

Mobile Phone Survey Estimates of Perinatal Mortality in Malawi: A Comparison of Data from Truncated and Full Pregnancy Histories

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Abstract

Objectives: In many Low- and Middle-Income Countries, perinatal mortality estimates are derived retrospectively from periodically conducted household surveys. Mobile phone surveys offer advantages in terms of cost and ease of implementation. However, their suitability for monitoring perinatal mortality has not been established.

Methods: We use data from the Malawi Rapid Mortality Mobile Phone Survey (RaMMPS) to estimate perinatal mortality rates from two versions of the survey instrument: a Full Pregnancy History (FPH) and a shorter Truncated Pregnancy History (TPH). Female respondents of reproductive age were randomly allocated to either of these instruments. The sample was generated through random digit dialling (RDD) with active strata monitoring. Post-stratification weighting was used to correct for sample selection bias, and estimates are reported with bootstrap confidence intervals. We estimated the stillbirth rate as the synthetic cohort probability of a foetal death with 28+ weeks of gestation over all pregnancies reaching the same gestational age. The perinatal and extended perinatal mortality rates were defined as the probabilities of dying between 28 weeks and 7 or 28 days of life, respectively. RaMMPS estimates are compared to the 2015-16 Malawi Demographic and Health Survey, and estimates published by the United Nations Inter-agency Group for Child Mortality Estimation (UN-IGME).

Results: TPH and FPH were administered for 2,117 and 2,086 women, respectively. Weighted point estimates of the stillbirth (19.38 deaths per 1,000 pregnancies, 95%-Confidence Interval (CI): 14.03-25.42), perinatal (42.00, 95%-CI: 34.27-50.78), and extended perinatal mortality rates (49.57, 95%-CI: 41.62-59.43) from the FPH instrument are in line with DHS and UN-IGME estimates. In comparison, the stillbirth rate from the TPH instrument is biased upwards. Post-stratification weighting produces a small upwards adjustment in the estimates.

Conclusion. MPS are a promising method for collecting perinatal mortality data. The FPH instrument produces more plausible results than the shorter TPH questionnaire where the window of retrospection is restricted.

Keywords

Mobile phone surveys, stillbirth rate, perinatal mortality rate, Malawi.

Introduction and background

The UN estimated that 1.9 million babies were stillborn in 2021, and 2.3 million children died in the first month of life(1). Regional disparities in the burden of perinatal mortality are large, and recent progress in the reduction of stillbirths and neonatal mortality has been modest in comparison to maternal and post-neonatal mortality. UNICEF labelled this *a neglected tragedy* (2). It is also *an invisible tragedy* because most perinatal deaths, including stillbirths, occur in countries where routine administrative data (e.g., Civil Registration and Vital Statistics or Health Management Information Systems) are insufficiently performant to produce estimates that are useful for monitoring progress towards global targets(3, 4). In these settings, perinatal mortality estimates are derived from periodically conducted household surveys, including the Demographic and Health Surveys (DHS).

Owing to the rapid expansion in mobile phone ownership, mobile phone surveys have become an appealing alternative to traditional household surveys. They can be deployed rapidly and without the need for in-person contact; a key feature that makes them more suitable to field in the context of epidemic outbreaks or other humanitarian crisis situations(5). Whereas mobile phone surveys are increasingly common (6, 7), they have not yet been used for measuring stillbirth and neonatal mortality. This study thus aims to ascertain whether plausible perinatal mortality estimates can be generated from a mobile phone survey, and complements another manuscript wherein we used mobile phone survey data to estimate infant and under-five mortality (8).

There are severable possible methodological pitfalls associated with mortality estimation from mobile phone surveys, including acceptability, sample selectivity, and data quality concerns (9-13). One element that might affect acceptability and data quality is the duration of the interview in the sense that longer interviews are more susceptible to interruptions and the respondent's loss of concentration. The empirical evidence for the latter is not very strong(14), but as long as data quality can be upheld, short duration interviews are desirable for the mere reason that they reduce the burden on the respondent and fieldwork operational costs. In this contribution, we use data from the Malawi *Rapid Mortality Mobile Phone Survey* (RaMMPS) where women of reproductive age were randomly administered one of two different versions of a questionnaire module designed to measure stillbirth and neonatal mortality. One of the criteria on which they differed was the length of the module.

The *Full Pregnancy History* (FPH) questionnaire was adapted from the model DHS questionnaire that was introduced in 2020 (DHS round VIII), after it was established that it was better suited to identify stillbirths than Full Birth Histories with a reproductive calendar (DHS round IV) and supplementary questions for identifying non-live births (DHS round VII)(15, 16). The FPH instrument elicits information about all pregnancies in chronological order, starting with the first pregnancy. We compare the FPH estimates of perinatal mortality with those from a *Truncated Pregnancy History* (TPH) instrument, whereby the data is collected in reverse chronological order until an a-priori defined date is reached. This questionnaire was modelled after truncated birth histories collected in Malaria Indicator Surveys (MIS). Early methodological work evaluating instruments and the order wherein birth or pregnancy histories are to be collected were not always conclusive, but a recent comparison of truncated versus full birth histories suggests that the former produces estimates of child mortality that are biased downwards (17-20).

In the following sections, we describe the data and estimation procedures, and compare the Malawi RaMMPS estimates of the stillbirth and perinatal mortality rates from both questionnaires with estimates from the 2015-16 Malawi DHS and the UN Inter-agency Group for Child Mortality Estimation (UN IGME)(21, 22).

Data and Methods

Data and survey instruments

We use data from the national Malawi RaMMPS conducted between 24 January 2021 and 28 July 2023. The fieldwork for this study was coordinated by the Institute of Public Opinion and Research (IPOR, <https://www.ipormw.org/>) in Zomba, Malawi. The sample for the Malawi RaMMPS was generated via (screened) Random Digit Dialling (RDD) without replacement. Using the mobile phone numbering structure in Malawi, a set of random numbers was generated by Sample Solutions (<https://sample.solutions/>), and verified against the *Home Location Register* (HLR), which is a database of registered (including pre-paid) numbers on the GSM network. The screening using the HLR identifies the bulk of numbers that are not in use. Thereafter, trained enumerators conducted Computer Assisted Telephone Interviews (CATI) with active strata monitoring(23). Strata were a-priori defined in terms of broad age groups (18-49 and 50-64), sex, region (North, Central, and South), and residential setting (urban/rural). Quotas for each stratum were derived from the 2018 census(24). Once a stratum was filled, respondents with these attributes were no longer eligible to participate in the study. Fieldwork was divided into four blocks of 4 to 5 months each, and quotas were re-set at the beginning of each fieldwork block. Minors below the age of 18 were not

interviewed to ensure that all respondents could consent to the interviews themselves. Respondents received 1,200 Malawian Kwacha (~1.5 USD in 2021) in airtime as compensation for completing the interview. Enumerators worked from their homes, and a random sample of interviews were recorded (with consent) for quality control purposes. A fieldwork supervisor also conducted follow-up calls with respondents who completed the interview.

In comparison to other sub-Saharan African countries, mobile phone ownership in Malawi is relatively low. In 2021, the number of issued SIM cards per 100 individuals in Malawi was estimated at 60% and falls short of the sub-Saharan African average where mobile phone penetration was 93%(25). Mobile phone ownership is particularly low in rural areas, where the gender gap in ownership is also more pronounced. According to the 2015-‘16 Malawi DHS, 73.8 and 63.9% of men and women in urban areas owned a mobile phone. In rural areas, 47.1 and 25.9% of men and women owned a phone, respectively (26). In addition, a large majority of the Malawian population lives in rural areas (84% according to the 2018 census (24)). Given these imbalances in population distribution and mobile phone ownership, enumerators had difficulty filling the quotas for rural respondents (women in particular), and this reduced the yield of completed CATIs towards the end of each fieldwork block when the quotas for the easiest to reach respondents had been filled. To alleviate this, we fielded an Interactive Voice Response (IVR) survey to identify rural respondents, and the details are described elsewhere(27).

Starting in the second fieldwork block (26 May 2022), consenting female respondents aged 18-49 were randomly allocated to the TPH or FPH set of questions (supporting information, SI-1). The FPH questions were modelled on the instrument that was used in round VIII of DHS, and solicited information on pregnancy dates, pregnancy outcomes, time of gestation, and the survival status of children(16). As in the DHS, this detailed reproductive history was preceded by a summary pregnancy history, to determine the total number of pregnancies to each woman.

TPH left censored the pregnancies with an end date more than seven years before the interview. Unlike FPH, TPH were recorded in reverse chronological order, an approach that was adapted from the *Malaria Indicator Surveys* (MIS). In order to keep the instrument as short as possible, the TPH instrument did not contain a set of summary pregnancy history questions. The TPH and FPH questionnaire modules used the same set of questions to collect information on the day of birth or pregnancy termination, as well as the gestational age.

