·01, 224·25–305·77, respectively), the difference was not significant.

Substantial differences in life expectancy at birth associated with household wealth were evident for women in the periods 2001–03 and 2004–07, with the lowest life expectancy being seen in the poorest wealth quintile, but the difference progressively narrowed and became non-significant from 2008–10 (figure 2, appendix). The lowest life expectancy at birth was also seen in the poorest quintile for men, but significant differences persisted throughout the study period (figure 2 , appendix).

	2001 (n=70 809)	2005 (n=71 830)	2009 (n=75 603)	2013 (n=79 912)
Age group (years)				
<5	12·4%	11·4%	12·4%	11·7%
5–14	26·9%	24·6%	21·9%	21·3%
15–64	56·4%	59·2%	61·0%	62·3%
≥65	4·3%	4·8%	4·7%	4·7%
Education attainment among population aged ≥20 years				
No schooling	28·9%	23·9%	18·7%	14·2%
Higher education	4·8%	5·6%	5·9%	7·7%
Matriculated	8·8%	13·6%	18·4%	25·4%
Living conditions				
Dwelling materials				
Brick walls	1·5%	2·5%	6·2%	4·6%
Cement walls	75·9%	86·1%	89·1%	93·8%
Tiled roof	3·3%	6·0%	10·3%	15·8%
Corrugated iron roof	90·7%	90·9%	88·8%	83·8%
Tiled floor	0·5%	1·9%	4·8%	15·0%
Cement floor	90·7%	93·9%	93·8%	84·4%
Toilet facility				
Inside dwelling	0·2%	0·1%	0·6%	2·1%
Modern or flush toilet	0·2%	0·2%	0·2%	2·1%
Water supply				
Piped inside dwelling	0·9%	0·6%	1·6%	0·5%
Piped in the yard	18·1%	17·4%	28·0%	33·8%
Electricity				
For lighting	70·8%	90·5%	95·3%	97·0%
For cooking	13·2%	17·7%	36·0%	45·8%
Modern assets				
Mobile telephone	43·3%	82·2%	95·3%	98·8%
Television	59·2%	65·9%	78·0%	88·0%
Satellite television	0·3%	0·5%	6·0%	19·9%
Landline telephone	3·6%	1·8%	1·2%	0·9%
Motor car	17·5%	17·5%	22·0%	23·5%
Refrigerator	46·4%	64·5%	80·8%	90·2%
Electric or gas stove	40·9%	52·2%	76·3%	86·2%

Table 1: Changes in distribution of age, education, and asset indicators over time

In all time periods, the relative and absolute inequalities for summary mortality outcomes were inversely associated with household socioeconomic status (table 3). All RIIs for mortality were greater than 1, indicating greater mortality at the lower end of the socioeconomic continuum. For children younger than 5 years, the RIIs decreased in 2004–07 compared with those in 2001–03, but increased steadily thereafter, although the differences over time were not significant. For adults, the RIIs were significant within time periods, but the differences over time were not significant for men or women. Among women, however, the RIIs for mortality decreased steadily from the 2001–03 time period to the 2011–13 time period, whereas among men the values fluctuated.

	2001–03	2004–07	2008–10	2011–13	2001–13
Women and girls					
Person-years	110 608	155 062	138 883	145 799	550 352
Number of deaths					
All	1019 (100%)	1651 (100%)	1229 (100%)	1096 (100%)	4995 (100%)
HIV/AIDS and tuberculosis	505 (49·6%)	825 (50%)	476 (38·7%)	286 (26·1%)	2092 (41·9%)
Other communicable, maternal, perinatal, or nutritional causes	126 (12·4%)	219 (13·3%)	220 (17·9%)	237 (21·6%)	802 (16·1%)
Non-communicable	238 (23·4%)	391 (23·7%)	424 (34·5%)	452 (41·2%)	1 505 (30·1%)
Injuries	38 (3·7%)	46 (2·8%)	29 (2·4%)	31 (2·8%)	144 (2·9%)
Indeterminate	44 (4·3%)	93 (5·6%)	48 (3·9%)	41 (3·7%)	226 (4·5%)
Verbal autopsy interview not done	68 (6·7%)	77 (4·7%)	32 (2·6%)	49 (4·5%)	226 (4·5%)
Crude mortality per 1000 person-years	9·2	10·6	8·8	7·5	9·1
Men and boys					
Person-years	102 972	143 188	127 695	134 331	508 186
Number of deaths					
All	1115 (100%)	1833 (100%)	1363 (100%)	1108 (100%)	5419 (100%)
HIV/AIDS and tuberculosis	480 (43%)	755 (41·2%)	528 (38·7%)	300 (27·1%)	2063 (38·1%)
Other communicable, maternal, perinatal, or nutritional causes	126 (11·3%)	236 (12·9%)	271 (19·9%)	221 (19·9%)	854 (15·8%)
Non-communicable	230 (20·6%)	420 (22·9%)	337 (24·7%)	352 (31·8%)	1339 (24·7%)
Injuries	119 (10·7%)	160 (8·7%)	102 (7·5%)	127 (11·5%)	508 (9·4%)
Indeterminate	40 (3·6%)	74 (4%)	49 (3·6%)	46 (4·2%)	209 (3·9%)
Verbal autopsy interview not done	120 (10·8%)	188 (10·3%)	76 (5·6%)	62 (5·6%)	446 (8·2%)
Crude mortality per 1000 person-years	10·8	12·8	10·7	8·2	10·7
All					
Person-years	213 580	298 250	266 578	280 130	1 058 538
Number of deaths					
All	2134 (100%)	3484 (100%)	2592 (100%)	2204 (100%)	10 414 (100%)
HIV/AIDS and tuberculosis	985 (46·2%)	1580 (45·4%)	1004 (38·7%)	586 (26·6%)	4155 (39·9%)
Other communicable, maternal, perinatal, or nutritional causes	252 (11·8%)	455 (13·1%)	491 (18·9%)	458 (20·8%)	1 656 (15·9%)
Non-communicable	468 (21·9%)	811 (23·3%)	761 (29·4%)	804 (36·5%)	2844 (27·3%)
Injuries	157 (7·4%)	206 (5·9%)	131 (5·1%)	158 (7·2%)	652 (6·3%)
Indeterminate	84 (3·9%)	167 (4·8%)	97 (3·7%)	87 (3·9%)	435 (4·2%)
Verbal autopsy interview not done	188 (8·8%)	265 (7·6%)	108 (4·2%)	111 (5·0%)	672 (6·5%)
Crude mortality per 1000 person-years	10·0	11·7	9·7	7·9	9·8

