


Maternal mortality decline in Zimbabwe, 2007/2008 to 2018/2019: findings from mortality surveys using civil registration, vital statistics and health system data

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ABSTRACT

Background Sustainable Development Goal (SDG) 3.1 target is to reduce the global maternal mortality ratio (MMR) to less than 70 maternal deaths per 100 000 live births by 2030. In the Ending Preventable Maternal Mortality strategy, a supplementary target was added, that no country has an MMR above 140 by 2030. We conducted two cross-sectional reproductive age mortality surveys to analyse changes in Zimbabwe's MMR between 2007–2008 and 2018–2019 towards the SDG target.

Methods We collected data from civil registration, vital statistics and medical records on deaths of women of reproductive ages (WRAs), including maternal deaths from 11 districts, randomly selected from each province ($n=10$) using cluster sampling. We calculated weighted mortality rates and MMRs using negative binomial models, with 95% CIs, performed a one-way analysis of variance of the MMRs and calculated the annual average reduction rate (ARR) for the MMR.

Results In 2007–2008 we identified 6188 deaths of WRAs, 325 pregnancy-related deaths and 296 maternal deaths, and in 2018–2019, 1856, 137 and 130, respectively. The reproductive age mortality rate, weighted by district, declined from 11 to 3 deaths per 1000 women. The MMR (95% CI) declined from 657 (485 to 829) to 217 (164 to 269) deaths per 100 000 live births at an annual ARR of 10.1%.

Conclusions Zimbabwe's MMR declined by an annual ARR of 10.1%, against a target of 10.2%, alongside declining reproductive age mortality. Zimbabwe should continue scaling up interventions against direct maternal mortality causes to achieve the SDG 3.1 target by 2030.

BACKGROUND

Reducing maternal mortality is a global priority, which is promoted by the Sustainable Development Goals (SDGs).^{1–3} The SDG 3.1 target is to achieve a global average maternal

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Zimbabwe's maternal mortality ratio (MMR) was last estimated at 462 maternal deaths per 100 000 live births against the Sustainable Development Goal (SDG) supplementary target for individual countries of an MMR no more than 140 by 2030.

WHAT THIS STUDY ADDS

⇒ Zimbabwe's MMR declined between 2007–2008 and 2018–2019 from 657 (95% CI: 485 to 829) to 217 (95% CI: 164 to 269) deaths per 100 000 live births at an annual average reduction rate (ARR) of 10.1% against an annual ARR of 10.2% needed to achieve the 2030 SDG target.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This decline in Zimbabwe's MMR was supported by temporal stability in the economy, substantial external funding and HIV treatment which has been optimised, hence Zimbabwe needs sustained maternal health funding to continue scaling up interventions against the direct causes of maternal mortality and regular assessment of the MMR, to achieve the SDG 3.1 target.

mortality ratio (MMR) of less than 70 maternal deaths per 100 000 live births by 2030. This global target requires every country to calculate and achieve its national target by 2030. Countries calculate their targets using the annual average reduction rate (ARR) needed to reduce the global average MMR to 70 and the country's 2015 MMR as a baseline. High-burden countries whose targets remain high are to reduce their MMRs to no more than 140 per 100 000 by 2030.^{1 4 5}

Zimbabwe is a sub-Saharan Africa lower-middle-income country with an estimated population of 15 million, a gross national income per capita of US\$1100 in 2020 and a high MMR estimated at 462 maternal deaths per 100 000 live births in 2019.^{6–9} In 2007–2008, Zimbabwe was experiencing a socioeconomic crisis that started in the late 1990s,^{10–12} and resulted in severe hyperinflation and near-collapse of the country's economic and social sectors.^{10 11 13–15} The gross domestic product shrunk from an annual growth rate of +10.4% in 2000 to –17.7% in 2008.¹⁶ Amid these economic challenges, significant improvements occurred in maternal, neonatal and child health (MNCH) and other health interventions—HIV, malaria and tuberculosis, with potential impact on maternal mortality (online supplemental table S1).

To analyse the epidemiology of maternal mortality in Zimbabwe we conducted two cross-sectional Reproductive Age Mortality Surveys (RAMOS) in 2007–2008 and 2018–2019, assessing the changes in the MMR and causes of death over this period. The protocol for this study and analysis of the causes of death has been published elsewhere.^{17 18} This paper describes changes in the MMR.

METHODS

Interventions implemented

Findings of the 2007–2008 Zimbabwe Maternal and Perinatal Mortality Survey (ZMPMS) prompted the Zimbabwe Ministry of Health and Child Care (MoHCC) to implement a raft of interventions to reduce maternal mortality. A maternal and neonatal health roadmap was developed to address the direct and indirect causes of maternal mortality.¹⁹ Family planning services, prevention of mother-to-child transmission (PMTCT) of HIV services and community mobilisation for safe motherhood were scaled up through community health workers. Basic and comprehensive emergency obstetric and newborn care was rolled out in primary care and secondary/tertiary health facilities, respectively.^{20–22} The UK's Royal College of Obstetricians and Gynaecologists and the Liverpool School of Tropical Medicine and Bristol University conducted training of trainers for 120 doctors and nurse–midwives who trained over 700 other doctors and nurses nationwide on the management of obstetrical and neonatal emergencies.²⁰ Maternity waiting homes, which the MoHCC started establishing in the 1980s, were expanded in different districts, allowing women to stay at maternity facilities from the third trimester until delivery,^{23–26} increasing access to antenatal care and reducing home deliveries. The government developed guidelines for maternal and perinatal death surveillance and response system,²⁷ and instituted maternal and perinatal death audits.²¹ Through a US\$235 million health transition fund (2012–2015) and US\$682 million health development fund (2016–2020), the government introduced free maternity services and doctors' and nurses' retention allowances in the rural provinces and supplied health facilities with essential commodities, among other

initiatives, to improve maternity, neonatal and child healthcare.^{11 12 28 29}

The 2007–2008 survey found that HIV was the major cause of maternal mortality, contributing 26% of maternal deaths; meaning that HIV interventions would significantly impact maternal mortality. In 2007–2008, Zimbabwe had high adult (15–49 years) HIV mortality.^{30–33} Antiretroviral therapy (ART) roll-out was in the early phases at this time.³⁴ ART was available in only 5.2% (86/1643) of the health facilities by December 2007 and 17% (282/1643) by December 2008; mostly in secondary and tertiary hospitals that are less accessible to communities.³⁴ In 2008 only 24% (148 144/596 965) of individuals needing ART received it and the need for ART was defined by a CD4 count below 350 cells/ μ of blood at the time.^{34 35} However, HIV programmes received significant funding over the years, exceeding US\$400 million annually.^{36 37} Consequently, ART was rolled out to 91% (1566/1722) of all health facilities in the country by 2017, and in 2019, 97% of adults with known HIV-positive status received ART.^{38 39} Adult HIV mortality substantially declined from an estimated 83 000 deaths in 2009 to 14 000 in 2018.^{33 35 36}

In PMTCT, Zimbabwe rolled out WHO 2010 ('Option A') and 2013 ('Option B+') guidelines.^{40 41} Option 'A' was rolled out to 85% (1320/1560) MNCH facilities in 9 months and Option 'B+' to 88% (1385/1560) facilities in 5 months.⁴¹ All HIV-infected pregnant and breastfeeding women were initiated on lifelong ART, under the 'Option B+' guidelines, irrespective of disease stage. The combined impact of the ART and PMTCT programmes was that by 2019, 88% of adult women (15–49 years) living with HIV had known HIV-positive status, of which 98% were on ART.³⁹ In 2018, 94% of HIV-positive pregnant women received ART for PMTCT.³⁶ Without ART, pregnant women can die from AIDS-related complications including pneumonia, tuberculosis and meningitis. With a weakened immune system, HIV-infected pregnant women also have a higher risk of mortality from pregnancy-related sepsis, haemorrhage and other direct causes.^{42–44} The ART and PMTCT interventions should have contributed to the 91% reduction in HIV-related maternal mortality found in the causes of death analysis from this study.¹⁸

Study design

A before-and-after analysis was performed using data from the two RAMOS conducted in 2007–2008 and 2018–2019. The surveys collected births and deaths among women in the reproductive ages (WRAs) 12–49 years, including maternal deaths, to analyse changes in Zimbabwe's MMR in the context of the interventions described.

Sampling method and sample size

The sampling method was designed for the first survey in 2007 and maintained in the second survey for comparability of the study findings. Two-stage cluster sampling was applied in the two surveys. In the first stage, the study

population was clustered into the 10 provinces of the country, and one district was simple-randomly selected from each province. Two districts were selected from Harare province because of its large population and that several provinces refer complicated maternal cases to two central hospitals in the province. In the second stage, all births and deaths among WRAs 12–49 years from the selected districts were included in each survey.