For the purposes of the analyses presented here, the pregnancy history data were administratively (left) censored on 1 January 2014. Results with a left censoring date of 1 January 2016 are included as supporting information (SI-3).

Post-stratification weighting

Mortality estimates from MPS may be affected by selection bias because mobile phone ownership –and possibly also respondent consent– is correlated with respondent characteristics that have a bearing on mortality. The imposition of quotas for the a-priori defined strata only partially alleviates this problem because these are limited to key demographic (age group and sex) and geographic (region and urban/rural place of residence) attributes. It is more challenging to impose quotas on educational background or wealth in a sample constituted via RDD because little or no a-priori information is available on these attributes. We therefore resorted to post-stratification to ensure that the RaMMPS sample is representative of the entire population in terms of a broader number of attributes, including education, household size and household wealth.

Post-stratification weights were estimated by Iterative Proportional Fitting–also known as raking; a method that is regularly used in mobile phone surveys (28). For each fieldwork block, marginal distributions of the RaMMPS data were matched to the female population aged 18-49 in the household roster of the 2015-16 Malawi DHS, which was the most recent nationally representative survey available at the time of writing. Weights were computed and applied for the following attributes: (i) age group (18-29, 30-39, or 40-49); (ii) urban versus rural place of residence; (iii) region (northern, central, or southern); (iv) educational attainment (incomplete primary or less, completed primary and incomplete secondary, completed secondary or higher); (v) household size (1-4, 5-8, or 9+); and (vi) an indicator variable for household-level access to a source of electricity. Post-stratification weights ranged from 0.02 to 12.54 with a mean value of 1.0. Untrimmed weights are used in the manuscript, as this is sometimes recommended for small samples (29, 30). Estimates with trimmed weights are included as supplementary material (SI-3b).

Stillbirth and perinatal mortality rate estimation

We calculated the–late–stillbirth rate from the RaMMPS data as the synthetic cohort probability of a pregnancy loss with at least 28 weeks of gestation, $q(28w, Birth)$, and is reported as the number of stillbirths per 1,000 live and stillbirths combined. The perinatal mortality rate is defined analogously but expands the exposure time to the first week of life: $q(28w, 7d)$. For analytical purposes, we also present the extended perinatal mortality rate, covering the first 28 days of life: $q(28w, 28d)$. The latter circumvents the problem of heaping at 7 days and allows us to compare RaMMPS with UN-IGME estimates. UN-IGME estimates are available for the stillbirth rate and the Neonatal Mortality Rate (NMR), but no estimates are published for the probability of dying during the first week of life (i.e., the

Early Neonatal Mortality Rate, ENMR). UN-IGME estimates for the perinatal mortality rate are computed by the authors, assuming a log-normal distribution of these indicators.

In order to facilitate direct comparisons with the RaMMPS data, the DHS sample was restricted to women aged 18-49. Further, we used the DHS day of birth—as reported by the mother—and the approximate date of termination (month and year) as informed by the reproductive calendar. UN-IGME estimates are reported for all women of reproductive age, including adolescents aged 15-17, not included in the RaMMPS data.

Confidence intervals (CIs) for RaMMPS estimates were computed via nonparametric bootstrapping, resampling the total number of interviews 1,000 times with replacement. For each sample, probabilities of selection were proportional to the post-stratification weights. The 50th percentile is reported as the central tendency of these distributions; and the 2.5th and 97.5th percentiles were used to report 95% CIs and to test for statistical significance. Confidence intervals for the DHS data are produced using a similar procedure. UN-IGME estimates are reported with 90% confidence bounds.

Results

Out of the 56,072 mobile phone numbers that were tried, a RaMMPS CATI interview was completed with 13,800 respondents (men and women aged 18-64). Response and refusal rates were 26.55 and 10.42 percent, respectively. These are defined as the number of completed interviews or refusals over the number of respondents who either met the inclusion criteria, or, whose eligibility for inclusion in the study could not be established. As described elsewhere, this response rate is a lower bound estimate because cases with unknown eligibility are included in the denominator(31). The analyses in the remainder of this manuscript are restricted to 4,203 interviews with women aged 18-49. About half of these women were administered a TPH and about half received the FPH instrument (SI-2). The median duration to administer the FPH instrument (including summary pregnancy history questions) was 3.20 minutes (Q1-Q3: 0.80-5.20). The median duration to administer the TPH instrument (not including summary pregnancy history questions) was 2.11 minutes (Q1-Q3: 0.38-3.10).

Table 1 provides the individual and household attributes of the RaMMPS respondents in the two pregnancy history modules and the DHS reference dataset. For the RaMMPS data, we present estimates before and after post-stratification weighting. DHS estimates are given for all female respondents aged 18-49 and for the subgroup of women who own a mobile phone. The DHS data confirm that mobile phone owners are more frequently urban, better educated and more often have access to electricity. This is also reflected in the distribution of these attributes in the unweighted RaMMPS samples (columns 2 and 4). Malawi RaMMPS respondents also appear to come from slightly larger households, and that may be due to the fact that larger households have a greater likelihood of being sampled via RDD, or, that estimated household sizes are biased upwards in RaMMPS. After weighting (columns 1 and 3), the imbalance in the RaMMPS data is largely rectified, and the marginal distribution of these background characteristics matches that in the DHS sample for all women (column 6).

--- Table 1 about here ---

Figure 1 contains two representations of the stillbirth and perinatal mortality indicators. The top row (panels A-C) compares the bootstrapping distribution of the estimates from the two RaMMPS pregnancy history modules along with the UN IGME estimates; and the 2011-16 DHS estimates. The bottom row of Figure 1 (panels D-F) shows the same estimates on a time scale. Figure 1 contains estimates after post-stratification. Both weighted and unweighted estimates are reported in Table 2. As supplementary material (SI-4), we also provide perinatal mortality estimates by the background characteristics that are used for post-stratification weighting. Unless stated differently, we refer to weighted RaMMPS estimates.

--- Figure 1 about here ---

--- Table 2 about here ---

The RaMMPS FPH estimate for the stillbirth rate (19.38 per 1,000, 95%-CI: 14.03-25.42) is comparable to that of the UN-IGME estimate for 2019 (16.15, 90%-CI: 14.44-18.10). The DHS estimate is lower, but the difference is not statistically significant. It is also worth noting that the 2015-16 Malawi DHS used the Full Birth History instrument along with a reproductive calendar, and this is now considered to be inferior to a FPH questionnaire for capturing stillbirths(15). The RaMMPS TPH estimate (30.25, 95%-CI: 22.20-40.07) is considerably higher.

The RaMMPS FPH estimate of perinatal mortality (42.00 per 1,000, 95%-CI: 34.27-50.78) and extended perinatal mortality rate (49.57, 95%-CI: 41.62-59.43) exceed estimates from other published sources, but the differences are

again not statistically significant. The 2019 UN-IGME estimate for the extended perinatal mortality rate, for example, is 35.96 (90%-CI: 29.43-45.17).

Post-stratification weighting produces a modest upwards adjustment in the RaMMPS perinatal mortality estimates, but they are never significantly different from the unweighted estimates. Application of the post-stratification weighting procedure produces a small downwards correction to the perinatal mortality estimates from the subsample of mobile phone owners from the DHS. Again, the confidence intervals of the weighted, unweighted and full samples overlap.

Figure 3 (SI-5) contains stillbirth and perinatal mortality estimates from the RaMMPS FPH instrument disaggregated by 2-year intervals. Point estimates are indicative of a mortality decline between 2014 to 2020 for each of the indicators that are considered, but they are also suggestive of a temporary mortality reversal in the calendar years corresponding with the COVID-19 outbreak (i.e., 2020-22). The uncertainty around the period-specific FPH estimates is, however, large. Further, the mortality estimates for the period just before and after 2020-22 are very low. While this may result from the stochastic variability in perinatal deaths, it is also possible that there is some displacement of events that artificially inflates the mortality estimates for 2020-22.

--- Figure 2 about here ---

One of the complications with evaluating perinatal mortality data and estimates is the absence of a gold standard measurement for most high mortality settings. As done elsewhere, we therefore revert to an evaluation of the age patterns of mortality to ascertain whether stillbirth and early childhood mortality estimates are plausible. In Table 3, this is done in terms of two ratios: (i) the stillbirth to neonatal mortality rate (NMR) ratio, and (ii) the early neonatal (ENMR) to neonatal mortality rate (NMR) ratio.

