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Do biomass fuel use and consumption of unsafe water mediate educational inequalities in stillbirth risk? An analysis of the 2007 Ghana Maternal Health Survey

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ABSTRACT

Background Numerous studies have explored the association between educational inequalities and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that household use of biomass fuels and unsafe drinking water resources related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage.

Methods Data from the 2007 Ghana Maternal Health Survey, a nationally representative population-based survey were analyzed for this study. A total of 10,370 women aged 15-49 years were interviewed, with information on the household and socioeconomic characteristics, and a wide range of maternal health-related issues collected from both mothers and household heads in structured questionnaires.

Results Applying generalized linear models adjusting for potential confounders, lower maternal primary education was associated with a 59% (Odds ratio [OR] = 1.59; 95% CI: 1.02, 2.48) increased lifetime risk of stillbirth with biomass fuel use and consumption of unsafe water mediating respectively 17% and 5% of the observed low educational attainment. Jointly these two exposures explained 22% of the observed effects. In an adjusted multinomial logistic regression analysis, low educational attainment was found not to be risk factor for two or more stillbirth experiences in a woman's lifetime. When generalized additive model was applied to allow for possible non-linearity, the smoothed curve depicted an inverted spoon-shape with a leveling off around the null value from about 6.5 to 12.5 years of schooling. No appreciable change in the shape of the curves was observed in the mediation models.

Conclusions Our results show the importance of addressing educational inequalities in developing countries so as to ensure household choices that curtail environmental exposures, and ultimately improve pregnancy outcomes.

Strengths and limitations of this study

- This population-based study has shown for the first time that biomass fuel use and consumption of unsafe water are important pathways through which low maternal educational attainment leads to increased risk of stillbirth.
- The predictor-risk relationship was further illustrated through curve fitting with generalized additive modeling.
- There are limitations with the exposure assessment method applied but they have been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure.
- It was impossible to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the study participants with the potential for exposure misclassification in the study.

INTRODUCTION

Stillbirth, defined by WHO as the intrauterine death of any conceptus at any time during pregnancy[1] is a major public health concern in developing countries. An estimated 3.2 million stillbirths occurs worldwide annually with 98% of these stillbirths found in developing countries.[2] Important causes of stillbirths globally are asphyxia and infection associated with obstructed or prolonged labour, pre-eclampsia and eclampsia, chorioamnionitis, syphilis, malaria and poor nutritional status.[3] Stillbirth rates among ethnic minority, disadvantaged, marginalized and rural populations have however been noted to be much higher[4-6] thus revealing the very important role of socioeconomic factors.

The stillbirth problem in low-income countries is as a result of several factors that are associated with poverty[7] including solid fuel use and consumption of unsafe drinking water. Many households in developing countries rely on ground and surface water resources for domestic purposes due to limited access to pipe-borne water, erratic supply, and high connection and utility charges. These water resources are often polluted by mining and agricultural activities, as well as nearby pit latrines which are also in widespread use in developing countries. Mining activities leads to the deposition/leaching of substantial amounts of chemicals and heavy metals such as cyanide, sulfuric acid, mercury, arsenic, lead and cadmium into nearby water bodies especially in unregulated mines. Agricultural runoffs can introduce sediments, pesticides, fertilizers and pathogens into water bodies. Pit latrines are also widely documented to leach microbial and chemical contaminants including coliforms, *Escherichia coli,* fecal streptococci, ammonia, nitrates and nitrites into groundwater sources.[8] Poverty further hampers most households from treating these unsafe water resources before usage.

Poverty and limited access to clean fuels in developing countries have also resulted in solid fuels being the predominant cooking fuel in these countries[9] with Bonjour et al.[10] estimating the proportion of households in Africa and Southeast Asia relying on solid fuels for cooking to be more than 60%. These fuels are usually burnt in open fires or inefficient traditional stoves, often in poorly ventilated cooking spaces, resulting in the release of high levels of air pollutants including particulate matter and carbon monoxide to which women and their young children are most heavily exposed.[9] Studies have associated use of solid fuels,[11] and consumption of contaminated drinking water[12-14] with stillbirth and other adverse pregnancy outcomes.

Socioeconomic characteristics including educational attainment clearly have a major influence on cooking fuel and drinking water choices in developing countries. Socioeconomic characteristics is also well-documented to have strong effects on health outcomes and certainly contributes to the burden of adverse maternal and fetal health outcomes in Ghana and other developing countries. Numerous studies mostly emanating from high-income countries have explored the relationship between educational attainment and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that household use of biomass fuels and unsafe drinking water resources related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage. As noted by Kramer,[15] research that identifies and quantifies the causal pathways and mechanisms whereby social disadvantage leads to higher risks of unfavorable pregnancy outcomes may eventually help to reduce current disparities and improve pregnancy outcome across the entire socioeconomic spectrum. We relied on data from the 2007 Ghana Maternal Health Survey,[16] a nationally representative population-based survey that collected comprehensive information at both the household and individual woman's level on maternal health issues including pregnancies, stillbirths, abortions and miscarriages, and maternal deaths in the country.

METHODS

Data from the 2007 Ghana Maternal Health Survey (GMHS)[16] was analyzed for this study. GMHS was a nationally representative population-based survey that collected comprehensive information on maternal health and mortality in the country to provide baseline information for the Reducing Maternal Morbidity and Mortality (R3M) program initiated in three regions (Greater Accra, Eastern, Ashanti) of Ghana in 2006. The survey design of GMHS involved the selection of 1600 primary sampling units from the 10 administrative regions of the country, across urban and rural areas. The primary sampling units consisted of wards or sub-wards drawn from the 2001 Population Census.

Data collection was carried out in two phases with a short household questionnaire administered in Phase I in 240,000 households to identify deaths in each household in the five years preceding the survey. In Phase II, a verbal autopsy questionnaire was used to conduct verbal autopsies on the causes of death of 4,203 women aged 12-49 years identified in Phase I. Also in phase II, a long household questionnaire and a women's questionnaire was respectively administered in a subsample of 10,858 households (response rate, 98.8%) and to 10,370 women age 15-49 (response rate, 97.6%) identified from these households. These households were selected randomly and independently from the households identified in the first phase as having experienced a female death. The long household questionnaires collected information on the demographic and socioeconomic characteristics of members of the households sampled whereas the women's questionnaire gathered information on a wide range of maternal health-related issues including live births, stillbirths, abortions and miscarriages, and utilization of health services in relation to these events. Of the 10370 women aged 15-49 years, 7183 primi- and multi- parous women were eligible for this study.

Ascertainment of educational attainment

In the women's questionnaire, respondents were asked whether they have ever attended school and if they answered "yes" they were further asked about the highest level of school they attended, and the highest grade they completed at that level. Maternal education was treated both as a continuous and categorical variable in the analysis. In treating maternal educational attainment as a continuous variable, we combined the information obtained from mothers who reported ever attending school into years of schooling (1 to 15 years). Mothers who never attended school were ranked zero on this scale. The following levels of maternal education were applied in the analysis: none, lower primary (1 to 4 years of schooling), upper primary (5 to 6 years of schooling), some middle/junior high school (JHS) (7 to 8 years of schooling), completed middle school/JHS (9 years of schooling), secondary/senior high school (SHS) (10 to 12 years of schooling), and higher (≥13 years of schooling).

Assessment of exposure

Maternal exposure to household air pollution (HAP) was assessed by the type of fuel used by households for cooking. This information was obtained from the long household questionnaire. In this questionnaire, household heads were asked *"What type of fuel does your household mainly use for cooking?"* Mothers living in households using electricity, liquefied petroleum gas (LPG) and natural gas served as the reference category with those residing in households using charcoal, firewood and straw/shrubs/grass representing the exposed category. Kerosene, a non-solid fuel but with uncertainties about its cleanliness was excluded from the reference category. Very few households used coal/lignite, a non-biomass fuel for cooking and was thus excluded from the analysis.

Maternal exposure to contaminated drinking water was ascertained by the type of drinking water sources of the household. This information was also obtained from the long household questionnaire in which household heads were asked *"What is the main source of drinking water for members of your household?"* Mothers residing in households using piped and bottled/sachet water served as the reference category with those living in households sourcing water from surface (rivers, streams, lakes, dams, ponds etc.) and ground (wells, boreholes) waters representing the exposed categories. Mothers in households using spring water, rainwater and tanker water were excluded from the analysis because of the small number of household using these water resources.

Outcome of interest

The main outcome of interest was lifetime experience of stillbirth among women who have had at least one previous birth (primi- and multi- parous women). This information was extracted from the women's questionnaire where mothers were asked whether they have ever given birth in late pregnancy (7 months or more) to a dead child and if they answered "yes", they were further asked about the number of stillbirths they have had in their lifetime. Prior to these questions women were asked whether they have ever given birth with those answering "yes" representing the primi- and multi- parous women.

Covariates

The following core potential confounders were adjusted for in the analysis: area of residence (urban, rural), age of woman, marital status, ethnicity, and history of previous stillbirth.

Ethical consideration

The GMHS was conducted under the scientific and technical supervision of the Ghana Statistical Service and Ghana Health Service. The MEASURE DHS project at Macro International, Calverton, Maryland, USA approved the survey and provided technical assistance. Informed consent was obtained from all the participants before the interview.

Statistical analysis

We applied multivariate methods to assess the relation of interest. First, we applied generalized linear models (PROC LOGISTIC) to estimate the effects of maternal education on the risk of stillbirth in a woman's lifetime. Second, we applied multinomial logistic regression to assess the effects of maternal education on the likelihood of multiple stillbirths in a woman's lifetime. All models were adjusted for the core potential confounders. We performed a causal pathway analysis using the difference method[17] with computation of the percentages of mediation to establish the independent and joint mediating effect of biomass fuel use and consumption of unsafe drinking water in the observed educational differences in stillbirth risk.

In allowing for possible nonlinearities in the maternal education (years of schooling) data, we further explored the education - stillbirth relation by applying the generalized additive model with four degrees of freedom to obtain cubic smoothing splines and accompanying 95% confidence bands.

SAS version 9.3 was used to perform all the analysis with the exception of the generalized additive modeling which was performed with Stata 12.0.

RESULTS

The characteristics of the study population are presented in Tables 1 and 2. More than half (61.1%) of the respondents were within the age group 20-39 years. Half of the women reported being married with about 32% reporting that they have never been married. About half (50%) of the study population were resident in the R3M regions (Greater Accra, Eastern and Ashanti) with 17% of the women living in the three northern regions (Northern, Upper East, Upper West). More than half (52%) of the respondents were rural dwellers with about 22% of the respondents identified as city dwellers. Majority of the women (77%) were Christians with Muslims making up about 16% of the study respondents. Close to half (47%) of the women were Akans. A quarter of the respondents had no formal education with only 3.5% of the women educated up to the tertiary level or higher.

Biomass fuel, notably charcoal and firewood were the dominant cooking fuels of respondent's households with 88% of households using these fuels. LPG was used by 11% of the respondent's households. Whereas among highly educated mothers, LPG was the dominant fuel used (63%), among uneducated (76%) and primary educated (59%) mothers firewood was the fuel mostly used. Piped water (43%) and well/borehole (38%) were the dominant drinking water sources of the respondents. About 7% and 9% of the respondents used bottled/sachet and surface water, respectively. Secondary (63%) and highly (61%) educated mothers patronized piped water mostly. Among uneducated mothers, 52% accessed well/borehole water resources with 27% using piped water. Among primary and middle school/JHS educated women, the proportion using piped and well/borehole water resources were about the same.

The obstetric history and lifetime stillbirth experience of the women interviewed are presented in Table 3. About 12% of the respondents were primigravida with about 60% of the respondents found to be multigravida. About 69% of the respondents were primi/multi parous and of these women, 6% reported experiencing stillbirth in their lifetime with a small proportion (13%) of them experiencing this occurrence more than once. Uneducated mothers and mothers who completed middle/JHS recorded the highest proportion of lifetime stillbirths; 32% and 26%, respectively.

Table 4 presents the odds ratios (OR) for the association of maternal education and lifetime stillbirth experience calculated from logistic regression. No formal, lower primary and some middle school/JHS education was respectively associated with a 14% (OR = 1.14, 95% CI: 0.75, 1.72), 59% (OR = 1.59, 95% CI: 1.02, 2.48) and 25% (OR = 1.25, 95% CI: 0.77, 2.01) increased risk of stillbirth in a lifetime after adjustment for the core covariates. All the observed relations with the exception of lower primary education were however not statistically significant. Biomass fuel use and unsafe water consumption mediated 16.9% and 5.1% of the observed association of lower primary education on lifetime stillbirth risk. In the joint model, the mediation fraction was 22.0%. No consistent educational gradient was observed. Table 5 presents the ORs for the association of maternal education and lifetime multiple stillbirth experience calculated from multinomial logistic regression. For all the education categories with the exception of upper primary, the effect estimates for woman experiencing two or more stillbirths in a lifetime was quite lower than their counterparts with one stillbirth experience. All the observed associations with the exception of one stillbirth experience among lower primary educated mothers (OR = 1.63; 95% CI: 1.02, 2.61) were not statistically significant. On the relation of lower primary education with one stillbirth experience in a woman's lifetime, biomass fuel use mediated 7.9% of the observed effects. In the model adjusting for unsafe water consumption, no noticeably change in the effect estimate was observed.

