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The contribution of unimproved water and toilet facilities to pregnancy-related mortality in Afghanistan: analysis of the Afghan Mortality Survey

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Abstract

OBJECTIVE To estimate the effect of unimproved household water and toilet facilities on pregnancy-related mortality in Afghanistan.

METHODS The data source was a population-based cross-sectional study, the Afghan Mortality Survey 2010. Descriptive, univariate and multivariate logistic regression analyses were carried out, comparing 69 pregnancy-related deaths (cases) and 15386 surviving women (non-cases) who had a live birth or stillbirth between 2007 and 2010.

RESULTS After adjusting for confounders, households with unimproved water access had 1.91 the odds of pregnancy-related mortality [95% confidence interval (CI) 1.11–3.30] compared to households with improved water access. We also found an association between unimproved toilet facilities and pregnancy-related mortality (OR = 2.25; 95% CI 0.71–7.19; *P*-value = 0.169), but it was not statistically significant.

CONCLUSIONS Unimproved household water access was an important risk factor for pregnancy-related mortality in Afghanistan. However, we were unable to discern whether unimproved water source is a marker of unhygienic environments or socio-economic position. There was weak evidence for the association between unimproved toilet facilities and pregnancy-related mortality; this association requires confirmation from larger studies.

keywords water resources, sanitation, toilet facilities, maternal mortality, cross-sectional study, Afghanistan

Introduction

Two widely recognised public health problems in low- and middle-income countries drive our research: reducing maternal mortality and improving access to safe drinking water and basic sanitation facilities, embedded, respectively, in the Millennium Development Goals 5a and 7c. Large improvements have been achieved in the past decade regarding both (Requejo *et al.* 2012; WHO, UNICEF, Joint Water Supply & Sanitation Monitoring Program 2013). Yet, in 2010, there still were 287 000 maternal deaths worldwide; almost all of these occurred in low- and middle-income countries, and most were preventable (Nour 2008; Maternal Mortality Estimation Inter-agency Group, UNICEF, UNFPA, The World Bank 2012; Requejo *et al.* 2012). By 2011, an estimated 1 billion people still used open defecation and 185 million people relied on using surface water for drinking (WHO, UNICEF, Joint Water Supply & Sanitation Monitoring Program 2013).

Only one systematic review exists – which identified 14 studies – on the link between poor water and toilet access and maternal mortality (Benova *et al.* 2014). A meta-analysis of the two individual-level studies that adjust for potential confounders suggests that households with poor toilet facilities have three times (OR = 3.07, 95% CI 1.72–5.49) the odds of maternal mortality compared to those with improved toilet facilities (Benova *et al.* 2014). The single adjusted individual-level study that investigates water finds that women in households with unimproved water have 1.50 (95% CI 1.10–2.10) the odds of maternal mortality compared to those with improved water facilities (WHO, UNICEF, Joint Water Supply & Sanitation Monitoring Program 2013). None of the

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individual-level studies in the review explicitly set out to test the association between maternal mortality and water or toilet facilities.

A shared, and crucial, limitation of the studies identified by the systematic review is the potential for residual confounding, particularly as few adequately adjust for socio-economic factors (Benova *et al.* 2014). Because socio-economic factors are potentially important confounders, we constructed variables indicating socio-economic factors at all levels (individual, household and cluster level). We emphasise these variables in our conceptual framework (Figure 1) to show how socio-economic factors fit in the causal pathway investigated.

The associations between poor toilet or poor water access and maternal mortality may be causal and may go beyond the direct impact of puerperal sepsis. Our conceptual framework (Figure 1) summarises ways in which poor toilet, poor water access or poor hygiene during a woman's pregnancy may lead to infection, and in turn to pregnancy-related mortality. For example, water-related insect vector-borne infections, such as malaria and dengue, are associated with anaemia during pregnancy, which in turn can affect the risk of death (Shulman *et al.* 2002; da Mota *et al.* 2011). Anaemia during pregnancy is also associated with hookworm infection (Brooker *et al.* 2008). A more proximate mechanism is infection contracted at the time of birth; worldwide, about 15% of maternal deaths are directly attributed to infection (Nour 2008). Indeed, faecal-oral infections driven by poor personal hygiene, such as lack of hand washing by the person assisting labour, can lead to puerperal sepsis (Ali *et al.* 2006; Darmstadt *et al.* 2009).

The Afghanistan Mortality Survey (AMS), carried out in 2010, estimated that there were 374 pregnancy-related deaths per 100 000 live births for the period 2007–10 (Afghan Public Health Institute, Central Statistics Organization, ICF Macro, Indian Institute of Health Management Research, WHO/EMRO 2011). The AMS is the most recent source of robust data currently published on pregnancy-related mortality in the country. These estimates are higher than those for other countries in the same region (Bangladesh, Nepal and Pakistan) (Requejo *et al.* 2012), although they are substantially lower, nearly half, than the levels reported earlier (Bartlett *et al.* 2005). Access to improved water and toilets in Afghanistan in 2010 was poor and unequally distributed between rural and urban areas (Afghan Public Health Institute, Central Statistics Organization, ICF Macro, Indian Institute of Health Management Research, WHO/EMRO 2011; Requejo *et al.* 2012). 80.6% of the population had no access to improved toilet facilities, and 40.7% lacked improved water sources (Requejo *et al.* 2012).