The stillbirth to NMR ratio from the FPH instrument in the Malawi RaMMPS (0.63, 95%-CI: 0.41-0.93) is on par with the 2015-16 Malawi DHS. Median values for the stillbirth to NMR across DHS rounds (all countries) with birth/pregnancy histories range from 0.43 to 0.67(16). Estimates of the ratio from population-based prospectively-collected data in LMICs are somewhat higher: 0.83 (95%-CI: 0.78-.89)(32). The TPH instrument estimate of the stillbirth to NMR ratio (1.46, 95%-CI: 0.95-2.33) is considerably higher than empirical estimates that are reported elsewhere.

The ENMR to NMR ratio from the FPH instrument in the Malawi RaMMPS (0.74, 95%-CI: 0.64-0.86) also compares well to the Malawi DHS estimates included in Table 3. Median estimates of this ratio across DHS rounds ranges from 0.69 to 0.81 (16). Again, the TPH estimate is higher than estimates from other sources.

Discussion

We have used –for the first time– mobile phone survey data for estimating perinatal mortality via the Truncated and Full Pregnancy History instruments (TPH and FPH). These questionnaires were adapted from those used in face-to-face surveys, and female respondents (aged 18-49) were randomly allocated to either of these two instruments.

The FPH instrument produces point estimates of the stillbirth (19.38, 95%-CI: 14.03-25.42) and (extended) perinatal mortality rates (49.57, 95%-CI: 41.62-59.43) that are comparable to those published by the UN-IGME and the 2015-16 Malawi DHS. The TPH estimate for the stillbirth rate is considerably higher and less plausible. This is corroborated by the data quality checks in terms of the stillbirth to NMR ratio, which is uncharacteristically high for the TPH instrument. The same holds for the fraction of neonatal deaths that occur in the first week (i.e., the ENMR to NMR ratio). In contrast, the extended perinatal mortality rate estimates for both survey instruments are statistically equivalent and also comparable to the DHS and UN-IGME.

The time gained from administering the shorter TPH instrument –amounting to a difference in the median duration of just over one minute– hardly justifies the use of the truncated survey instrument, so our results support the use of FPH as the preferred questionnaire for measuring perinatal mortality in a mobile phone survey. Further, it is worth noting that the time needed to collect pregnancy histories over the phone (typically less than 5 minutes) was considerably shorter than data collection in a face-to-face survey, for which a mean duration of around 10 minutes has been reported (15). Whether this has repercussions for data quality could not be established, but it is certainly an element that requires further consideration. Factors that might contribute to shorter interview durations in a mobile phone survey are the lower fertility rates among mobile phone owners, and differences in the conversational style in a telephone versus an in-person interview.

Selection bias is a systemic problem in mobile phone surveys, and particularly so in circumstances where mobile phone ownership is not universal and possibly correlated with the outcomes of interest. To minimize or circumvent

this problem, we have (i) used a quota sample with active strata monitoring and (ii) used post-stratification weights to ensure that our sample represents the population of interest on a number of socio-demographic background characteristics. Because we imposed sampling quotas for urban and rural respondents, the application of post-stratification weights produced a relatively small upwards adjustment in the perinatal mortality estimates only. As argued elsewhere, this approach seems suitable for correcting mobile phone-based mortality estimates, but may be insufficient to recover population estimates for indicators (e.g., contraceptive use or fertility) that are an expression of preferences in addition to one's socio-demographic attributes (11, 12).

This study was limited by its relatively small sample size. First, this was driven by the difficulty to identify and reach rural women; a problem that may be less pronounced in populations where mobile phone ownership is higher and the gender divide smaller than in Malawi. Second, we introduced the FPH and the randomized comparison of both survey instruments only during the fourth month of fieldwork, following the publication of another study that suggested shortened (a.k.a. *truncated*) instruments tend to produce biased mortality estimates of under-five mortality (17). Owing to the relatively small sample sizes in this study, it is not possible to draw firm conclusions about mortality differentials over time, or, mortality differentials by the respondent's background characteristics.

Conclusion

Mobile phone surveys are a promising tool for collecting perinatal mortality data where birth and death registration is incomplete, and whenever an alternative to an in-person survey is needed. In comparison to the Truncated Pregnancy History (TPH) instrument, Full Pregnancy Histories (FPH) produce more plausible estimates of both mortality levels and age patterns. Because the additional time needed to collect FPH is marginal, we advocate the use of the latter in future mobile phone surveys.

Declarations

Ethics approval and consent to participate

The study protocol was reviewed Ethics Committee of the London School of Hygiene and Tropical Medicine (reference: 26393/RR/24486) and the University of Malawi Research Ethics Committee (reference: P.07/21/76). All participants provided oral consent for the survey, including consent for storing anonymized data in a public repository and consent to audio record the interview.

Availability of data and materials

Malawi RaMMPS data can be requested via email to the corresponding author or rammps@lshtm.ac.uk. Code to reproduce the results is available from a GitHub repository (https://github.com/rammps-lshtm/RaMMPS_Malawi_perinatal)

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Authors' contributions

GR: conceptualization, funding acquisition, fieldwork supervision, methodology, writing. JRP: conceptualization, methodology, formal analysis and visualisation, data curation, writing. MC: fieldwork supervision, review & editing, data curation. FM: fieldwork supervision, review & editing, data curation. SW: methodology, review & editing. BM: funding acquisition, methodology, review & editing. ES: methodology, review & editing. BD: funding acquisition, fieldwork supervision, review & editing, data curation.

All authors read and approved the final version of the manuscript. GR had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

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Tables

Table 1: Background characteristics of female respondents aged 18-49 in RaMMPS (weighted and unweighted) and the 2015-16 Malawi DHS (all women and the subset of mobile phone owners)

Attributes/Instrument & method :	TPH		FPH		DHS VII	
	<i>weighted</i>	<i>unweighted</i>	<i>weighted</i>	<i>unweighted</i>	<i>all</i>	<i>m. owner</i>
^A Place of residence: urban	18.80 [17.24, 20.50]	37.13 [35.10, 39.13]	17.98 [16.20, 19.56]	37.78 [35.71, 39.96]	18.40 [18.11, 18.69]	35.50 ^A [34.86, 36.10]
^B Region: North	12.28 [10.94, 13.67]	16.96 [15.40, 18.54]	10.83 [9.49, 12.22]	16.49 [14.91, 18.17]	11.68 [11.55, 11.83]	15.04 ^B [14.76, 15.34]
^C Central	40.58 [38.55, 42.75]	36.47 [34.48, 38.47]	44.10 [41.88, 46.48]	37.15 [35.19, 39.21]	42.84 [42.58, 43.10]	41.04 ^C [40.48, 41.62]
^D South	47.05 [44.92, 49.22]	46.53 [44.50, 48.72]	45.01 [42.67, 47.17]	46.31 [44.22, 48.39]	45.48 [45.23, 45.73]	43.91 ^D [43.42, 44.39]
^E Education: less than complete primary	64.90 [62.73, 66.89]	14.64 [13.18, 16.20]	66.01 [63.81, 67.86]	14.33 [12.90, 15.82]	64.65 [63.96, 65.37]	41.78 ^E [40.50, 43.19]
^F incomplete secondary	24.61 [22.79, 26.22]	29.90 [28.06, 31.88]	24.35 [22.58, 26.13]	30.73 [28.62, 32.89]	24.74 [24.07, 25.39]	33.27 ^F [32.02, 34.63]
^G complete secondary or more	10.53 [9.21, 11.81]	55.41 [53.38, 57.44]	9.68 [8.49, 10.93]	54.89 [52.76, 57.09]	10.61 [10.11, 11.09]	24.96 ^G [23.68, 26.10]
^H Household size: 1-4	37.60 [35.55, 39.68]	35.47 [33.54, 37.55]	42.52 [40.41, 44.85]	38.78 [36.67, 40.94]	40.21 [39.43, 41.09]	41.42 ^H [39.88, 42.81]
^I 5-8	55.13 [52.93, 57.13]	54.42 [52.24, 56.47]	51.05 [48.66, 53.19]	52.16 [49.98, 54.48]	52.85 [51.92, 53.66]	51.82 ^I [50.41, 53.40]
^J 9+	7.27 [6.24, 8.46]	10.01 [8.83, 11.38]	6.42 [5.39, 7.50]	9.06 [7.81, 10.26]	6.92 [6.45, 7.44]	6.78 ^J [5.98, 7.61]
^K Electricity: access	13.60 [12.23, 15.21]	52.10 [49.98, 54.18]	12.94 [11.48, 14.29]	53.55 [51.37, 55.80]	13.74 [13.22, 14.25]	30.42 ^K [29.16, 31.70]
^L Observations	2117	2117	2086	2086	21392	8263 ^L

Notes: Both RaMMPS and DHS estimates are reported with bootstrapped 95%-percentile CIs and report the median value of the bootstrap distribution as the point estimate. For the DHS, women were resampled within the same cluster. The distribution of background characteristics for the DHS are given for all women aged 18-49 (the reference for computing the post-stratification weights), and the subset of mobile phone owners.