Percentages may not sum to 100 because of rounding.

Table 2: **Numbers of person-years and deaths, by time period and cause**

All SIIs for mortality were positive, indicating greater mortality at the lower end of the socioeconomic continuum. The SIIs for children younger than 5 years decreased in 2004–07 compared with those in 2001–03, but increased steadily thereafter, although the differences over time were not significant. The SIIs for adult mortality among women were significant within time periods, and steady decline over the entire study period meant that the differences were also significant over time. Among men, the SII values fluctuated and no significant difference was seen over time.

Relative inequalities in life expectancy at birth narrowed over time for men and women, but to a greater degree in women (table 3). The difference over time, therefore, was significant among women but not men. The SII values for life expectancy at birth also decreased steadily for women and men, again more so and significantly over time for women and in a non-significant fluctuating pattern for men.

The predicted probabilities of dying from different causes according to household wealth quintiles, adjusted for age, sex, and time period, are shown in figure 3, with

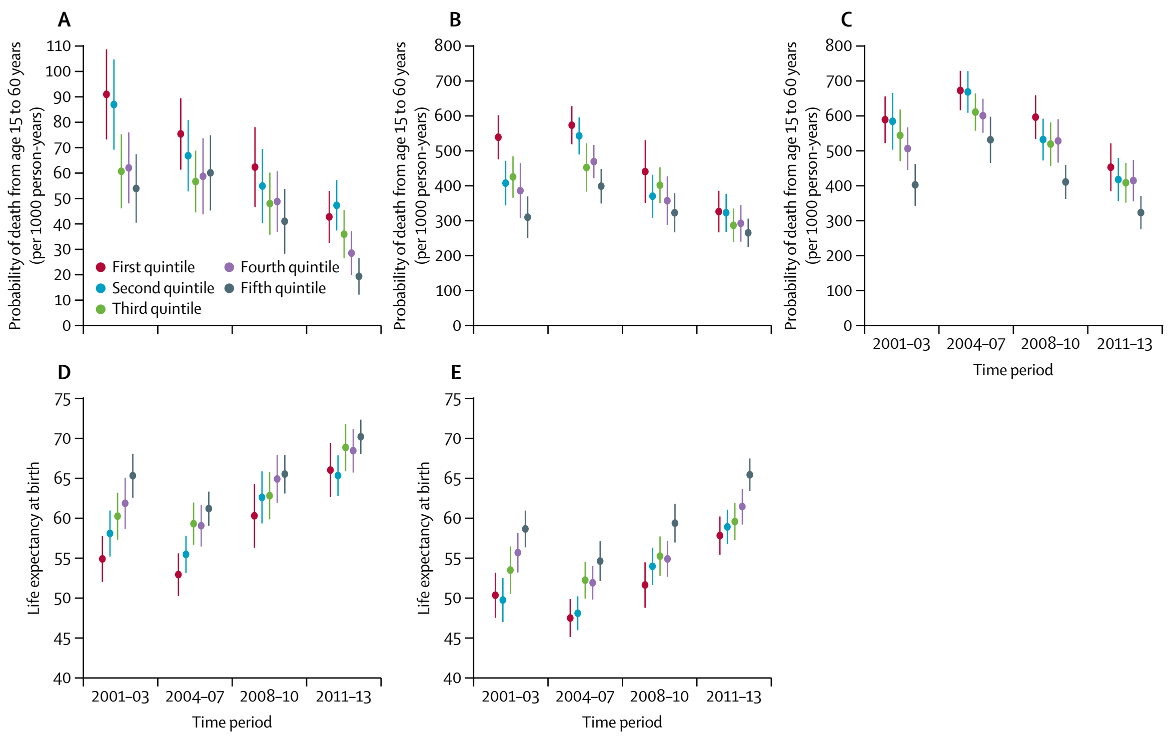

***Figure 2*: Differences in mortality and life expectancy at birth by household wealth and time period**
(A) Mortality in children younger than 5 years. (B) Mortality in women. (C) Mortality in men. (D) Life expectancy at birth in women. (E) Life expectancy at birth in men.