This paper aims to illustrate how to capitalise on existing Demographic Health Surveys (DHS) to investigate the

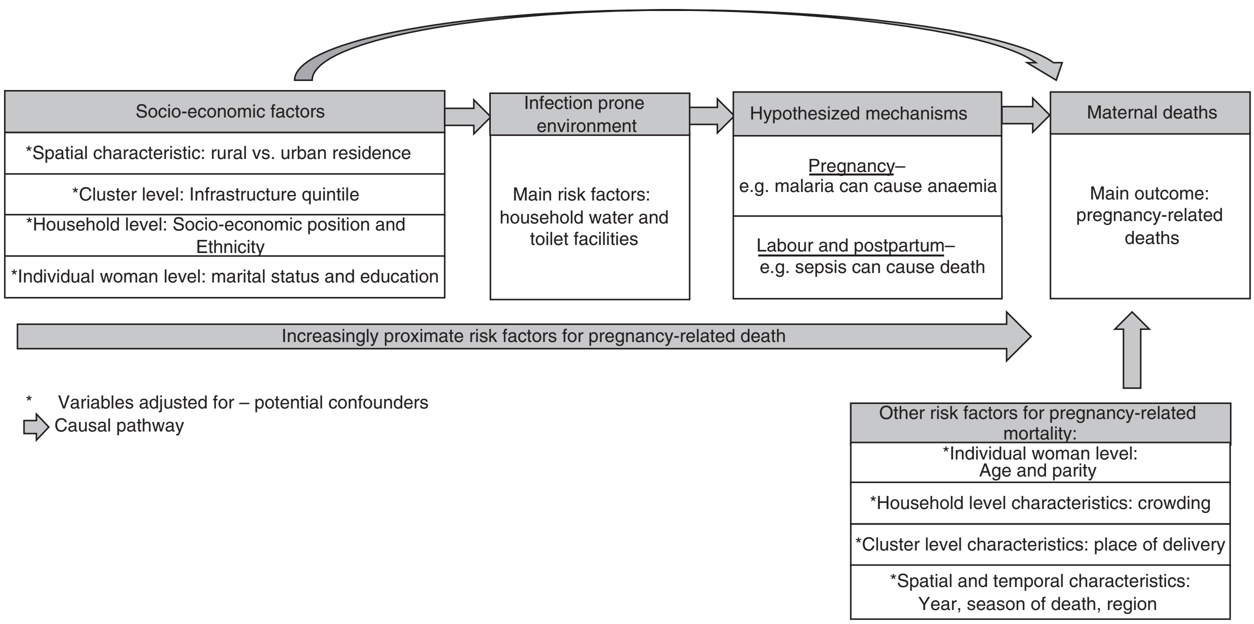

Figure 1 Conceptual framework: The hypothesized causal pathway between household level water and toilet facilities and pregnacy-related death.

independent effect of unimproved water sources and toilet facilities on pregnancy-related mortality. This is performed using the AMS which allowed us to pursue the following objectives: (i) assessing whether there is an independent effect of unimproved water sources and toilet facilities on pregnancy-related mortality; (ii) examining whether there is a dose–response relationship between the quality of water sources or toilet facilities and pregnancy-related mortality; and (iii) investigating whether the magnitude of the independent association between unimproved water or toilet and pregnancy-related mortality is higher for women who reached labour, compared to all pregnancy-related deaths.

If unimproved water and toilet access are markers of an infection-prone environment, we hypothesise that the risk of pregnancy-related mortality could be higher among households with poor water and toilet facilities than among households with improved facilities. The causal mechanisms postulated suggest that the risk of pregnancy-related mortality should increase as the quality of the water source or the toilet facilities worsen.

The pivotal role of infections contracted during labour in driving pregnancy-related mortality was established as early as in the 18th century (Gould 2010). If this mechanism is indeed the main driver, we hypothesise that the effect of unimproved water or toilet facilities will be stronger among women who died during or after labour than among all women who died of pregnancy-related causes.

Methods

Our data source was the AMS 2010, a cross-sectional survey carried out in Afghanistan according to standard MEASURE DHS methodology (Afghan Public Health Institute, Central Statistics Organization, ICF Macro, Indian Institute of Health Management Research, WHO/EMRO 2011). It used a two-stage sampling design, representative at the country level, for rural and urban areas and for the North, Central and South geographical domains. Helmand, Kandahar and Zabul regions were excluded from the South domain for security reasons. The non-response rate was minimal (2%) (Afghan Public Health Institute, Central Statistics Organization, ICF Macro, Indian Institute of Health Management Research, WHO/ EMRO 2011).

The main outcome of interest is pregnancy-related mortality. We defined it according to the 2010 International Classification of Disease (ICD)-10th, as a woman who died during pregnancy or within 42 days of termination of pregnancy irrespective of her cause of death. Cases were women who died of pregnancy-related causes between 21st March, 2007 and the completion of the survey, December 31st, 2010. Non-cases were women who had a live birth or stillbirth in the same time period. Cases and non-cases were included if 12–49 years old at the time of death or birth, respectively. Abortion deaths and women dying before 12 weeks of gestation were excluded because women who survived an early pregnancy loss were not part of the sample of non-cases. A secondary outcome was constructed, that is mortality in women who reached labour. This included all cases and non-cases as defined per the main outcome but excluding the women who died during pregnancy.