Table 2: Malawi stillbirth and perinatal mortality rates by source, before and after post-stratification weighting

Instrument/post-stratification	Stillbirth [28w,B)		Perinatal [28w,7d)		Perinatal [28w,28d)	
	<i>weighted</i>	<i>unweighted</i>	<i>weighted</i>	<i>unweighted</i>	<i>weighted</i>	<i>unweighted</i>
^A TPH, 2014.0-2023.6	30.25 [22.20, 40.07]	24.47 [16.88, 33.71]	50.47 [40.43, 61.39]	43.59 [33.57, 55.86]	50.55 [40.52, 61.47]	44.27 ^A [34.25, 56.53]
^B FPH, 2014.0-2023.6	19.38 [14.03, 25.42]	16.06 [10.67, 22.48]	42.00 [34.27, 50.78]	40.45 [30.36, 50.89]	49.57 [41.62, 59.43]	44.50 ^B [34.44, 55.57]
^C DHS VII, 2011.0-2016.0 Women 18-49	13.60 [11.28, 16.06]		33.89 [30.49, 37.83]		38.01 [34.24, 42.14]	^C
^D DHS VII, 2011.0-2016.0 Women 18-49, mobile owners	16.52 [11.83, 21.85]	18.49 [13.08, 24.64]	36.26 [29.03, 43.71]	39.80 [32.06, 47.99]	38.92 [31.65, 46.29]	43.05 ^D [35.55, 51.35]
^E UN IGME, 2019.5	16.15 [14.44, 18.10]				35.96 [29.43, 45.17]	^E
^F UN IGME, 2020.5	16.00 [13.66, 18.68]				35.39 [28.26, 46.12]	^F
^G UN IGME, 2021.5	15.80 [13.04, 19.06]				34.74 [26.81, 46.62]	^G

Notes: DHS estimates were computed for all women aged 18-49, and for the subset of mobile phone owners before and after post-stratification weighting. Both RaMMPS and DHS estimates are reported with bootstrapped 95%-percentile CIs and report the median value of the bootstrap distribution as the point estimate. UN-IGME estimates of perinatal mortality are computed by the authors from the stillbirth mortality rate and the neonatal mortality rate.

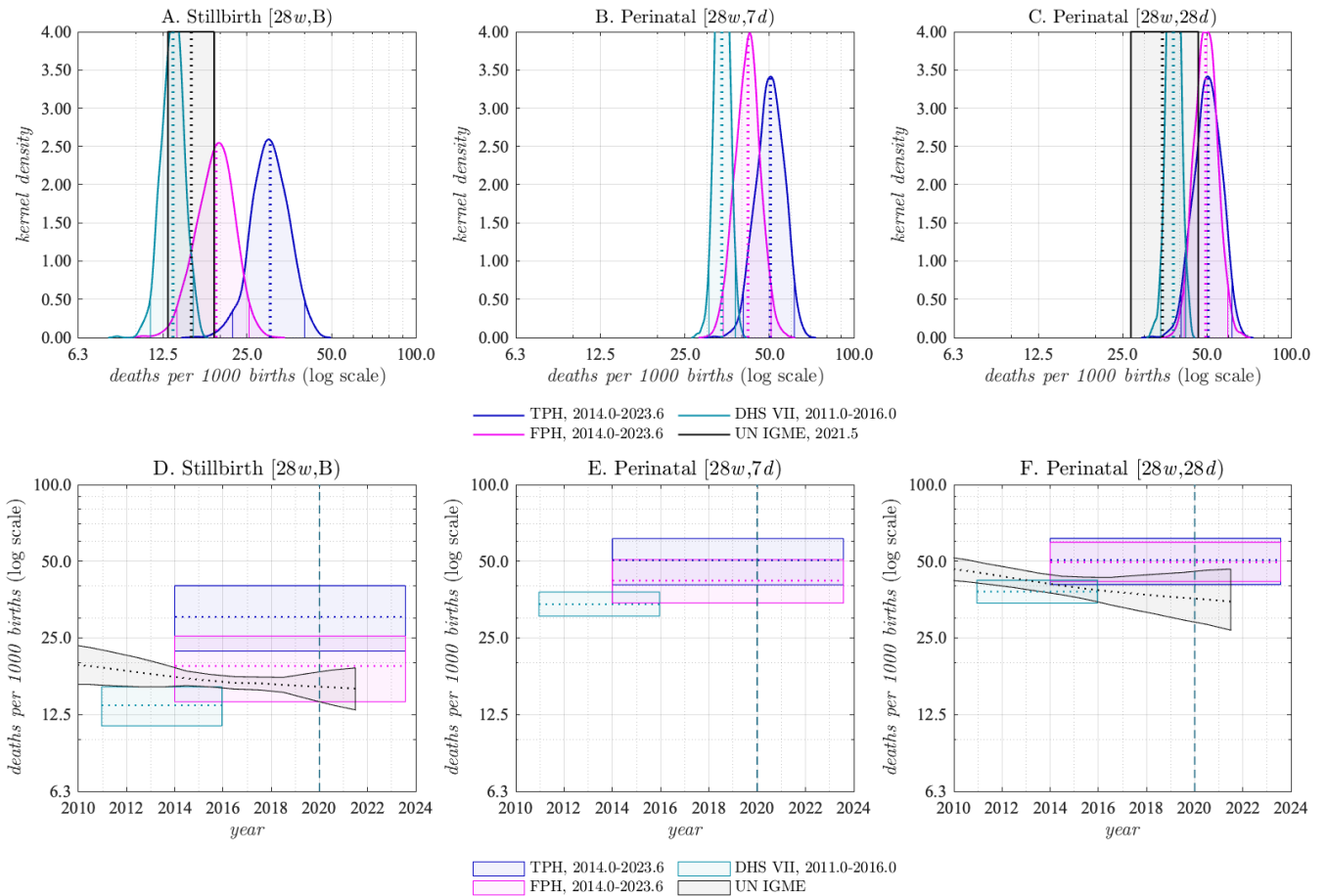
Table 3: Data quality checks: perinatal mortality rate ratios

Instrument/post-stratification	Stillbirth [28w,B)		ENMR - $q(7d)$		NMR - $q(28d)$		Stillbirth/NMR		ENMR/NMR	
	weighted	unweighted	weighted	unweighted	weighted	unweighted	weighted	unweighted	weighted	unweighted
TPH, 2014.0-2023.6	30.25 [22.20, 40.07]	24.47 [16.88, 33.71]	20.55 [14.73, 27.45]	19.38 [12.98, 27.14]	20.64 [14.80, 27.45]	20.08 [13.55, 27.92]	1.46 [0.95, 2.33]	1.23 [0.75, 2.04]	1.00 [0.97, 1.00]	0.97 [0.89, 1.00]
FPH, 2014.0-2023.6	19.38 [14.03, 25.42]	16.06 [10.67, 22.48]	23.05 [16.69, 29.62]	24.62 [17.40, 33.08]	30.96 [23.63, 38.60]	28.85 [21.05, 37.52]	0.63 [0.41, 0.93]	0.56 [0.34, 0.89]	0.74 [0.64, 0.86]	0.86 [0.75, 0.95]
DHS VII, 2011.0-2016.0 Women 18-49	13.60 [11.28, 16.06]		20.62 [18.07, 23.58]		24.78 [21.75, 27.92]		0.55 [0.44, 0.67]		0.83 [0.79, 0.87]	
DHS VII, 2011.0-2016.0 Women 18-49, mobile owners	16.52 [11.83, 21.85]	18.49 [13.08, 24.64]	19.89 [14.59, 25.74]	21.69 [16.47, 27.76]	22.68 [17.23, 28.64]	25.07 [18.95, 31.35]	0.73 [0.48, 1.08]	0.74 [0.50, 1.08]	0.88 [0.81, 0.94]	0.87 [0.80, 0.93]

Notes: 95% Bootstrap confidence intervals.

