Maternal mortality and distance to facility-based obstetric care in rural southern Tanzania: a secondary analysis of cross-sectional census data in 226 000 households

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Summary

Background **Access to skilled obstetric delivery and emergency care is deemed crucial for reducing maternal mortality. We assessed pregnancy-related mortality by distance to health facilities and by cause of death in a disadvantaged rural area of southern Tanzania.**

Methods **We did a secondary analysis of cross-sectional georeferenced census data collected from June to October, 2007, in five rural districts of southern Tanzania. Heads of georeferenced households were asked about household deaths in the period June 1, 2004, to May 31, 2007, and women aged 13–49 years were interviewed about birth history in the same time period. Causes of death in women of reproductive age were ascertained by verbal autopsy. We also asked for sociodemographic information. Multilevel logistic regression was used to analyse the effects of distance to health facilities providing delivery care on pregnancy-related mortality (direct and indirect maternal and coincidental deaths).**

Findings **The study included 818 583 people living in 225 980 households. Pregnancy-related mortality was high at 712 deaths per 100 000 livebirths, with haemorrhage being the leading cause of death. Deaths due to direct causes of maternal mortality were strongly related to distance, with mortality increasing from 111 per 100 000 livebirths among women who lived within 5 km to 422 deaths per 100 000 livebirths among those who lived more than 35 km from a hospital (adjusted odds ratio 3·68; 95% CI 1·37–9·88). Neither pregnancy-related nor indirect maternal mortality was associated with distance to hospital. Among women who lived within 5 km of a hospital, pregnancy-related mortality was 664 deaths per 100 000 livebirths even though 72% gave birth in hospital and 8% had delivery by caesarean section.**

Interpretation **Large distances to hospital contribute to high levels of direct obstetric mortality. High pregnancy-related mortality in those living near to a hospital suggests deficiencies in quality of care.**

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See Comment page e346

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Introduction

A reduction in maternal mortality by 75% between 1990 and 2015 was the fifth Millennium Development Goal, and maternal survival is deemed an important measurement of poverty reduction. Worldwide, maternal deaths have declined by 45% per year since 1990, with the estimated number in 2013 being 289 000. Nevertheless, in sub-Saharan Africa alone, 179 000 women die each year during pregnancy and childbirth.[1]

Maternal mortality includes two groups of related deaths: direct obstetric causes, including haemorrhage and eclampsia, and indirect causes, such as malaria, HIV, and anaemia, that might be aggravated in pregnancy. The term pregnancy-related deaths includes all deaths during pregnancy, childbirth, and the postpartum period, irrespective of cause.[1] Conceptualisation of reasons and causes of maternal mortality has been based on the road-to-death framework, which highlights that multiple factors along a chain of events lead to maternal deaths, and that these are likely to be different for direct and indirect causes of death.[2]

Strategies to reduce maternal mortality have involved multiple approaches but with the main goals of improving access to a skilled attendant[3] and emergency obstetric care.[4,5] Although it seems obvious that access to professional care during childbirth should reduce maternal mortality, the evidence from observational studies on the effect of the presence of a skilled attendant at birth is difficult to interpret as women with complications are more likely to access skilled care.[6] Thus any association is biased in places where facility delivery is low. Intervention studies are rare and do not provide conclusive evidence.[7] One indirect way to assess the role of professional care during childbirth in reducing maternal mortality is to assess maternal mortality by distance to a health facility as complications should less bias this effect. Women who live near to a health facility are more likely to give birth there than those who live further away[8] and, therefore, might be expected to have lower mortality.

However, results from the few population-based studies that have investigated this effect, although adjusted for sociodemographic factors, provide contradictory results.[9–11] By contrast, the evidence for the effect of distance to care and child health is stronger. Mortality among children, infants, and neonates increases with increasing distance from health facilities,[12] although not in all settings, among them Kenya and Malawi.[13,14]

Tanzania is committed to reducing maternal mortality[15] and policies are focused on increasing the availability to and quality of childbirth care,[16] but maternal mortality remains high. According to the 1996, 2004, and 2010 Demographic and Health Surveys, the maternal mortality ratios were 529, 578, and 454 per 100 000 livebirths, respectively, with wide CIs.[17,18] Estimates from WHO and the Institute for Health Metrics and Evaluation for 2013 are, respectively, 410 and 390 (95% CI 267–549) deaths per 100 000 livebirths.[1,19] In Tanzania in 2011, 51% of all women gave birth in a health facility, and the proportion delivering by caesarean section was 4·5%.[18]

We analysed pregnancy-related mortality and direct and indirect maternal mortality by distance to hospitals and other health facilities offering delivery care. By separating direct and indirect maternal deaths, we aimed to elucidate the mechanisms through which access to facilities affect pregnancy-related mortality.