The main exposures – the type of water and toilet facilities – reflected household facilities at the time of interview. We used the Joint Water Supply and Sanitation Monitoring Program (JMP) classification to operationalise the main exposures into binary variables (WHO, UNICEF, Joint Water Supply & Sanitation Monitoring Program 2013). Improved toilet facilities comprised flush toilets, pit latrines with ventilation or slabs if these were not shared with other households. Unimproved toilet facilities comprised any shared facilities, in addition to all other types (Table 1). Improved water sources were piped water, public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs and rainwater collection. Unimproved water sources comprised all other types (Table 1). The exposures were also recoded to allow for more than two levels used in the dose–response analysis (see Table 1): low, medium (upper medium and lower medium for toilet facilities only) and high level of facility quality.

AMS used distinct questionnaires for cases (verbal autopsy questionnaire) and non-cases (women questionnaire), so the information available about independent variables was limited. For time-dependent variables such as current marital status, the data used for cases applied to the time of death and to the time of the survey for non-cases; this time variation is marginal and unlikely to later affect the reliability of the information. Age, however, captures the time of labour for non-cases and the time of death for cases. Years of death or birth were originally coded as per the Afghan calendar; we approximated these to the nearest Gregorian year.

Individual women's risk factors for pregnancy-related mortality were considered potential confounders: age (categorised into 5-year age bands), current marital status (married or not married), education (none, any formal education or madrassa), ethnicity of the household head (Pashtun, Tajik or other) and parity (number of births experienced by a woman excluding the index pregnancy) (Campbell & Graham 1991; Walsh *et al.* 1993; Blanc *et al.* 2013).

Household measures of crowding and socio-economic position were constructed. Crowding (>2 people per bedroom), a proxy for unhygienic environments, was calculated by dividing the number of household members by the number of bedrooms (WHO, UNICEF, Joint Water Supply & Sanitation Monitoring Program 2013). Socio-economic position is a risk factor for pregnancy-related mortality and a potentially important confounder (Figure 1) (Ronsmans & Graham 2006); for example, women in lower socio-economic positions tend to have lower access to health services, and to water and toilet facilities (Gabrysch & Campbell 2009). We created a socio-economic position indicator using principal component analysis (PCA) on the entire cross-sectional sample. It included 30 assets (see the Appendix S1, section 1). Water, toilet and assets owned by fewer than 30 households in either rural or urban areas were excluded. The asset index score explained 15% of variation in assets ownership. The socio-economic position indicator, generated from the asset index score, grouped households into tertiles.

We investigated two cluster-level (the country's enumeration area) variables. Firstly, the level of infrastructure was used to reflect the cluster-level access to infrastructure and health services that are in turn a measure of the cluster socio-economic characteristics. An infrastructure quintile, constructed using a PCA-like methodology (Afghan Public Health Institute, Central Statistics Organization, ICF Macro, Indian Institute of Health Management Research, WHO/EMRO 2011), was available in the household data set. Secondly, home birth is associated with a higher risk of pregnancy-related mortality than facility-based birth, usually because of the lack of skilled assistance or an appropriate environment for managing complications (Koblinsky *et al.* 2006). Where skilled birth attendance is rare, women will seek care in facilities only when they are ill; therefore, controlling for place of delivery at the individual level when valid information on intended birthplace is unavailable – as was the case for our data set – may yield misleading results (Lohela *et al.* 2012). We thus constructed a variable indicating the place of delivery (facility or home) for the median of non-cases in each cluster.

Four independent variables related to the temporal and spatial environment were also considered as potential confounders: a woman's place of residence (rural or urban); her region (Central, South or North); the year and the season of birth (non-cases) and death (cases).

The survey command – set with six strata, 717 clusters, and individual (non-cases) and household (cases) weights – was used when running the following analyses to exploit the opportunity to calculate country representative estimates. All statistical analyses were run in STATA/IC 13.

Cross-tabulations were used to describe the sample, and the timing and causes of death for cases. We used the ICD-10 criteria available in the verbal autopsies to classify the latter (see Appendix S1, section 2). Crude

Table 1 Classification of sanitation and water exposures. (a) Water sources. (b) Toilet facilities

Type of facility at household level	Binary	Ordered categorical – three categories
(a)		
Surface water (river/dam/lake/pond/stream); Other	Unimproved	Low
Bottled water; Dug well – unprotected; Spring – unprotected; Cart with small tank; Tanker truck	Unimproved	Medium
Piped – into dwelling; Piped – into yard/plot; Piped – public tap/standpipe; Tube well or borehole; Dug well – protected; Spring – protected; Rainwater	Improved	High

Type of facility at household level	Shared with other households	Binary	Ordered categorical – three categories
(b)			
Open defecation – no facility/bush/field; Other	Not applicable	Unimproved	Low
Flush – to somewhere; Flush-don't know where; Pit latrine – without slab	Not applicable	Unimproved	Lower medium
Flush – to piped sewage; Flush – to septic tank; Flush – to pit latrine; Pit latrine – ventilation; Pit latrine – with slab	Yes	Unimproved	Upper medium
Flush – to piped sewage; Flush – to septic tank; Flush – to pit latrine; Pit latrine – ventilation; Pit latrine – with slab	No	Improved	High

odds ratios between each independent variable and pregnancy-related mortality were calculated using logistic regression. Multivariate logistic regressions were used to build four models. Both water and toilet exposures were included in the four models to investigate their independent multiplicative effects.