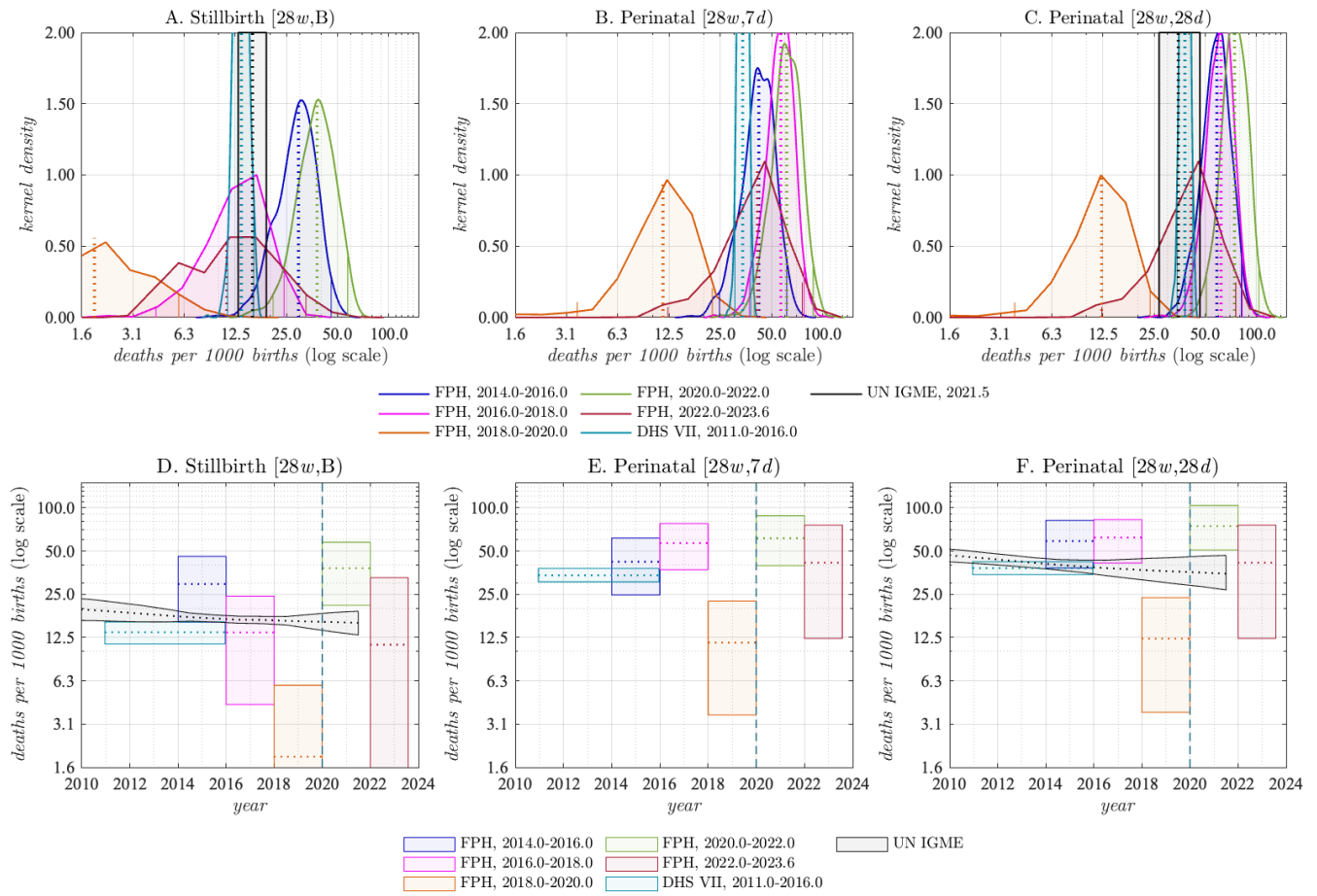
Figures

Figure 1: Stillbirth and the perinatal mortality estimates in the Malawi RaMMPS (by survey instrument) compared with UN-IGME and DHS estimates



Notes: Panels A-C contain the bootstrap distributions of the RaMMPS and DHS perinatal mortality estimates along with estimates from UN-IGME. In panels D-E, the same estimates are plotted on a time scale and are restricted to the 95%-bootstrap CIs. RaMMPS and DHS estimates pertain to all women aged 18-49. The UN-IGME estimates in panels C and F have been computed by the authors using estimates of stillbirth ratios and the neonatal mortality rate, and assuming a log-normal distribution of these parameters. UN-IGME does not publish separate mortality estimates for the first 7 days of life and it is not possible to compute the UN-IGME equivalent for the indicator in panels B and E. UN-IGME estimates are reported with 90% uncertainty bounds.

Figure 2: Stillbirth and the perinatal mortality rates in the Malawi RaMMPS by period (FPH instrument only) compared with UN-IGME and DHS estimates



Notes: See Figure 1.

Supporting Information

SI-1 Pregnancy history instruments used in the Malawi RaMMPS

Starting on 26 May 2022, female respondents of reproductive age were randomly administered a full or truncated pregnancy history questionnaire.

A. Full Pregnancy History (FPH) questions

The FPH questionnaire module, was modelled after the standard questionnaire used in the DHS round VIII and starts with question FPH215. This module was preceded by a number of questions about the modalities for the interview (FPH0a-FPH1d), and a set of summary pregnancy history questions (FPH201-FPH211).

#	Question	Response categories	Filter
FPH0a	Is the respondent still available?	Yes No	EA3
FPH0b	Please select your (enumerator) gender	Male Female	PH1a PH1b
FPH1a	<p>INSTRUCTIONS:</p> <ul style="list-style-type: none"> Introduce the topic and ensure that the respondent is sufficiently comfortable discussing births and pregnancies at this time e.g. "I would now like to discuss the births and pregnancies that you have had in your life. Before we do that, I would like to make sure that you are comfortable discussing this topic with me and where you are right now. If you prefer, I can ask a female colleague of mine to call you back at the time that you choose. This follow-up call should not last for more than 5 minutes." Discuss whether the respondent can move to a location with greater privacy (if relevant) and record whether the respondent wishes to proceed with the interview. <p>Do you wish to proceed with the pregnancy history questions at this time? If not, would you prefer to discuss this topic with a female colleague of mine?</p>	Yes No Need female interviewer	PH2 PH1c Reassign
FPH1b	<p>INSTRUCTIONS:</p> <ul style="list-style-type: none"> Introduce the topic and reassure yourself that the respondent is sufficiently comfortable discussing births and pregnancies at her current location, e.g., "I would now like to discuss the births and pregnancies that you have had in your life. Before we do that, I would like to make sure that you are in a place where you are comfortable discussing this topic." Discuss whether the respondent can move to a location with greater privacy (if need be (and practically feasible) and record whether the respondent wishes to proceed with the interview. <p>Do you wish to proceed with the pregnancy history questions at this present time?</p>	Yes No	PH2
FPH1c	<p>On which day do you prefer that we call you back?</p> <p>INSTRUCTION: A checkbox will allow selection of multiple options. Select as many as apply.</p>	No preference Monday Tuesday Wednesday Thursday Friday Saturday Refuses callback	END
FPH1d	<p>At which time of the day do you prefer that we call you back?</p> <p>INSTRUCTION: A checkbox will allow selection of multiple options. Select as many as applicable.</p> <p>For interviews that are rescheduled with the same enumerator, the call outcome should be classified as INCOMPLETE. If the CASE is assigned to another enumerator, the call outcome should be classified as REASSIGNED.</p>	No preference Before 09:00 9.00-12.00 12.00-14.00 14.00-17.00 17.00-19.00 After 19:00 Refuses callback	END END END END END END END END
FPH201	<p>Now I would like to ask about all the births you have had during your life.</p> <p>Have you ever given birth?</p>	Yes No Refuse	FPH206 FPH210

FPH202	Do you have any sons or daughters to whom you have given birth who are now living with you?	Yes No Refuse	FPH204 FPH204
FPH203a	How many sons live with you?	Number	
FPH203b	How many daughters live with you?	Number	
FPH204	Do you have any sons or daughters to whom you have given birth who are alive but do not live with you?	Yes No Refuse	FPH206 FPH206
FPH205a	How many sons are alive but do not live with you?	Number	
FPH205b	How many daughters are alive but do not live with you?	Number	
FPH206	Have you ever given birth to a boy or girl who was born alive but later died? IF NO, PROBE: Any baby who cried, who made any movement, sound, or effort to breathe, or who showed any other signs of life even if for a very short time.	Yes No Refuse	FPH208 FPH208
FPH207a	How many boys have died?	Number	
FPH207b	How many girls have died?	Number	
FPH208	Just to make sure that I have this right: you have had in total [= 203a + 203b + 205a + 205b + 207a + 207b] births during your life. Is that correct? <i>INSTRUCTION: Please make sure to go back and change where necessary if the respondent doesn't agree with the Total births</i>	Yes No	
FPH210	Women sometimes have a pregnancy that does not result in a live birth. For example, a pregnancy can end in a miscarriage, an abortion, or the child can be born dead. Have you ever had a pregnancy that did not end in a live birth?	Yes No	FPH Check 1
FPH211	How many miscarriages, abortions and stillbirths have you had?	Number	
FPH CHECK 1: Compute the total number of pregnancy outcomes: PO = FPH203a + FPH203b + FPH205a + FPH205b + FPH207a + FPH207b + FPH211 If [PO] = 0: DO Else if PO > 0: continue			