	2001–03	2004–07	2008–10	2011–13	p value*
Relative inequalities (RII, 95% CI)					
Mortality					
Children <5 years	2·06 (1·50 to 2·82)	1·37 (1·05 to 1·78)	1·62 (1·38 to 1·90)	2·38 (1·45 to 3·91)	0·075
Women	1·81 (1·33 to 2·45)	1·55 (1·30 to 1·84)	1·39 (1·13 to 1·71)	1·29 (1·16 to 1·44)	0·211
Men	1·54 (1·29 to 1·84)	1·33 (1·22 to 1·45)	1·43 (1·15 to 1·78)	1·38 (1·12 to 1·71)	0·629
Life expectancy at birth (years)					
Women	0·82 (0·79 to 0·84)	0·85 (0·79 to 0·91)	0·91 (0·88 to 0·93)	0·92 (0·88 to 0·96)	0·001
Men	0·81 (0·76 to 0·86)	0·84 (0·79 to 0·90)	0·86 (0·81 to 0·92)	0·86 (0·82 to 0·91)	0·414
Absolute inequalities (SII, 95% CI)					
Mortality					
Children <5 years	49·30 (26·18 to 72·41)	18·76 (1·99 to 35·53)	24·04 (15·57 to 32·51)	32·47 (18·42 to 46·52)	0·057
Women	237·12 (113·72 to 360·51)	208·11 (124·70 to 291·53)	122·63 (45·72 to 199·54)	75·55 (44·07 to 107·03)	0·031
Men	231·08 (152·01 to 310·16)	175·60 (125·07 to 226·12)	186·93 (80·34 to 293·53)	132·28 (50·08 to 214·48)	0·423
Life expectancy at birth (years)					
Women	–12·22 (–14·06 to –10·38)	–9·82 (–13·67 to –5·98)	–6·26 (–8·18 to –4·35)	–5·70 (–8·90 to –2·50)	0·004
Men	–11·37 (–14·66 to –8·08)	–8·96 (–12·32 to –5·60)	–8·17 (–11·90 to –4·44)	–8·93 (–12·20 to –5·67)	0·593

Mortality indicator values for socioeconomic groups are regressed on modified ridit scores, representing the relative ranks of groups in the cumulative distribution of household socioeconomic statuses, in generalised linear models. RII is the relative effect on the mortality indicator of moving from the lowest socioeconomic group to the highest. RII=1 implies that mortality in the lower and higher ends of the socioeconomic continuum do not differ, RII >1 implies greater mortality at the lower end, and RII <1 implies greater mortality at the higher end. SII is the absolute effect on the mortality indicator of moving from the lowest socioeconomic group through to the highest. SII=0 indicates that mortality at the lower and higher ends of the socioeconomic continuum do not differ, a positive SII indicates greater mortality at the lower end, and a negative SII indicates greater mortality at the higher end. RII and SII estimates are obtained from separate models for each time period and sex (except for in children <5 years), with only the modified ridit score as the independent variable. RII=relative index of inequality. SII=slope index of inequality. *For comparison of the RII or SII values in the different time periods (measured through two-way interaction terms between time periods and modified ridit scores).