We built Model 1 to assess whether there was an association between unimproved water or toilet and pregnancy-related mortality. All available potential confounders were introduced into Model 1 in a stepwise fashion from the most distal to the most proximate risk factors for pregnancy-related mortality (Victora *et al.* 1997). There was no multicollinearity between each potential confounder, and water and toilet independently. Parity was excluded because it had a large proportion of missing values among cases; marital status was excluded because all cases were married. Two sensitivity analyses were carried out to assess the potential confounding effect of parity assuming that missing values had the parity category with the lowest possible risk to pregnancy-related mortality (2–4 children) (Model 1a), and with the parity category with the highest possible risk (>4 children) (Model 1b) (Blanc *et al.* 2013).

If an independent effect of an exposure was found, first, we investigated whether the type of water or toilet facilities showed a linear trend with pregnancy-related mortality. This analysis was carried out if the univariate results showed increasingly higher odds of pregnancy-related mortality as the quality of water or toilet facility worsened. To test for a dose–response relationship, the ordered categorical variables for the main exposures were introduced in Model 1 as quantitative terms. Second, we built Model 2 to test whether the association between water or toilet and pregnancy-related mortality was stronger once the sample was restricted to women who reached labour; it included the same variables as Model 1.

The study was approved by the Research Ethics Committee of the London School of Hygiene and Tropical Medicine, UK.

Results

After applying inclusion and exclusion criteria, the final data set contained 69 cases and 15386 non-cases. Univariate results and Model 1, 1a and 1b included 60 cases and 14 970 non-cases. Model 2 included 59 cases and 14 970 non-cases.

Table 2 shows the descriptive characteristics for cases and non-cases. A higher proportion of cases had unimproved water (63.7%) and unimproved toilet facilities (90.8%) than non-cases (44.5% and 80.7%, respectively). Eight of ten potential confounders had up to 1% missing values. Parity had 56% missing observations among cases. The most common causes of pregnancy-related death were haemorrhage (42%, non-weighted) and hypertension (20%, non-weighted) (Figure 2). Most cases died during labour (62%, non-weighted) or prior to it (9%, non-weighted) (Figure 3). All infection-related deaths (9%, non-weighted) occurred during or after labour.

Households with unimproved water had 2.15 (95% CI 1.21–3.82; *P*-value = 0.009) the odds of a pregnancy-related death compared to households with improved water (Table 2). Households with unimproved toilet facilities had 2.59 (95% CI 0.86–7.79; *P*-value = 0.089) the odds of a pregnancy-related death compared to households with improved toilet facilities. The odds of pregnancy-related mortality increased as the quality of both water and toilet facility worsened (Table 2).

Model 1 in Table 3 shows that after adjustment, there was good evidence (*P*-value = 0.020) that households with unimproved water sources had 1.91 (95% CI 1.11–3.30) the odds of a pregnancy-related death compared to households with improved water sources. There was an association between toilet facilities and pregnancy-related mortality (OR = 2.25; 95% CI 0.71–7.19; *P*-value = 0.169), but the strength of the evidence to reject the null hypothesis of no association was weak. The effect estimate for water source did not substantially change when we ran the sensitivity analyses (Table 4, full Models 1a and 1b not shown).

The dose–response analysis and the analysis restricted to women who reached labour were conducted for water sources because it was the one exposure for which we found good evidence for the association with pregnancy-related mortality. There was some evidence (*P*-value = 0.066) that the odds of death increased by 1.42 (95% CI 1.01–2.00) from high to medium quality of water source, and from medium to low, supporting the hypothesis of a dose–response relationship (full model in Appendix S1, section 3). Model 2 in Table 3 shows that among women who reached labour, the odds of death for households with unimproved water were 1.98 (95% CI 1.12–3.50; *P*-value = 0.018) compared to households with improved water.