Now I would like to ask a few more questions about each of the pregnancies that you had, starting with the first pregnancy that you had			
Define a pregnancy outcome counter POC=1			
REPEAT QUESTION 215-230 FOR EACH PREGNANCY			
FPH215	Think back to your [first/next] pregnancy. Was that a single or multiple pregnancy?	Single Multiple Don't know	216 216
FPH215b	Were you pregnant with twins, triplets or more?	Number Don't know	MP LOOP
REPEAT QUESTIONS FPH216 TO FH230 FOR EACH BABY IN 215b.			
FPH216	Was the [First/Second...] baby born alive, born dead, or did you have a miscarriage or abortion?	Alive Dead Miscarriage Abortion Don't know	218 229 229 229
FPH217	Did the baby cry, move or breathe?	Yes No Don't know	229 229
FPH218	Was a name given to this baby?	Yes No	219
FPH218b	Write the name	Name	
FPH219	Is/was [NAME/the baby] a boy or a girl?	Boy Girl Don't know	
FPH220	What year was (NAME) born? INSTRUCTION: Please enter -98 if the respondent does not know the year {NAME} was born.	Year	
FPH221	What month was (NAME) born?	January February March April May June July August September	

		October November December Don't know Refuse	
FPH222	What day of {month – FPH221} was {NAME} born?	NUMERIC (1-31)	
FPH224	Is name still alive?	Alive Dead Refuse	228
FPH225	How old was [Name] at a his/her last birthday? INSTRUCTION: record age in completed years (00 for children below the age of 1 year)	Years	FPH CHECK3
FPH228	How old was (NAME) when (he/she) died? INSTRUCTION: record completed days if less than 1 month; completed months if less than two years or completed years if more than two years old.	Days Months Years	
FPH CHECK 2: IF 228 = 12 months OR 1 year à 228a IF 228 != 12 months OR 1 year à 230			
FPH228a	Did (NAME) have his/her first birthday?	Yes No	
FPH228b	Exactly how many months old was (NAME) when (he/she) died? RECORD DAYS IF LESS THAN 1 MONTH; MONTHS IF LESS THAN TWO YEARS; OR YEARS.	Days Months	FPH CHECK 3 FPH CHECK 3
FPH229	What year did the pregnancy end?	Year Don't know	FPH229b
FPH229a	Record the year	Year	
FPH229b	What month did the pregnancy end?	January February March April May June July August September October November December Don't know Refuse	
FPH230	How long did this pregnancy last in weeks OR months INSTRUCTION: record in completed weeks/months	Weeks Months	
FPH Check 3 MPLoop incomplete à FPH216 MPLoop complete à continue to Update POC + FPH Check 4			
Update POC <ul style="list-style-type: none"> • Replace POC= POC + 1 if FPH215= [SINGLE/DK] • Replace POC=POC+ [NUMBER] if FPH215 = MULTIPLE FPH check 4 <ul style="list-style-type: none"> • If POC < PO à FPH215 (next pregnancy) • If POC ≥ PO à FPH Check 5 			
FPH231	Is there any pregnancy that is missing from this list? This could be a pregnancy was not carried to term, a child that is not currently living with you, or a child who passed away.	Yes No Don't know	FPH215 (POC = POC+1) D0 D0

B. Truncated Pregnancy History (TBH) questions

The TBH instrument was also preceded by a number of questions about the interview modalities. These are identical to those used in the FPH instrument (FPH0-FPH1) and not repeated here. The TPH instrument loops through pregnancies in reverse chronological order, starting with the most recent pregnancy and ending whenever the last reported pregnancy's end date was more than 7 years before the survey.

PH10	I would now like to ask you more details about recent pregnancies that you may have had, including pregnancies that did not result in a live birth. Are you currently pregnant?	Yes No Don't know Refuse	PH CHECK 1 PH CHECK 1 PH CHECK 1
PH11	In how many weeks or months do you expect the baby to come?	Months Weeks	
PH CHECK 1: IF (PH10 = NO or PH10 = DK or PH10 =Refuse): PH12 ELSE IF PH10=YES: PH13			
PH12	Have you ever been pregnant?	Yes No Don't know Refuse	PH14a SSH0 SSH0 SSH0
PH13	Have you ever had a pregnancy before the current one?	Yes No Don't know Refuse	PH14b SSH0 SSH0 SSH0
PH14a	I would now like you to think about the last pregnancy that you have had. Was that a single or multiple pregnancy?	Single Multiple Don't know	PH16 PH15 PH16-MP LOOPx1
PH14b	I would now like you to think about the previous pregnancy that you had before the one we just discussed. Was that a single or multiple pregnancy?	Single Multiple Don't know	PH16 PH15 PH16
PH15	Were you pregnant with twins, triplets or more?	Number Don't know	MP LOOP x2
PH15a	How many (twins, triplets, or more?)?	Number	MP LOOP x N
PH16	Was the (first/second/third) baby born alive, born dead, or did you have a miscarriage or abortion?	Alive Dead Miscarriage Abortion Refuse Don't know	PH18 PH25 PH25 PH25
PH17	Did the baby cry, move, or breathe?	Yes No Don't know	PH25 PH25
PH18	Was a name was given to this baby?	Yes No	PH19
PH18a	What is the name?	Name	
PH19	Is/Was [NAME/the baby] a boy or a girl?	Boy Girl Don't know	
PH20	In which month was [NAME/the baby] born?	January February March April May June July August September October November December Don't know	
PH20b	In which year was [NAME/the baby] born?	Year	
PH21	How long did this pregnancy last in weeks or months? INSTRUCTION: record in completed weeks/months	Weeks Months	
PH22	Is [NAME/the baby] still alive?	ALIVE DEAD Refuse	PH24 PH CHECK 2
PH23	How old is [NAME/the baby] today? Hint: {NAME} was born in {birth month}, {birth year}. INSTRUCTION: record days if less than 1 month; completed months if less than two years or completed years if more than two years old.	DAYS MONTHS YEARS	PH23b PH23c

PH24	How old was (NAME) when s/he died? INSTRUCTION: record completed days if less than 1 month; completed months if less than two years or completed years if more than two years old.	DAYS MONTHS YEARS Refuse	PH24b PH24c PS CHECK 2
PH25	In which month did the pregnancy end?	January February March April May June July August September October November December Don't know	
PH25a	In which year did the pregnancy end?	INTEGER (4 digits)	
PH26	How long did this pregnancy last in weeks or months INSTRUCTION: record in completed weeks/months	WEEKS MONTH	
PH CHECK 2: Multiple pregnancy loop incomplete: PH16 Multiple pregnancy loop complete: PH CHECK 3			
PH CHECK 3: Date (interview) – (PH20b or PH25a) ≤ 7 years: PH26loop Date (interview) – (PH20b or PH25a) > 7 years: PH Check 4			
PH26 loop	Have you ever had a pregnancy before the one we just discussed?	Yes No Don't know Refuse	NOTE 1 Continue Continue Continue
PH Check 4: Thank you for providing all these details about your recent pregnancies. I would now quickly like to review these with you. I have so far recorded that you have had the following pregnancies since 2015: INSTRUCTION: Please go back to the table to review, modify or proceed. *Interactive table shows up in SurveyCTO on previous screen and throughout the loops*			
PH27	Is there any pregnancy that is missing from this list? This could be a pregnancy was not carried to term, a child that is not currently living with you, or a child who passed away.	YES NO DK	NOTE 2 END END
NOTE1	INSTRUCTION: Do not read this aloud to the respondent. Add a new group to discuss the pregnancy. <add screenshot of what to do>		Restart loop w/ PH14b

SI-2: Pregnancy history data used in the analyses

Table SI-2: Malawi RaMMPS aggregated pregnancy history data, by survey instrument

Selection Group	TPH		FPH	
	weighted	unweighted	weighted	unweighted
^A Women total number	2117	2117	2086	2086
^B Women reporting events from 01/01/2014 onward	1404.70 [1361.50, 1445.50]	1172.67 [1126.50, 1219.00]	1325.46 [1283.00, 1368.00]	1117.93 [1072.00, 1163.50]
^C Livebirths from 01/01/2014	1749.45 [1677.50, 1820.00]	1475.16 [1400.50, 1546.00]	2062.45 [1980.00, 2147.50]	1604.38 [1524.50, 1684.00]
^D Fetal deaths from 01/01/2014	222.10 [192.00, 256.00]	174.34 [146.00, 203.00]	215.26 [185.00, 248.50]	188.16 [159.50, 218.00]
^E (–) Actual livebirths: breathing, moving, or crying from 01/01/2014	24.97 [15.00, 36.00]	21.91 [13.00, 32.00]	34.93 [24.00, 46.00]	24.93 [16.00, 35.00]
^F (–) Fetal deaths with missing gestation from 01/01/2014	113.15 [92.00, 134.00]	102.25 [81.00, 124.00]	124.10 [101.00, 151.00]	125.30 [101.00, 150.00]
^G (–) Fetal deaths with less than 28 weeks (miscarriages) from 01/01/2014	28.17 [14.00, 44.50]	12.21 [5.00, 21.00]	8.72 [3.00, 15.00]	8.94 [4.00, 15.00]
^H (=) Stillbirths (28 weeks or more) from 01/01/2014	55.82 [40.00, 73.00]	37.97 [26.00, 52.00]	47.50 [35.00, 61.00]	28.99 [19.00, 40.00]
^I (–) Stillbirths (overlapping a birth interval) from 01/01/2014	0.00	0.00	5.98 [1.50, 11.00]	2.02 [0.00, 5.00]
^J (=) Stillbirths (28 weeks or more & clear birth interval) from 01/01/2014	55.82 [40.00, 73.00]	37.97 [26.00, 52.00]	41.52 [30.00, 54.00]	26.98 [18.00, 37.00]
^K Stillbirth Rate (per 1,000 pregnancies) from 01/01/2014	30.25 [22.20, 40.07]	24.47 [16.88, 33.71]	19.38 [14.03, 25.42]	16.06 [10.67, 22.48]