***Table 3*: Relative and absolute socioeconomic inequalities in summary mortality indicators**

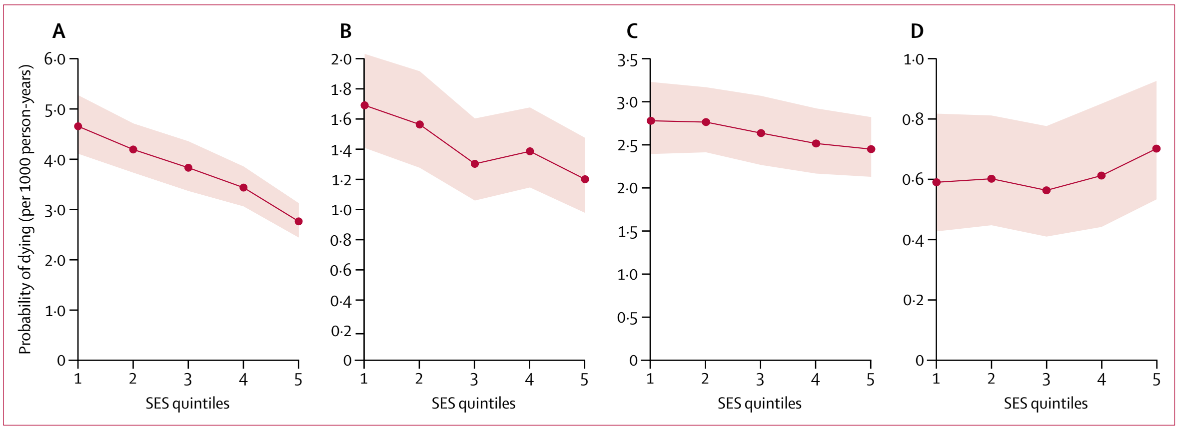

***Figure 3*: Annual probability of dying, by cause and quintile of household wealth for 2001–13**

(A) HIV/AIDS and tuberculosis. (B) Other communicable diseases (excluding HIV/AIDS and tuberculosis) and maternal, perinatal, and nutritional causes. (C) Non-communicable diseases. (D) Injuries. Data are predicted summed annual probabilities of death per 1000 person-years, by cause of death and household wealth quintiles that were estimated by multinomial logistic regression. All measures are adjusted for age, sex, and time period. SES=socioeconomic status.

corresponding relative risk ratios presented in the appendix. We found a strong and significant inverse relation between household wealth and death from HIV/AIDS and tuberculosis (p<0·0001). A significant inverse relation was also seen between household wealth and death from other communicable diseases and maternal, perinatal, and nutritional causes (p=0·009), although this was of a smaller magnitude and less consistent than that for HIV/AIDS and tuberculosis. Mortality from non-communicable diseases showed a non-significant inverse relation with household wealth, whereas mortality from injuries showed a non-significant positive relation with household wealth.

For men, boys, women, and girls, relative and absolute inequalities in mortality from HIV/AIDS and tuberculosis showed a persistent and significant inverse relation with socioeconomic status, with the highest values being in 2008–10 for men and boys and in 2004–07 for women and girls (table 4). For both sexes, the RIIs and SIIs associated with other causes of death fluctuated between being significant and non-significant over the period 2001–13. The RIIs for other communicable diseases and maternal, perinatal, and nutritional causes showed significant inverse relations with socioeconomic status only in 2011–13 for men and boys and in 2008–13 for women and girls. The SIIs for this cause-of-death category showed significant inverse relations with socioeconomic status only in 2011–13 for both sexes. For non-communicable diseases, no effect of socioeconomic status was seen on RIIs or SIIs in any period for women and girls, but a significant inverse relation was seen for men and boys in the RIIs for 2004–07 and 2008–10 and in the SIIs for 2004–07 and 2011–13. For injuries, only the RIIs for men and boys in 2004–07 and 2008–10 showed significant relations with socioeconomic status, but the relation was inverse in the earlier period and positive in the later period. No differences in SII and RII over time were significant for any cause of death except for the RII for injuries in men and boys.

Discussion

In a rural South African population, we found that socioeconomic disparities in mortality and life exepectancy at birth have evolved over the period 2001–13. Our findings update and improve those from earlier studies of socioeconomic differences in mortality in the Agincourt HDSS study population.[12,23,46] We included years in our analysis that cover the period before and after free ART was introduced. ART was first available from three district hospitals around the study area in 2004 and 2005.[23,47] From 2007, ART was also available within the study area from a privately funded community health centre specialising in HIV and tuberculosis care and treatment services, and run in partnership with the Department of Health (the Bhubezi Community Health Centre). Extension to public-sector primary-health-care facilities occurred in 2008 and 2009, and ART has been widely available since 2010.[47] We used a later version of the InterVA model than in previous studies, which strengthened cause-of-death assignment, and our analytical approach allowed us to estimate the relative and absolute socioeconomic inequalities in mortality across household wealth quintiles and to account for changes over time in the distribution of socioeconomic status. Our study additionally complements the second National Burden of Disease Study in South Africa,[27] which focused on differences between ethnic groups and provinces in mortality by focusing on socioeconomic differences at the local level in a resource-poor rural area and used data from rigorous longitudinal population surveillance.

Over the period 2001–13, the proportion of the population in Agincourt that lived in households owning assets associated with modern wealth increased substantially and polarisation in socioeconomic status declined,[17] although differences remained. Nevertheless, the population has undergone diverse health transitions