Methods

Population

We did secondary analysis of cross-sectional census data collected through a georeferenced household survey in 2007 in the regions of Lindi (Lindi Rural, Nachingwea, and Ruangwa districts) and Mtwara (Newala and Tandahimba districts) in southern Tanzania (total population around 850 000). The study area is described in detail elsewhere.[20,21] Briefly, the population is disadvantaged,[18] having no well established local industry. Cashew nuts comprise the main cash crop, but income is unreliable. In 2009, the area was served by a dense network of public or mission health facilities, which together provided six hospitals, 13 health centres, and 143 dispensaries, plus two hospitals just outside the area.[22] In this study we included any type of facility that offered intrapartum care. None of the health centres or dispensaries provided all seven basic emergency obstetric care functions of administering parenteral antibiotics, uterotonic drugs, and anticonvulsants, manual removal of placenta, removal of retained products, assisted vaginal deliveries, and neonatal resuscitation. Ambulance services were inadequate because human and financial resources limited their operational ability. Hospitals provided caesarean section and blood transfusions but other emergency obstetric interventions were not consistently implemented.[22] HIV prevalence in 2008 was 4·0% in Lindi region and 2·7% in Mtwara region.[23] Malaria is highly endemic, although parasite prevalence in infants aged 2–11 months dropped from 57% in 2004 to 19% in 2007.[24] Reproductive health services are provided without charge in public facilities, but quality is constrained by inadequate staffing and a weak health system.[25] In Newala, Tandahimba, and Ruangwa 95% and in Lindi Rural 75% of the population live within 30 km of a hospital, and in Nachingwea 5% of the population live more than 70 km from a hospital.[26]

Survey

The census method is described elsewhere.[24] In brief, 200 field staff who were trained for 3 weeks visited every household between the end of June and the end of October, 2007, after obtaining updated population and household lists from village leaders. Quality-control measures included logical checks and skip patterns, accompanied interviews, repeat interviews, and daily reports to check data completeness and consistency.

We used a modular questionnaire that included established sequences of questions as used in Demographic and Health surveys and similar assessment tools. The household module was used to gather sociodemographic information for all members of the household and information on household assets, with ownership of a radio, bicycle, telephone, and animals and housing characteristics used as proxy markers of household wealth. All women of reproductive age