Notes: Reported values correspond to the mean (not median) and the 2.5th and 97.5th percentiles of the Bootstrap distribution. Unweighted counts assume that all women have the same probability of selection, while weighted estimates use the post-stratification weights for resampling purposes.

This table summarizes the pregnancy history data that were used in the analyses. In total, 4,203 women were administered either the full (N=2,086) or truncated (N=2,117) pregnancy history instruments. The analyses reported in this study were restricted to events from the 1 January 2014 onwards, which restricts the effective sample size for the study (row B). Because bootstrapping was used for computing CIs, the totals in rows B-K contain decimals.

The total number of fetal deaths are listed in row D, and the following three rows contain the deductions (e.g., reclassified livebirths, fetal deaths <28 weeks) to arrive at the estimated number of stillbirths. Row I contains the number of reported stillbirths with an implausible pregnancy interval, and these were also dropped from the analyses. The number of stillbirths to compute the stillbirth rate are reported in row J.

SI-3: Sensitivity analyses

In this set of sensitivity analyses, estimates from Table 3 in the manuscript are reproduced with an alternative left censoring date (Table SI-3a) and trimmed post-stratification weights (Table SI-3b).

Table SI-3a is useful to evaluate whether transference of events into or out reference window for the TPH instrument affected estimates.

Post-stratification weights ranged from 0.0213 to 12.5398 (with an average value of 1.0000). The median value for the weights weight is 0.3217 and 95% of the weights are less or equal than 5.7347. Estimates where weights were capped at the value for the 95th percentile of the weight distribution are presented in Table SI-3b.

Table SI-3a: Estimates with left censoring on 1 January 2016

Instrument/post-stratification	Stillbirth [28w,B]		ENMR - $q(7d)$		NMR - $q(28d)$		Stillbirth/NMR		ENMR/NMR	
	weighted	unweighted	weighted	unweighted	weighted	unweighted	weighted	unweighted	weighted	unweighted
TPH, 2016.0-2023.6	35.90 [26.34, 48.03]	26.44 [17.42, 37.19]	19.37 [13.13, 26.39]	18.64 [11.97, 27.12]	19.44 [13.15, 26.49]	19.39 [12.49, 27.97]	1.86 [1.22, 3.07]	1.36 [0.81, 2.41]	1.00 [0.96, 1.00]	0.96 [0.86, 1.00]
FPH, 2016.0-2023.6	16.20 [11.14, 22.43]	16.09 [9.51, 23.67]	25.88 [17.84, 33.94]	18.77 [11.68, 28.00]	31.25 [22.32, 40.03]	21.85 [13.83, 31.22]	0.52 [0.33, 0.84]	0.74 [0.39, 1.35]	0.83 [0.73, 0.93]	0.86 [0.72, 0.97]
DHS VII, 2011.0-2016.0 Women 18-49	13.60 [11.28, 16.06]		20.62 [18.07, 23.58]		24.78 [21.75, 27.92]		0.55 [0.44, 0.67]		0.83 [0.79, 0.87]	
DHS VII, 2011.0-2016.0 Women 18-49, mobile owners	16.52 [11.83, 21.85]	18.49 [13.08, 24.64]	19.89 [14.59, 25.74]	21.69 [16.47, 27.76]	22.68 [17.23, 28.64]	25.07 [18.95, 31.35]	0.73 [0.48, 1.08]	0.74 [0.50, 1.08]	0.88 [0.81, 0.94]	0.87 [0.80, 0.93]

Notes: Estimates are reported with 95% Bootstrap CIs.

Table SI-3b: Estimates with trimmed post-stratification weights

Instrument/post-stratification	Stillbirth [28w,B]		ENMR - $q(7d)$		NMR - $q(28d)$		Stillbirth/NMR		ENMR/NMR	
	weighted	unweighted	weighted	unweighted	weighted	unweighted	weighted	unweighted	weighted	unweighted
TPH, 2014.0-2023.6	31.35 [22.89, 41.16]	24.47 [16.88, 33.71]	19.21 [12.90, 25.64]	19.38 [12.98, 27.14]	19.30 [13.20, 25.67]	20.08 [13.55, 27.92]	1.62 [1.05, 2.57]	1.23 [0.73, 2.04]	1.00 [0.96, 1.00]	0.97 [0.89, 1.00]
FPH, 2014.0-2023.6	15.33 [10.42, 21.14]	16.06 [10.67, 22.48]	23.97 [17.43, 30.97]	24.62 [17.40, 33.08]	30.76 [23.70, 38.68]	28.85 [21.05, 37.52]	0.50 [0.32, 0.75]	0.56 [0.34, 0.89]	0.79 [0.66, 0.88]	0.86 [0.75, 0.95]
DHS VII, 2011.0-2016.0 Women 18-49	13.60 [11.28, 16.06]		20.62 [18.07, 23.58]		24.78 [21.75, 27.92]		0.55 [0.44, 0.67]		0.83 [0.79, 0.87]	
DHS VII, 2011.0-2016.0 Women 18-49, mobile owners	15.54 [11.44, 20.19]	18.49 [13.08, 24.64]	19.78 [14.75, 25.09]	21.69 [16.47, 27.76]	22.76 [17.65, 28.50]	25.07 [18.95, 31.35]	0.68 [0.46, 0.98]	0.74 [0.50, 1.08]	0.87 [0.80, 0.93]	0.87 [0.80, 0.93]

Notes: Estimates are reported with 95% Bootstrap CIs.

SI-4: Stillbirth and perinatal mortality rates by mother's attributes

Tables SI-4a and SI-4b summarize mortality differentials by the background characteristics that are also used as post-stratification weighting variables. As expected, these are suggestive of a social gradient in mortality, but the differences typically fail to reach statistical significance. FPH perinatal mortality estimates are, however, significantly higher for rural areas and for women living in households without electricity (Table SI-4b).

Table SI-4a: Stillbirth rates by mother's attributes; RaMMPS vs. DHS-VII

Instrument/post-stratification	TPH, 2014.0-2023.6		FPH, 2014.0-2023.6		DHS-VII, 2011.0-2016.0		
	<i>weighted</i>	<i>unweighted</i>	<i>weighted</i>	<i>unweighted</i>	<i>All women</i>	<i>MP owners*</i>	<i>MP owners</i>
^a All women	30.25 [22.20, 40.07]	24.47 [16.88, 33.71]	19.38 [14.03, 25.42]	16.06 [10.67, 22.48]	13.60 [11.28, 16.06]	16.52 [11.83, 21.85]	18.49 ^a [13.08, 24.64]
^b Place of residence: urban	51.59 [28.12, 78.70]	36.97 [20.68, 55.18]	11.13 [2.71, 24.06]	14.63 [5.52, 26.24]	17.13 [9.57, 27.03]	22.72 [9.38, 38.93]	21.94 ^b [10.04, 37.14]
^c rural	25.50 [17.40, 34.99]	17.76 [9.77, 28.05]	20.74 [14.79, 27.81]	16.69 [9.77, 24.53]	13.05 [10.69, 15.56]	15.51 [10.34, 21.05]	16.96 ^c [11.34, 23.07]
^d Region: North	11.30 [0.00, 29.96]	19.87 [4.62, 40.00]	25.70 [8.68, 50.89]	29.66 [8.51, 53.85]	16.22 [10.12, 23.03]	7.17 [2.75, 12.82]	10.17 ^d [3.74, 18.25]
^e Central	28.74 [17.34, 43.26]	29.13 [16.44, 46.67]	33.45 [23.53, 45.67]	20.30 [9.90, 32.09]	16.42 [12.05, 21.25]	19.59 [10.71, 29.46]	25.67 ^e [15.11, 38.49]
^f South	34.81 [22.58, 49.15]	22.19 [11.45, 34.86]	3.97 [0.96, 8.17]	8.63 [2.57, 15.30]	10.27 [7.74, 12.95]	15.79 [9.63, 24.26]	14.65 ^f [8.75, 22.28]
^g Education: less than complete secondary	31.54 [22.60, 42.01]	28.38 [17.08, 41.92]	19.85 [14.07, 26.16]	16.41 [8.77, 25.47]	12.89 [10.58, 15.29]	15.66 [10.77, 21.43]	16.91 ^g [11.41, 23.42]
^h complete secondary or more	13.89 [0.00, 38.76]	20.37 [11.11, 31.38]	13.70 [0.00, 36.54]	15.45 [6.99, 25.99]	22.44 [9.95, 38.77]	26.03 [10.15, 48.42]	24.44 ^h [10.50, 41.87]
ⁱ Electricity: access	25.06 [5.42, 51.02]	26.65 [15.80, 40.86]	5.78 [0.00, 25.14]	12.93 [5.21, 22.71]	21.78 [11.96, 34.73]	16.21 [5.90, 29.73]	19.98 ⁱ [7.57, 36.46]
^j no access	30.88 [22.07, 41.24]	22.41 [12.54, 34.84]	20.47 [14.72, 26.92]	18.66 [10.58, 29.26]	12.73 [10.42, 15.24]	16.56 [11.41, 22.31]	17.95 ^j [12.24, 24.19]