Figure 1 depicts the smoothed curves for odds ratio of stillbirth in a lifetime in relation to maternal years of schooling. Among all mothers, an inverted spoon-shape smoothed curve was observed with the odds ratio of stillbirth in a lifetime rising sharply away from the null value up to about 2.5 years of schooling, decreasing afterwards with further schooling to about 6.5 years and then leveling off on the null value up to about 12.5 years of schooling before declining sharply with further years of education. The 95% confidence band was generally wide especially towards the tail end of the smoothed curve. Among urban dwellers, the smoothed curve was very similar to the trend observed among all respondents except the confidence band was slightly narrower over the range of 0 to 9 years of schooling and much wider towards the tail end of the smoothed curve. Among rural dwellers, an s-shape smoothed curve with a generally wide 95% confidence band over the whole range of the maternal schooling years was observed.

For all study participants (p=0.3284) and rural dwellers (p=0.7056), the nonlinearity chi-square was not statistically significant. Among urban dwellers, the nonlinearity chi-square was statistically significant (p=0.0413) thereby indicating possible departure from linearity. No appreciable change in the smoothed curves was observed after adjusting for the mediating effect of biomass fuel use and unsafe water consumption.

DISCUSSION

Validity issues

The GMHS survey was a population-based study with sampling from all ten administrative regions of the country and across urban and rural areas. This sampling strategy together with the high response rate (97.6%) achieved certainly minimizes selection bias. Also the standardized data collection instruments and procedures of DHS surveys including the present and the extensive training of interviewers guarantees the collection of reliable information from survey participants.

We studied educational attainment of mothers which according to some authors is a strong determinant of future employment and income,[18,19] and certainly has implications for maternal health and pregnancy outcomes. We first applied maternal education as a categorical variable to describe the association with stillbirth in terms of relative risk and to also establish whether a gradient in the risk exist. We next applied maternal education as a continuous variable to account for possible nonlinearities, increase power and better illustrate the predictor-risk relationship. We stratified the curve fitting by urban and rural residence to ascertain whether there exist any marked differences.

Even though the outcome of interest was subjectively reported by the respondents, stillbirth is a very traumatic experience that every mother with such an experience can vividly recollect and as a result the potential for outcome measurement bias is reduced in our study. Exposure to HAP and drinking water contaminants was assessed based on the primary cooking fuels and main drinking water sources of maternal households. There are limitations with the exposure assessment method applied but they have been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure. There is nonetheless the potential for exposure misclassification in the study with the direction of bias unclear. It was impossible to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the mothers interviewed. Regarding cooking fuel choices, it is often the case of households transitioning to fuels higher up the energy ladder with improved socioeconomic conditions and back to their traditional fuels as conditions deteriorate. With regards to drinking water sources, except in situations where communities have been connected to pipe-borne water, household water sources traditionally remains the same irrespective of improvement in socioeconomic conditions. It is possible households that have been connected to pipe-borne water after years of relying on ground and surface water resources will report use of pipe-borne water as their main drinking water source, but again this information bias would rather underestimate the true effect.

The study was restricted to primi- and multi- parous women and adjusted for the effect of age of respondent, marital status, area of residence (urban vs. rural), ethnicity and history of previous stillbirth. We had no information on the smoking status of the mothers, but in Ghana only few women smoke. The 2008 Ghana Demographic and Health Survey[20] estimated the proportion of women smoking cigarettes and other tobacco products to be 0.4%. Maternal smoking can therefore not be considered as a serious threat to validity in this study. We were unable to examine the confounding effect of maternal nutrition and anthropometry as well as malaria and sexually transmitted infections. However, with regards to infections it has been suggested by Silver et al.[21] that they are more clearly associated with early stillbirth (20 weeks) than with late stillbirth (after 28 weeks). Therefore with the GMHS survey ascertaining stillbirths with a cut-off point of 7 or more months, we can assume that in the present study the association is not likely to be confounded by maternal infections.

Synthesis with previous evidence

Our study adds to the weight of evidence which emanates mostly from high-income countries[22-26] on the adverse perinatal effects of low maternal educational attainment. We found lower primary education to be associated with a 59% increased risk of lifetime stillbirth. The smoothing curves also revealed a sharp rise in the odds ratio of stillbirth in a lifetime at low levels of schooling (up to 2.5 years), a leveling off around the null value up to about 12.5 years of schooling and a sharp decline with further years of schooling. A multi-country study[27] conducted in six low-income and one middle-income countries reported a 40% (RR=1.4; 95% CI: 1.2, 1.5) increased risk of stillbirth with no formal maternal schooling. Two recent population-based studies conducted in rural Ghana,[28,29] however, found no association between maternal education and stillbirth. Ha et al.[28] reported a small and statistically insignificant increased odds of antepartum and intrapartum stillbirth with no formal and primary maternal education. Engmann et al.[29] reported a much higher increased odds of stillbirth with no formal (OR=1.47; 95% CI: 0.94, 2.29) and primary/JHS maternal education (OR=1.48, 95% CI: 0.95, 2.30), but again the associations were not statistically significant. A systematic review and meta-analysis of the available evidence on the major risk factors for stillbirth in high-income countries[26] found low educational attainment (<10 years of schooling) to be associated with 70% (OR=1.7; 95% CI: 1.4, 2.0; n=5) increased odds of stillbirth. The findings of our study are consistent with the findings of McClure et al.[27] and Flenady et al.[26]

From the multinomial logistic regression analysis, multiple stillbirth experience in a lifetime appeared not to be related to maternal education. This finding is not surprising because as is well documented in the reproductive biology literature, previous stillbirth experience is expected to strongly influence the trajectory of subsequent pregnancies.

Causal pathways

Medical care has been mentioned as the route through which education leads to inequality in stillbirth from placental abruption and cord compression.[30] Suboptimal care including delayed recognition of medical problems or poor management has been noted to contribute to a significant proportion of stillbirths.[31] Delayed access of prenatal care services owing to ignorance, and mothers inability to translate nutritional and other health education messages provided at these service centers into practice for improved maternal and fetal health also due to lack of or low education is very common in developing countries. Galobardes et al.[32] stated that the knowledge and skills acquired through education may affect an individual's cognitive functioning, make them more receptive to health education messages, or better communicate with and access appropriate health services. Stephansson et al.[33] have also suggested that differences in the risk of stillbirth between socioeconomic groups can be attributed to social differences in seeking care for signs of pathological pregnancy such as reduced fetal movements.

In developing countries, besides access and utilization of health services, there are other important pathways through which low educational attainment impacts on perinatal outcomes with our study, the first to explore the mediating role of environmental factors in the maternal education - stillbirth relationship. Biomass fuel use and unsafe water consumption explained about 17% and 5% of the observed effects of low maternal educational attainment on lifetime stillbirth risk. Jointly, they mediated almost a quarter (22%) of the observed effect. A study in Ghana found the effects of low educational attainment on average birth weight to be substantially (62%) mediated by biomass fuel use.[34] Studies in Ghana,[35,36] Ethiopia,[37,38] Cameroun[39] and Kenya[40] have reported educational attainment to be an important determinant of cooking fuel choices in households.

CONCLUSIONS

In conclusion, we provide evidence that in Ghana and similar developing country settings, biomass fuel use and unsafe water consumption are important pathways through which low maternal educational attainment leads to stillbirths. Women with no or low education should therefore receive extra care and support, and be alerted to household environmental risks to their pregnancies during prenatal visits to help curb the high stillbirth incidence in developing countries. According to Goldenberg et al.,[41] each geographical area must understand the local causes of and risk factors for stillbirth, and the contexts in which they occur to enable prevention strategies can be developed and implemented.

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Authors contribution AKA conceived and designed the study, and performed the data analysis with guidance from SN and JJKJ. AKA wrote the manuscript with SN and JJKJ reviewing drafts for intellectual content. All authors read and approved the final version.

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Competing interests None declared.

Ethics approval The Ghana Maternal Health Survey was approved by the Ghana Statistical Service, Ghana Health Service and MEASURE DHS.

Data sharing statement No additional data are available.

Table 1 Demographic and background characteristics of respondents (N=10370)

Characteristic	No. (%)
Age (years)[1]	
<20	2056 (19.8)
20-29	3465 (33.4)
30-39	2873 (27.7)
>39	1976 (19.1)
Marital status[2]	
Married	5143 (49.6)
Cohabitation	984 (9.5)
Never married	3265 (31.5)
Divorced/Separated	770 (7.4)
Widowed	205 (2.0)
Missing	3 (0.03)
Region of residence	
Western	835 (8.1)
Central	891 (8.6)
Greater Accra	1850 (17.8)
Volta	836 (8.1)
Eastern	1565 (15.1)
Ashanti	1723 (16.6)
Brong Ahafo	911 (8.8)
Northern	818 (7.9)
Upper East	526 (5.1)
Upper West	415 (4.0)
Area of residence[3]	
City	2231 (21.5)
Town	2729 (26.3)
Rural	5410 (52.2)
Education	
None	2588 (25.0)
Lower Primary (1 - 4 years of schooling)	996 (9.6)
Upper Primary (5 - 6 years of schooling)	1170 (11.3)
Some Middle/JSS (7 - 8 years of schooling)	1331 (12.8)
Completed Middle/JSS (9 years of schooling)	2721 (26.2)
Secondary/SSS (10 - 12 years of schooling)	1190 (11.5)
Higher (≥13 years of schooling)	367 (3.5)
Missing	7(0.07)
Religion	
Christian	7976 (76.9)
Moslem	1626 (15.7)
Traditional/Spiritualist	308 (3.0)
Other	7 (0.1)
No religion	449 (4.3)
Missing	4 (0.04)
Ethnic group[4]	
Akan	4886 (47.1)
Ga/Dangme	922 (8.9)
Ewe	1422 (13.7)
Guan	223 (2.2)
Mole – Dagbani	890 (8.6)
Grussi	451 (4.4)
Gruma	562 (5.4)
Hausa	141 (1.4)
Other	869 (8.4)
Missing	4 (0.04)

Covariates: [1]Age group 20-29 years, [2]Married/cohabitation, [3]Urban (City & town), and [4]Akan served as reference category

Table 2 Cooking fuel choices and drinking water sources of respondents households

	None n (%)	Lower primary n (%)	Upper primary n (%)	Some Middle/JSS n (%)	Completed Middle/JSS n (%)	Secondary/ SSS n (%)	Higher n (%)	Total N (%)
Type of cooking fuel								
Electricity	1 (0.04)	1 (0.1)	2 (0.2)	1 (0.1)	3 (0.1)	5 (0.4)	5 (1.4)	18 (0.2)
LPG	24 (0.9)	43 (4.3)	54 (4.6)	82 (6.2)	347 (12.8)	373 (31.3)	231 (62.9)	1154 (11.0)
Natural gas	1 (0.04)	1 (0.1)	0 (0.0)	1 (0.1)	5 (0.2)	3 (0.3)	5 (1.4)	16 (0.2)
Kerosene	0 (0.0)	0 (0.0)	4 (0.34)	3 (0.2)	10 (0.4)	6 (0.5)	3 (0.8)	26 (0.3)
Coal/Lignite	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)	3 (0.3)	1 (0.3)	5 (0.05)
Charcoal	573 (22.1)	323 (32.3)	450 (38.5)	503 (37.7)	1232 (45.3)	587 (49.3)	108 (29.4)	3776 (36.4)
Firewood	1969 (76.1)	626 (62.7)	652 (55.7)	737 (55.3)	1113 (40.9)	207 (17.4)	13 (3.5)	5317 (51.3)
Straw/Shrub/Grass	19 (0.7)	1 (0.1)	3 (0.26)	1 (0.1)	0 (0.0)	2 (0.2)	0 (0.0)	26 (0.3)
No cooking	0 (0.0)	4 (0.4)	3 (0.26)	6 (0.5)	9 (0.33)	4 (0.3)	0 (0.0)	26 (0.3)
Missing	1 (0.04)	0 (0.0)	1 (0.1)	0 (0.0)	2 (0.1)	0 (0.0)	1 (0.3)	5 (0.1)
Source of drinking water								
Piped water	707 (27.3)	374 (37.4)	471 (40.3)	568 (42.6)	1370 (50.4)	749 (62.9)	224 (61.0)	4463 (43.0)
Well/Borehole	1353 (52.3)	418 (41.8)	462 (39.5)	549 (41.2)	911 (33.5)	199 (16.7)	40 (10.9)	3932 (37.9)
Spring	77 (3.0)	18 (1.8)	25 (2.1)	29 (2.2)	31 (1.1)	3 (0.3)	0 (0.0)	183 (1.8)
Surface water	388 (15.0)	138 (13.8)	140 (12.0)	118 (8.9)	163 (6.0)	23 (1.9)	2 (0.5)	972 (9.4)
Rainwater	11 (0.4)	6 (0.6)	8 (0.7)	11 (0.8)	30 (1.1)	8 (0.7)	0 (0.0)	74 (0.7)
Tanker truck	9 (0.4)	11 (1.1)	7 (0.6)	2 (0.2)	14 (0.5)	7 (0.6)	3 (0.8)	53 (0.5)
Bottled/Sachet water	42 (1.6)	34 (3.4)	56 (4.8)	57 (4.3)	199 (7.3)	201 (16.9)	98 (26.7)	687 (6.6)
Other	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.04)	0 (0.0)	0 (0.0)	1 (0.01)
Missing	1 (0.04)	0 (0.0)	1 (0.1)	0 (0.0)	2 (0.1)	0 (0.0)	0 (0.0)	4 (0.04)