	2001–03	2004–07	2008–10	2011–13	p value*
Relative inequalities (RII, 95% CI)					
Men and boys					
HIV/AIDS and tuberculosis	1·67 (1·45 to 1·94)	1·74 (1·31 to 2·32)	4·70 (2·47 to 8·96)	2·09 (1·16 to 3·76)	0·125
Other communicable, maternal, perinatal, or nutritional causes	1·41 (0·92 to 2·16)	1·16 (0·79 to 1·70)	1·09 (0·85 to 1·39)	1·78 (1·28 to 2·49)	0·667
Non-communicable	0·84 (0·43 to 1·67)	1·54 (1·40 to 1·68)	1·49 (1·17 to 1·89)	1·36 (0·95 to 1·95)	0·334
Injuries	0·89 (0·50 to 1·61)	1·45 (1·11 to 1·89)	0·40 (0·22 to 0·73)	1·03 (0·52 to 2·08)	0·011
Women and girls					
HIV/AIDS and tuberculosis	1·89 (1·29 to 2·78)	2·73 (1·95 to 3·80)	1·42 (1·13 to 1·77)	2·53 (1·66 to 3·86)	0·118
Other communicable, maternal, perinatal, or nutritional causes	1·83 (0·83 to 4·03)	1·03 (0·62 to 1·70)	1·56 (1·13 to 2·17)	1·65 (1·10 to 2·48)	0·668
Non-communicable	0·96 (0·58 to 1·59)	1·06 (0·81 to 1·38)	0·99 (0·84 to 1·17)	0·84 (0·63 to 1·12)	0·648
Injuries	1·32 (0·45 to 3·90)	1·02 (0·25 to 4·18)	0·87 (0·37 to 2·06)	0·86 (0·25 to 2·93)	0·932
Absolute inequalities (SII, 95% CI)					
Men and boys					
HIV/AIDS and tuberculosis	4·94 (3·02 to 6·86)	5·67 (2·87 to 8·46)	8·17 (2·47 to 13·86)	3·71 (1·10 to 6·32)	0·603
Other communicable, maternal, perinatal, or nutritional causes	0·61 (–0·58 to 1·81)	0·75 (–0·38 to 1·88)	0·37 (–0·56 to 1·31)	2·45 (1·33 to 3·57)	0·643
Non-communicable	–0·36 (–6·29 to 5·57)	4·26 (1·13 to 7·40)	3·88 (–0·56 to 8·32)	4·28 (0·70 to 7·86)	0·658
Injuries	–0·11 (–0·79 to 0·58)	0·35 (–0·14 to 0·84)	–0·58 (–1·20 to 0·04)	0·11 (–0·52 to 0·74)	0·325
Women and girls					
HIV/AIDS and tuberculosis	3·28 (1·11 to 5·44)	5·04 (2·38 to 7·70)	1·58 (0·76 to 2·40)	1·94 (0·94 to 2·94)	0·186
Other communicable, maternal, perinatal, or nutritional causes	0·27 (–1·57 to 2·10)	0·16 (–0·99 to 1·32)	0·93 (–0·01 to 1·87)	1·27 (0·29 to 2·24)	0·705
Non-communicable	0·53 (–1·70 to 2·77)	0·87 (–0·70 to 2·45)	0·14 (–1·16 to 1·45)	–0·92 (–3·24 to 1·40)	0·619
Injuries	0·13 (–0·25 to 0·51)	0·02 (–0·29 to 0·34)	–0·02 (–0·22 to 0·19)	–0·03 (–0·31 to 0·25)	0·941

Cause-specific mortality is regressed on modified ridit scores representing the relative ranks of the socioeconomic groups in the cumulative distribution of household socioeconomic and age, in generalised linear models. RII is the relative effect on mortality of moving from the lowest socioeconomic group to the highest. RII=1 implies that mortality at the lower and higher ends of the socioeconomic continuum do not differ, RII >1 implies greater mortality at the lower end, and RII <1 implies greater mortality at the higher end. SII is the absolute effect on mortality of moving from the lowest socioeconomic group to the highest. SII=0 implies that mortality at the lower and higher ends of the socioeconomic continuum do not differ, a positive SII implies greater mortality at the lower end, and a negative SII implies greater mortality at the higher end. RII and SII estimates are obtained from separate models for each cause of death category, time period, and sex, with the modified ridit score and age group as the independent variables. RII=relative index of inequality. SII=slope index of inequality. *For comparison of RII or SII values in the different time periods (measured through the two-way interaction terms between time periods and modified ridit scores).

***Table 4*: Relative and absolute inequalities in mortality by cause of death and sex**

because of these changes. Our key findings are the significant relative and absolute socioeconomic gradients for mortality among children younger than 5 years, mortality in men and women, and life expectancy at birth throughout the 13-year study period, with outcomes being best in the wealthiest households. Despite ART being widely available and provided free of charge at public health facilities and HIV/AIDS-related mortality declining in recent years, the relative and absolute measures showed that significant inverse gradients in HIV/AIDS and tuberculosis mortality by household wealth have persisted. Although the proportion and number of deaths from non-communicable diseases are increasing, no significant difference associated with socioeconomic status was found. By contrast, in an earlier study, a persistent and significant inverse relation was reported between deaths from non-communicable diseases and household socioeconomic status for the period 2001–09.[23] This inconsistency between findings, however, might be due to version 4.0 of the InterVA model being used in the previous study. We applied version 4.0 to assign causes of death for the data used in this study and reproduced the significant inverse relation. Of note, our finding of a persistent significant inverse gradient between HIV/AIDS and tuberculosis mortality and household wealth, which was also reported in the earlier study, was not affected by which version of the InterVA model was used.

Several factors might explain the robustness of the finding that HIV/AIDS-related mortality is inversely related to socioeconomic status. First, a cross-sectional study of HIV prevalence in the Agincourt HDSS population in 2010–11 found a lower probability of being HIV positive among people living in households in the wealthiest socioeconomic status quintile than among those living in households in the poorest quintile.[48] Second, a negative gradient seems to exist in the availability of and access to resources that enable HIV-infected individuals to adopt strategies to improve their health and avoid HIV/AIDS-related mortality. No household in the Agincourt HDSS study area is more than 10 km from a primary health care facility, but the persistence of the significant inverse relation we saw between socioeconomic status and HIV/AIDS and tuberculosis mortality suggests that barriers to accessing HIV care and treatment services persist for individuals living in households with low socioeconomic status. Associated costs, such as transport to the health facility, probably hinder such individuals from accessing care and treatment services, despite ART being free of charge. Abgrall and del Amo[49] found that socioeconomic factors also affect retention in care and adherence to ART, which in turn affects survival for people living with HIV/AIDS. These factors might also contribute to the inverse socioeconomic gradient in HIV/AIDS-related mortality in the Agincourt population.