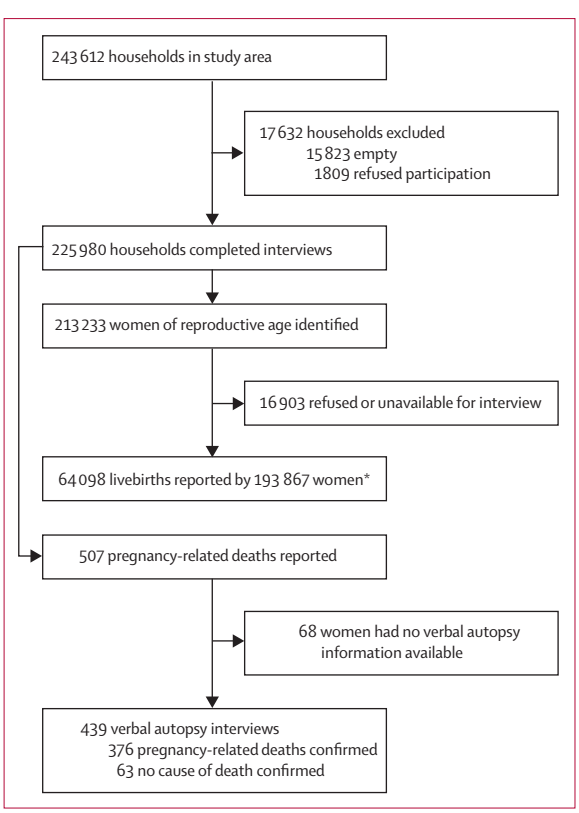

***Figure 1*: Study profile**
*22 243 livebirths were in the year before the census.

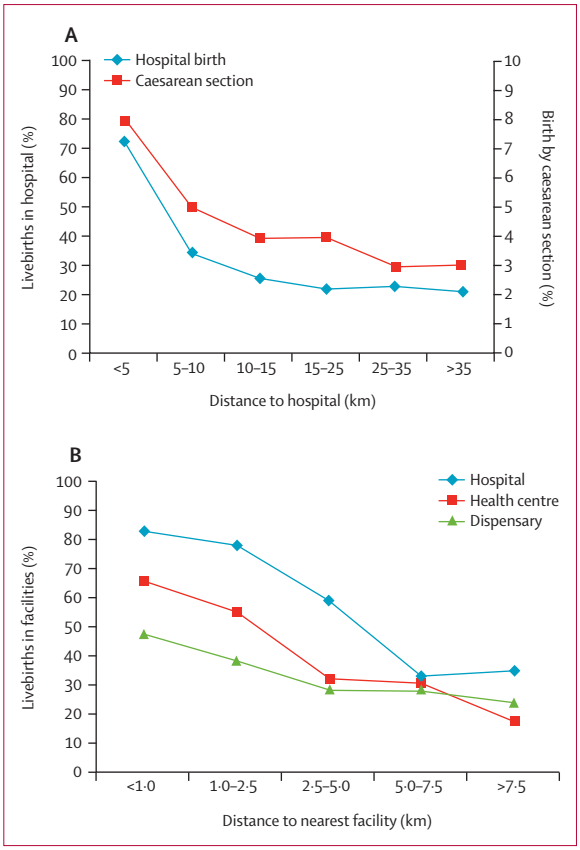

***Figure 2*: Relations between distance and livebirths and caesarean sections**
Based on the 22 243 livebirths in the year before the study. (A) Distance to nearest hospital. (B) Distance to nearest facility if a hospital, health centre, or dispensary.

	Number of deaths ([%] n=376)
Direct maternal deaths	
Antepartum/postpartum haemorrhage	86 (23%)
Eclampsia	23 (6%)
Puerperal sepsis	16 (4%)
Abortion complication	11 (3%)
Obstructed labour	9 (2%)
Tetanus	1 (0·3%)
Other	16 (5%)
All	162 (43%)
Indirect maternal deaths	
Malaria	31 (8%)
Anaemia	27 (7%)
AIDS or tuberculosis	20 (5%)
Cardiovascular disease	1 (0·3%)
Cervical cancer	1 (0·3%)
Other	15 (4%)
All	95 (25%)
Coincidental deaths	
Injuries or accidents	2 (1%)
Unknown cause of death	
Undetermined*	8 (2%)
Unresolved†	109 (29%)
All	117 (31%)

*Term used for deaths that two physicians could not determine on the basis of the available information. †Term used when three physicians could not agree on cause of death.

***Table 1*: Causes of pregnancy-related deaths confirmed by verbal autopsy**

(13–49 years) were asked about livebirths in the previous 5 years, including dates of birth. For all livebirths within 1 year before the census we also recorded the place and mode of delivery.

The household head was asked whether any deaths had occurred in the household since Jan 1, 2004, to June 30, 2007, and, if so, the age, sex, and date of death of the person or people who had died. For women of reproductive age who had died, we asked whether the death occurred during pregnancy, childbirth, or within 2 months after childbirth. Households with a pregnancy-related death were visited by a separate team of four interviewers who did verbal autopsy interviews based on a standard questionnaire.[27] Two physicians independently assigned causes of death based on a shortlist of items from the International Classification of Disease, tenth revision.[28] If they could not agree on a cause of death, a third physician was asked to give an independent opinion. If all three physicians could not agree, the cause of death was defined as unresolved.

Ethics approval

We obtained ethics approval from the institutional review boards of the London School of Hygiene and Tropical Medicine, London, UK, the Ifakara Health Institute, Dar es Salaam, Tanzania, the Ethics Commission of the Cantons of Basel-Stadt and Basel-Land, Basel, Switzerland, and the Medical Research Coordinating Committee of the National Institute of Medical Research in Tanzania through the Tanzanian Commission of Science & Technology, Dar es Salaam. Written informed consent was obtained from household heads and from bereaved relatives interviewed for the verbal autopsy questionnaires.

Definition of variables

The pregnancy-related mortality ratio was defined as the number of pregnancy-related deaths reported by the household head between June 1, 2004, and May 31, 2007, divided by the number of livebirths reported in the same period. 9% of women were unavailable for the interview and, therefore, we adjusted the number of livebirths in the denominator by multiplying the number of women with missing data by the age-standardised birth rate for interviewed women. Causes of death were classified as direct (obstetric), indirect (aggravated during pregnancy), coincidental (injuries or accidents), or unknown.[29]