Table 3 Obstetric history and lifetime stillbirth experience of respondents classified by maternal education

	None n (%)	Lower primary n (%)	Upper primary n (%)	Some middle/JSS n (%)	Completed middle/JSS n (%)	Secondary/ SSS n (%)	Higher n (%)	Total N (%)
Gravidity								
Nulligravida								2842 (27.4)
Primigravida								1266 (12.2)
Multigravida								6262 (60.4)
Parity								
Nulliparous								3187 (30.7)
Primi/Multi parous								7183 (69.3)
Lifetime stillbirth experience								
No	2183 (32.3)	727 (10.8)	764 (11.3)	658 (9.7)	1831 (27.1)	458 (6.8)	144 (2.1)	6766 (94.2)
Yes	133 (31.9)	62 (14.9)	37 (8.9)	41 (9.8)	110 (26.4)	27 (6.5)	7 (1.7)	417 (5.8)
No. of stillbirths in lifetime								
One	114 (31.3)	54 (14.8)	30 (8.2)	37 (10.2)	99 (27.2)	23 (6.3)	7 (1.9)	364 (87.3)
Two or more	19 (35.9)	8 (15.1)	7 (13.2)	4 (7.6)	11 (20.8)	4 (7.6)	0 (0.0)	53 (12.7)

Table 4 Binary logistic regression of lifetime stillbirth experience on maternal education (n=7183)

Education	**Unadjusted**	**Adjustment for:**			
		Model 1: Core covariates[1]	**Model 2: +**Biomass fuel use	**Model 3: +**Unsafe water consumption	**Model 4: +**Biomass fuel use and unsafe water consumption
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
None	1.08 (0.73, 1.59)	1.14 (0.75, 1.72)			
Lower primary	1.51 (0.98, 2.33)	1.59 (1.02, 2.48)	1.49 (0.93, 2.37)	1.56 (0.99, 2.44)	1.46 (0.91, 2.33)
Upper primary	0.86 (0.53, 1.38)	0.96 (0.59, 1.56)			
Some middle/JSS	1.10 (0.69, 1.76)	1.25 (0.77, 2.01)			
Completed middle/JSS	1.06 (0.72, 1.58)	1.10 (0.74, 1.64)			
Secondary+	1.00	1.00	1.00	1.00	1.00

[1]Core covariates were age of mother, marital status, area of residence and ethnic group
Mediation fractions: Lower primary education (Biomass fuel: 16.9%; Unsafe water: 5.1%; Joint: 22.0%)

Table 5 Multinomial logistic regression of lifetime stillbirth experience on maternal education (n=7183)

		Unadjusted	**Adjustment for:**			
			Model 1: Core covariates[1]	**Model 2: +**Biomass fuel use	**Model 3: +**Unsafe water consumption	**Model 4: +**Biomass fuel use and unsafe water consumption
Education		**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
	No. of stillbirths in lifetime					
None	One	1.05 (0.69, 1.58)	1.17 (0.75, 1.81)			
	Two or more	1.31 (0.44, 3.87)	0.93 (0.29, 2.96)			
Lower primary	One	1.49 (0.94, 2.36)	1.63 (1.02, 2.61)	1.58 (0.96, 2.59)	1.62 (1.01, 2.60)	1.57 (0.95, 2.58)
	Two or more	1.66 (0.50, 5.53)	1.31 (0.38, 4.53)			
Upper primary	One	0.79 (0.47, 1.32)	0.91 (0.54, 1.53)			
	Two or more	1.38 (0.40, 4.73)	1.22 (0.35, 4.29)			
Some middle/JSS	One	1.13 (0.69, 1.85)	1.31 (0.79, 2.16)			
	Two or more	0.92 (0.23, 3.67)	0.84 (0.20, 3.44)			
Completed middle/JSS	One	1.09 (0.71, 1.65)	1.14 (0.75, 1.75)			
	Two or more	0.90 (0.29, 2.85)	0.80 (0.25, 2.57)			
Secondary+		1.00	1.00	1.00	1.00	1.00

[1]Core covariates were age of mother, marital status, area of residence, ethnic group and history of previous stillbirth

Mediation fractions: Lower primary education - One stillbirth (Biomass fuel: 7.9%)

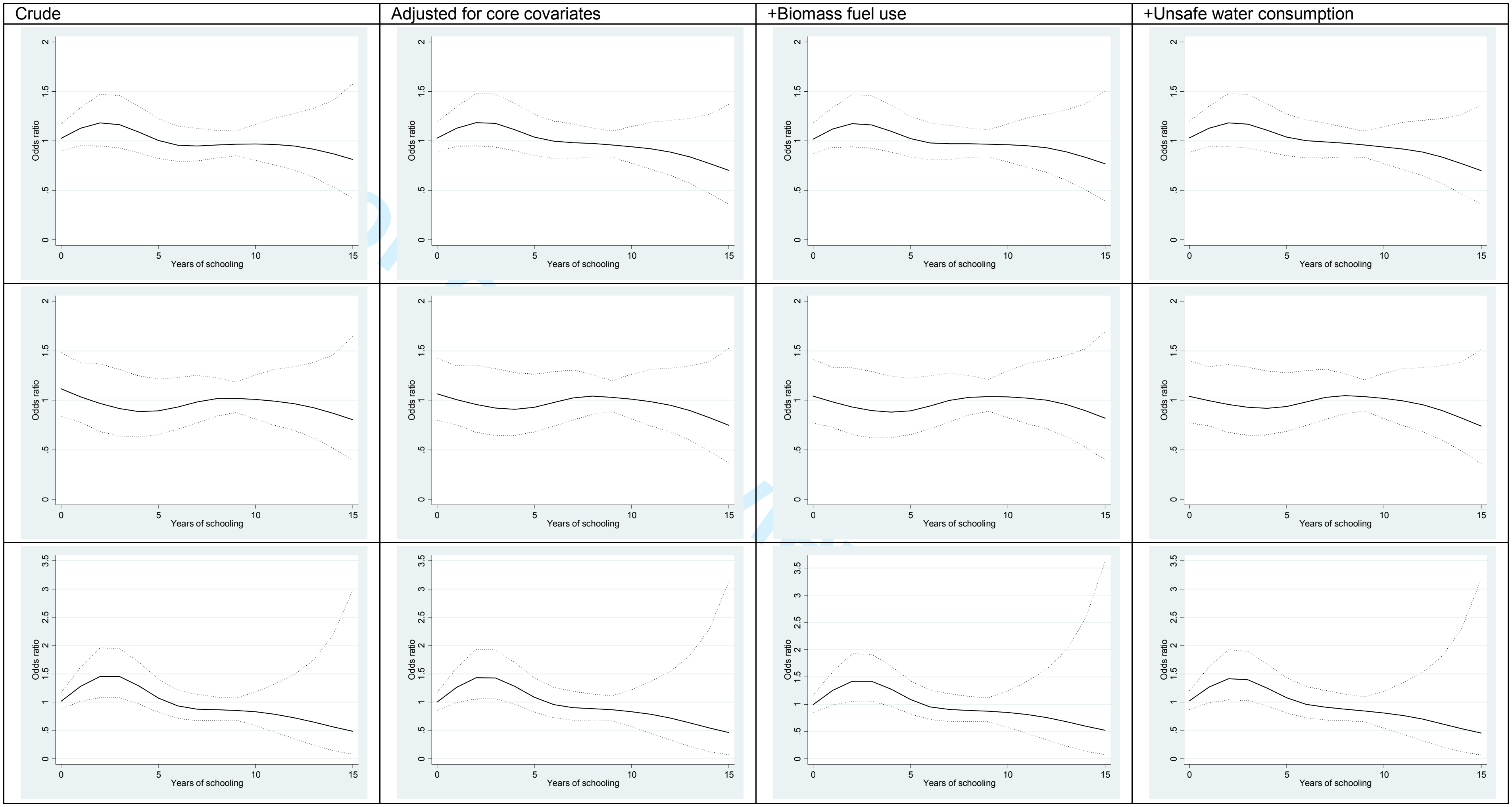

Figure 1 Odds ratios (Solid lines) and their corresponding 95% confidence bands (dotted lines) from generalized additive models (df = 4) regressing lifetime stillbirths on years of maternal schooling. Upper row: All respondents. Middle row: Rural dwellers. Lower row: Urban dwellers

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Do biomass fuel use and consumption of unsafe water mediate educational inequalities in stillbirth risk? An analysis of the 2007 Ghana Maternal Health Survey

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ABSTRACT

Background Numerous studies have explored the association between educational inequalities and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that household use of biomass fuels and unsafe drinking water resources related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage.

Methods Data from the 2007 Ghana Maternal Health Survey, a nationally representative population-based survey were analyzed for this study. Of the10,370 women aged 15-49 years interviewed via structured questionnaires for the survey, 7183 primi- and multi- parous women qualified for inclusion in the present study. .

Results Lower maternal primary education was associated with a 59% (Odds ratio [OR] = 1.59; 95% CI: 1.02, 2.48) increased lifetime risk of stillbirth in logistic regression analysis that adjusted for potential confounders. Biomass fuel use and consumption of unsafe water mediated 17% and 5% of the observed effects, respectively. Jointly these two exposures explained 22% of the observed effects. In an adjusted multinomial logistic regression analysis, low educational attainment was found not to be risk factor for two or more stillbirth experiences in a woman's lifetime. The generalized additive modeling revealed an inverted spoon-shaped smoothed curve which peaked at 2 to 3 years of schooling, corresponding to lower primary education and confirming the findings from the logistic regression modeling.

Conclusions Our results shows that biomass fuel use and unsafe water consumption could be important pathways through which low maternal educational attainment leads to stillbirths in Ghana and similar developing country settings. Addressing educational inequalities in developing countries is thus essential to ensuring household choices that curtail environmental exposures, and subsequently improve pregnancy outcomes.

Strengths and limitations of this study

- This population-based study has shown for the first time that biomass fuel use and consumption of unsafe water could be important pathways through which low maternal educational attainment leads to increased risk of stillbirth.
- The predictor-risk relationship was further illustrated through curve fitting with generalized additive modeling.
- There are limitations with the exposure assessment method applied but they have been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure.
- It was impossible to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the study participants with the potential for exposure misclassification in the study.

INTRODUCTION

Stillbirth, defined by WHO as the intrauterine death of any conceptus at any time during pregnancy[1] is a major public health concern in developing countries. An estimated 3.2 million stillbirths occurs worldwide annually with 98% of these stillbirths found in developing countries.[2] Important causes of stillbirths globally are asphyxia and infection associated with obstructed or prolonged labour, pre-eclampsia and eclampsia, chorioamnionitis, syphilis, malaria and poor nutritional status.[3] Stillbirth rates among ethnic minority, disadvantaged, marginalized and rural populations have however been noted to be much higher[4-6] thus revealing the very important role of socioeconomic factors.

The stillbirth problem in low-income countries is as a result of several factors that are associated with poverty[7] including solid fuel use and consumption of unsafe drinking water. Many households in developing countries rely on ground and surface water resources for domestic purposes due to limited access to pipe-borne water, erratic supply, and high connection and utility charges. These water resources are often polluted by mining and agricultural activities, as well as nearby pit latrines which are also in widespread use in developing countries. Mining activities leads to the deposition/leaching of substantial amounts of chemicals and heavy metals such as cyanide, sulfuric acid, mercury, arsenic, lead and cadmium into nearby water bodies especially in unregulated mines. Agricultural runoffs can introduce sediments, pesticides, fertilizers and pathogens into water bodies. Pit latrines are also widely documented to leach microbial and chemical contaminants including coliforms, *Escherichia coli,* fecal streptococci, ammonia, nitrates and nitrites into groundwater sources.[8] Poverty further hampers most households from treating these unsafe water resources before usage.