Sample sizes of births required to calculate the MMR were calculated for each survey. In the first step, simple random samples were calculated using the Wald Test for a one-sample proportion (treating the MMR as a proportion).^{45 46} The recent MMRs from the Zimbabwe Demographic and Health Survey (ZDHS) of 2005–2006⁴⁷ and 2015–2016 respectively were the expected proportions.⁴⁸ Power of 80% and the z-value for two-sided 95% CI, continuity correction for normal approximation of the expected proportion and 2.5% error margin for the alternative hypothesis of MMR outside the 95% CI of the expected proportion were applied. In the second step, the random sample sizes were multiplied by the design effect (DE) to obtain the final sample sizes. The DE for the 2007–2008 survey was calculated from the pilot study and the DE for the 2018–2019 survey was calculated from the 2007–2008 survey (online supplemental table S2). The detailed procedure for calculating the sample size is also described in the study protocol.¹⁷ The two

surveys required sample sizes of 45 000 and 71 500 births respectively.

Study setting

Figure 1 shows the 11 study districts. Nkulumane (Bulawayo province), Western and South-Eastern districts (Harare province) are urban districts, while Mutare (Manicaland province), Bindura (Mashonaland East province) and Kwekwe (Midlands province) are semi-urban districts and the rest are rural districts.

Study variables

For each death (including pregnancy-related deaths) among WRAs, we collected location information (province, district and place of residence—urban or rural), age (in completed years), pregnancy status (pregnant or not) and cause of death (as stated on medical records and death certificates). For pregnancy-related deaths, we also collected information on parity, gestational age, antenatal care, pregnancy and delivery complications, referrals to other health institutions, delivery outcome and place of death (home or institutional).

Data collection period

The first survey collected data for the period 1 May 2007 to 15 June 2008 and the second for the period 1 May 2018 to 15 June 2019. Data for the first survey were collected prospectively during the study period and data for the

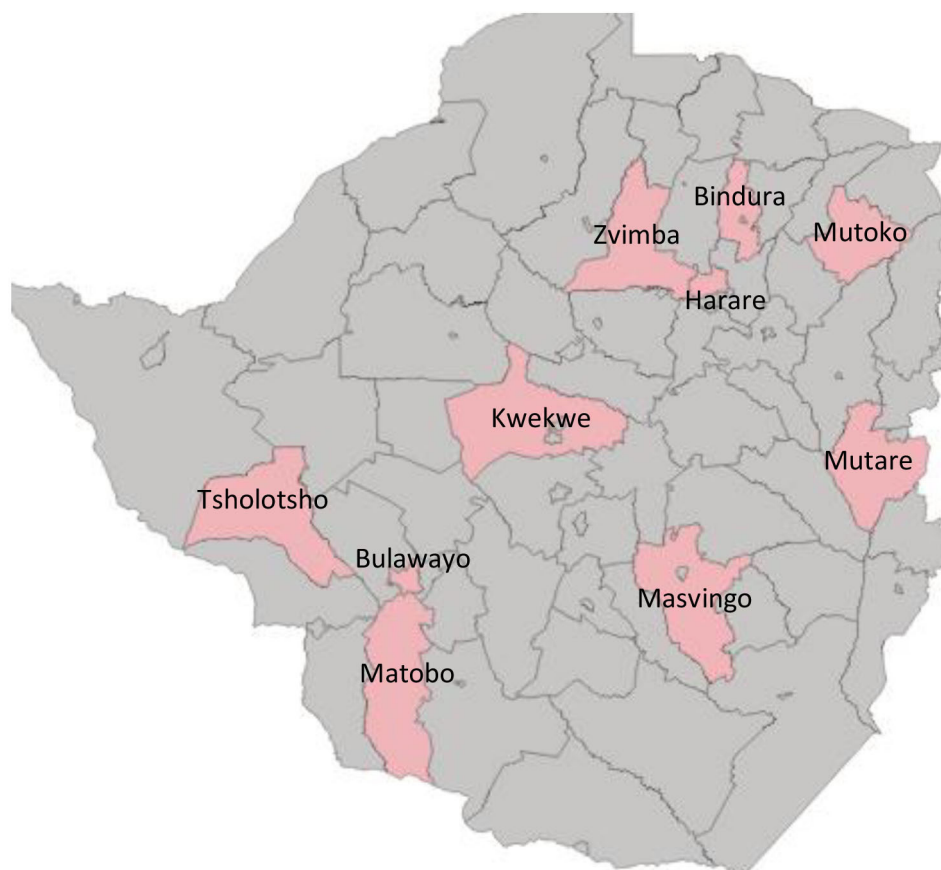


Figure 1 Map of study districts for Zimbabwe maternal and perinatal mortality study 2007–2008 and 2018–19.

second survey were collected retrospectively from 1 May 2020 to 31 July 2020 and from 3 May 2021 to 20 July 2021.

Data collection procedures

The 2007–2008 survey collected data from civil registration and vital statistics (CRVS) records at the government Registrar General (RG)'s offices, health facilities and the community. Study nurse–midwives trained on the study protocol and supervised by the investigators collected the data. They collected data on deaths of WRAs from RG's offices and data for live births and pregnancy-related deaths in health facilities and the community for eligible women. Data for health facility deaths occurring during pregnancy or post-delivery were collected from medical records in the labour ward, theatre, high dependency and intensive care units, medical and surgical female wards, mortuaries and police posts. The survey was approved to collect identified data, hence, data collectors used the women's personally identifying information (PII)—name, address, age and national identity numbers, to link individual women across these records.

Deliveries and deaths of WRAs occurring outside health institutions were enumerated in the community. Village health workers and village heads recorded them in study-provided register books. The research nurses followed up on every delivery and death recorded in the registers and interviewed the mothers (for births) and relatives (husband, mother, sister, aunt) for deaths, using study questionnaires. They collected additional data (dates when the death occurred, pregnancy status and signs and symptoms of sickness at death) for deaths of WRAs using a verbal autopsy (VA) form adapted from WHO.⁴⁹ The data collectors used the women's PII to cross-check and de-duplicate deaths identified in health facilities, the community and CRVS records. A group of six obstetrician–gynaecologists reviewed the data collection and VA forms for all pregnancy-related deaths, classified the deaths as maternal and non-maternal and assigned the causes of death.

In the 2018–2019 survey another group of nurse–midwives collected the data from the RG's offices and health facility records (as in the 2007–2008 survey) and maternal death notification forms at the MoHCC's district, provincial and national reproductive health offices. They cross-checked and de-duplicated the deaths using PII (as above). Live births data were collected from the MoHCC's District Health Information System V.2 (DHIS2), a database system for health indicators.⁵⁰ Nurses in the MNCH units recorded all institutional and home births presented at health facilities in birth registers. The nurses summarised the data on a standard monthly report form and submitted the reports to health information officers who entered the data into the DHIS2 database. Given the health system structure where deliveries occur in private and public health institutions, and health centres (rural and urban) refer complicated maternal cases to district hospitals, which refers to provincial hospitals, which also refers to central hospitals in Harare and Bulawayo, we

counted the live births for women referred from the study districts to private, provincial and central hospitals, and added them to the DHIS2 births. We collected population data for WRAs for the study districts from the Zimbabwe National Statistics Agency (ZimStat).⁵¹

Data verification, cleaning and classifying of the deaths

During the collection of 2018–2019 data, 2007–2008 deaths were verified in the CRVS records at the RG's offices and health facility records (same sources as above). All questionnaires and VA forms for 2007–2008 deaths were reviewed by a new group of obstetrician–gynaecologists in 2020, the causes of death re-assigned and maternal deaths confirmed using the International Classification of Diseases V.10 manual for deaths during pregnancy, childbirth and puerperium (ICD-10 MM). The database for 2007–2008 deaths was cleaned for completeness and accurate data entry. The 2018–2019 data were collected in two rounds to ensure that all deaths in the source records were identified and correctly captured in the study.