Notes: Estimates are reported with 95% Bootstrap CIs. * weighted estimates using the subsample of mobile phone owners

Table SI-4b: Perinatal mortality rates by mother's attributes, RaMMPS vs. DHS-VII

Instrument/post-stratification	TPH, 2014.0-2023.6		FPH, 2014.0-2023.6		DHS-VII, 2011.0-2016.0		
	<i>weighted</i>	<i>unweighted</i>	<i>weighted</i>	<i>unweighted</i>	<i>All women</i>	<i>MP owners*</i>	<i>MP owners</i>
^a All women	50.47 [40.43, 61.39]	43.59 [33.57, 55.86]	42.00 [34.27, 50.78]	40.45 [30.36, 50.89]	33.89 [30.49, 37.83]	36.26 [29.03, 43.71]	39.80 ^a [32.06, 47.99]
^b Place of residence: urban	62.55 [37.55, 91.89]	51.61 [32.46, 73.91]	15.31 [3.10, 30.23]	29.20 [16.50, 45.16]	40.22 [28.57, 54.04]	48.73 [29.98, 70.13]	47.29 ^b [31.30, 66.99]
^c rural	47.74 [36.51, 59.72]	39.04 [27.91, 52.04]	46.82 [38.21, 56.76]	45.40 [33.46, 59.00]	32.93 [29.51, 36.75]	33.95 [26.59, 41.63]	36.54 ^c [28.95, 44.72]
^d Region: North	16.14 [0.00, 37.19]	24.29 [7.98, 45.96]	58.92 [29.68, 94.25]	68.55 [37.51, 102.96]	31.73 [24.12, 40.57]	26.37 [17.11, 37.91]	29.41 ^d [18.76, 42.67]
^e Central	55.99 [39.82, 75.60]	53.45 [34.55, 75.17]	48.11 [35.78, 63.25]	39.07 [23.03, 56.19]	39.87 [34.10, 46.93]	40.67 [27.82, 53.70]	50.20 ^e [34.82, 65.14]
^f South	52.43 [37.74, 68.55]	42.17 [28.71, 58.99]	32.10 [20.60, 44.10]	32.23 [19.39, 45.67]	28.94 [24.56, 33.43]	34.72 [24.52, 45.22]	34.20 ^f [25.52, 44.48]
^g Education: less than complete secondary	51.38 [40.73, 62.78]	49.39 [35.58, 66.82]	42.34 [34.73, 51.93]	42.02 [30.14, 56.31]	32.86 [29.55, 36.67]	35.62 [27.98, 43.47]	38.54 ^g [30.89, 46.95]
^h complete secondary or more	36.55 [8.21, 70.10]	36.81 [23.75, 51.15]	34.22 [7.34, 71.89]	38.45 [23.15, 54.84]	48.39 [29.88, 68.34]	42.28 [22.75, 65.22]	44.43 ^h [25.28, 65.68]
ⁱ Electricity: access	51.39 [22.65, 90.81]	47.10 [31.59, 66.07]	22.11 [4.61, 48.93]	34.86 [20.61, 49.28]	47.97 [32.58, 65.97]	41.05 [24.76, 61.17]	44.03 ⁱ [28.26, 64.60]
^j no access	50.17 [39.44, 62.00]	40.39 [27.40, 55.63]	43.89 [35.91, 53.18]	45.19 [32.46, 59.20]	32.59 [29.14, 36.40]	35.67 [27.61, 43.45]	38.52 ^j [30.16, 46.90]

Notes: Estimates are reported with 95% Bootstrap CIs. * weighted estimates using the subsample of mobile phone owners

SI-5: Trends in stillbirth and perinatal mortality

Table SI-5: Trends in stillbirth and perinatal mortality estimates

Instrument/post-stratification	Stillbirth [28w,B)		Perinatal [28w,7d)		Perinatal [28w,28d)	
	<i>weighted</i>	<i>unweighted</i>	<i>weighted</i>	<i>unweighted</i>	<i>weighted</i>	<i>unweighted</i>
^A TPH, 2014.0-2016.0	0.00 [0.00, 7.07]	14.60 [3.56, 31.77]	28.54 [12.58, 49.02]	36.51 [16.63, 64.56]	28.54 [12.58, 49.02]	36.51 ^A [16.63, 64.56]
^B TPH, 2016.0-2018.0	15.42 [6.17, 27.69]	21.96 [8.68, 38.74]	24.27 [12.33, 39.55]	38.74 [22.13, 60.30]	24.27 [12.33, 39.55]	38.74 ^B [22.13, 60.30]
^C TPH, 2018.0-2020.0	6.84 [0.00, 15.00]	15.67 [5.12, 29.89]	34.54 [19.54, 52.13]	29.30 [13.45, 46.75]	34.82 [19.69, 52.49]	32.11 ^C [16.02, 50.39]
^D TPH, 2020.0-2022.0	50.62 [29.27, 73.99]	25.14 [10.84, 44.05]	75.10 [50.75, 103.67]	41.71 [20.39, 68.87]	75.10 [50.75, 103.67]	41.71 ^D [20.39, 68.87]
^E TPH, 2022.0-2023.6	108.70 [64.16, 160.89]	57.59 [27.16, 95.24]	119.78 [73.42, 171.86]	91.25 [53.52, 135.13]	119.78 [73.42, 171.86]	91.25 ^E [53.52, 135.13]
^F FPH, 2014.0-2016.0	29.47 [16.00, 45.96]	16.44 [5.29, 31.29]	42.10 [24.73, 61.47]	61.11 [37.71, 87.97]	58.52 [38.06, 81.69]	69.03 ^F [44.86, 96.68]
^G FPH, 2016.0-2018.0	13.57 [4.27, 24.24]	16.30 [5.48, 30.60]	56.75 [37.11, 77.68]	41.36 [20.02, 67.25]	62.01 [41.23, 82.65]	46.86 ^G [24.55, 73.45]
^H FPH, 2018.0-2020.0	1.86 [0.00, 5.81]	6.90 [0.00, 15.91]	11.52 [3.61, 22.45]	18.44 [6.78, 33.15]	12.28 [3.77, 23.68]	20.92 ^H [7.38, 35.74]
^I FPH, 2020.0-2022.0	37.95 [20.91, 57.51]	25.07 [8.84, 43.22]	61.40 [39.57, 87.88]	41.73 [22.89, 65.52]	74.49 [50.87, 103.59]	44.80 ^I [24.71, 68.88]
^J FPH, 2022.0-2023.6	11.14 [0.00, 32.61]	17.96 [0.00, 43.75]	41.43 [12.31, 75.74]	43.07 [12.29, 85.22]	41.43 [12.31, 75.74]	43.07 ^J [12.29, 85.22]
^K UN IGME, 2019.5	16.15 [14.44, 18.10]				35.96 [29.43, 45.17]	^K
^L UN IGME, 2020.5	16.00 [13.66, 18.68]				35.39 [28.26, 46.12]	^L
^M UN IGME, 2021.5	15.80 [13.04, 19.06]				34.74 [26.81, 46.62]	^M

Note: RaMMPS TPH and FPH estimates are reported with 95% Bootstrap CIs. UN-IGME estimates of perinatal mortality are computed by the authors using the stillbirth mortality rate and the neonatal mortality rate. UN-IGME reports 90% confidence bounds