Poverty and limited access to clean fuels in developing countries have also resulted in solid fuels being the predominant cooking fuel in these countries[9] with Bonjour et al.[10] estimating the proportion of households in Africa and Southeast Asia relying on solid fuels for cooking to be more than 60%. These fuels are usually burnt in open fires or inefficient traditional stoves, often in poorly ventilated cooking spaces, resulting in the release of high levels of air pollutants including particulate matter and carbon monoxide to which women and their young children are most heavily exposed.[9] Studies have associated use of solid fuels,[11] and consumption of contaminated drinking water[12-14] with stillbirth and other adverse pregnancy outcomes.

Socioeconomic characteristics including educational attainment clearly have a major influence on cooking fuel and drinking water choices in developing countries. Socioeconomic characteristics is also well-documented to have strong effects on health outcomes and certainly contributes to the burden of adverse maternal and fetal health outcomes in Ghana and other developing countries. Numerous studies mostly emanating from high-income countries have explored the relationship between educational attainment and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that household use of biomass fuels and unsafe drinking water resources related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage. As noted by Kramer,[15] research that identifies and quantifies the causal pathways and mechanisms whereby social disadvantage leads to higher risks of unfavorable pregnancy outcomes may eventually help to reduce current disparities and improve pregnancy outcome across the entire socioeconomic spectrum. We relied on data from the 2007 Ghana Maternal Health Survey,[16] a nationally representative population-based survey that collected comprehensive information at both the household and individual woman's level on maternal health issues including pregnancies, stillbirths, abortions and miscarriages, and maternal deaths in the country.

METHODS

Data from the 2007 Ghana Maternal Health Survey (GMHS)[16] was analyzed for this study. GMHS was a nationally representative population-based survey that collected comprehensive information on maternal health and mortality in the country to provide baseline information for the Reducing Maternal Morbidity and Mortality (R3M) program initiated in three regions (Greater Accra, Eastern, Ashanti) of Ghana in 2006. The survey design of GMHS involved the selection of 1600 primary sampling units from the 10 administrative regions of the country, across urban and rural areas. The primary sampling units consisted of wards or sub-wards drawn from the 2001 Population Census.

Data collection was carried out in two phases with data for the present study deriving from the second phase. In the second phase, a long household questionnaire was administered in 10,858 households (response rate, 98.8%) randomly and independently selected from 240,000 households sampled in the first phase for profiling maternal deaths. Also in the second phase, a women's questionnaire was administered to 10,370 women age 15-49 (response rate, 97.6%) identified from the 10,858 households. The long household questionnaires collected information on the demographic and socioeconomic characteristics of members of the households sampled whereas the women's questionnaire gathered information on a wide range of maternal health-related issues including live births, stillbirths, abortions and miscarriages, and utilization of health services in relation to these events.

Eligibility criteria

To be eligible for inclusion in the present study, a woman must have given birth at least once (i.e. primi- and multi- parous women). Of the 10370 women aged 15-49 years, 7183 (69.3%) primi- and multi- parous women were eligible for the present study.

Ascertainment of educational attainment

In the women's questionnaire, respondents were asked whether they have ever attended school and if they answered "yes" they were further asked about the highest level of school they attended, and the highest grade they completed at that level. Maternal education was treated both as a continuous and categorical variable in the analysis. In treating maternal educational attainment as a continuous variable, we combined the information obtained from mothers who reported ever attending school into years of schooling (1 to 15 years). Mothers who never attended school were ranked zero on this scale. The following levels of maternal education were applied in the analysis: none, lower primary (1 to 4 years of schooling), upper primary (5 to 6 years of schooling), some middle/junior high school (JHS) (7 to 8 years of schooling), completed middle school/JHS (9 years of schooling), secondary/senior high school (SHS) (10 to 12 years of schooling), and higher (≥13 years of schooling).

Assessment of exposure

Maternal exposure to household air pollution (HAP) was assessed by the type of fuel used by households for cooking. This information was obtained from the long household questionnaire. In this questionnaire, household heads were asked *"What type of fuel does your household mainly use for cooking?"* Mothers living in households using electricity, liquefied petroleum gas (LPG) and natural gas served as the reference category with those residing in households using charcoal, firewood and straw/shrubs/grass representing the exposed category. Kerosene, a non-solid fuel but with uncertainties about its cleanliness was excluded from the reference category. Very few households used coal/lignite, a non-biomass fuel for cooking and was thus excluded from the analysis.

Maternal exposure to contaminated drinking water was ascertained by the type of drinking water sources of the household. This information was also obtained from the long household questionnaire in which household heads were asked *"What is the main source of drinking water for members of your household?"* Mothers residing in households using piped and bottled/sachet water served as the reference category with those living in households sourcing water from surface (rivers, streams, lakes, dams, ponds etc.) and ground (wells, boreholes) waters representing the exposed categories. Mothers in households using spring water, rainwater and tanker water were excluded from the analysis because of the small number of household using these water resources.

Outcome of interest

The outcome of interest was lifetime experience of stillbirth among primi- and multi- parous women. This information was extracted from the women's questionnaire where mothers were asked whether they have ever given birth in late pregnancy (7 months or more) to a dead child and if they answered "yes", they were further asked about the number of stillbirths they have had in their lifetime. Prior to these questions women were asked whether they have ever given birth with those answering "yes" representing the primi- and multi- parous women. The study outcome was stillbirth experience (yes vs. no) and number of stillbirths (0, 1, 2 or more).

Covariates

The following core potential confounders were adjusted for in the analysis: area of residence (urban, rural), age of woman, marital status and ethnicity.

Ethical consideration

The GMHS was conducted under the scientific and technical supervision of the Ghana Statistical Service and Ghana Health Service. The MEASURE DHS project at Macro International, Calverton, Maryland, USA approved the survey and provided technical assistance. Informed consent was obtained from all the participants before the interview.

Statistical analysis

We applied multivariate methods to assess the relation of interest. First, we applied generalized linear models (PROC LOGISTIC) to estimate the effects of maternal education on the risk of stillbirth (yes, coded 1 vs. no, coded 0) in a woman's lifetime and to also establish whether a gradient in the risk exist. Second, we applied multinomial logistic regression to assess the effects of maternal education on the likelihood of multiple stillbirths (0, 1, 2 or more) in a woman's lifetime. All models were adjusted for the core potential confounders. We performed a causal pathway analysis using the difference method[17] with computation of the percentages of mediation to establish the independent and joint mediating effect of biomass fuel use and consumption of unsafe drinking water in the observed educational differences in stillbirth risk. In brief, after controlling for the core confounders, biomass fuel use and unsafe water consumption were further independently and jointly added to the adjusted model with the mediation fractions computed using the formula below:

$$\frac{OR_{adjusted} - OR_{mediation}}{1 - OR_{adjusted}} \times 100\%$$

where $OR_{adjusted}$ is the odds ratio in the adjusted model and $OR_{mediation}$ is the odds ratio in the independent and joint mediation models

In allowing for possible nonlinearities in the maternal education (years of schooling) data, we further explored the education - stillbirth relation by applying the generalized additive model with four degrees of freedom to obtain cubic smoothing splines and accompanying 95% confidence bands. Four degrees of freedom was chosen because it has been demonstrated to fit most data well.[18,19] Too many degrees of freedom can lead to overfitting i.e. describing random error rather than a true underlying relationship, whereas choosing too few causes too much smoothing and can lead to the missing of important trends.[19] We stratified the curve fitting by urban and rural residence to ascertain whether there exist any marked differences.

SAS version 9.3 was used to perform all the analysis with the exception of the generalized additive modeling which was performed with Stata 12.0.

RESULTS

The characteristics of the study population are presented in Tables 1 and 2. Close to one-third (31.9%) of the respondents were within the age group 20-39 years. More than half (68.6%) of the women reported being married with very few (6.4%) reporting that they have never been married. Close to half (46.3%) of the study population were resident in the R3M regions (Greater Accra, Eastern and Ashanti) with 19% of the women living in the three northern regions (Northern, Upper East, Upper West). More than half (58%) of the respondents were rural dwellers with about 17% of the respondents identified as city dwellers. Majority of the women (75%) were Christians with Muslims making up about 16% of the study respondents. Close to half (46%) of the women were Akans. Close to one-third (32.3%) of the respondents had no formal education with only 2.1% of the women educated up to the tertiary level or higher.

Biomass fuel, notably charcoal and firewood were the dominant cooking fuels of respondent's households with 91% of households using these fuels. LPG was used by 8% of the respondent's households. Whereas among highly educated mothers, LPG was the dominant fuel used (69%), among uneducated (77%) and primary educated (64%) mothers firewood was the fuel mostly used. Piped water (40%) and well/borehole (41%) were the dominant drinking water sources of the respondents. About 5% and 11% of the respondents used bottled/sachet and surface water, respectively. Secondary (59%) and highly (64%) educated mothers patronized piped water mostly. A quarter of highly educated mothers used bottled/sachet water. Among uneducated mothers, 53% accessed well/borehole water resources with 26% using piped water. Among primary and some middle school/JHS educated women, the proportion using piped and well/borehole water resources were about the same.

The gravidity status and lifetime stillbirth experience of the women interviewed are presented in Table 3. About 14% of the respondents were primigravida. About 6% of the respondents reported experiencing stillbirth in their lifetime with a small proportion (13%) of them experiencing this occurrence more than once. Uneducated mothers and mothers who

completed middle/JHS recorded the highest proportion of lifetime stillbirths; 32% and 26%, respectively.

Table 4 presents the odds ratios (OR) for the association of maternal education and lifetime stillbirth experience calculated from logistic regression. No formal, lower primary and some middle school/JHS education was respectively associated with a 14% (OR = 1.14, 95% CI: 0.75, 1.72), 59% (OR = 1.59, 95% CI: 1.02, 2.48) and 25% (OR = 1.25, 95% CI: 0.77, 2.01) increased risk of stillbirth in a lifetime after adjustment for the core covariates. All the observed relations with the exception of lower primary education were however not statistically significant. Biomass fuel use and unsafe water consumption mediated 16.9% and 5.1% of the observed association of lower primary education on lifetime stillbirth risk. In the joint model, the mediation fraction was 22.0%. No consistent educational gradient was observed. Table 5 presents the ORs for the association of maternal education and lifetime multiple stillbirth experience calculated from multinomial logistic regression. For all the education categories with the exception of upper primary, the effect estimates for woman experiencing two or more stillbirths in a lifetime was quite lower than their counterparts with one stillbirth experience. All the observed associations with the exception of one stillbirth experience among lower primary educated mothers (OR = 1.63; 95% CI: 1.02, 2.61) were not statistically significant. On the relation of lower primary education with one stillbirth experience in a woman's lifetime, biomass fuel use mediated 7.9% of the observed effects. In the model adjusting for unsafe water consumption, no noticeably change in the effect estimate was observed.

Figure 1 depicts the smoothed curves for odds ratio of stillbirth in a lifetime in relation to maternal years of schooling. Among all mothers, an inverted spoon-shaped smoothed curve was observed with the odds ratio of stillbirth in a lifetime rising sharply away from the reference level up to about 2.5 years of schooling, decreasing afterwards with further schooling to about 6.5 years and then leveling off on the reference level up to about 12.5 years of schooling before declining sharply with further years of education. The 95% confidence band was generally wide especially towards the tail end of the smoothed curve. Among rural dwellers, the smoothed curve was very similar to the trend observed among all respondents except the confidence band was slightly narrower over the range of 0 to 9 years of schooling and much wider towards the tail end of the smoothed curve. Among urban dwellers, an s-shape smoothed curve with a generally wide 95% confidence band over the whole range of the maternal schooling years was observed.

For all study participants (p = 0.3284) and urban dwellers (p = 0.7056), the nonlinearity chi-square was not statistically significant. Among rural dwellers, the nonlinearity chi-square was statistically significant (p = 0.0413) thereby indicating possible departure from linearity. No appreciable change in the smoothed curves was observed after adjusting for the mediating effect of biomass fuel use and unsafe water consumption.

DISCUSSION

Validity issues

Selection bias is minimized in the study owing to the population-based nature of the GMHS survey together with the high response rate (97.6%) achieved. Also the standardized data collection instruments and procedures of DHS surveys including the present and the extensive training of interviewers guarantees the collection of reliable information from survey participants. On the issue of missing data, of the variables of interest concerned (education, marital status, ethnic group, cooking fuel type, drinking water source), the proportion of respondents with missing data was very low (< 0.04%).

We studied educational attainment of mothers which according to some authors is a strong determinant of future employment and income,[20,21] and certainly has implications for maternal health and pregnancy outcomes. The association of maternal education with stillbirth was first described in terms of relative risk by educational categories. The generalized additive modeling enabled maternal education to be applied as a continuous variable to increase statistical power and help better illustrate the predictor-risk relationship.