CRVS and health record systems in Zimbabwe

In Zimbabwe legislation regulates CRVS and medical records. The birth and death registration act mandates the registration and issuance of certificates for all births and deaths.⁵² The legislation mandates parents, health workers at institutions where the birth occurs or community leaders (for community births) to notify the RG's office of the birth. Similarly, for persons who died at home, relatives or village heads are required by the law to notify the RG's office, for the creation of a death record and issuance of a death certificate. Deaths that occur in health institutions get a medical death certificate signed by the doctor or nurse who attended the death. Home or community deaths attended to by the police are taken to hospitals where a doctor conducts a postmortem and issues another medical death certificate, stating the cause of death. The medical death certificates are deposited at the local RG's office, where a record is created, and a civil death certificate is issued. The RG's offices file birth and death records by date and year of registration and store them in secure record rooms. The public health act guides the recording, collection, storage, access, use, protection and confidentiality of health data.⁵³

Other studies reviewed

Reports presenting estimates of the MMR for Zimbabwe 2000–2019 were reviewed, including the ZDHS for 2000, 2005–2006, 2010–2011, 2015–2016^{47 48 54}; the Multiple Cluster Indicator Survey (MICS) in 2014 and 2019^{55 56}; population census in 2002 and 2012,^{54 57} the Maternal and Perinatal Death Surveillance Response in 2018 and 2019,²⁷ and the United Nation's Maternal Mortality Estimation Inter-Agency Group (MMEIG) MMR estimates for 2000 to 2017.^{6 58–60}

Definitions

WRAs are women aged 15–49 years, but children aged 12–14 years were included as some gave birth and died

from maternal causes at this age. Pregnancy-related deaths were female deaths in which the woman was pregnant or within 42-days of termination of pregnancy, irrespective of the cause of death. Maternal deaths were deaths of women during pregnancy or within 42-days of pregnancy termination, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management, but not from accidental or incidental causes.⁶¹

Data analysis

We adjusted the number of maternal death for 2018–2019 for missed community deaths, using the 2007–2008 data as a standard, which comprehensively collected community deaths.^{17 62} The number of community deaths missed in 2018–2019 was estimated by equating the proportion of community to institutional deaths in the two surveys (online supplemental table S3).

We triangulated the total number of live births identified with the expected number of live births and estimated pregnancies obtained from ZimStat,⁵¹ to assess the completeness of the former. We calculated the expected number of live births by multiplying the 2018 populations of WRAs for each district with general fertility rates (GFRs) from the 2019 MICS survey,⁵⁵ using the rural or urban GFR as applicable to each district. WHO recommends that when calculating MMRs using data from CRVS or health records, the live births must be corrected for missed births.⁶³ As such, we calculated correction factors (expected/identified births), ranging from 1.0 to 1.3 (online supplemental table S4), and used them to correct the number of live births for each district for missed births.

We performed a before-and-after analysis of mortality using data from the two surveys calculating mortality incidence rates (IRs) of WRAs (number of deaths/1000 women) for each survey and the incidence rate ratios (IRRs) (mortality rate 2018–2019/mortality rate 2007–2008) and 95% CIs by district, age group and totally. Similarly, we computed the MMRs (number of maternal deaths/100 000 live births) and their IRRs for each district and totally. IRRs applied because the total person-years for each district cluster equalled the district population in 1 year. Half person-years were assigned to women who died during the year. We calculated the IRs using negative binomial models in Stata (V.17.0) immediate commands,⁶⁴ treating the two surveys as cohorts, to use IRRs to estimate the magnitude of change in mortality levels between the two surveys. Stata immediate commands were employed because of the aggregate live births data in the IR denominators. Overall the IRs, MMRs and IRRs were weighted using the location variable (district) (online supplemental tables S5 and S6), to account for the clustering of the deaths within districts in the pooled samples. MMR 95% CIs were calculated using sampling errors (SEs) for the location variable. We calculated the SEs using the Jackknife repeated replication

method used in the DHS⁴⁸ (online supplemental table S5).

We also performed repeated measures' one-way analysis of variance (ANOVA),⁶⁵ for before-and-after comparison to confirm the statistical significance of the changes in the MMRs (online supplemental table S7). Using the WHO online calculator,⁶⁶ we calculated the annual ARR for the country's MMR from the study and the ARR needed to achieve the SDG target of 140 maternal deaths per 100 000 live births by 2030 from a 2015 ZDHS baseline MMR of 651 and 2019 MICS estimate of 462⁵⁵ (online supplemental table S8).

Patient and public involvement

There was no patient or public involvement in this study.

RESULTS

We identified 6188 deaths of WRAs in 2007–2008, of which 325 were pregnancy-related deaths and 296 were maternal deaths. The corresponding numbers for 2018–2019 were 1856, 137 and 130, respectively. In 2007–2008, community deaths constituted 50% (95/296) of the total maternal deaths. The unadjusted number of community deaths in 2018–2019 made up 19% (25/130) of the total maternal deaths identified. The number of maternal deaths for 2018–2019 adjusted for missed community deaths was 173 (table 1). The proportion of unadjusted maternal deaths (out of total deaths among WRAs) increased from 4.8% (296/6188) to 7.0% (130/1856) and 9.3% (173/1856) when adjusted for missed community deaths. The number of live births identified in the study constituted 81% of GFR-estimated live births and 83% of the expected pregnancies, justifying an average correction factor of 1.2 for the number of live births (online supplemental table S4). The unadjusted number of live births (for 2018–2019) was 67 225 and the adjusted number was 80 116.

Mortality among WRAs declined significantly in all districts. The smallest decline occurred in Matobo (55%) and the greatest in Kwekwe district (88%). Mortality also declined in all age groups; the greatest decline occurred in the 30–34 (83%) and 35–39 (81%) year age groups, and the smallest in the 15–19 year group (48%). Weighted by district, mortality among WRAs declined by 76%, from 11 to 3 women per 1000 (table 2).

MMRs declined in 9 of the 11 districts; the smallest decline occurring in Mutoko (41%) and the greatest in Bindura district (89%). The weighted overall MMR declined by 67%, from 657 (95% CI: 485 to 829) to 217 (95% CI: 164 to 269) per 100 000 live births (table 1), at an annual ARR of 10.1%. The annual ARR required to reach the 2030 target of 140 per 100 000, calculated using the 2015 ZDHS baseline MMR of 651, was 10.2%. The repeated measures ANOVA showed statistical significance in the decline in MMR between the two study periods ($p < 0.05$) (online supplemental table S7).

Table 1 Maternal mortality ratio (MMR) in Zimbabwe 2007–2008 and 2018–2019 by district

District	2007–2008*				2018–2019†				IRR (95% CI)	
	Unweighted live births	Unweighted maternal deaths	Weighted live births	Weighted maternal deaths	Unweighted live births	Unweighted maternal deaths‡	Weighted live births	Weighted maternal deaths		
Nkulumane§	4002	51	4387	62	1274 (950 to 1672)	23.5	5748	27	448 (287 to 665)	0.34 (0.20 to 0.56)
Harare SE§	1911	12	1995	13	628 (325 to 1094)	4.3	3022	‡	137 (37 to 351)	0.22 (0.05 to 0.72)
Harare W§	4958	30	5563	33	605 (409 to 863)	16.0	8977	18	198 (113 to 322)	0.33 (0.17 to 0.62)
Mutare	7975	57	9666	71	715 (542 to 925)	29.0	18129	35	196 (131 to 282)	0.27 (0.17 to 0.44)
Bindura	3016	27	3230	30	895 (591 to 1300)	8.4	8613	9	103 (40 to 203)	0.11 (0.05 to 0.26)
Mutoko	3035	22	3252	24	725 (455 to 1095)	19.8	6662	22	325 (199 to 502)	0.45 (0.23 to 0.86)
Zvimba	5863	25	6729	27	426 (267 to 629)	27.3	12497	32	250 (165 to 363)	0.59 (0.33 to 1.1)
Chivi	3834	22	4186	24	574 (360 to 867)	9.8	6863	10	158 (76 to 291)	0.28 (0.12 to 0.61)
Tsholotsho	2697	14	2867	15	519 (284 to 869)	4.2	4418	‡	96 (26 to 244)	0.18 (0.04 to 0.59)
Matobo	1961	6	2049	6	306 (112 to 665)	12.0	3485	13	359 (186 to 627)	1.2 (0.41 to 3.8)
Kwekwe	6327	30	7347	33	474 (320 to 676)	18.6	11949	21	183 (110 to 285)	0.39 (0.21 to 0.71)
Total unweighted	45 579	296	51 270	337	649 (576 to 723)	172.9	90 363	196	215 (183 to 248)	0.33 (0.27 to 0.40)
Total weighted¶					657 (485 to 829)				217 (164 to 269)	0.33 (0.28 to 0.39)

*April 2007 to 15 May 2008.

†April 2018 to 15 May 2019.

‡Adjusted for missed community deaths.

§Nkulumane district in Bulawayo, and South-Eastern and Western districts in Harare are entirely urban districts.

¶Weighted by district location to account for clustering of deaths within districts (where mortality risk factors are similar) in the pooled sample. IRR, incidence rate ratio.