The overall mortality in this study was unexpectedly low for a poor rural setting, although the overall estimates for mortality among children younger than 5 years, mortality in adults, and life expectancy at birth in 2011–13 period were consistent with the unexpectedly low 2012 overall average estimates for Limpopo province reported in the second National Burden of Disease Study in South Africa.[27,50] Although the Agincourt HDSS study area is in Mpumalanga province, it is adjacent to and was previously within Limpopo province, from 1994 to 2005. Hence, the similarity in overall mortality is not too surprising, although the factors affecting mortality are not easy to explain.

Our study has several limitations. We acknowledge that using a household wealth index constructed from information on ownership of household assets is not the only way to measure socioeconomic status. Therefore, our findings might only partly reflect the evolution of socioeconomic disparities in mortality indicators. As in earlier studies, such as that by Houle and colleagues,[23] the data we used did not include individual-level measures of HIV seroprevalence or access to HIV care and treatment services. We are, therefore, unable to determine the magnitude of excess HIV/AIDS-related mortality among individuals from poor households that resulted specifically from increased risk of infection and barriers to care and treatment. Future analyses based on information generated by linking data in the Agincourt HDSS and the local health-care facilities will allow us to further refine our understanding of the mechanisms underlying our main findings.

Beyond HIV/AIDS and tuberculosis commonly occurring comcomitantly, difficulty in distinguishing HIV-related from non-HIV-related tuberculosis deaths with the verbal autopsy method made estimating the contribution of HIV/AIDS mortality alone to the socio-economic gradient difficult. Substantially increased rates of tuberculosis, other communicable diseases, and non-communicable diseases were seen in the Agincourt population during the peak of HIV/AIDS mortality.[11] This pattern could make the socioeconomic differences in cause-specific mortality we identified less certain, although perhaps not substantially so, as another study showed that the InterVA-4 model had high specificity for HIV/AIDS-related mortality in relation to serostatus.[51] The data we used came from one geographically defined resource-poor rural area in South Africa, but the Agincourt area has similarities with other rural areas in South Africa. Therefore, although not directly transferable, our findings are likely to be relevant to other populations, especially those living in the north and northeast of the country, including areas bordering other countries. Our findings also highlight the need to include socioeconomic differences in assessments of health outcomes at the local level, even in resource-poor rural areas, because individuals in different socioeconomic positions might have different health and mortality profiles. Finally, we did not have sufficiently robust measures to assess social capital in the study area, and were unable to assess effects of this factor on risk of mortality.

HIV/AIDS and tuberculosis mortality in Agincourt is associated with disparities in socioeconomic status that does not seem to have changed over the period 2001–13, despite widespread availability and provision of free ART at public health facilities. This finding suggests that individuals from the poorest households continue to bear a disproportionately high burden of increased mortality and shortened lives related to the long-standing HIV/AIDS epidemic. The burden of mortality from non-communicable diseases is rising, and the association with household socioeconomic status is likely to become prominent. Integrated health-care planning and programme delivery strategies are needed to increase access to and uptake of HIV testing, linkage to care and ART, and prevention and treatment of non-communicable diseases among the poorest individuals to reduce the inequalities in cause-specific and overall mortality.

Contributors

CWK, BH, MAC, ST, and SJC conceived the study. CWK analysed the data with the support of BH. MAC and FXG-O oversaw the surveillance activities in the Agincourt Health and socio-Demographic Surveillance System. KK led the InterVA analysis of causes of death. MAC, KK, ST, and SJC provided overall guidance to the conduct of the study. CWK wrote the paper, which all authors reviewed and approved for submission.

Declaration of interests

We declare no competing interests.

Acknowledgments

The MRC/Wits Rural Public Health and Health Transitions Research Unit, which runs the Agincourt Health and socio-Demographic Surveillance System, was supported by the Wellcome Trust (grants 058893/Z/99/A, 069683/Z/02/Z, 085477/Z/08/Z, and 085477/B/08/Z), the South African Medical Research Council, and University of the Witwatersrand, Johannesburg South Africa. We thank the respondents, field staff, and management of the Agincourt Health and socio-Demographic Surveillance System for contributing to the production of the data.

References

1 Adler NE, Newman K. Socioeconomic disparities in health: pathways and policies. *Health Aff (Millwood)* 2002; **21:** 60–76.

2 Braveman P, Tarimo E. Social inequalities in health within countries: not only an issue for affluent nations. *Soc Sci Med* 2002; **54:** 1621–35.