Even though the outcome of interest was subjectively reported by the respondents, stillbirth is a very traumatic experience that every mother with such an experience can vividly recollect and as a result the potential for outcome measurement bias is reduced in our study. Exposure to HAP and drinking water contaminants was assessed based on the primary cooking fuels and main drinking water sources of maternal households. There are limitations with the exposure assessment method applied but they have been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure. There is nonetheless the potential for exposure misclassification in the study with the direction of bias unclear. It was impossible to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the mothers interviewed. Regarding cooking fuel choices, it is often the case of households transitioning to fuels higher up the energy ladder with improved socioeconomic conditions and back to their traditional fuels as conditions deteriorate. With regards to drinking water sources, except in situations where communities have been connected to pipe-borne water, household water sources traditionally remains the same irrespective of improvement in socioeconomic conditions. It is possible households that have been connected to pipe-borne water after years of relying on ground and surface water resources will report use of pipe-borne water as their main drinking water source, but again this information bias would rather underestimate the true effect.

The study adjusted for the effect of age of respondent, marital status, area of residence (urban vs. rural) and ethnicity. We had no information on the smoking status of the mothers, but in Ghana only few women smoke. The 2008 Ghana Demographic and Health Survey[22] estimated the proportion of women smoking cigarettes and other tobacco products to be 0.4%. Maternal smoking can therefore not be considered as a serious threat to validity in this study.

We were unable to examine the confounding effect of prenatal and intrapartum care, maternal nutrition and anthropometry as well as malaria and sexually transmitted infections. However, with regards to infections it has been suggested by Silver et al.[23] that they are more clearly associated with early stillbirth (20 weeks) than with late stillbirth (after 28 weeks). Therefore with the GMHS survey ascertaining stillbirths with a cut-off point of 7 or more months, we can assume that in the present study the association is not likely to be confounded by maternal infections.

Synthesis with previous evidence

Our study adds to the weight of evidence which emanates mostly from high-income countries[24-28] on the adverse perinatal effects of low maternal educational attainment. We found lower primary education to be associated with a 59% increased risk of lifetime stillbirth. The smoothing curves also peaked at low levels of schooling (2 to 3 years) and declined sharply with high levels of schooling (> 12.5 years). A multi-country study[29] conducted in six low-income and one middle-income countries reported a 40% (RR=1.4; 95% CI: 1.2, 1.5) increased risk of stillbirth with no formal maternal schooling. Two recent population-based studies conducted in rural Ghana,[30,31] however, found no association between maternal education and stillbirth. Ha et al.[30] reported a small and statistically insignificant increased odds of antepartum and intrapartum stillbirth with no formal and primary maternal education. Engmann et al.[31] reported a much higher increased odds of stillbirth with no formal (OR=1.47; 95% CI: 0.94, 2.29) and primary/JHS maternal education (OR=1.48, 95% CI: 0.95, 2.30), but again the associations were not statistically significant. A systematic review and meta-analysis of the available evidence on the major risk factors for stillbirth in high-income countries[28] found low educational attainment (<10 years of schooling) to be associated with 70% (OR=1.7; 95% CI: 1.4, 2.0; n=5) increased odds of stillbirth. The findings of our study are consistent with the findings of McClure et al.[29] and Flenady et al.[28]

From the multinomial logistic regression analysis, multiple stillbirth experience in a lifetime appeared not to be related to maternal education. This finding is not surprising because as is well documented in the reproductive biology literature, previous stillbirth experience is expected to strongly influence the trajectory of subsequent pregnancies.

Causal pathways

Medical care has been mentioned as the route through which education leads to inequality in stillbirth from placental abruption and cord compression.[32] Suboptimal care including delayed recognition of medical problems or poor management has been noted to contribute to a significant proportion of stillbirths.[33] Delayed access of prenatal care services owing to ignorance is very common in developing countries. Also common in these countries is mothers inability to put into practice, the nutritional and other health education messages received during prenatal visits for improved maternal and fetal health due to lack of or low education. Galobardes et al.[34] stated that the knowledge and skills acquired through education may affect an individual's cognitive functioning, make them more receptive to health education messages, or better communicate with and access appropriate health services. Stephansson et al.[35] have also suggested that differences in the risk of stillbirth between socioeconomic groups can be attributed to social differences in seeking care for signs of pathological pregnancy such as reduced fetal movements.

In developing countries, besides access and utilization of health services, there are other important pathways through which low educational attainment impacts on perinatal outcomes with our study, the first to explore the mediating role of environmental factors in the maternal education - stillbirth relationship. Biomass fuel use and unsafe water consumption explained about 17% and 5% of the observed effects of low maternal educational attainment on lifetime stillbirth risk. Jointly, they mediated almost a quarter (22%) of the observed effect. A study in Ghana found the effects of low educational attainment on average birth weight to be substantially (62%) mediated by biomass fuel use.[36] Studies in Ghana,[37,38] Ethiopia,[39,40] Cameroun[41] and Kenya[42] have reported educational attainment to be an important determinant of cooking fuel choices in households.

We must mention that the mediation fraction reported is likely to be overestimated and should be interpreted with caution. This is because prenatal and intrapartum care, maternal nutrition and other social factors which we were unable to control in the analysis are associated with educational attainment just as much as fuel and drinking water choices. It is thus possible biomass fuel use and unsafe water consumption is essentially a proxy for these confounding variables and as a result, biasing the causal effect away from null.

CONCLUSIONS

In conclusion, we provide evidence that in Ghana and similar developing country settings, biomass fuel use and unsafe water consumption could be important pathways through which low maternal educational attainment leads to stillbirths. Women with no or low education should therefore receive extra care and support, and be alerted to household environmental risks to their pregnancies during prenatal visits to help curb the high stillbirth incidence in developing countries. According to Goldenberg et al.,[43] each geographical area must understand the local causes of and risk factors for stillbirth, and the contexts in which they occur to enable prevention strategies to be developed and implemented.

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Authors contribution AKA conceived and designed the study, and performed the data analysis with guidance from SN and JJKJ. AKA wrote the manuscript with SN and JJKJ reviewing drafts for intellectual content. All authors read and approved the final version.

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Competing interests None declared.

Ethics approval The Ghana Maternal Health Survey was approved by the Ghana Statistical Service, Ghana Health Service and MEASURE DHS.

Data sharing statement No additional data are available.

Table 1 Demographic and background characteristics of the study respondents (n=7183)

Characteristic	**No. (%)**
Age (years)[1]	
<20	247 (3.4)
20-29	2293 (31.9)
30-39	2713 (37.8)
>39	1930 (26.9)
Marital status[2]	
Married	4925 (68.6)
Cohabitation	878 (12.2)
Never married	457 (6.4)
Divorced/Separated	721 (10.0)
Widowed	200 (2.8)
Missing	2 (0.03)
Region of residence	
Western	569 (7.9)
Central	642 (8.9)
Greater Accra	1071 (14.9)
Volta	590 (8.2)
Eastern	1084 (15.1)
Ashanti	1173 (16.3)
Brong Ahafo	684 (9.5)
Northern	637 (8.9)
Upper East	409 (5.7)
Upper West	324 (4.5)
Area of residence[3]	
City	1249 (17.4)
Town	1782 (24.8)
Rural	4152 (57.8)
Education	
None	2316 (32.3)
Lower Primary (1 - 4 years of schooling)	789 (11.0)
Upper Primary (5 - 6 years of schooling)	801 (11.2)
Some Middle/JSS (7 - 8 years of schooling)	699 (9.7)
Completed Middle/JSS (9 years of schooling)	1941 (27.0)
Secondary/SSS (10 - 12 years of schooling)	485 (6.8)
Higher (≥13 years of schooling)	151 (2.1)
Missing	1 (0.01)
Religion	
Christian	5364 (74.7)
Moslem	1142 (15.9)
Traditional/Spiritualist	284 (4.0)
Other	5 (0.1)
No religion	385 (5.4)
Missing	3 (0.04)
Ethnic group[4]	
Akan	3303 (46.0)
Ga/Dangme	624 (8.7)
Ewe	985 (13.7)
Guan	155 (2.2)
Mole – Dagbani	683 (9.5)
Grussi	341 (4.8)
Gruma	416 (5.8)
Hausa	77 (1.1)
Other	597 (8.3)
Missing	2 (0.03)

Covariates: [1]Age group 20-29 years, [2]Married/cohabitation, [3]Urban (City & town), and [4]Akan served as reference category

Table 2 Cooking fuel choices and drinking water sources of study respondents households (n = 7183)

	None n (%)	Lower primary n (%)	Upper primary n (%)	Some Middle/JSS n (%)	Completed Middle/JSS n (%)	Secondary/ SSS n (%)	Higher n (%)	Total N (%)
Type of cooking fuel								
Electricity	1 (0.04)	1 (0.13)	0 (0.00)	0 (0.00)	2 (0.10)	3 (0.62)	4 (2.65)	11 (0.15)
LPG	14 (0.60)	24 (3.04)	29 (3.62)	30 (4.29)	232 (11.95)	158 (32.58)	104 (68.87)	591 (8.23)
Natural gas	1 (0.04)	1 (0.13)	0 (0.00)	1 (0.14)	3 (0.15)	0 (0.00)	1 (0.66)	7 (0.10)
Kerosene	0 (0.00)	0 (0.00)	2 (0.25)	1 (0.14)	7 (0.36)	0 (0.00)	0 (0.00)	10 (0.14)
Coal/Lignite	0 (0.00)	0 (0.00)	1 (0.12)	0 (0.00)	0 (0.00)	1 (0.21)	0 (0.00)	2 (0.03)
Charcoal	492 (21.24)	256 (32.45)	334 (41.70)	267 (38.20)	872 (44.93)	221 (45.57)	34 (22.52)	2476 (34.48)
Firewood	1789 (77.25)	504 (63.88)	433 (54.06)	397 (56.80)	819 (42.19)	100 (20.62)	8 (5.30)	4050 (56.39)
Straw/Shrub/Grass	18 (0.78)	0 (0.00)	2 (0.25)	1 (0.14)	0 (0.00)	1 (0.21)	0 (0.00)	22 (0.31)
No cooking	0 (0.00)	3 (0.38)	0 (0.00)	2 (0.29)	5 (0.26)	1 (0.21)	0 (0.00)	11 (0.15)
Missing	1 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	2 (0.03)
Source of drinking water								
Piped water	606 (26.17)	290 (36.76)	325 (40.57)	276 (39.48)	959 (49.41)	287 (59.18)	97 (64.24)	2840 (39.54)
Well/Borehole	1232 (53.19)	330 (41.82)	312 (38.96)	296 (42.34)	671 (34.57)	88 (18.14)	16 (10.59)	2945 (41.00)
Spring	72 (3.11)	16 (2.02)	18 (2.24)	15 (2.14)	24 (1.24)	2 (0.42)	0 (0.00)	147 (2.04)
Surface water	356 (15.37)	112 (14.20)	98 (12.23)	70 (10.01)	122 (6.29)	13 (2.68)	1 (0.66)	772 (10.75)
Rainwater	9 (0.39)	4 (0.51)	6 (0.75)	6 (0.86)	24 (1.24)	3 (0.62)	0 (0.00)	52 (0.72)
Tanker truck	8 (0.35)	10 (1.27)	4 (0.50)	1 (0.14)	9 (0.46)	4 (0.82)	0 (0.00)	36 (0.50)
Bottled/Sachet water	32 (1.38)	27 (3.42)	38 (4.74)	35 (5.01)	130 (6.70)	88 (18.14)	37 (24.50)	387 (5.39)
Other	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	1 (0.01)
Missing	1 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	2 (0.03)

Table 3 Gravidity status and lifetime stillbirth experience of study respondents classified by maternal education

	None n (%)	Lower primary n (%)	Upper primary n (%)	Some middle/JSS n (%)	Completed middle/JSS n (%)	Secondary/ SSS n (%)	Higher n (%)	Total N (%)
Gravidity								
Primigravida								1029 (14.3)
Multigravida								6154 (85.7)
Lifetime stillbirth experience								
No	2183 (32.3)	727 (10.8)	764 (11.3)	658 (9.7)	1831 (27.1)	458 (6.8)	144 (2.1)	6766 (94.2)
Yes	133 (31.9)	62 (14.9)	37 (8.9)	41 (9.8)	110 (26.4)	27 (6.5)	7 (1.7)	417 (5.8)
No. of stillbirths in lifetime								
One	114 (31.3)	54 (14.8)	30 (8.2)	37 (10.2)	99 (27.2)	23 (6.3)	7 (1.9)	364 (87.3)
Two or more	19 (35.9)	8 (15.1)	7 (13.2)	4 (7.6)	11 (20.8)	4 (7.6)	0 (0.0)	53 (12.7)