Table 2 Mortality rate in women of reproductive ages 12–49 years in Zimbabwe 2007–2008 and 2018–2019 by district, age of women and whether the death was pregnancy-related or not

District	2007–2008			2018–2019			IRR* (95% CI)
	Population†	Deaths	IR‡	Population†	Deaths	IR‡	
Nkulumane	41 464	1479	35.7	42 985	397	9.2	0.26 (0.23 to 0.29)
Harare SE§	24 193	141	5.8	31 755	54	1.7	0.29 (0.21 to 0.40)
Harare W§	62 211	635	10.2	81 655	227	2.8	0.27 (0.23 to 0.32)
Mutare	123 954	974	7.9	148 616	367	2.5	0.31 (0.28 to 0.35)
Bindura	43 220	326	7.5	58 789	133	2.3	0.30 (0.24 to 0.37)
Mutoko	37 956	331	8.7	44 069	82	1.9	0.21 (0.17 to 0.27)
Zvimba	67 396	548	8.1	85 113	156	1.8	0.23 (0.19 to 0.27)
Chivi	47 866	264	5.5	49 311	114	2.3	0.42 (0.33 to 0.52)
Tsholotsho	34 533	357	10.3	31 363	79	2.5	0.24 (0.19 to 0.31)
Matobo	28 037	314	11.2	25 052	128	5.1	0.46 (0.37 to 0.56)
Kwekwe	89 516	819	9.1	105 468	119	1.1	0.12 (0.10 to 0.15)
Age-group							
12–14	77 544	82	1.1	87 675	26	0.3	0.28 (0.17 to 0.44)
15–19	133 104	228	1.7	132 452	117	0.9	0.52 (0.41 to 0.65)
20–24	115 701	589	5.1	115 236	159	1.4	0.27 (0.23 to 0.32)
25–29	89 201	1090	12.2	104 593	194	1.9	0.15 (0.13 to 0.18)
30–34	63 110	1358	21.5	90 122	321	3.6	0.17 (0.15 to 0.19)
35–39	47 467	1278	26.9	73 296	383	5.2	0.19 (0.17 to 0.22)
40–44	41 202	794	19.3	60 250	348	5.8	0.30 (0.26 to 0.34)
45–49	33 015	769	23.3	40 551	308	7.6	0.33 (0.28 to 0.37)
Pregnancy-related death							
Yes	45 579	325	7.1	59 576	137	2.3	0.32 (0.26 to 0.39)
No	554 765	5863	10.6	644 600	1719	2.7	0.25 (0.24 to 0.27)
Total unweighted	600 344	6188	10.3	704 176	1856	2.6	0.26 (0.24 to 0.27)
Total weighted**	681 634	7176	10.5	803 614	2145	2.7	0.25 (0.24 to 0.27)

*Weighted by district location to account for clustering of deaths within districts (where mortality risk factors are similar) in the pooled sample.
 †Year 2007 and 2018 population projections were from Zimbabwe's Statistics Department (ZimStats).
 ‡Mortality rate obtained using the formula: (number died / population) × 1000.
 §Harare South-Eastern and Harare Western Districts.
 .IR, incidence rate; IRR, incidence rate ratio.

DISCUSSION

We found a significant decline in Zimbabwe's MMR from 657 (95% CI: 485 to 829) in 2007–2008 to 217 (95% CI: 164 to 269) in 2018–2019, which is supported by other data sources (figure 2) and accompanied by a decline in overall reproductive age mortality. MMEIG estimated a decline from 790 in 2008 to 458 in 2017 at an annual ARR of 6.1%. The ZDHS estimated a decline from 960 in 2010 to 651 in 2015 at an ARR of 7.8%.

The decline in Zimbabwe's MMR in this study translated to an annual ARR of 10.1%, against a target of 10.2% based on the 2015 ZDHS baseline MMR of 651, and a target of 10.9% based on the MICS MMR estimate of 462 in 2019 (online supplemental table S8).^{55 66} The targets are the ARRs required to achieve the SDG 3.1

supplementary target of individual countries reducing their MMRs to no more than 140 maternal deaths per 100 000 live births by 2030.⁶ Similar MMR declines have been recorded in other countries. Egypt's MMR declined from 174 in 1992–1993 to 94 in 2000, at an annual ARR of 7.7%,⁶⁷ and South Africa's from 191 in 2007 to 101 in 2015, at an annual ARR of 8.0%.⁶⁸

HIV interventions implemented between 2008 and 2018 could have contributed to the decline in Zimbabwe's MMR. Analysis of the changes in causes of death from this study showed that HIV mortality decreased by 81% in WRAs and by 91% in pregnant women.¹⁸ The interventions against the direct causes of maternal mortality must have also contributed to the decline in the MMR, as the cause of death analysis showed a 61%

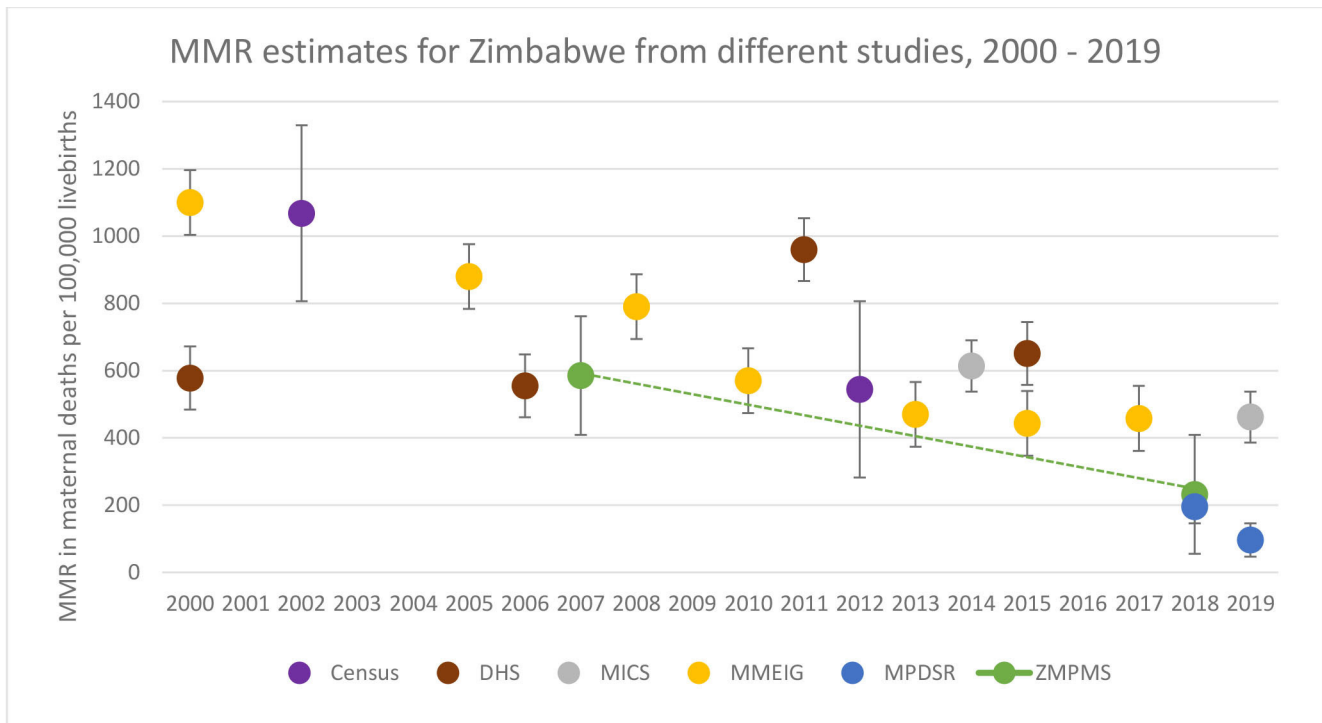


Figure 2 Zimbabwe MMR estimates from different data sources, 2002–2019. Census, Zimbabwe population census; DHS, Demographic and Health Survey; MICS, Multiple Cluster Indicator Survey; MMEIG, Maternal Mortality Estimation Inter-Agency Group; MMR, maternal mortality ratio; MPDSR, Maternal and Perinatal Death Surveillance and Response; ZMPMS, Zimbabwe Maternal and Perinatal Mortality Survey.