	Number of deaths ([%] n=507)	Number of livebirths ([%] n=64 098)	Deaths per 100 000 livebirths*	Crude OR (95% CI)†	Adjusted OR (95% CI)†‡
Distance to hospital (km)					
<5	42 (8%)	5632 (9%)	664	1·00	1·00
5–10	60 (12%)	6938 (11%)	783	1·12 (0·72–1·76)	1·02 (0·64–1·62)
10–15	72 (14%)	10 782 (17%)	602	0·89 (0·57–1·38)	0·78 (0·50–1·24)
15–25	137 (27%)	20 798 (32%)	592	0·86 (0·57–1·29)	0·75 (0·49–1·15)
25–35	104 (21%)	10 237 (16%)	918	1·28 (0·83–1·97)	1·14 (0·72–1·80)
>35	37 (7%)	3475 (5%)	976	1·40 (0·82–2·36)	1·14 (0·65–2·00)
Missing	55 (11%)	6236 (10%)	787	1·11 (0·70–1·77)	1·06 (0·66–1·72)
Per 1 km increase	..	..	..	1·01 (1·00–1·02)	1·01 (1·00–1·01)
District					
Lindi Rural	170 (34%)	16 032 (25%)	959	1·00	1·00
Nachingwea	98 (19%)	12 757 (20%)	705	0·75 (0·56–1·01)	0·82 (0·58–1·16)
Ruangwa	63 (12%)	9022 (14%)	634	0·69 (0·49–0·97)	0·75 (0·50–1·10)
Newala	83 (16%)	11 978 (19%)	620	0·67 (0·48–0·92)	0·85 (0·58–1·23)
Tandahimba	93 (18%)	14 309 (22%)	573	0·64 (0·47–0·86)	0·90 (0·62–1·31)
Ethnic group					
Makonde	254 (50%)	34 334 (54%)	661	1·00	1·00
Mwera	172 (34%)	20 309 (32%)	771	1·18 (0·94–1·48)	1·17 (0·86–1·60)
Makua	25 (5%)	3191 (5%)	710	1·05 (0·68–1·62)	1·02 (0·62–1·68)
Yao	27 (5%)	2414 (4%)	1015	1·48 (0·98–2·24)	1·55 (0·98–2·43)
Other	29 (6%)	3850 (6%)	681	0·99 (0·66–1·50)	0·94 (0·59–1·51)
Wealth quintile§					
Most poor	87 (17%)	10 120 (16%)	796	1·00	1·00
Very poor	90 (18%)	11 373 (18%)	723	0·92 (0·70–1·26)	0·96 (0·71–1·29)
Poor	101 (20%)	13 196 (21%)	692	0·89 (0·67–1·19)	0·93 (0·70–1·29)
Less poor	103 (20%)	13 528 (21%)	682	0·90 (0·68–1·20)	0·95 (0·71–1·28)
Least poor	89 (18%)	13 454 (21%)	581	0·79 (0·58–1·07)	0·91 (0·66–1·24)
Missing	39 (7%)	2417 (4%)	1317	..	..
Per quintile increase	..	..	..	0·95 (0·89–1·02)	0·98 (0·92–1·06)
Education of household head					
None	162 (32%)	15 887 (25%)	916	1·00	1·00
Some primary	130 (26%)	11 293 (18%)	1021	1·16 (0·92–1·46)	1·27 (0·99–1·63)
Completed primary	201 (40%)	34 425 (54%)	529	0·59 (0·48–0·73)	0·69 (0·54–0·86)
Secondary or higher	3 (1%)	491 (1%)	514	0·62 (0·20–1·97)	0·78 (0·24–2·52)
Missing	11 (2%)	2002 (3%)	507	..	..
Per 1 year increase	..	..	..	0·93 (0·91–0·96)¶	0·95 (0·92–0·98)¶

OR=odds ratio. *Number of livebirths adjusted to 71 198 in mortality ratio calculation by multiplying the number of women unavailable for interview by the age-standardised birth rate among interviewed women. †Calculated with multilevel logistic regression specifying ward and subvillage levels; intercluster correlation coefficients were 3% and 11%, respectively. ‡Adjusted for district, ethnic group, wealth, and education of household head. §Based on ownership of a radio, a bicycle, a telephone, and animals and housing characteristics as proxy markers of relative household wealth. ¶p<0·0001.