Table 4 Binary logistic regression of lifetime stillbirth experience on maternal education (n=7183)

Education	**Unadjusted**	**Adjustment for:**			
		Model 1: Core covariates[1]	**Model 2:** **+**Biomass fuel use	**Model 3:** **+**Unsafe water consumption	**Model 4:** **+**Biomass fuel use and unsafe water consumption
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
None	1.08 (0.73, 1.59)	1.14 (0.75, 1.72)			
Lower primary	1.51 (0.98, 2.33)	1.59 (1.02, 2.48)	1.49 (0.93, 2.37)	1.56 (0.99, 2.44)	1.46 (0.91, 2.33)
Upper primary	0.86 (0.53, 1.38)	0.96 (0.59, 1.56)			
Some middle/JSS	1.10 (0.69, 1.76)	1.25 (0.77, 2.01)			
Completed middle/JSS	1.06 (0.72, 1.58)	1.10 (0.74, 1.64)			
Secondary+	1.00	1.00	1.00	1.00	1.00

[1]Core covariates were age of mother, marital status, area of residence and ethnic group

Mediation fractions: Lower primary education (Biomass fuel: 16.9%; Unsafe water: 5.1%; Joint: 22.0%)

Table 5 Multinomial logistic regression of lifetime stillbirth experience on maternal education (n=7183)

Stillbirths/Education	**Unadjusted**	**Adjustment for:**			
		Model 1: Core covariates[1]	**Model 2: +**Biomass fuel use	**Model 3: +**Unsafe water consumption	**Model 4: +**Biomass fuel use and unsafe water consumption
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
One stillbirth					
None	1.05 (0.69, 1.58)	1.16 (0.75, 1.81)			
Lower primary	1.49 (0.94, 2.36)	1.63 (1.02, 2.61)	1.58 (0.96, 2.59)	1.61 (1.01, 2.59)	1.57 (0.95, 2.58)
Upper primary	0.79 (0.47, 1.32)	0.91 (0.54, 1.53)			
Some middle/JSS	1.13 (0.69, 1.85)	1.31 (0.79, 2.16)			
Completed middle/JSS	1.08 (0.71, 1.65)	1.14 (0.75, 1.75)			
Secondary+	1.00	1.00	1.00	1.00	1.00
Two or more stillbirths					
None	1.31 (0.44, 3.86)	0.93 (0.29, 2.96)			
Lowerprimary	1.66 (0.50, 5.53)	1.31 (0.38, 4.53)			
Upper primary	1.38 (0.40, 4.73)	1.22 (0.35, 4.29)			
Some middle/JSS	0.91 (0.23, 3.67)	0.83 (0.20, 3.44)			
Completed middle/JSS	0.90 (0.29, 2.85)	0.80 (0.25, 2.57)			
Secondary+	1.00	1.00	1.00	1.00	1.00

[1]Core covariates were age of mother, marital status, area of residence and ethnic group.

Mediation fractions: Lower primary education - One stillbirth (Biomass fuel: 7.9%)

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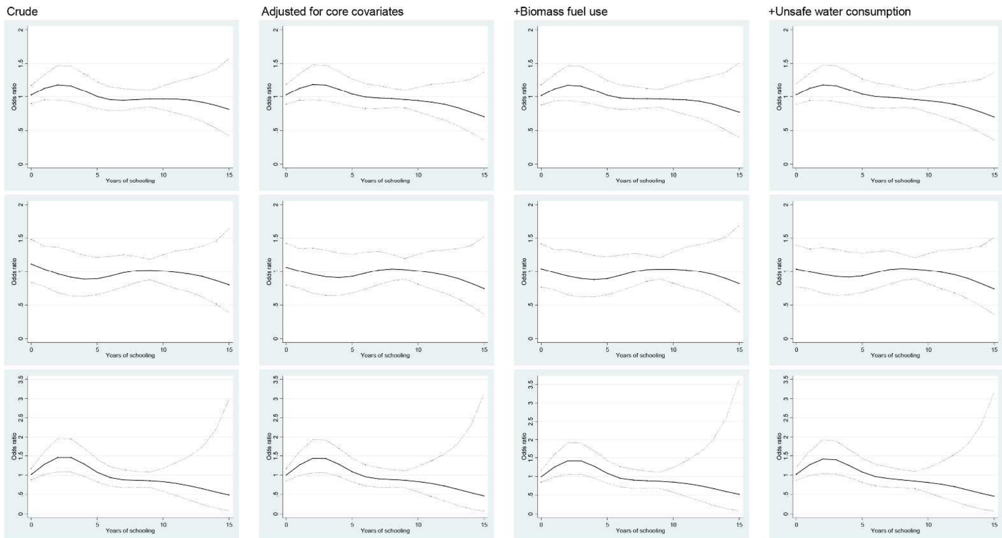

Odds ratios (Solid lines) and their corresponding 95% confidence bands (dotted lines) from generalized additive models (df = 4) regressing lifetime stillbirths on years of maternal schooling. Upper row: All respondents. Middle row: Urban dwellers. Lower row: Rural dwellers

245x133mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2	Abstract: Methods
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2	Abstract: Methods, Results
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5	Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses	5	Introduction
Methods				
Study design	4	Present key elements of study design early in the paper	5-6	Methods
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-8	Methods
Participants	6	*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6	Eligibility criteria
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8	Assessment of exposure, Outcome of interest, Ascertainment of educational attainment , Covariates
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8	
Bias	9	Describe any efforts to address potential sources of bias	12-14	Validity issues
Study size	10	Explain how the study size was arrived at	5-6	Methods

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8- 9	Statistical analysis
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9	Statistical analysis
		(*b*) Describe any methods used to examine subgroups and interactions		
		(*c*) Explain how missing data were addressed	12	Validity issues
		(*d*) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		
		(*e*) Describe any sensitivity analyses		
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5-6	Methods, Eligibility criteria
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	18, 19	Table 1, Table 2
		(b) Indicate number of participants with missing data for each variable of interest	18, 19	Table 1, Table 2
		Cross-sectional study—Report numbers of outcome events or summary measures	20-21	Table 3, Table 4, Table 5
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	20-21	Table 4, Table 5
		(*b*) Report category boundaries when continuous variables were categorized		
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		

Continued on next page

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		Figure 1
Discussion				
Key results	18	Summarise key results with reference to study objectives	14	Synthesis with previous evidence
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	12-14	Validity issues
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-16	Synthesis with previous evidence, Causal pathways
Generalisability	21	Discuss the generalisability (external validity) of the study results	12	Validity issues
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16	Funding

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Do biomass fuel use and consumption of unsafe water mediate educational inequalities in stillbirth risk? An analysis of the 2007 Ghana Maternal Health Survey

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ABSTRACT

Background Numerous studies have explored the association between educational inequalities and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that use of biomass fuels and consumption of unsafe water related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage.

Methods Data from the 2007 Ghana Maternal Health Survey, a nationally representative population-based survey was analyzed for this study. Of the10,370 women aged 15-49 years interviewed via structured questionnaires for the survey, 7183 primi- and multi- parous women qualified for inclusion in the present study.

Results In logistic regression analysis that adjusted for age, area of residence, marital status and ethnicity of women, lower maternal primary education was associated with a 62% (Odds ratio [OR] = 1.62; 95% CI: 1.04, 2.52) increased lifetime risk of stillbirth. Biomass fuel use and consumption of unsafe water mediated 18% and 8% of the observed effects, respectively. Jointly these two exposures explained 24% of the observed effects. The generalized additive modeling revealed a very flat inverted spoon-shaped smoothed curve which peaked at low levels of schooling (2 to 3 years) and confirms the findings from the logistic regression analysis.

Conclusions Our results shows that biomass fuel use and unsafe water consumption could be important pathways through which low maternal educational attainment leads to stillbirths in Ghana and similar developing countries. Addressing educational inequalities in developing countries is thus essential for ensuring household choices that curtail environmental exposures, and help improve pregnancy outcomes.

Strengths and limitations of this study

- The study was based on a large and representative sample.
- The education-stillbirth relationship was illustrated in terms of smoothed curves of school-years.
- The exposure assessment method applied has limitations but has been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure.
- Exposure misclassification was possible in the study owing to the inability to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the study participants.

INTRODUCTION

Stillbirth, the intrauterine death of any conceptus at any time during pregnancy,[1] is a major public health concern in developing countries. An estimated 3.2 million stillbirths occurs worldwide annually with 98% of these stillbirths found in developing countries.[2] Important causes of stillbirths globally are asphyxia and infection associated with obstructed or prolonged labour, pre-eclampsia and eclampsia, chorioamnionitis, syphilis, malaria and poor nutritional status.[3] Stillbirth occurrence has been noted to be much higher among ethnic minority, disadvantaged, marginalized and rural populations. [4-6] This observation demonstrates the important role of socioeconomic factors in the etiology of stillbirth.

The risk factors of stillbirth in low-income countries are associated with poverty[7] including solid fuel use and consumption of unsafe water. Many households in developing countries rely on ground and surface water resources due to limited access to pipe-borne water, erratic supply, and high connection and utility charges. These water resources are often polluted by mining and agricultural activities, as well as nearby pit latrines which are also in widespread use in developing countries. Mining activities especially in unregulated mines leads to deposition/leaching of substantial amounts of chemicals such as cyanide and sulfuric acid, and heavy metals into nearby water bodies. Agricultural runoffs also introduces sediments, pesticides, fertilizers and pathogens into water bodies. Pit latrines have also been widely documented to leach microbial and chemical contaminants including coliforms, *Escherichia coli,* fecal streptococci, ammonia, nitrates and nitrites into groundwater resources.[8] Poverty further hampers many households from treating these unwholesome water resources before usage. Solid fuels are also the predominant cooking fuel in developing countries owing to poverty and limited access to clean fuels.[9] Bonjour et al.[10] estimated the proportion of households in Africa and Southeast Asia relying on solid fuels for cooking to be more than 60%. Studies have associated use of solid fuels,[11] and consumption of contaminated drinking water[12-14] with stillbirth and other adverse pregnancy outcomes.

Socioeconomic characteristics including educational attainment are well-documented to have strong effects on health outcomes including pregnancy outcomes. Several studies mostly emanating from high-income countries have explored the relationship between educational attainment and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that household use of biomass fuels and consumption of unsafe water related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage. As noted by Kramer,[15] research that identifies and quantifies the causal pathways and mechanisms through which social disadvantage leads to higher risks of adverse pregnancy outcomes may help to reduce disparities and improve pregnancy outcomes across the entire socioeconomic spectrum.

We relied on data from the 2007 Ghana Maternal Health Survey,[16] a nationally representative population-based survey that collected comprehensive information at both the household and individual woman's level on maternal health issues including pregnancies, stillbirths, abortions and miscarriages, and maternal deaths in the country.

METHODS

Data from the 2007 Ghana Maternal Health Survey (GMHS)[16] was analyzed for this study. GMHS was a nationally representative population-based survey that collected comprehensive information on maternal health and mortality in the country to provide baseline information for the Reducing Maternal Morbidity and Mortality (R3M) program initiated in three regions (Greater Accra, Eastern, Ashanti) of Ghana in 2006. The survey design of GMHS involved the selection of 1600 primary sampling units (clusters) from the 10 administrative regions of the country, across urban and rural areas. The primary sampling units consisted of wards or sub-wards drawn from the 2001 Population Census.

Data collection was carried out in two phases with data for the present study deriving from the second phase. In the second phase, 400 clusters were randomly selected from the

1600 clusters with a long household questionnaire administered in 10,858 households (response rate, 98.8%) randomly selected from these clusters. These households were selected independently from the 227,715 households identified in the first phase (from the 1600 clusters) for profiling maternal deaths. Also in the second phase, a women's questionnaire was administered to 10,370 women age 15-49 (response rate, 97.6%) identified from the 10,858 households. The long household questionnaires collected information on the demographic and socioeconomic characteristics of members of the households sampled whereas the women's questionnaire gathered information on a wide range of maternal health-related issues including live births, stillbirths, abortions and miscarriages, and utilization of health services in relation to these events.

To be eligible for inclusion in the present study, a woman must have given birth at least once (i.e. primi- and multi- parous women). Of the 10,370 women aged 15-49 years, 7183 (69.3%) primi- and multi- parous women were eligible for the present study.

A flowchart of the survey sampling procedure and mothers included in the present study is depicted in figure 1.

Ascertainment of educational attainment

In the women's questionnaire, respondents were asked whether they have ever attended school and if they answered "yes" they were further asked about the highest level of school they attended, and the highest grade they completed at that level. Maternal education was treated both as a continuous and categorical variable in the analysis.

In treating maternal educational attainment as a continuous variable, we combined the information obtained from mothers who reported ever attending school into years of schooling (1 to 15 years). Mothers who never attended school were ranked zero on this scale.