decrease in pregnancy-related deaths due to direct causes.¹⁸

The 2018–2019 MMR estimate of 217 (95% CI: 164 to 269) is considerably lower than MICS' 462 (95% CI: 288 to 538) and MMEIG's 458 (95% CI: 360 to 577) estimates which used different methods. MICS used the sisterhood method (asking all adult respondents about the deaths of their sisters) to identify pregnancy-related deaths in a household survey that sampled enumeration areas (survey clusters) from the country's provinces and estimated a 7-year (2013 to 2019) MMR.^{69 70 70–72 72} MMEIG used country data from different sources (CRVS, population-based sisterhood surveys, confidential enquiries into maternal deaths, RAMOS and any other sources that have clear data collection methods), along with robust statistical modelling.^{6 7 69 73}

The SDG 3.1 and Ending Preventable Maternal Mortality supplementary targets are broad goals and statements of intent, set in full recognition of the absence of precise methods of measuring MMRs in different countries and that country targets depend on the baseline MMRs used. Zimbabwe's estimates are not exempt from these nuances. Regardless, Zimbabwe's MMR cannot continue declining at the annual ARR of 2009–2019 until 2030, for several reasons. Stabilisation of the economy from 2009 onwards from the 2000 to 2008 economic crisis led to stabilising of the health system and reduction of maternal mortality from the high levels of 2007–2008.⁷⁴ However, health system constraints have resurfaced due to the rebounded economic challenges.¹⁶

The causes of death analysis showed a huge decline in deaths from indirect causes—mainly HIV deaths, due to increased ART coverage.¹⁸ However, the reduction in HIV mortality is flattening. At the same time, the causes of death analysis showed that mortality from direct causes is still three times higher than from indirect causes.¹⁸ Thus, Zimbabwe is unlikely to sustain the ARR of the 2009–2019 period.

Strengths and weaknesses of the study

The strengths of our study are that it produced single-year MMRs while other studies estimated MMRs for a 5–7 year period. Our study includes a before-and-after analysis which allows us to report the ARR required to monitor the SDG 3.1 supplementary targets. Our study identified more maternal deaths, with causes of death information, compared with the sisterhood method studies.^{48 55} Trained obstetrician–gynaecologists classified the deaths into maternal and non-maternal deaths using the ICD-10 MM manual; therefore, misclassification of deaths may be low. Our study methods offer alternative approaches to assessing maternal mortality levels in limited-resource settings using CRVS and health records. Regular use of this method will strengthen these records, as documentation and classification of deaths and storage of records are interrogated during the data collection. The comprehensive data collected through this method enables the analysis of the causes of death to complement the MMR estimates. The sampling method used in 2007–2008 has

some limitations, but the results can be generalised to the country since the district cluster samples followed the health system structure and geographically represented the country's population. The sample sizes were powered to measure the MMR within acceptable error margins.

The limitations of our study are the use of different data sources for births and community deaths in the two surveys. Whereas the first survey enumerated births and deaths prospectively in the health facilities and community, the second survey used secondary data from CRVS and health records which would miss community births and deaths not registered in these data systems. To mitigate this, we statistically adjusted the births and maternal deaths data for 2018–2019, an approach which has its limitations. Notwithstanding, the adjustment for live births was validated. The triangulating data suggested undercounting of the live births by a consistent 20% (online supplemental table S4).

The adjustment of the number of maternal deaths in 2018–2019 would have a positive bias. The ZDHS reported an increase in institutional deliveries from 65% (57% rural and 85% urban) in 2010/2011 to 72% in 2015 (68% rural and 81% urban) and MICS reported 86% (82% rural and 94% urban) in 2019.⁴⁸ Increase in institutional deliveries reduces pregnancy-related community deaths.^{3 6 68 73} Thus, by standardising the ratio of community to institutional deaths for 2018–2019 to the 2007–2008 ratio, the adjustment could inflate the 2018–19 maternal deaths and the MMR estimate.

CONCLUSIONS

Between 2007–2008 and 2018–2019, Zimbabwe's MMR declined from 657 to 217 alongside a decline in reproductive age mortality. The decline may be a result of the reduction in HIV mortality due to increased ART coverage and the impact of targeted MNCH interventions. However, since the reduction in HIV mortality may be flattening and mortality due to direct causes is still high, Zimbabwe may not sustain the annual ARR of 2009–2019. Therefore, we recommend scaling up interventions to reduce deaths due to direct maternal causes while sustaining interventions against HIV and other indirect causes.

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Contributors SM developed the 2007–2008 survey protocol with the first ZMPMS group. RMu developed the 2018–2019 survey and the combined data analysis protocol with the second ZMPMS group. DM, SN, TM, RP and SM contributed to data collection and gathering of contextual information. RMu developed the manuscript and all authors critically reviewed the data analysis and several versions of the manuscript. All authors took responsibility for the final manuscript. SM, RP, JC and SN are the guarantors.

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Supplementary online document

Table S1: Background to Zimbabwe's maternal mortality ratio (MMR) changes, 2007-08 to 2018-19.

Zimbabwe experienced a severe socio-economic crisis that started in the late 1990s and reached its peak in 2008. The crisis caused hyperinflation and erosion of revenues, leading to government failure to adequately fund essential services, including health. Zimbabwe government's health strategies and numerous health sector assessments acknowledge this crisis.¹⁻⁴ The crisis caused deterioration of the health system to near-collapse, such that by 2009, about 80% of health facilities offering maternal, neonatal and child health services lacked essential commodities.⁵ Skilled and experienced health workers deserted the health sector, such that in 2010, only 34% of doctors, 66% of nurses, 28% of pharmacists, 23% of environmental health officers and 45% of health services' administrator positions were staffed.⁴ As the effects of the crisis continued, the health system scored 42% on general service availability, 69% on health infrastructure availability, 36% on core health workforce availability and 22% on service utilisation in a 2015 assessment.⁶

Zimbabwe being one of Southern Africa's high HIV burden countries, the HIV epidemic was taking its toll on the country in 2007-2008.⁷⁻¹⁰ The roll-out of antiretroviral treatment (ART) had started in 2004 but was slow and was still in the early scaling-up phase by 2007-2008.¹¹ ART services were rolled out to only 5.2% (86 out of 1,643) of health facilities country-wide by December 2007 – mostly in provincial and tertiary hospitals, which are few and less accessible to communities.¹² In December 2008, 17% (282 out of 1643) health facilities offered ART services country-wide, and 24% (148,144/596,965) HIV-positive people were on ART (the need for ART defined by a CD4 count below 350 cells per microlitre (cells/ μ L) of blood).^{12,13} In the same period, a debilitating cholera epidemic broke out in all provinces of the country from July to November 2008.¹⁴

In 2007-2008, the Ministry of Health commissioned the first of the two maternal mortality surveys included in this study. Preliminary findings of this survey reported an MMR of 725 maternal deaths per 100 000 livebirths, HIV complications being the leading cause, contributing to 26% of the deaths.¹⁵ Concern arose locally and internationally about the findings. Consequently, the Ministry of Health and its partners instituted a raft of measures to address the maternal health situation. A maternal and neonatal health roadmap was developed to promote the four pillars of Safe Motherhood;¹⁶ namely: (i) family planning and antenatal care, (ii) clean and safe delivery for the mother and newborn, (iii) essential obstetric and neonatal care – including obstetric and neonatal first aid, and (iv) basic emergency obstetric and neonatal care (BEmONC) and comprehensive obstetric and neonatal care (CEmONC). The strategies were (i) to train healthcare workers in these interventions, (ii) roll out BEmONC in primary care facilities and CEmONC in secondary and tertiary facilities, (iii) integrate family planning and prevention of mother-to-child transmission (PMTCT) of HIV services in Maternal, Newborn and Child Health (MNCH), and (iv) community mobilisation.

Following the crisis of 2007-2008, a government of national unity was formed in 2009, which began to reverse the socio-economic crisis.^{17,18} Donor funding increased to support the country's socio-economic recovery, targeting strategic sectors such as health.³ MNCH donors created two grants to revitalise the health system and improve MNCH services. The health transition fund (HTF) of US\$ 235 million was implemented from 2012 to 2015, and the health development fund (HDF) of US\$ 682 million, from 2016 to 2020.¹⁷⁻¹⁹ European governments pooled the grants

through UNICEF. The HTF and HDF supported retention allowances for the health workforce (nurses and doctors) in rural areas and supply of essential medicines and commodities. Through a result-based financing (RBF) component, the grants funded operations and renovations in rural health facilities and community interventions. User fees were removed in rural health facilities. The availability of essential commodities such as antibiotics and blood for obstetric emergencies improved due to a dedicated monthly resupply program of emergency obstetric and neonatal care consumables.^{5,20} Overall, fundamentals of Zimbabwe's health system began to improve.²¹

In the execution of the MNCH roadmap activities, the Ministry of Health rolled out trainings in the management of obstetric and neonatal emergencies nationwide, supported by the UK's Royal College of Obstetricians and Gynaecologists (RCOG)²². Trainers from the Liverpool School of Tropical Medicine (Making it Happen Project) and Bristol University (Alarm Project) facilitated the training of local trainers (120 doctors and nurse midwives became certified national trainers). In the end, more than 700 doctors and nurse midwives received the downstream training. During this time, the Ministry of Health established twelve new midwifery schools. The Ministry also resumed the training of advanced clinical officers, and expanded the training of nurse anaesthetists who were all recruited from rural district hospitals. Maternity waiting homes, which started in the 1980s, were expanded.^{20,23-25} An additional 105 were established or renovated in rural health institutions, funded by the HTF and HDF, and other donors.