***Table 2*: Association between pregnancy-related mortality reported in census and distance to hospital and socioeconomic variable**

The geographical locations of households were mapped with a global positioning system (GPS) receiver by fieldworkers who visited all households on the day before the census interviews. Locations of health facilities were available from a health facility census done in 2009.[25] We calculated straight-line distances between each household and the nearest hospital or health facility providing delivery care with the nearstat command in Stata 12 (version 12.1). If GPS data were unavailable, we used the median coordinates of the data from other nearby subvillage-level households (a subvillage is a cluster with typically 90 households spread over a 400 m radius) to estimate positions of missing households. For houses that had missing data after this process, we did not impute missing distances as no association was seen between missing data and maternal mortality.[30] A sensitivity analysis was done by comparing results of the distance analysis for houses with missing coordinates before and after positions were imputed.

	Direct maternal mortality (n=162)				Indirect maternal mortality (n=95)			
	Number of deaths (%)	Deaths per 100 000 livebirths*	Crude OR (95% CI)†	Adjusted OR (95% CI)†‡	Number of deaths (%)	Deaths per 100 000 livebirths*	Crude OR (95% CI)†	Adjusted OR (95% CI)†‡
<5 km	7 (4%)	111	1·00	1·00	10 (11%)	158	1·00	1·00
5–10 km	14 (9%)	183	1·61 (0·63–4·14)	1·69 (0·63–4·53)	12 (13%)	157	0·98 (0·41–2·33)	0·69 (0·26–1·83)
10–15 km	25 (15%)	209	1·89 (0·78–4·47)	1·94 (0·77–4·88)	9 (10%)	75	0·47 (0·18–1·18)	0·39 (0·14–1·05)
15–25 km	49 (30%)	212	1·93 (0·84–4·47)	1·84 (0·76–4·44)	25 (26%)	108	0·67 (0·31–1·42)	0·56 (0·25–1·28)
25–35 km	31 (19%)	274	2·45 (1·03–5·87)	2·63 (1·06–6·53)	23 (24%)	203	1·24 (0·57–2·70)	0·83 (0·18–2·22)
>35 km	16 (10%)	422	3·74 (1·44–9·70)	3·68 (1·37–9·88)	5 (5%)	132	0·81 (0·27–2·46)	0·63 (0·18–2·49)
Missing	20 (12%)	286	..	..	11 (12%)	157	..	..
Per 1 km increase	..	..	1·01 (1·00–1·03)	1·01 (1·00–1·03)	..	..	1·00 (0·99–1·02)	1·00 (0·98–1·02)

OR=odds ratio. *Number of livebirths adjusted from 64 098 to 71 198 in mortality ratio calculation by multiplying the number of women unavailable for interview by the age-standardized birth rate among interviewed women. †Calculated with multilevel logistic regression specifying ward and subvillage levels. ‡Adjusted for district, ethnic group, wealth, and education of the household head.

***Table* 3: Associations between direct and indirect maternal mortality and distance to hospital**

We created an index of household wealth based on the weighted sums of household assets and characteristics. The weights were generated with principal components analysis and separated into quintiles.[31] Information on education was missing for many deceased women and, therefore, we assigned household level of education according to the number of years the head was in full-time education.

Statistical analysis

The primary aim was to describe pregnancy-related mortality by distance to health facilities for the study period (June 1, 2004, to May 31, 2007). We also calculated the proportions of livebirths in health facilities and the proportion of livebirths delivered by caesarean section in the year before the census (June 1, 2006, to May 31, 2007), categorised by distance to the nearest facility providing delivery care. We calculated the ratio of pregnancy-related mortality to livebirths for the whole study period (June 1, 2004, to May 31, 2007). We used multilevel logistic regression to calculate separately crude and adjusted odds ratios (ORs) and 95% CIs of the effect of distance to hospital and distance to any facility providing delivery care on pregnancy-related, direct, and indirect maternal mortality, taking into account clustering of livebirths at the subvillage and ward levels. Data were available for wealth, ethnic group, district, and education of the head of the household for all deaths and livebirths. Maternal age was not associated with distance and, therefore, was not included in this study. We tested for interaction between district, wealth, ethnic group, and education, but none of the interaction terms reached significance. Analyses were done with Stata/IC, version 12.1