The following levels of maternal education were applied in the analysis: none, lower primary (1 to 4 years of schooling), upper primary (5 to 6 years of schooling), some middle/junior high school (JHS) (7 to 8 years of schooling), completed middle school/JHS (9 years of schooling), secondary/senior high school (SHS) (10 to 12 years of schooling), and higher (≥13 years of schooling).

Assessment of exposure

Maternal exposure to household air pollution (HAP) was assessed by the type of fuel used by households for cooking. This information was obtained from the long household questionnaire. In this questionnaire, household heads were asked *"What type of fuel does your household mainly use for cooking?"* Mothers living in households using electricity, liquefied petroleum gas (LPG) and natural gas served as the reference category with those residing in households using charcoal, firewood and straw/shrubs/grass representing the exposed category. Kerosene, a non-solid fuel but with uncertainties about its cleanliness was excluded from the reference category. Very few households used coal/lignite, a non-biomass fuel for cooking and was thus excluded from the analysis.

Maternal exposure to contaminated drinking water was ascertained by the type of drinking water sources of the household. This information was also obtained from the long household questionnaire in which household heads were asked *"What is the main source of drinking water for members of your household?"* Mothers residing in households using piped and bottled/sachet water served as the reference category with those living in households sourcing water from surface (rivers, streams, lakes, dams, ponds etc.) and ground (wells, boreholes) waters representing the exposed categories. Mothers in households using spring water, rainwater and tanker water were excluded from the analysis because of the small number of household using these water resources.

Outcome of interest

The outcome of interest was lifetime experience of stillbirth (yes vs. no) among primi- and multi-parous women. This information was extracted from the women's questionnaire where mothers were asked whether they have ever given birth in late pregnancy (7 months or more) to a dead child and if they answered "yes", they were further asked about the number of stillbirths they have had in their lifetime.

Covariates

The following core potential confounders were adjusted for in the analysis: area of residence (urban, rural), age of woman, marital status and ethnicity.

Ethical consideration

The GMHS was conducted under the scientific and technical supervision of the Ghana Statistical Service and Ghana Health Service. The MEASURE DHS project at Macro International, Calverton, Maryland, USA approved the survey and provided technical assistance. Informed consent was obtained from all the participants before the interview.

Statistical analysis

We first described the education-stillbirth relationship in terms of relative risk by educational categories using logistic regression (PROC LOGISTIC). PROC LOGISTIC was used to estimate the effects of maternal education on the risk of stillbirth (yes, coded 1 vs. no, coded 0) in a woman's lifetime, and to also establish whether a gradient in the risk exists. The analysis was adjusted for the core potential confounders.

We performed a causal pathway analysis using the difference method[17] to establish the independent and joint mediating effect of biomass fuel use and consumption of unsafe drinking water in the observed educational differences in stillbirth risk. In brief, after controlling for the core confounders, biomass fuel use and unsafe water consumption were further independently and jointly added to the adjusted model with the mediation fractions computed using the formula below:

$$\frac{OR_{adjusted} - OR_{mediation}}{1 - OR_{adjusted}} \times 100\%$$

where $OR_{adjusted}$ is the odds ratio in the adjusted model and $OR_{mediation}$ is the odds ratio in the independent and joint mediation models.

We next illustrated the education-stillbirth relationship in terms of cubic smoothing splines using generalized additive modeling (GAM) with three degrees of freedom (df). Three df was chosen after fitting six separate models (df = 3, 4, 5, 6, 7 and 8) and identifying the model with 3df to have the best fit. The Akaike Information Criterion (AIC) was used to evaluate goodness of fit of the models fitted. AIC was estimated using the formula below:

$$\text{AIC} = D(\theta) + 2p$$

where $D(\theta)$ is the deviance and p is the number of parameters (df) in the model. The model with the smaller AIC value was deemed a better fit. The AIC values are presented in Table S1.

GAM allowed maternal education to be applied as a continuous variable (school-years), thereby increasing statistical power and enabling a better illustration of the predictor-risk relationship. Possible nonlinearities in the maternal education data was explored by performing chi square test of nonlinearity. We stratified the curve fitting by urban and rural residence to ascertain whether there exist any marked differences.

SAS version 9.3 was used to perform all the analysis with the exception of the generalized additive modeling which was performed with Stata 12.0.

RESULTS

The characteristics of the study population are presented in Tables 1 and 2. Close to one-third (31.9%) of the respondents were within the age group 20-39 years. More than half (68.6%) of the women reported being married with very few (6.4%) reporting that they have never been married. Close to half (46.3%) of the study population were resident in the R3M regions (Greater Accra, Eastern and Ashanti) with 19% of the women living in the three northern regions (Northern, Upper East, Upper West). More than half (58%) of the respondents were rural dwellers with about 17% of the respondents identified as city dwellers. Majority of the women (75%) were Christians with Muslims making up about 16% of the study respondents. Close to half (46%) of the women were Akans. Close to one-third (32.3%) of the respondents had no formal education with only 2.1% of the women educated up to the tertiary level or higher.

Biomass fuel, notably charcoal and firewood were the dominant cooking fuels of respondent's households with 91% of households using these fuels. LPG was used by 8% of the respondent's households. Whereas among highly educated mothers, LPG was the dominant fuel used (69%), among uneducated (77%) and primary educated (64%) mothers firewood was the fuel mostly used. Piped water (40%) and well/borehole (41%) were the dominant drinking water sources of the respondents. About 5% and 11% of the respondents used bottled/sachet and surface water, respectively. Secondary (59%) and highly (64%) educated mothers patronized piped water mostly. A quarter of highly educated mothers used bottled/sachet water. Among uneducated mothers, 53% accessed well/borehole water resources with 26% using piped water. Among primary and some middle school/JHS educated women, the proportion using piped and well/borehole water resources were about the same.

The gravidity status and lifetime stillbirth experience of the women interviewed are presented in Table 3. About 14% of the respondents were primigravida. About 6% of the respondents reported experiencing stillbirth in their lifetime with a small proportion (13%) of them experiencing this occurrence more than once. Uneducated mothers and mothers who

completed middle/JHS recorded the highest proportion of lifetime stillbirths; 32% and 26%, respectively.

Table 4 and S2 presents the odds ratios (OR) for the association of maternal education and lifetime stillbirth experience calculated from logistic regression. Lower primary education was associated with a statistically significant 62% (OR = 1.62, 95% CI: 1.04, 2.52) increased risk of stillbirth in a lifetime after adjustment for the core covariates. Biomass fuel use and unsafe water consumption mediated 17.7% and 8.1% of the observed association of lower primary education on lifetime stillbirth risk. In the joint model, the mediation fraction was 24.2%. No consistent educational gradient was observed.

Figure S1 depicts the smoothed curves for odds ratio of stillbirth in a lifetime in relation to maternal years of schooling. Among all mothers, a very flat inverted spoon-shaped smoothed curve was observed. The odds ratio of lifetime stillbirth increased slightly away from the reference level up to about 2.5 years of schooling, and declined slowly afterwards with further schooling . The 95% confidence band was generally wide especially towards the tail end of the smoothed curve. Among rural dwellers, a more pronounced inverted spoon-shaped smoothed curve was observed. Among urban dwellers, an s-shape smoothed curve with a generally wide 95% confidence band over the whole range of the maternal schooling years was observed.

For all study participants (p = 0.4166), and urban dwellers (p = 0.6003), the nonlinearity chi-square was not statistically significant. Among rural dwellers, the nonlinearity chi-square was borderline significant (p = 0.0558) thereby indicating possible departure from linearity. In the model adjusting for the mediating effect of biomass fuel use, the decrease in the odds ratio of lifetime stillbirth after 6.5 years of schooling was very gentle. In the model adjusting for the mediating effect of unsafe water consumption, no appreciable change in the smoothed curve was observed and possibly confirms the small mediation fraction estimated in the logistic regression.

DISCUSSION

We found lower maternal primary education to be associated with a 62% (Odds ratio [OR] = 1.62; 95% CI: 1.04, 2.52) increased lifetime risk of stillbirth. Biomass fuel use and consumption of unsafe water mediated 18% and 8% of the observed effects, respectively. Jointly these two exposures explained 24% of the observed effects. The generalized additive modeling revealed a very flat inverted spoon-shaped smoothed curve which peaked at low levels of schooling (2 to 3 years) and confirms the findings from the logistic regression modeling.

Validity issues

Selection bias was minimized in the study owing to the population-based nature of the GMHS survey and the high response rate (97.6%) achieved. Also the standardized data collection instruments and procedures of DHS surveys including the present, and the extensive training of interviewers guarantees the collection of reliable information from survey participants. On the issue of missing data, of the variables of interest concerned (education, marital status, ethnic group, cooking fuel type, drinking water source), the proportion of respondents with missing data was very low (< 0.04%).

Educational attainment is a strong determinant of future employment and income,[18,19] and certainly has implications for maternal health and pregnancy outcomes. The potential for outcome measurement bias is reduced in our study even though the outcome of interest was subjectively reported by the respondents. This is because stillbirth is a very traumatic experience that every mother with such an experience can vividly recollect. .

Exposure to HAP and drinking water contaminants was assessed based on the primary cooking fuels and main drinking water sources of maternal households. There are limitations with the exposure assessment method applied but they have been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure. There is nonetheless the potential for exposure misclassification in the study with the direction of bias unclear. It was impossible to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the mothers interviewed. Regarding cooking fuel choices, it is often the case of households transitioning to fuels higher up the energy ladder with improved socioeconomic conditions and back to their traditional fuels as conditions deteriorate. With regards to drinking water sources, except in situations where communities have been connected to pipe-borne water, household water sources traditionally remains the same irrespective of improvement in socioeconomic conditions. It is possible households that have been connected to pipe-borne water after years of relying on ground and surface water resources will report use of pipe-borne water as their main drinking water source. This information bias, however, would rather underestimate the true effect.

The study adjusted for the effect of age of respondent, marital status, area of residence (urban vs. rural) and ethnicity. We had no information on the smoking status of the mothers, but in Ghana only few women smoke. The 2008 Ghana Demographic and Health Survey[20] estimated the proportion of women smoking cigarettes and other tobacco products to be 0.4%. Maternal smoking can therefore not be considered as a serious threat to validity in this study. We were unable to examine the confounding effect of prenatal and intrapartum care, maternal nutrition and anthropometry as well as malaria and sexually transmitted infections. However, with regards to infections it has been suggested by Silver et al.[21] that they are more clearly associated with early stillbirth (20 weeks) than with late stillbirth (after 28 weeks). With the GMHS survey ascertaining stillbirths with a cut-off point of 7 or more months, we can assume that the associations reported are not likely to be confounded by maternal infections.

Synthesis with previous evidence

Our study adds to the weight of evidence emanating mostly from high-income countries[22-26] on the adverse perinatal effects of low maternal educational attainment. We found lower primary education to be associated with a 62% increased risk of lifetime stillbirth. The smoothing curves also peaked at low levels of schooling (2 to 3 years) and declined with further schooling. A multi-country study[27] conducted in six low-income and one middle-income countries reported a 40% (RR=1.4; 95% CI: 1.2, 1.5) increased risk of stillbirth with no formal maternal schooling. Two recent population-based studies conducted in rural Ghana,[28,29] however, found no association between maternal education and stillbirth. Ha et al.[28] reported a small and statistically insignificant increased odds of antepartum and intrapartum stillbirth with no formal and primary maternal education. Engmann et al.[29] reported a much higher increased odds of stillbirth with no formal (OR=1.47; 95% CI: 0.94, 2.29) and primary/JHS (OR=1.48, 95% CI: 0.95, 2.30) maternal education. These associations were also not statistically significant. A systematic review and meta-analysis of the available evidence on the major risk factors for stillbirth in high-income countries[26] found low educational attainment (<10 years of schooling) to be associated with 70% (OR=1.7; 95% CI: 1.4, 2.0; n=5) increased odds of stillbirth. The findings of our study are consistent with the findings of McClure et al.[27] and Flenady et al.[26]

Causal pathways

Medical care has been mentioned as the route through which education leads to inequality in stillbirth from placental abruption and cord compression.[30] Suboptimal care including delayed recognition of medical problems or poor management has been noted to contribute to a significant proportion of stillbirths.[31] Delayed access of prenatal care services owing to ignorance is very common in developing countries. Also common in developing countries is the inability of mothers to apply the nutritional and health messages received during prenatal visits for improved maternal and fetal health. This situation arises as a result of lack of education or low educational attainment of mothers. According to Galobardes et al.,[32] education may affect an individual's cognitive functioning and enable him/her to access appropriate health services, to better communicate with healthcare workers, and to be more receptive to health education messages. Stephansson et al.[33] have also suggested that, the socioeconomic differences in the risk of stillbirth can be attributed to social differences in seeking care for signs of pathological pregnancy such as reduced fetal movements.