3 Link BG, Phelan J. Social conditions as fundamental causes of disease. *J Health Soc Behav* 1995; Spec No: 80–94.

4 McKinnon B, Harper S, Kaufman JS, Bergevin Y. Socioeconomic inequality in neonatal mortality in countries of low and middle income: a multicountry analysis. *Lancet Glob Health* 2014; **2:** e165–73.

5 Link BG, Phelan JC. Fundamental sources of health inequalities. In: Mechanic D, Rogut LB, Colby DC, Knickman JR, eds. Policy challenges in modern health care. New Brunswick, NJ: Rutgers University Press, 2004.

6 Link BG, Phelan JC, Miech R, Westin EL. The resources that matter: fundamental social causes of health disparities and the challenge of intelligence. *J Health Soc Behav* 2008; **49:** 72–91.

7 Phelan JC, Link BG, Tehranifar P. Social conditions as fundamental causes of health inequalities theory, evidence, and policy implications. *J Health Soc Behav* 2010; **51** (1 suppl)**:** S28–40.

8 Karim SSA, Churchyard GJ, Karim QA, Lawn SD. HIV infection and tuberculosis in South Africa: an urgent need to escalate the public health response. *Lancet* 2009; **374:** 921–33.

9 Department of Economic and Social Affairs Population Division. World population prospects: the 2010 revision. New York, NY: United Nations, 2011.

10 Bradshaw D, Laubscher R, Dorrington R, Bourne DE, Timaeus IM. Unabated rise in number of adult deaths in South Africa. *S Afr Med J* 2004; **94:** 278–79.

11 Kabudula CW, Tollman S, Mee P, et al. Two decades of mortality change in rural northeast South Africa. *Glob Health Action* 2014; **7:** 25596.

12 Kahn K, Garenne ML, Collinson MA, Tollman SM. Mortality trends in a new South Africa: hard to make a fresh start. *Scand J Public Health Suppl* 2007; **69:** 26–34.

13 Zwang J, Garenne M, Kahn K, Collinson M, Tollman SM. Trends in mortality from pulmonary tuberculosis and HIV/AIDS co-infection in rural South Africa (Agincourt). *Trans R Soc Trop Med Hyg* 2007; **101:** 893–98.

14 Tollman SM, Kahn K, Garenne M, Gear JS. Reversal in mortality trends: evidence from the Agincourt field site, South Africa, 1992–1995. *AIDS* 1999; **13:** 1091–97.

15 Herbst AJ, Cooke GS, Bärnighausen T, KanyKany A, Tanser F, Newell ML. Adult mortality and antiretroviral treatment roll-out in rural KwaZulu-Natal, South Africa. *Bull World Health Organ* 2009; **87:** 754–62.

16 Herbst AJ, Mafojane T, Newell ML, et al. Verbal autopsy-based cause-specific mortality trends in rural KwaZulu-Natal, South Africa, 2000–2009. *Popul Health Metr* 2011; **9:** 47.

17 Kabudula CW, Houle B, Collinson MA, Kahn K, Tollman S, Clark S. Assessing changes in household socioeconomic status in rural South Africa, 2001–2013: a distributional analysis using household asset indicators. *Soc Indic Res* 2016; published online June 28. DOI:10.1007/s11205-016-1397-z.

18 Bradshaw D, Groenewald P, Laubscher R, et al. Initial burden of disease estimates for South Africa, 2000. *S Afr Med J* 2003; **93:** 682–88.

19 Bradshaw D, Nannan N, Groenewald P, et al. Provincial mortality in South Africa, 2000-priority-setting for now and benchmark for the future. *S Afr Med J* 2005; **95:** 496–503.

20 Groenewald P, Bradshaw D, Daniels J, et al. Local-level mortality surveillance in resource-limited settings: a case study of Cape Town highlights disparities in health. *Bull World Health Organ* 2010; **88:** 444–51.

21 Hosegood V, Vanneste AM, Timæus IM. Levels and causes of adult mortality in rural South Africa: the impact of AIDS. *AIDS* 2004; **18:** 663–71.

22 Tollman SM, Kahn K, Sartorius B, Collinson MA, Clark SJ, Garenne ML. Implications of mortality transition for primary health care in rural South Africa: a population-based surveillance study. *Lancet* 2008; **372:** 893–901.

23 Houle B, Clark SJ, Gómez-Olivé FX, Kahn K, Tollman SM. The unfolding counter-transition in rural South Africa: mortality and cause of death, 1994–2009. *PLoS One* 2014; **9:** e100420.

24 Bradshaw D, Schneider M, Dorrington R, Bourne DE, Laubscher R. South African cause-of-death profile in transition—1996 and future trends. *S Afr Med J* 2002; **92:** 618–23.

25 Kahn K, Tollman SM, Garenne M, Gear JSS. Who dies from what? Determining cause of death in South Africa's rural north-east. *Trop Med Int Health* 1999; **4:** 433–41.

26 Kabudula CW, Houle B, Collinson MA, et al. Progression of the epidemiological transition in a rural South African setting: findings from population surveillance in Agincourt, 1993–2013. *BMC Public Health* 2017; **17:** 424.

27 Pillay-van Wyk V, Msemburi W, Laubscher R, et al. Mortality trends and differentials in South Africa from 1997 to 2012: second National Burden of Disease Study. *Lancet Glob Health* 2016; **4:** e642–53.