UNFPA, WHO, UNICEF and others supported the Ministry of Health to set up a Maternal and Perinatal Death Surveillance and Response (MPDSR) system.²⁶ Guidelines for maternal and perinatal death audits were developed.²⁷ The Ministry instituted the audit system, establishing audit committees at all health facilities providing maternity services and district, provincial and national levels of the Ministry. A surveillance system for reporting maternal deaths from health facilities to the Ministry's head office was established. Health facilities began to audit deaths, and complete and submit maternal death audit forms to the national level where the data were analysed. The national maternal and perinatal death audit committee audited some of the deaths reported by the sub-national committees. They gave feedback to the lower committees to improve the audits and management of maternal and neonatal cases at those levels. However, the surveillance system experienced challenges such as delayed and incomplete reporting but routine analysis of the data informed policies, scaling up of the interventions and resource allocation, while most audit recommendations would not be implemented because of limited resources.²⁸

HIV programs also received significant funding through the crisis period, which exceeded US\$ 400 million annually.^{29,30} The Global Fund to Fight AIDS, Tuberculosis and Malaria and the United States President's Emergency Program for AIDS Relief (PEPFAR) were the main funders. Private donors and domestic funding from 3% of all taxable employee and business incomes complemented the donor funding.^{30,31} With this funding, the country rolled out ART to 91% (1,566/1,722) health facilities by December 2017,³² and about 97% of adults (15-49 years) with known HIV-positive status were on ART by 2019.³³

Through the Elizabeth Glaser Pediatric AIDS Foundation (EGPAF), the Children's Investment Fund Foundation (CIFF) funded the roll-out of WHO 2010 ("Option A") and 2013 ("Option B+") guidelines for PMTCT by over US\$ 100 million from 2011 to 2019. Under the "Option B+" guidelines, HIV-infected pregnant women were initiated on life-long ART irrespective of disease stage.^{34,35} The ART and PMTCT programs had such an impact that by the year 2019,

88% of adult women (15-49 years) living with HIV had known status, of which 98% were on ART.³³ Consequently, a substantial decline in HIV-associated mortality in the adult populations was observed in 2009.¹⁰

Zimbabwe achieved these gains in the health sector because of targeted, evidence-based interventions implemented by the government and its partners. Maternal and perinatal health improved, despite a continued depression in other sectors of the country – farming, manufacturing, food security, employment, education, and others. The Government of Zimbabwe contributed to the funding of these interventions through its fiscus and the AIDS trust fund^{3,36} but a significant proportion of the resources came from international donors.

Table S2: Design effect calculations for 2007-08 and 2018-19 surveys

District	Population (n _i)	Deaths (d _i)		Y _i	X _i	R(i)	R _i	R _i -R	(R _i -R) ²
						R(i)=Y _i /X _i	R _i =K _r -(k-1)R(i)		
Nkulumane	4387	62		46883	275	0.005871	0.013564577	0.00699438	4.89214E-05
Harare SE	1995	13		49275	324	0.006582	0.006448824	-0.0001214	1.47312E-08
Harare W	5563	33		45707	303	0.006639	0.005877185	-0.000693	4.80265E-07
Mutare	9666	71		41603	266	0.0064	0.008273054	0.00170286	2.89972E-06
Bindura	3230	30		48040	307	0.006393	0.00833751	0.00176731	3.1234E-06
Mutoko	3252	24		48018	313	0.00652	0.007070706	0.00050051	2.50509E-07
Zvimba	6729	27		44541	310	0.00695	0.002775653	-0.0037945	1.43986E-05
Chivi	4186	24		47084	313	0.00665	0.005776449	-0.0007937	6.30035E-07
Tsholotsho	2867	15		48403	322	0.006656	0.005715037	-0.0008552	7.31298E-07
Matobo	2049	6		49221	331	0.006719	0.005079101	-0.0014911	2.22337E-06
Kwekwe	7347	33		43923	303	0.006909	0.00318091	-0.0033893	1.14873E-05
Total	51270	337		512698	3369	0.072289		-0.000173	0.000085160500
k=11	R =	0.006570197						SE ² =	7.74186E-07
CIs for MMR	0.004846	0.006570197	0.008295					SE (CDS)	0.000879879
100000	484.5635	657.0196581	829.4759					S ² (SRS)	0.005776361
								SE ² (SRS)	1.26733E-07
								DE (2007-08)	6.108790912
District	Population (n _i)	Deaths (d _i)		Y _i	X _i	R(i)	R _i	R _i -R	(R _i -R) ²
						R(i)=Y _i /X _i	R _i =K _r -(k-1)R(i)		
Nkulumane	5748	27		84615	169	0.001992	0.00391621	0.00174888	3.05858E-06
Harare SE	3022	4		87341	192	0.002195	0.001886315	-0.000281	7.89689E-08
Harare W	8977	18		81386	178	0.00219	0.001943584	-0.0002237	5.00621E-08
Mutare	18129	35		72234	161	0.002229	0.001553225	-0.0006141	3.77125E-07
Bindura	8613	9		81751	187	0.002287	0.000969152	-0.0011982	1.43563E-06
Mutoko	6662	22		83702	173	0.002073	0.003114492	0.00094716	8.97117E-07
Zvimba	12497	32		77866	163	0.002099	0.002848688	0.00068136	4.64249E-07
Chivi	6863	10		83500	185	0.002221	0.001627148	-0.0005402	2.91796E-07
Tsholotsho	4418	4		85945	192	0.002229	0.001554031	-0.0006133	3.76135E-07
Matobo	3485	13		86878	183	0.002106	0.002782394	0.00061506	3.78304E-07

Kwekwe	11949	21		78414	175	0.002232	0.001518568	-0.0006488	4.20891E-07
Total	90363	195.8	0.00217	903631	1958	0.023853		-0.000127	0.000007828862
k=11	R =	0.00216733						SE^2 =	7.11715E-08
CIs for MMR	0.001644	0.00216733	0.00269					SE (CDS)	0.00026678
100000	164.4441	216.732964	269.0218					SE^2(SRS)	4.03517E-08
								DE (2018-19)	1.763779567

Table S3: Calculations for adjustment of community maternal deaths missed in 2018-19, using the proportion of 2007-08 maternal deaths as a standard.

District	2007-08 Deaths			2018-19 Unadjusted Deaths			2018-19 Adjusted Deaths	
	Community (a)	Institutional (b)	Total	Community (d)	Institutional (e)	Total (t)	Missed Community Deaths (x)	Total Adjusted Deaths (T)
	a	b	-	d	e	t	x	T
Nkulumane-Bulawayo	12	39	51	1	18	19	5	23.5
Harare SE	0	12	12	0	4	4	0	4.0
Harare W	3	27	30	5	11	16	0	16.0
Mutare	13	44	57	7	22	29	0	29.0
Bindura	11	16	27	3	5	8	0	8.4
Mutoko	12	10	22	3	9	12	8	19.8
Zvimba	14	11	25	2	12	14	13	27.3
Chivi	13	9	22	1	4	5	5	9.8
Tsholotsho.	4	10	14	0	3	3	1	4.2
Matobo	4	2	6	0	4	4	8	12.0
Kwekwe	9	21	30	3	13	16	3	18.6
Total	95	201	296	25	105	130	43	172.6

NB: a to T denote the variables used in the model. The adjustment model formulas are: $x = ae/b - d$; $T = t + ae/b - d$

Table S4: Adjustment of DHIS2 live births (2018-19) using correction factors from 2019 MICS' GFR and expected pregnancies data from ZimStat.