Role of the funding source

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

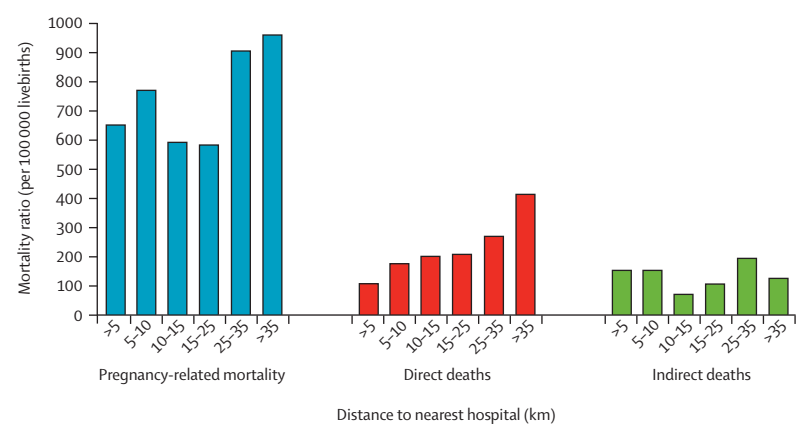

***Figure* 3: Pregnancy-related, direct maternal, and indirect maternal mortality ratios by distance to hospital**

Results

Of 243 612 households in the five districts, interviews were done in 225 980 (figure 1) with a population of 818 583 individuals. Data were complete for district and ethnic group, but were missing for distance for 6291 (10%), for wealth for 2456 (4%), and for education of household head for 2013 (3%) of the 64 605 births and deaths included in the study. We identified 213 233 women of reproductive age among whom interviews on births in the previous 5 years were completed for 193 867 (91%). 64 098 livebirths were reported between June 1, 2004, and May 31, 2007. After adjustment for the 9% of women unavailable for birth history interviews, this number increased to 71 198.

Of the 22 243 livebirths reported in the 1 year before the census, 6475 (29%) were delivered in a hospital, 2571 (12%) in primary facilities (dispensaries or health centres), and 13 197 (59%) at home. 913 (4%) women had

	Pregnancy-related mortality (n=507)			Direct maternal mortality (n=162)			Indirect maternal mortality (n= 95)		
	Number of deaths (%)	Crude OR (95% CI)*	Adjusted OR (95% CI)*†	Number of deaths (%)	Crude OR (95% CI)*	Adjusted OR (95% CI)*†	Number of deaths (%)	Crude OR*	Adjusted OR*
<1·0 km	150 (30%)	1·00	1·00	44 (27%)	1·00	1·00	31 (32%)	1·00	1·00
1·0–2·5 km	78 (16%)	0·85 (0·63–0·14)	0·86 (0·63–1·17)	20 (12%)	0·76 (0·45–1·30)	0·79 (0·45–1·38)	16 (17%)	0·83 (0·44–1·54)	1·01 (0·52–1·98)
2·5–5·0 km	127 (25%)	0·84 (0·65–1·08)	0·86 (0·66–1·12)	44 (27%)	0·98 (0·64–1·50)	0·99 (0·63–1·54)	25 (26%)	0·78 (0·45–1·34)	0·90 (0·50–1·64)
5·0–7·5 km	74 (15%)	0·96 (0·71–1·29)	1·01 (0·74–1·39)	25 (15%)	1·07 (0·64–1·79)	1·07 (0·62–1·82)	8 (8%)	0·52 (0·24–1·16)	0·66 (0·29–1·51)
>7·5 km	23 (5%)	0·78 (0·49–1·25)	0·76 (0·45–1·24)	9 (6%)	1·05 (0·50–2·20)	1·13 (0·53–2·41)	4 (4%)	0·68 (0·23–1·98)	0·94 (0·31–2·85)
Missing	55 (11%)	..	..	20 (12%)	..	..	11 (12%)	..	..
Per 1·0 km increase	..	0·98 (0·94–1·02)	0·99 (0·95–1·03)	..	1·00 (0·94–1·08)	1·00 (0·94–1·08)	..	0·93 (0·85–1·02)	0·96 (0·87–1·06)

OR=odds ratio. *Calculated with multilevel logistic regression specifying ward and subvillage levels. †Adjusted for district, ethnic group, wealth, and education of household head.

Table 4: **Associations between pregnancy-related, direct, and indirect maternal mortality and distance to any facility providing delivery care**

delivery by caesarean section. Childbirth in hospitals was more common for women living within 5 km of a facility (1328 [72%] of 1828) than those living within 5–10 km (824 [34%] of 2420).

Among women who lived more than 35 km from a hospital 269 (21%) of 1261 had a delivery in a hospital and 35 of 1254 had a delivery by caesarean section. Of women who lived within 1 km of a dispensary or health centre, 2353 (48%) of 4869 and 398 (66%) of 603, respectively gave birth in a facility (figure 2).