Discussion

Our analysis of the cross-sectional in the 2010 AMS provides an example of how DHS data sets can be used to investigate the independent effect of unimproved water and toilet facilities on pregnancy-related mortality. Larger maternal mortality data sets could be assembled to test

Table 2 Descriptive characteristics of the sample and unadjusted odds ratio for the association between each independent variable and pregnancy-related death

Variables	Total weighted (%)	Pregnancy-related death: Cases *N* weighted (%) cases = 69	Pregnancy-related death: Non-cases *N* weighted (%) non-cases = 15 386	Crude odds ratio (95% CI)	Wald test *P*-value*
Exposures					
Improved source water					
Yes	8528 (55.2)	25 (36.3)	8503 (55.3)	1	0.009
No	6897 (44.6)	44 (63.7)	6853 (44.5)	2.15 (1.21–3.82)	
Missing	30 (0.2)	0	30 (0.2)		
Type of water source					
High	8528 (55.2)	25 (36.3)	8503 (55.3)	1	0.030
Medium	4254 (27.5)	27 (38.3)	4227 (27.5)	2.04 (1.02–4.09)	
Low	2643 (17.1)	18 (25.4)	2626 (17.1)	2.32 (1.12–4.79)	
Missing	30 (0.2)	0	30 (0.2)		
Improved sanitation					
Yes	2782 (18.0)	5 (7.6)	2777 (18.0)	1	0.089
No	12 481 (80.8)	63 (90.8)	12 418 (80.7)	2.59 (0.86–7.79)	
Missing	191 (1.2)	1 (1.6)	190 (1.2)		
Type of sanitation facility					
High	2782 (18.0)	5 (7.6)	2777 (18.0)	1	0.217
Upper medium	2611 (16.9)	11 (15.8)	2600 (16.9)	2.04 (0.58–7.26)	
Lower medium	6604 (42.7)	32 (45.8)	6572 (42.7)	2.47 (0.79–7.68)	
Low	3266 (21.1)	20 (29.2)	3246 (21.1)	3.29 (1.03–10.48)	
Missing	191 (1.2)	1 (1.6)	190 (1.2)		
Demographic characteristics					
Parity					
0–1	4759 (30.8)	15 (21.1)	4745 (30.8)	1	0.077
2–4	5798 (37.5)	7 (9.9)	5791 (37.6)	0.39 (0.17–0.90)	
>4	4859 (31.4)	10 (14.5)	4849 (31.5)	0.62 (0.23–1.66)	
Missing	38 (0.2)	38 (54.5)	0		
Age group					
<20	2057 (13.9)	15 (22.2)	2137 (13.9)	1	<0.001
20–24	4640 (29.5)	13 (19.4)	4542 (29.5)	0.41 (0.19–0.90)	
25–29	4024 (25.6)	9 (13.3)	3946 (25.6)	0.30 (0.11–0.80)	
30–34	2497 (15.7)	7 (10.5)	2426 (15.8)	0.37 (0.12–1.13)	
35–39	1667 (10.8)	11 (16.0)	1654 (10.7)	0.94 (0.35–2.47)	
40+	661 (4.5)	13 (18.5)	681 (4.4)	2.37 (0.98–5.73)	
Ethnicity					
Pashtun	6803 (44.0)	32 (45.6)	6771 (44.0)	1	0.227
Tajik	4717 (30.5)	13 (19.3)	4704 (30.6)	0.66 (0.28–1.52)	
Other	3887 (25.2)	24 (35.1)	3862 (25.1)	1.46 (0.76–2.82)	
Missing	48 (0.3)	0	48 (0.3)		
Current marital status					
Non-married	76 (0.5)	0	76 (0.5)	†	†
Married	15 378 (99.5)	69 (100)	15 309 (99.5)		
Education level					
None	13 668 (88.4)	62 (90.3)	13 605 (88.4)	1	0.654
Madrassa	184 (1.2)	2 (3.1)	182 (1.2)	1.31 (0.30–5.64)	
Any formal education	1603 (10.4)	5 (6.6)	1599 (10.4)	0.64 (0.22–1.86)	
Household level characteristics					
Socio-economic position					
Lower	6681 (43.2)	33 (47.7)	6648 (43.2)	1	0.702
Middle	5154 (33.4)	23 (33.4)	5131 (33.4)	0.91 (0.47–1.79)	
Upper	3620 (23.4)	13 (19.0)	3606 (23.4)	0.73 (0.35–1.54)	

Table 2 (*Continued*)