District	Population	General Fertility rate	Estimated births	Expected pregnancies 2019	DHIS2 Births	Proportion DHIS2 to GFR estimated livebirths	Proportion DHIS2 to expected pregnancies	Birth adjustment / correction factor	Adjusted births
Nkulumane-Bulawayo	42985	0.1006	4324	2775	5363	124%	193%	1.00	5363
Harare SE	31755	0.1006	3195	2057	2240	70%	109%	1.30	2912
Harare W	81655	0.1006	8214	5036	7081	86%	141%	1.14	8072
Mutare	148616	0.1006	14951	17112	13200	88%	77%	1.12	14784
Bindura	58789	0.1424	8372	6426	5982	71%	93%	1.30	7777
Mutoko	44069	0.1424	6275	5560	5348	85%	96%	1.15	6150
Zvimba	85113	0.1424	12120	10007	8316	69%	83%	1.30	10811
Chivi	49311	0.1424	7022	6318	4863	69%	77%	1.30	6322
Tsholotsho.	31363	0.1424	4466	4380	3221	72%	74%	1.30	4187
Matobo	25052	0.1424	3567	3574	2569	72%	72%	1.30	3340

Kwekwe	105468	0.1006	10610	11854	9042	85%	76%	1.15	10398
Total	704176		83117	75099	67225	81%	90%	1.21	80116

MICS - Multiple Indicator Cluster Survey; GFR - General Fertility Rate; ZimStat - Zimbabwe Statistical Agency

Table S5: Weighting calculation for clustering-adjusted mortality rates among women of reproductive ages, 2007-08 and 2018-19, weighting by location (districts).

a) Weighting for population of women of reproductive ages, 2007-08

District	Population (n _i)	Deaths (d _i)	Proportion died (p _i)	Variance ¹	Weight ² (w _i)	Product (w _i *p _i)
				(v _i)		
Nkulumane	41464	1479	0.069066838	1.55E-06	6.45E+05	4.45E+04
Harare SE ¹	24193	141	0.040298428	1.60E-06	6.26E+05	2.52E+04
Harare W ¹	62211	635	0.103625243	1.49E-06	6.70E+05	6.94E+04
Mutare	123954	974	0.206470935	1.32E-06	7.57E+05	1.56E+05
Bindura	43220	326	0.071991818	1.55E-06	6.47E+05	4.66E+04
Mutoko	37956	331	0.063223541	1.56E-06	6.41E+05	4.05E+04
Zvimba	67396	548	0.112261929	1.48E-06	6.76E+05	7.59E+04
Chivi	47866	264	0.079730689	1.53E-06	6.52E+05	5.20E+04
Tsholotsho	34533	357	0.057521829	1.57E-06	6.37E+05	3.66E+04
Matobo	28037	314	0.046701402	1.59E-06	6.30E+05	2.94E+04
Kwekwe	89516	819	0.149107348	1.42E-06	7.06E+05	1.05E+05
Total	600346	6188	1.000000000	0.00E+00	7285440	681634

¹ Variance = $\pi(1-\pi)/n$; ² Weight = $1/v_i$; ³ Mortality rate = $(\sum w_i * p_i / \sum w_i) * 1000$

b) Weighting for deaths of women of reproductive ages, Incidence Rate (IR) and 95% Confidence Intervals (CI), 2007-08

District	Population (n _i)	Deaths (d _i)	Proportion died (p _i)	Variance ¹	Weight ² (w _i)	Product (w _i *p _i)
				(v _i)		
Nkulumane	41464	1479	0.239010989	1.23E-04	8.13E+03	1.94E+03
Harare SE ¹	24193	141	0.022786037	1.58E-04	6.33E+03	1.44E+02
Harare W ¹	62211	635	0.10261797	1.45E-04	6.90E+03	7.08E+02
Mutare	123954	974	0.157401422	1.36E-04	7.34E+03	1.16E+03
Bindura	43220	326	0.052682612	1.53E-04	6.53E+03	3.44E+02
Mutoko	37956	331	0.053490627	1.53E-04	6.54E+03	3.50E+02
Zvimba	67396	548	0.0885585	1.47E-04	6.79E+03	6.01E+02
Chivi	47866	264	0.042663219	1.55E-04	6.46E+03	2.76E+02
Tsholotsho	34533	357	0.057692308	1.52E-04	6.57E+03	3.79E+02
Matobo	28037	314	0.050743374	1.53E-04	6.52E+03	3.31E+02
Kwekwe	89516	819	0.132352941	1.40E-04	7.13E+03	9.44E+02
Total	600346	6188	1.000000000	-3.70E-22	75244	7176
IR			0.01052734	1.03E+01	10.53	1.08E+01

c) Weighting for population of women of reproductive ages, 2018-19

District	Population (n _i)	Deaths (d _i)	Proportion died (p _i)	Variance ¹	Weight ² (w _i)	Product (w _i *p _i)
				(v _i)		
Nkulumane	42985	397	0.061042978	1.33E-06	7.50E+05	4.58E+04
Harare SE ¹	31755	54	0.04509526	1.36E-06	7.37E+05	3.33E+04
Harare W ¹	81655	227	0.115958226	1.26E-06	7.97E+05	9.24E+04
Mutare	148616	367	0.21104951	1.12E-06	8.93E+05	1.88E+05
Bindura	58789	133	0.083486231	1.30E-06	7.68E+05	6.41E+04
Mutoko	44069	82	0.062582366	1.33E-06	7.51E+05	4.70E+04
Zvimba	85113	156	0.12086893	1.25E-06	8.01E+05	9.68E+04
Chivi	49311	114	0.070026527	1.32E-06	7.57E+05	5.30E+04
Tsholotsho	31363	79	0.044538581	1.36E-06	7.37E+05	3.28E+04
Matobo	25052	128	0.035576333	1.37E-06	7.30E+05	2.60E+04
Kwekwe	105468	119	0.149775056	1.21E-06	8.28E+05	1.24E+05
Total	704176	1856	1.0000000000	0.00E+00	8549550	803614

¹ Variance (v_i) = p_i(1-p_i)/n_i; ² Weight (w_i) = 1/v_i; ³ Mortality rate = (∑w_i*p_i / ∑w_i)*1000; ⁴ 95% CI = (p' +/- z*SQRT(p'(1-p')/n))*1000;

d) Weighting for deaths of women of reproductive ages, Incidence Rate (IR) and 95% Confidence Intervals (CI), 2018-19

District	Population (n _i)	Deaths (d _i)	Proportion died (p _i)	Variance ¹	Weight ² (w _i)	Product (w _i *p _i)
				(v _i)		
Nkulumane	42985	397	0.213900862	4.24E-04	2.36E+03	5.05E+02
Harare SE ¹	31755	54	0.029094828	5.23E-04	1.91E+03	5.56E+01
Harare W ¹	81655	227	0.122306034	4.73E-04	2.11E+03	2.59E+02
Mutare	148616	367	0.197737069	4.32E-04	2.31E+03	4.57E+02
Bindura	58789	133	0.071659483	5.00E-04	2.00E+03	1.43E+02
Mutoko	44069	82	0.044181034	5.15E-04	1.94E+03	8.58E+01
Zvimba	85113	156	0.084051724	4.94E-04	2.03E+03	1.70E+02
Chivi	49311	114	0.061422414	5.06E-04	1.98E+03	1.21E+02
Tsholotsho	31363	79	0.042564655	5.16E-04	1.94E+03	8.25E+01
Matobo	25052	128	0.068965517	5.02E-04	1.99E+03	1.37E+02
Kwekwe	105468	119	0.064116379	5.04E-04	1.98E+03	1.27E+02
Total	704176	1856	1.0000000000	0.00E+00	22561	2145
IR, 95% CI			0.00266883	2.56E+00	2.67	2.78E+00

Table S6: Weighting calculations for clustering-adjusted maternal mortality ratio (MMR) among women of reproductive ages, 2007-08 and 2018-19.

a) Weighting for live births, 2007-08

District	Population (n _i)	Deaths (d _i)	Population proportion (p _i)	Variance ¹	Weight ² (w _i)	Product (w _i *p _i)
				(v _i)		
Nkulumane	4002	51	0.087804	2.00E-05	49966	4387

Harare SE	1911	12	0.041927	2.10E-05	47574	1995
Harare W	4958	30	0.108778	1.96E-05	51142	5563
Mutare	7975	57	0.174971	1.81E-05	55245	9666
Bindura	3016	27	0.066171	2.05E-05	48809	3230
Mutoko	3035	22	0.066588	2.05E-05	48831	3252
Zvimba	5863	25	0.128634	1.91E-05	52308	6729
Chivi	3834	22	0.084118	2.01E-05	49765	4186
Tsholotsho	2697	14	0.059172	2.06E-05	48446	2867
Matobo	1961	6	0.043024	2.10E-05	47628	2049
Kwekwe	6327	30	0.138814	1.89E-05	52926	7347
Total	45579	296	1.000000	0.00E+00	552639	51270
¹ Variance (v_i) = $p_i(1-p_i)/n_i$; ² Weight (w_i) = $1/v_i$; ³ Mortality rate = $(\sum w_i p_i / \sum w_i) * 1000$; ⁴ 95% CI = $(p' \pm z * \text{SQRT}(p'(1-p')/n)) * 1000$;						

b) Weighting for maternal deaths, unweighted and weighted MMR, and 95% CIs, 2007-08