3870 women of reproductive age died between Jan 1, 2004, and June, 2007, among whom 621 (16%) died from pregnancy-related causes. 507 pregnancy-related deaths during the study period (June 1, 2004, to May 31, 2007) were reported and verbal autopsy interviews were done for 439 (87%), which confirmed pregnancy-related deaths in 376 (figure 1). 162 (43%) of these deaths were due to direct causes, 95 (25%) to indirect causes, two (1%) were coincidental with other events and, 117 (31%) were unclassified (table 1). Antepartum or postpartum haemorrhage was the leading cause of death. 126 (34%) women died at home and 186 (50%) in a facility; locations for the other deaths were unknown. 104 (28%) women with confirmed pregnancy-related deaths had delivered in hospitals. Seven (4%) of the 162 women who died of direct causes lived within 5 km of a hospital. Of these, four delivered in a hospital, two at home, and for one woman the place of childbirth was unknown. Six of the seven women died in hospital.

See Online for appendix

The overall pregnancy-related mortality ratio was 712 deaths per 100 000 livebirths (95% CI 652–777). The ratios were similar in women living within 5 km up to within 25 km of a hospital, but increased notably to more than 900 per 100 000 among women who lived more than 25 km from a hospital, but the effect was not significant at any distance, even after adjustment for other sociodemographic factors (table 2). Pregnancy-related mortality was highest in Lindi Rural district and lowest in Tandahimba District. The pregnancy-related mortality ratio was slightly higher in the poorest wealth quintile than in the least poor wealth quintile, but this difference was not significant. Pregnancy-related mortality declined with increasing years of education of the household head (table 2).

Direct maternal mortality was strongly related to distance to hospital, with an increase in number of deaths from 111 deaths per 100 000 livebirths among women living within 5 km of a hospital to 422 deaths per 100 000 among those living more than 35 km from a hospital (table 3, figure 3). No effect of distance to hospital was seen on indirect maternal deaths (table 3, figure 3). When assessed by any health facility providing delivery care, we found no association between distance and pregnancy-related, direct, or indirect maternal mortality (table 4).

The associations between direct and indirect maternal mortality and district, ethnic group, wealth, and education of the household head were similar to those seen for pregnancy-related mortality (appendix). A sensitivity analysis restricted to assessing distance and mortality for the 71% of livebirths with complete GPS data also yielded similar results (appendix).

Discussion

We found very high pregnancy-related mortality in Tanzania, and this study provided strong evidence that direct maternal mortality was associated with distance to hospital, since the mortality ratios increased by almost four times between distances less than 5 km and those further than 35 km. Distance had no effect on indirect maternal or pregnancy-related mortality.

The pregnancy-related mortality ratio we found is higher than the national estimates from the Demographic and Health Surveys and various models.[1,18,19] Our direct measurement through a census might have been more accurate, but the differences could also be due to subnational variation. Although households in southern Tanzania are generally poor and remote, the proportions of births in hospitals and by caesarean section in our data were similar to the national rates for rural Tanzania in 2010, where 26% of rural women gave birth in a hospital and 3% had delivery by caesarean section.[18] The prevalence of HIV in women in our study area was 5% in 2007, compared with 7% nationally and, therefore, does not

explain differences between our findings and the national data.[23] 63 (14%) deaths initially reported to be pregnancy-related were not confirmed in the verbal autopsies as being temporal to pregnancy or the 6 week postpartum period. 27 of these deaths were reclassified to late maternal deaths. Thus, our approach of including all deaths reported to be pregnancy-related during the census might have overestimated the ratio, although we used this initial report to align to the common approach of using the intial reports from heads of households.[32]

Pregnancy-related mortality overestimates maternal mortality because accidental and incidental causes are included. If we classified the 109 unresolved causes of death as being coincidental to pregnancy, the overall maternal mortality ratio would be reduced by 29% to 506 deaths per 100 000 livebirths. All these deaths being coincidental, however, is very unlikely since coincidental deaths generally represent only 10–15% of pregnancy-related deaths.[33] A substantial proportion of the deaths from unknown causes could be due to HIV, which is difficult to ascertain through verbal autopsies.[34] Alternatively, deaths in early pregnancy might have been missed or misclassified, particularly abortion-related deaths, which would lead to an underestimate of maternal mortality.[35]

The lack of an overall association between pregnancy-related mortality and distance to hospital is consistent with the findings from a study in rural Burkina Faso,[7] but they contrast with those from studies in Bangladesh and Indonesia (panel).[9] Of note, only 11% of women in our study gave birth in primary facilities, whereas 29% gave birth in a hospital and, therefore, we would not expect any strong effect of distance to primary facility on mortality.