28 Kahn K, Collinson MA, Gómez-Olivé FX, et al. Profile: Agincourt Health and Socio-demographic Surveillance System. *Int J Epidemiol* 2012; **41:** 988–1001.

29 Kahn K, Tollman SM, Collinson MA, et al. Research into health, population and social transitions in rural South Africa: data and methods of the Agincourt Health and Demographic Surveillance System. *Scand J Public Health* 2007; **35** (69 suppl)**:** 8–20.

30 Byass P, Chandramohan D, Clark SJ, et al. Strengthening standardised interpretation of verbal autopsy data: the new InterVA-4 tool. *Glob Health Action* 2012; **5:** 19281.

31 Kahn K, Tollman SM, Garenne M, Gear JSS. Validation and application of verbal autopsies in a rural area of South Africa. *Trop Med Int Health* 2000; **5:** 824–31.

32 Houle B, Stein A, Kahn K, et al. Household context and child mortality in rural South Africa: the effects of birth spacing, shared mortality, household composition and socio-economic status. *Int J Epidemiol* 2013; **42:** 1444–54.

33 Houle B, Pantazis A, Kabudula C, Tollman S, Clark SJ. Social patterns and differentials in the fertility transition in the context of HIV/AIDS: evidence from population surveillance, rural South Africa, 1993–2013. *Popul Health Metr* 2016; **14:** 10.

34 Houle B, Clark SJ, Kahn K, Tollman S, Yamin AE. The impacts of maternal mortality and cause of death on children's risk of dying in rural South Africa: evidence from a population based surveillance study (1992–2013). *Reprod Health* 2015; **12:** S7.

35 Mackenbach JP, Kunst AE. Measuring the magnitude of socio-economic inequalities in health: an overview of available measures illustrated with two examples from Europe. *Soc Sci Med* 1997; **44:** 757–71.

36 Wagstaff A, Paci P, Van Doorslaer E. On the measurement of inequalities in health. *Soc Sci Med* 1991; **33:** 545–57.

37 Allison PD. Event history analysis: regression for longitudinal event data. Thousand Oaks, CA: Sage, 1984.

38 Allison PD. Discrete-time methods for the analysis of event histories. *Sociol Methodol* 1982; **13:** 61–98.

39 Allison PD. Survival analysis using SAS®: a practical guide, 2nd edn. London: SAS Institute, 2010.

40 Efron B. Logistic regression, survival analysis, and the Kaplan-Meier curve. *J Am Stat Assoc* 1988; **83:** 414–25.

41 Ernstsen L, Strand BH, Nilsen SM, Espnes GA, Krokstad S. Trends in absolute and relative educational inequalities in four modifiable ischaemic heart disease risk factors: repeated cross-sectional surveys from the Nord-Trøndelag Health Study (HUNT) 1984-2008. *BMC Public Health* 2012; **12**(1)**:** 266.

42 Wamala S, Blakely T, Atkinson J. Trends in absolute socioeconomic inequalities in mortality in Sweden and New Zealand. A 20-year gender perspective. *BMC Public Health* 2006; **6**(1)**:** 164.

43 Van Hook J, Altman CE. Using discrete-time event history fertility models to simulate total fertility rates and other fertility measures. *Popul Res Policy Rev* 2013; **32:** 585–610.

44 Galobardes B, Shaw M, Lawlor DA, Lynch JW, Smith GD. Indicators of socioeconomic position (part 1). *J Epidemiol Community Health* 2006; **60:** 7–12.

45 Howe LD, Galobardes B, Matijasevich A, et al. Measuring socio-economic position for epidemiological studies in low-and middle-income countries: a methods of measurement in epidemiology paper. *Int J Epidemiol* 2012; **41:** 871–86.

46 Sartorius B, Kahn K, Collinson MA, Sartorius K, Tollman SM. Dying in their prime: determinants and space-time risk of adult mortality in rural South Africa. *Geospatial Health* 2013; **7:** 237.

47 Mee P, Collinson MA, Madhavan S, et al. Evidence for localised HIV related micro-epidemics associated with the decentralised provision of antiretroviral treatment in rural South Africa: a spatio-temporal analysis of changing mortality patterns (2007–2010). *J Glob Health* 2014; **4:** 010403.

48 Gómez-Olivé FX, Angotti N, Houle B, et al. Prevalence of HIV among those 15 and older in rural South Africa. *AIDS Care* 2013; **25:** 1122–28.

49 Abgrall S, Del Amo J. Effect of sociodemographic factors on survival of people living with HIV. *Curr Opin HIV AIDS* 2016; **11:** 501–06.

50 Msemburi W, Pillay-van Wyk V, Dorrington R, et al. Second national burden of disease study for South Africa: cause-of-death profile for South Africa, 1997–2010. Cape Town: South African Medical Research Council, 2016.

51 Byass P, Calvert C, Miiro-Nakiyingi J, et al. InterVA-4 as a public health tool for measuring HIV/AIDS mortality: a validation study from five African countries. *Glob Health Action* 2013; **6:** 22448.