District	Population (n_i)	Deaths (d_i)	Proportion died (p_i)	Variance ¹	Weight ² (w_i)	Product ($w_i p_i$)
				(v_i)		
Nkulumane	4002	51	0.172297	2.80E-03	358	62
Harare SE	1911	12	0.040541	3.24E-03	309	13
Harare W	4958	30	0.101351	3.04E-03	329	33
Mutare	7975	57	0.192568	2.73E-03	367	71
Bindura	3016	27	0.091216	3.07E-03	326	30
Mutoko	3035	22	0.074324	3.13E-03	320	24
Zvimba	5863	25	0.084459	3.09E-03	323	27
Chivi	3834	22	0.074324	3.13E-03	320	24
Tsholotsho	2697	14	0.047297	3.22E-03	311	15
Matobo	1961	6	0.020270	3.31E-03	302	6
Kwekwe	6327	30	0.101351	3.04E-03	329	33
Total	45579	296	1.000000	0.00E+00	3593	337
Unweighted MMR, 95% CI		0.0064942	0.00649422	5.7568E+02	649.42	7.232E+02
Weighted MMR, 95% CI			0.00657020	5.8709E+02	657.02	7.270E+02

c) Weighting for live births, 2018-19

District	Population (n_i)	Deaths (d_i)	Population proportion (p_i)	Variance ¹	Weight ² (w_i)	Product ($w_i p_i$)
				(v_i)		
Nkulumane	5363	23.5	0.066940	1.16E-05	85864	5748
Harare SE	2912	4.0	0.036347	1.20E-05	83138	3022
Harare W	8072	16.0	0.100758	1.12E-05	89093	8977
Mutare	14784	29.0	0.184532	1.02E-05	98246	18129
Bindura	7777	8.4	0.097067	1.13E-05	88729	8613
Mutoko	6150	19.8	0.076766	1.15E-05	86778	6662
Zvimba	10811	27.3	0.134939	1.08E-05	92613	12497
Chivi	6322	9.8	0.078909	1.15E-05	86980	6863
Tsholotsho	4187	4.2	0.052265	1.18E-05	84534	4418

Matobo	3340	12.0	0.041686	1.20E-05	83601	3485
Kwekwe	10398	18.6	0.129790	1.09E-05	92065	11949
Total	80116	172.6	1.000000	0.00E+00	971641	90363

d) Weighting for maternal deaths, unweighted and weighted MMRs, and 95% CIs, 2018-19

District	Population (n _i)	Deaths (d _i)	Proportion died (p _i)	Variance ¹	Weight ² (w _i)	Product (w _i *p _i)
				(v _i)		
Nkulumane	5363	23.5	0.136377	5.00E-03	200	27
Harare SE	2912	4.0	0.023175	5.66E-03	177	4
Harare W	8072	16.0	0.092701	5.26E-03	190	18
Mutare	14784	29.0	0.168021	4.82E-03	207	35
Bindura	7777	8.4	0.048885	5.51E-03	181	9
Mutoko	6150	19.8	0.114718	5.13E-03	195	22
Zvimba	10811	27.3	0.158013	4.88E-03	205	32
Chivi	6322	9.8	0.056651	5.47E-03	183	10
Tsholotsho	4187	4.2	0.024334	5.65E-03	177	4
Matobo	3340	12.0	0.069526	5.39E-03	185	13
Kwekwe	10398	18.6	0.107599	5.17E-03	193	21
Total	80116	172.6	1.000000	0.00E+00	2094	196
Unweighted MMR, 95% CI		0.0021543	0.00215435	1.8333E+02	215.43	2.475E+02
Weighted MMR, 95% CI			0.00216733	1.8641E+02	216.73	2.471E+02

Table S7: ANOVA Tables¹ for repeated measures, before-and-after comparison of 2008-07 and 2018-19 MMRs, Zimbabwe RAMOS.

Given that the second survey used the same district clusters as the first survey, we performed additional statistical comparison using the repeated-measures method of One-Way ANOVA, using the online calculator available at <https://www.socscistatistics.com/tests/anova/default2.aspx>. The assumptions of the analysis are that the interventions and contextual factors of the MMR changes before 2007-08 and to 2018-19 measurement points are two treatments and comparison of the MMRs is comparison of two treatment effects. The data are fitted to a one-way ANOVA model because one factor, location, was available in the data for analysis.

Below are the results of the analysis in three tables, as guided by Ardelean's paper.²

a) Values from MMR calculations

District	2007-08 MMR	2018-19 MMR
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¹ Calculations performed using the ANOVA online calculator available at <https://www.socscistatistics.com/tests/anova/default2.aspx> (Accessed 31 Jan 2022)

² MATEC Web of Conferences: Available at: chrome-extension://efaidnbmnncnqkngjlkpcmlkkkj/vviewer.html?pdfurl=https%3A%2F%2Fwww.matec-conferences.org%2Farticles%2Fmatecconf%2Fpdf%2F2017%2F40%2Fmatecconf_imtoradea2017_04008.pdf&len=413721&chunk=true (Accessed 31 Jan 2022).

Nkulumane	0.012744	0.004363
Harare South Eastern	0.006279	0.001920
Harare Western	0.006051	0.002260
Mutare	0.007147	0.002197
Bindura	0.008952	0.001404
Mutoko	0.007249	0.003871
Zvimba	0.004264	0.003283
Chivi	0.005738	0.001995
Tsholotsho	0.005191	0.001304
Matobo	0.003060	0.004671
Kwekwe	0.004742	0.002057
Mean	0.0065000	0.0027000

b) Summary of ANOVA results for the two periods

Groups	Count	Sum	STD Deviation	Variance
2008-08	11	0.0005	0.0026	
2018-19	11	0.0001	0.0012	
Total	22	0.0006	0.0028	

c) ANOVA results

Source of information	SS	df	MS	P-value	F Critical
Between-treatments	0.0001	1	0.0001	0.000263	F = 19.54935
Within-treatments	0.0001	20	0		
Total	0.0002	21			

Conclusion: The *f*-ratio value is 19.54935. The *p*-value is .000263. The result is significant at $p < .05$. Hence, the MMRs for the two study years are different.

Table S8: Calculations for Actual ARR and Required ARR to achieve the 2030 target of 140 per 100,000 from 2015 baseline MMR, Target ARR based on the 2007-08 RAMOS, 2015 ZDHS and 2019 MICS MMR Results.

ARR Calculated	Baseline Year (t0)	End year (t1)	Time (t1-t0)	MMR0	MMR1	ARR
Achieved 1 (ZMPMS)	2008	2019	11	657	217	-10.1
Achieved 2 (MMEIG)	2008	2017	9	790	458	-6.1
Achieved 3 (ZDHS)	2010	2015	5	960	651	-7.8
Target 1 (ZMPMS)	2008	2030	22	657	140	-7.0
Target 2 (ZDHS)	2015	2030	15	651	140	-10.2
Target 3 (MICS)	2019	2030	11	462	140	-10.9

Table S9: Zimbabwe Maternal and Perinatal Mortality Study (ZMPMS) Members 2007-08 and 2018-19

ZMPMS 2007-8 Group
 Stephen Munjanja
 Thulani Magwali
 Gwendoline Kandawasvika
 Davidzoyashe Makosa
 Maxwell Chirehwa

ZMPMS 2018-2019 Group
 Reuben Musarandega
 Stephen Munjanja
 Michael Nyakura
 Thulani Magwali
 Gerald Madziyire

Eunice Tahuringana
Margaret Nyandoro
Aveneni Mangombe
Esther Ngaru
Tsitsi Magure
Nhamo Gona
Vongai Dondo
Ronald Mataya
Bothwell Guzha
Jonathan Kasule
Taurai Gunguwo
Sarah Manyame
Julius Chirengwa
Velda Mushangwe

Gwendoline Chimhini
Sunhurai Mukwambo
McMillan Parirenyatwa
Agnes Mahomva
Bernard Madzima
Davidzoyashe Makosa
Lucia Gondongwe
Chipo Chimamise
Winston Chirombe
Grace Chaora
Solwayo Ngwenya
Enesia Ziki
Mercy Gaza
Chipo Gwanzura
Admire Chikutiro
Rumbidzai Makoni
Grant Murewanhema

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