Variables	Total weighted (%)	Pregnancy-related death: Cases *N* weighted (%) cases = 69	Non-cases *N* weighted (%) non-cases = 15 386	Crude odds ratio (95% CI)	Wald test *P*-value*
Crowding (>2 people per bedroom)					
No	2079 (13.5)	8 (10.9)	2071 (13.5)	1	0.654
Yes	13 376 (86.6)	62 (89.1)	13 314 (86.5)	1.20 (0.53–2.71)	
Cluster level characteristics					
Infrastructure quintile					
Most developed	4011 (26.0)	21 (31.0)	3990 (25.9)	1	0.847
Second	4314 (27.9)	17 (25.1)	4297 (27.9)	0.76 (0.38–1.54)	
Third	3057 (19.8)	15 (22.2)	3041 (19.8)	0.95 (0.38–2.37)	
Fourth	2574 (16.7)	8 (11.4)	2566 (16.7)	0.61 (0.23–1.59)	
Least developed	1499 (9.7)	7 (10.3)	1491 (9.7)	0.97 (0.30–3.15)	
Place of delivery (Median)					
Home	11 303 (73.1)	61 (87.8)	11 242 (73.1)	1	0.006
Facility	4152 (26.9)	8 (12.2)	4143 (26.9)	0.36 (0.18–0.74)	
Spatial and temporal characteristics					
Residence					
Urban	2844 (18.4)	5 (7.6)	2839 (18.5)	1	0.002
Rural	12 610 (81.6)	64 (92.4)	12 546 (81.5)	3.06 (1.49–6.31)	
Season of death (cases) or delivery (non-cases)					
Spring	6115 (39.6)	26 (38.2)	6089 (39.6)	1	0.874
Summer	4208 (27.2)	17 (25.0)	4191 (27.2)	0.89 (0.46–1.75)	
Autumn	2747 (17.8)	15 (21.3)	2732 (17.8)	1.24 (0.64–2.38)	
Winter	2221 (14.4)	9 (13.2)	2212 (14.4)	0.95 (0.42–2.17)	
Missing	164 (1.1)	2 (2.3)	162 (1.1)		
Year of death (cases) or delivery (non-cases)					
1386 (~2007)	2719 (17.6)	18 (25.7)	2701 (17.6)	1	0.102
1387 (~2008)	4209 (27.2)	21 (30.0)	4188 (27.2)	0.77 (0.37–1.57)	
1388 (~2009)	5875 (38.0)	15 (21.7)	5860 (38.1)	0.41 (0.18–0.91)	
1389 (~2010)	2651 (17.2)	16 (22.6)	2636 (17.1)	0.87 (0.39–1.94)	
Region					
North	4767 (30.9)	23 (32.7)	4745 (30.8)	1	0.150
Central	5368 (34.7)	15 (21.6)	5353 (34.8)	0.56 (0.25–1.28)	
South	5320 (34.4)	32 (45.8)	5288 (34.4)	1.20 (0.60–2.38)	

*Overall test *P*-value for all the categories of the relevant variable; it tests the null hypothesis of no association between the relevant variable and pregnancy-related death. Each of the 16 univariate regression models includes 66 cases and 14 970 (weighted).
†100% women were married, so odds ratio was not calculated.

whether infection-related mortality is the driver behind the association between unimproved water and toilet facilities and pregnancy-related death, but also to estimate the proportion of maternal death attributable to unimproved water and toilet facilities at the population level.

In the context of Afghanistan, we found good evidence for an independent association between unimproved water sources in households and pregnancy-related mortality (adjusted OR = 1.91; 95% CI 1.11–3.30). We also found an independent association between unimproved toilet facilities and pregnancy-related mortality, but this was not statistically significant (adjusted OR = 2.25; 95% CI 0.71–7.19; *P*-value = 0.169).

To our knowledge, this is the first individual-level study to explicitly test an association between unimproved water and toilet facilities and pregnancy-related mortality, and to attempt to adjust for socio-economic factors thoroughly. The main limitations stem from the small number of cases, which prevented us from carrying out cause-specific mortality analyses. The secondary nature of the study, which precluded obtaining the exact data ideally needed – such as a woman's obstetric history and further dimension of her social status – to adjust for potential confounding, is another limitation.

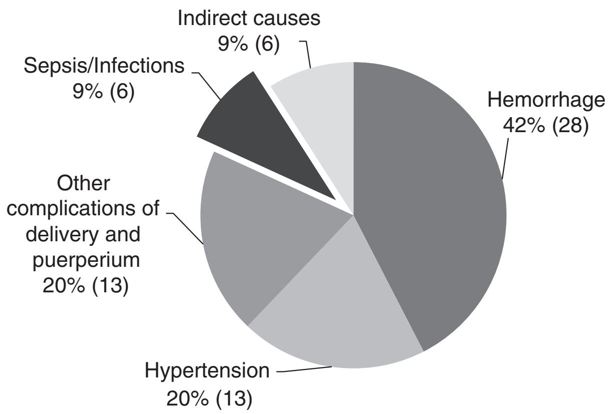

Figure 2 Leading causes of pregnancy-related mortality (percentage and number). $N = 66$ (non-weighted).

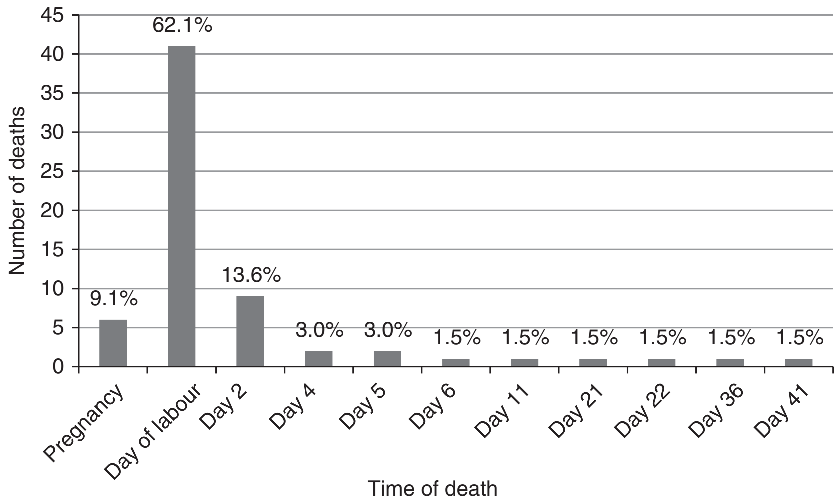

Figure 3 Timing of pregnancy-related death (numbers and percentage on the bar). $N = 66$ (non-weighted).