Although the overall pregnancy-related mortality ratio was high, the lower direct mortality among women living close to hospitals suggests that these facilities contribute to life-saving obstetric care in labour. Nevertheless, 111 direct deaths per 100 000 livebirths in a context where 72% of women deliver in hospital is concerning. Four (60%) of seven women who died and lived within 5 km of a hospital delivered and died in hospital, which might point to deficiencies in the quality of care; several other studies from Tanzania support this interpretation.[36–38]

Indirect maternal mortality was not associated with distance to any facility. While obstetric complications demand a very timely response, distance might not be an important factor in mortality risk from non-obstetric causes of deaths.[2] Other reasons for a lack of association might be that the maternity staff team members are better trained to deal with direct causes than indirect causes of death. The high share of indirect maternal mortality also raises the question of whether opportunities in detection and treatment are missed during antenatal care, including linking pregnant women to HIV programmes.

***Panel*: Research in context**

Systematic review

We searched PubMed for observational studies done in low-income or middle-income countries and published between January, 1966, and October, 2013, with the search string "("maternal mortality" OR "maternal death*") AND (distance OR "Travel time" OR geograph*)". We identified 14 observational studies from 15 countries that had assessed the effects of geographical accessibility on maternal mortality, three hospital-based studies from three countries, and 12 population-based studies from seven countries in Africa and Asia. Four population-based studies used travel time as the exposure. These studies reported that maternity mortality was higher among women who took longer to reach hospital than among those who took less time, but none of the studies adjusted for sociodemographic factors. The eight population-based studies reporting an association between distance to hospital or health facility and mortality gave inconclusive results. Some studies were of low quality and some used sisters' households instead of the household of the deceased to estimate accessibility. Two population-based studies were high quality. These used defined measures to estimate distance and adjusted for sociodemographic factors, but did not provide conclusive results. In studies from Indonesia and Bangladesh, longer distance to a health centre but not to a hospital was a risk factor for maternal death in women who were delivering with skilled attendants, and were adjusted for several sociodemographic factors.[9] A study from Burkina Faso reported no association between distance to a health facility and maternal mortality.[7] Two of the three hospital-based case-control studies indicated increased risk with increasing distances from hospital whereas the third compared travel time of more or less than 30 min and reported no increase in risk.

Interpretation

Although hospital-based studies and unadjusted analyses consistently suggest that maternal mortality is highest among women who travel long distances or for a long time, adjustment for potential confounders in population studies has led to inconsistent results. Most studies, however, do not differentiate between causes of death and between levels of care available in facilities. Our population-based study of the effect of distance to a hospital on maternal mortality, with adjustments for wealth, location, ethnic group, and education of the head of household, indicated that distance had a strong effect on direct maternal mortality whereas no effect was seen on indirect maternal or pregnancy-related mortality.

Our study was large and had broad scope, but had some limitations. 7% of households were unavailable for interview and a further 9% of women were unavailable for interview about livebirths. Adjustment to the number of births, however, make it unlikely that we substantially underestimated the denominator for the pregnancy-related mortality ratio.[26] The fertility in women of reproductive age in our study was lower than the national average, although this difference is in line with the very low growth rate of only 1% reported from the latest census of the study area.[39] Only 74% of pregnancy-related deaths were assessed by verbal autopsy, and only 71% of deaths with verbal autopsy data had an agreed cause. Additionally, verbal autopsies are imprecise in determining the causes of death. Straight-line distance between households and facilities is only an approximation of distance and time to reach a facility, which might have led to non-differential mis-classification of true distance. Our data might have been subject to recall bias for births and deaths and to selection bias, as some households and many women of

reproductive age were not interviewed. The effects of these biases, however, are likely to be limited.[26] Lastly, our study was based on a household census and women's reports and did not include obstetric risk factors or complications. Such factors are unlikely to have confounded the association between mortality and distance, as complications should be randomly distributed across households further from and nearer to any facility. We recognise, however, that our study only quantifies the effect of one factor leading to death and that many more factors contribute to high levels of maternal mortality.[2]

Our study suggests that long distances to hospitals contribute to high pregnancy-related mortality. The four times mortality difference in distance between the nearest and furthest households underpins the need to invest into improved access to maternal care. Additionally, the high levels of pregnancy-related mortality among women living within 5 km of a hospital, where most women delivered in hospitals, suggest that quality of care is an important issue. Finally, our results suggest that more attention needs to be paid to prevention and treatment of malaria, HIV, and severe anaemia.

Contributors

CH, CR, and JS designed the study with contributions from all authors, and wrote the first draft. FM, DS, and JS coordinated the data collection. CH did the statistical analysis with support from SG, CR, and JS. All authors contributed to the critical interpretation and writing of the paper and saw and approved the final version.

Declaration of interests

We declare no competing interests.

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