Our finding that households with unimproved water sources had 1.91 times the odds of pregnancy-related death compared to households with improved sources of water is consistent with previous research on the topic, including three individual-level studies and four ecological studies (Benova *et al.* 2014). In particular, one study conducted in Pakistan found an adjusted odds ratio for poor water access of 1.5 (95% CI 1.1–2.1) (Fikree *et al.* 1997). This study is well powered and adjusted for variables such as obstetric history that were not comparable between cases and non-cases in the AMS 2010. However, our control of socio-economic factors was more extensive. Contextual factors may explain the larger effect estimate found for Afghanistan. The insecurity and population displacements which characterised Afghanistan during the study (2007–2010) may have been more conducive to infections or may have prevented women from accessing healthcare services (Wallace *et al.* 2002). In the 1980s, when Fikree and colleagues conducted their study, Pakistan was the fastest growing economy in the region.

Our results from additional analyses provide further support to the main findings that unimproved water is associated with pregnancy-related mortality. The sensitivity analyses indicated that excluding parity because of missing values was unlikely to have affected the association observed. Evidence for a dose–response relationship was found, although this was weak (P-value = 0.066). We were also interested in whether unhygienic practices at delivery were a plausible mechanism for linking unimproved water to infection-related deaths. 9% of cases died of infection or sepsis – which is in line with esti-

Table 3 Adjusted effect of unimproved water sources and unimproved toilet facilities on pregnancy-mortality (Model 1), and on mortality among women who reached labour (Model 2)*

	Model 1		Model 2	
Variable	Odds ratio (95% CI)	Wald test *P*-value†	Odds ratio (95% CI)	Wald test *P*-value†
Improved source water				
Yes	1	0.020	1	0.018
No	1.91 (1.11–3.30)		1.98 (1.12–3.50)	
Improved sanitation				
Yes	1	0.169	1	0.260
No	2.25 (0.71–7.19)		1.96 (0.61–6.30)	
Age group				
<20	1	0.001	1	0.001
20–24	0.37 (0.16–0.86)		0.36 (0.15–0.83)	
25–29	0.27 (0.10–0.71)		0.25 (0.09–0.68)	
30–34	0.32 (0.10–1.00)		0.19 (0.05–0.67)	
35–39	0.80 (0.27–2,41)		0.72 (0.23–2.27)	
40+	1.98 (0.77–5.10)		1.42 (0.50–4.07)	
Ethnicity				
Pashtun	1	0.457	1	0.584
Tajik	1.08 (0.41–2.87)		1.11 (0.42–2.94)	
Other	1.76 (0.65–4.78)		1.60 (0.64–3.99)	
Education				
None	1	0.960	1	0.943
Madrassa	1.20 (0.27–5.39)		0.79 (0.10–6.04)	
Formal education	1.01 (0.32–3.16)		1.15 (0.37–3.62)	
Socio-economic position				
Lower	1	0.277	1	0.367
Middle	1.09 (0.54–2.19)		1.11 (0.57–2.17)	
Upper	1.84 (0.84–4.04)		1.77 (0.79–3.96)	
Place of delivery (median of cluster)				
Home	1	0.054	1	0.073
Facility	0.46 (0.21–1.01)		0.46 (0.19–1.07)	
Crowding				
Yes	1	0.504	1	0.437
No	1.31 (0.59–2.90)		1.42 (0.59–3.42)	
Infrastructure quintile				
Most developed	1	0.582	1	0.920
Second	0.82 (0.41–1.65)		0.84 (0.42–1.67)	
Third	1.21 (0.48–3.02)		0.94 (0.40–2.19)	
Fourth	0.75 (0.28–1.98)		0.70 (0.25–1.97)	
Least developed	1.85 (0.50–6.84)		1.24 (0.23–6.76)	
Residence				
Urban	1	0.194	1	0.226
Rural	1.95 (0.71–5.33)		1.95 (0.66–5.78)	
Season of death (cases) or delivery (non-cases)				
Spring	1	0.633	1	0.638
Summer	0.88 (0.45–1.74)		0.74 (0.36–1.50)	
Autumn	1.39 (0.71–2.71)		1.08 (0.51–2.29)	
Winter	1.28 (0.57–2.88)		1.25 (0.56–2.79)	
Year of death (cases) or delivery (non-cases)				
1386 (~2007)	1	0.162	1	0.123
1387 (~2008)	0.77 (0.37–1.58)		0.79 (0.37–1.68)	
1388 (~2009)	0.41 (0.18–0.95)		0.37 (0.15–0.90)	
1389 (~2010)	0.87 (0.41–1.87)		0.78 (0.34–1.79)	

Table 3 (*Continued*)

Variable	Model 1 Odds ratio (95% CI)	Model 1 Wald test *P*-value†	Model 2 Odds ratio (95% CI)	Model 2 Wald test *P*-value†
Region				
North	1	0.346	1	0.213
Central	0.75 (0.32–1.72)		0.60 (0.24–1.50)	
South	1.68 (0.57–4.91)		1.60 (0.62–4.14)	

*Model 1 includes 66 cases and 14 970 non-cases (weighted). Model 2 includes 59 cases and 14 970 non-cases (weighted).
†Overall test *P*-value for all the categories of the relevant variable; it tests the null hypothesis that there is no association between the relevant variable and pregnancy-related death after adjustment for all other independent variables in the model.

Table 4 Sensitivity analysis for parity: adjusted estimates for the effect of unimproved water sources on pregnancy-related mortality

Model (values assigned to the missing observations for parity)	Adjusted estimate for unimproved water source* OR (95% CI)	Wald test *P*-value†
Model 1 (parity not included)	1.91 (1.11–3.30)	0.018
Model 1a (all missing assumed to be in lowest risk category with 2–4 previous births)	1.97 (1.03–3.78)	0.042
Model 1b (all missing assumed to be in highest risk category with >4 previous births)	2.35 (1.25–4.43)	0.008

*Adjusted for what all variables in Model 1.
†Overall test *P*-value for all the categories of the relevant variable; it tests the H0 of no association between the unimproved water and pregnancy-related death after adjustment for all other independent variables in Model 1 (age group, ethnicity, education, socio-economic position, crowding, cluster median place of delivery, infrastructure quintile, residence, season, year and region) and the relevant variable for parity. Model 1a and 1b include 66 cases and 14 970 non-cases (weighted).

mates from other low- and middle-income countries (Nour 2008) – but which translated into only six infection-related deaths. Nevertheless, we attempted to investigate whether labour was a potential gateway to infection and found that the magnitude and strength of the evidence for the association between unimproved water and pregnancy-related mortality increased slightly when the analysis was restricted to women who reached labour.

We adjusted for socio-economic position and for other socio-economic dimensions captured by ethnicity, education, cluster-level infrastructure, place of delivery (cluster) and urban/rural residence to the extent possible given the secondary nature of the study. Our analysis found that, as expected, households from higher socio-economic position experienced fewer pregnancy-related deaths. However, even though the socio-economic indicator was constructed using a well-established methodology, we found poor evidence for its association with pregnancy-related mortality (Howe *et al.* 2012). Despite our efforts to avoid this, described in the methods, potentially, the socio-economic position indicator captured the rural–urban divide instead (Howe *et al.* 2012). Residual confounding from inadequate control for socio-economic factors remains therefore a possibility.

Questions have been raised about whether the AMS 2010 estimates of pregnancy-related mortality (374/100 000 live births) are too low for a country affected by war, population displacement and infrequent use of delivery care services (Bloomberg School of Public Health 2013, Johns Hopkins). The proportion of female deaths that are maternal are high in comparison with UN estimates (Maternal Mortality Estimation Inter-agency Group, UNICEF, UNFPA, The World Bank 2012), but the overall adult mortality ratio may be low. Exclusion of three of the poorest and most insecure areas in the South may partially explain the low pregnancy-related mortality estimates but under-reporting of pregnancy-related deaths cannot be excluded as a possibility. This is of concern whether households' under-reporting of pregnancy-related deaths could have biased our results. However, for under-reporting of death to lead to a spurious association between unimproved water and pregnancy-related mortality, households with improved water sources would have had to under-report pregnancy-related deaths more than households with worse water sources. We do not find this plausible.

If the association between unimproved water and pregnancy-related mortality is causal, it may be that having an unimproved water source marks an infection-prone environment at birth and during pregnancy. For example, poor personal hygiene, including by the person assisting labour, can cause puerperal sepsis (Ali *et al.* 2006; Darmstadt *et al.* 2009); but our conceptual framework spans beyond the direct impact of puerperal sepsis. Alternative mechanisms, such as hookworm infection, malaria and dengue leading to severe anaemia during pregnancy, which in turn can affect the risk of death, are also possible (Brooker *et al.* 2008). However, in Afghanistan, with widespread poverty, water may instead indicate socio-economic position and residual confounding may explain our effect. With the available information, it is not possible to discern whether unimproved water is a marker of an unhygienic environment or socio-economic position.

After adjustment, there was poor evidence for an independent association between unimproved toilet facilities and pregnancy-related mortality. However, because the study had limited power to detect this association [only five cases (weighted) had improved toilet facilities], we are not prepared to discard the potential for an association. The magnitude of effect, OR = 2.28, is consistent with the pooled analysis of two individual-level studies that presented adjusted estimated for toilet facilities of 3.07 (95% CI 1.72–5.49) (Requejo *et al.* 2012).

In summary, this paper illustrates how existing DHS data sets can be used to investigate the independent association between unimproved water and toilet facilities, and pregnancy-related mortality. Further analyses that capitalise on existing large data sets are needed to investigate the association between unimproved water and toilet facilities and cause-specific mortality. Future maternal mortality studies should explicitly collect data on the potential confounders and use analytical techniques such as instrumental variables to further investigate these associations.

There is already a wealth of evidence on the importance of water and sanitation interventions to improve childhood morbidity (Cairncross & Valdmanis 2006; Clasen *et al.* 2009, 2010; Waddington *et al.* 2009). If our findings are confirmed, suitable water and sanitation interventions may also prevent pregnancy-related infections and deaths.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Additional Supporting Information - Sections 1, 2, 3.

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