In developing countries, besides access and utilization of health services, there are other important pathways through which low educational attainment impacts on perinatal outcomes. Our study is the first to explore the mediating role of environmental factors in the maternal education - stillbirth relationship. Biomass fuel use and unsafe water consumption explained about 18% and 8% of the observed effects of low maternal educational attainment on lifetime stillbirth risk. Jointly, they mediated almost a quarter (24%) of the observed effect. A study in Ghana found the effects of low educational attainment on average birth weight to be substantially (62%) mediated by biomass fuel use.[34] Studies in Ghana,[35,36] Ethiopia,[37,38] Cameroun[39] and Kenya[40] have reported educational attainment to be an important determinant of cooking fuel choices of households.

We must mention that the mediation fraction reported is likely to be overestimated and should be interpreted with caution. This is because prenatal and intrapartum care, maternal nutrition and other social factors which we were unable to control in the analysis are associated with educational attainment just as much as fuel and drinking water choices. It is thus possible biomass fuel use and unsafe water consumption are essentially a proxy for these confounding variables and biasing the causal effect away from null as a result.

CONCLUSIONS

In conclusion, we provide evidence that in Ghana and similar developing countries, biomass fuel use and unsafe water consumption could be important pathways through which low maternal educational attainment leads to stillbirths. Women with no formal or low education should therefore receive extra care and support, and be alerted to household environmental risks to their pregnancies during prenatal visits. This recommendation could help curb the high stillbirth incidence in developing countries. According to Goldenberg et al.,[41] each geographical area must understand the local causes of stillbirth, and the contexts in which they occur to enable prevention strategies to be developed and implemented.

Acknowledgement We will like to thank Measure DHS for granting us permission to use the 2007 Ghana Maternal Health Survey dataset for this research.

Authors contribution AKA conceived and designed the study, and performed the data analysis with guidance from SN and JJKJ. AKA wrote the manuscript with SN and JJKJ reviewing drafts for intellectual content. All authors read and approved the final version.

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Competing interests None declared.

Ethics approval The Ghana Maternal Health Survey was approved by the Ghana Statistical Service, Ghana Health Service and MEASURE DHS.

Data sharing statement No additional data are available.

Table 1 Demographic and background characteristics of the study respondents (n=7183)

Characteristic	No. (%)
Age (years)[1]	
<20	247 (3.4)
20-29	2293 (31.9)
30-39	2713 (37.8)
>39	1930 (26.9)
Marital status[2]	
Married	4925 (68.6)
Cohabitation	878 (12.2)
Never married	457 (6.4)
Divorced/Separated	721 (10.0)
Widowed	200 (2.8)
Missing	2 (0.03)
Region of residence	
Western	569 (7.9)
Central	642 (8.9)
Greater Accra	1071 (14.9)
Volta	590 (8.2)
Eastern	1084 (15.1)
Ashanti	1173 (16.3)
Brong Ahafo	684 (9.5)
Northern	637 (8.9)
Upper East	409 (5.7)
Upper West	324 (4.5)
Area of residence[3]	
City	1249 (17.4)
Town	1782 (24.8)
Rural	4152 (57.8)
Education	
None	2316 (32.3)
Lower Primary (1 - 4 years of schooling)	789 (11.0)
Upper Primary (5 - 6 years of schooling)	801 (11.2)
Some Middle/JSS (7 - 8 years of schooling)	699 (9.7)
Completed Middle/JSS (9 years of schooling)	1941 (27.0)
Secondary/SSS (10 - 12 years of schooling)	485 (6.8)
Higher (≥13 years of schooling)	151 (2.1)
Missing	1 (0.01)
Religion	
Christian	5364 (74.7)
Moslem	1142 (15.9)
Traditional/Spiritualist	284 (4.0)
Other	5 (0.1)
No religion	385 (5.4)
Missing	3 (0.04)
Ethnic group[4]	
Akan	3303 (46.0)
Ga/Dangme	624 (8.7)
Ewe	985 (13.7)
Guan	155 (2.2)
Mole – Dagbani	683 (9.5)
Grussi	341 (4.8)
Gruma	416 (5.8)
Hausa	77 (1.1)
Other	597 (8.3)
Missing	2 (0.03)

Covariates: [1]Age group 20-29 years, [2]Married/cohabitation, [3]Urban (City & town), and [4]Akan served as reference category

Table 2 Cooking fuel choices and drinking water sources of study respondents households (n = 7182)

	None n (%)	**Lower primary n (%)**	**Upper primary n (%)**	**Some Middle/JSS n (%)**	**Completed Middle/JSS n (%)**	**Secondary/ SSS n (%)**	**Higher n (%)**	**Total N (%)**
Type of cooking fuel								
Electricity	1 (0.04)	1 (0.13)	0 (0.00)	0 (0.00)	2 (0.10)	3 (0.62)	4 (2.65)	11 (0.15)
LPG	14 (0.60)	24 (3.04)	29 (3.62)	30 (4.29)	232 (11.95)	158 (32.58)	104 (68.87)	591 (8.23)
Natural gas	1 (0.04)	1 (0.13)	0 (0.00)	1 (0.14)	3 (0.15)	0 (0.00)	1 (0.66)	7 (0.10)
Kerosene	0 (0.00)	0 (0.00)	2 (0.25)	1 (0.14)	7 (0.36)	0 (0.00)	0 (0.00)	10 (0.14)
Coal/Lignite	0 (0.00)	0 (0.00)	1 (0.12)	0 (0.00)	0 (0.00)	1 (0.21)	0 (0.00)	2 (0.03)
Charcoal	492 (21.24)	256 (32.45)	334 (41.70)	267 (38.20)	872 (44.93)	221 (45.57)	34 (22.52)	2476 (34.48)
Firewood	1789 (77.25)	504 (63.88)	433 (54.06)	397 (56.80)	819 (42.19)	100 (20.62)	8 (5.30)	4050 (56.39)
Straw/Shrub/Grass	18 (0.78)	0 (0.00)	2 (0.25)	1 (0.14)	0 (0.00)	1 (0.21)	0 (0.00)	22 (0.31)
No cooking	0 (0.00)	3 (0.38)	0 (0.00)	2 (0.29)	5 (0.26)	1 (0.21)	0 (0.00)	11 (0.15)
Missing	1 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	2 (0.03)
Source of drinking water								
Piped water	606 (26.17)	290 (36.76)	325 (40.57)	276 (39.48)	959 (49.41)	287 (59.18)	97 (64.24)	2840 (39.54)
Well/Borehole	1232 (53.19)	330 (41.82)	312 (38.96)	296 (42.34)	671 (34.57)	88 (18.14)	16 (10.59)	2945 (41.00)
Spring	72 (3.11)	16 (2.02)	18 (2.24)	15 (2.14)	24 (1.24)	2 (0.42)	0 (0.00)	147 (2.04)
Surface water	356 (15.37)	112 (14.20)	98 (12.23)	70 (10.01)	122 (6.29)	13 (2.68)	1 (0.66)	772 (10.75)
Rainwater	9 (0.39)	4 (0.51)	6 (0.75)	6 (0.86)	24 (1.24)	3 (0.62)	0 (0.00)	52 (0.72)
Tanker truck	8 (0.35)	10 (1.27)	4 (0.50)	1 (0.14)	9 (0.46)	4 (0.82)	0 (0.00)	36 (0.50)
Bottled/Sachet water	32 (1.38)	27 (3.42)	38 (4.74)	35 (5.01)	130 (6.70)	88 (18.14)	37 (24.50)	387 (5.39)
Other	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	1 (0.01)
Missing	1 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	2 (0.03)

The education category had one missing value

Table 3 Gravidity status and lifetime stillbirth experience of study respondents classified by maternal education

	None n (%)	Lower primary n (%)	Upper primary n (%)	Some middle/JSS n (%)	Completed middle/JSS n (%)	Secondary/ SSS n (%)	Higher n (%)	Total N (%)
Gravidity								
Primigravida								1029 (14.3)
Multigravida								6154 (85.7)
Lifetime stillbirth experience								
No	2183 (32.3)	727 (10.8)	764 (11.3)	658 (9.7)	1831 (27.1)	458 (6.8)	144 (2.1)	6766 (94.2)
Yes	133 (31.9)	62 (14.9)	37 (8.9)	41 (9.8)	110 (26.4)	27 (6.5)	7 (1.7)	417 (5.8)
No. of stillbirths in lifetime								
One	114 (31.3)	54 (14.8)	30 (8.2)	37 (10.2)	99 (27.2)	23 (6.3)	7 (1.9)	364 (87.3)
Two or more	19 (35.9)	8 (15.1)	7 (13.2)	4 (7.6)	11 (20.8)	4 (7.6)	0 (0.0)	53 (12.7)

Table 4 Binary logistic regression of lifetime stillbirth experience on maternal education (n=7183)

Education	**Unadjusted**	**Adjustment for:**			
		Model 1: Core covariates[1]	**Model 2: +**Biomass fuel use	**Model 3: +**Unsafe water consumption	**Model 4: +**Biomass fuel use and unsafe water consumption
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
None	1.08 (0.73, 1.59)	1.19 (0.78, 1.82)			
Lower primary	1.51 (0.98, 2.33)	1.62 (1.04, 2.52)	1.51 (0.95, 2.41)	1.57 (1.00, 2.47)	1.47 (0.92, 2.37)
Upper primary	0.86 (0.53, 1.38)	0.98 (0.60, 1.60)			
Some middle/JSS	1.10 (0.69, 1.76)	1.26 (0.78, 2.02)			
Completed middle/JSS	1.06 (0.72, 1.58)	1.11 (0.74, 1.65)			
Secondary+	1.00	1.00	1.00	1.00	1.00

[1]Core covariates were age of mother, marital status, area of residence and ethnic group
Mediation fractions: Lower primary education (Biomass fuel: 17.7%; Unsafe water: 8.1%; Joint: 24.2%)

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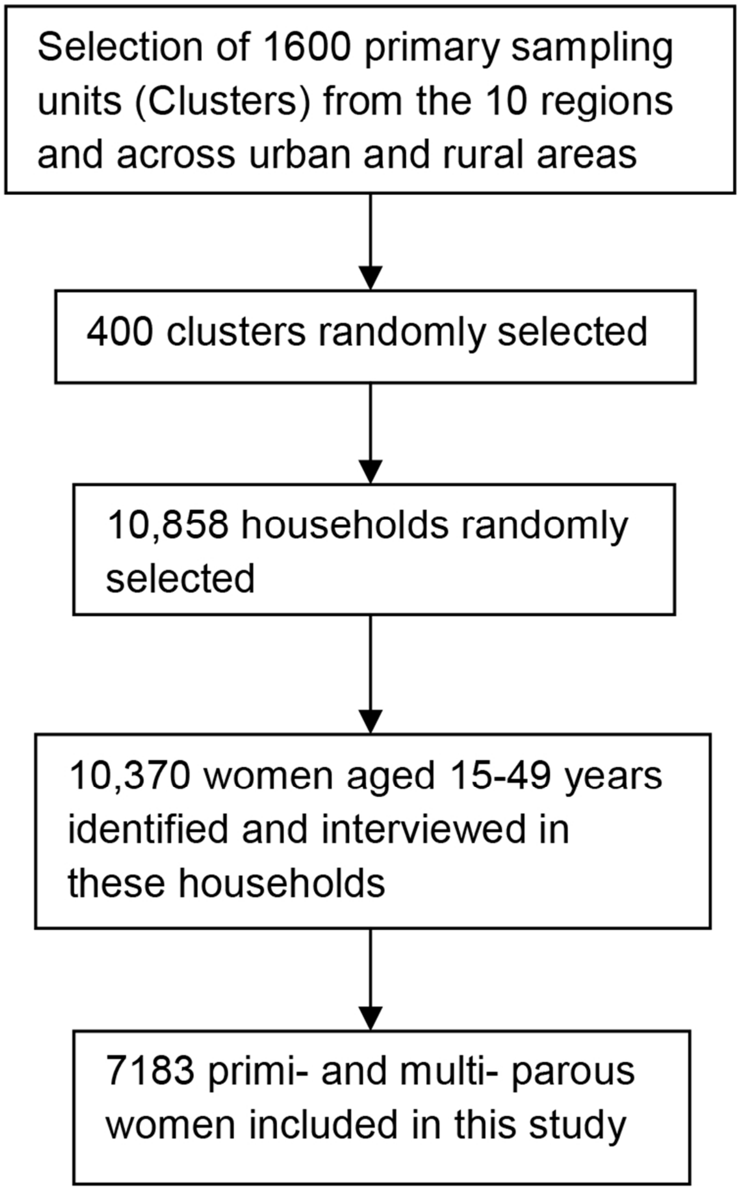

Figure 1. Flowchart of the survey sampling procedure and mothers included in present study

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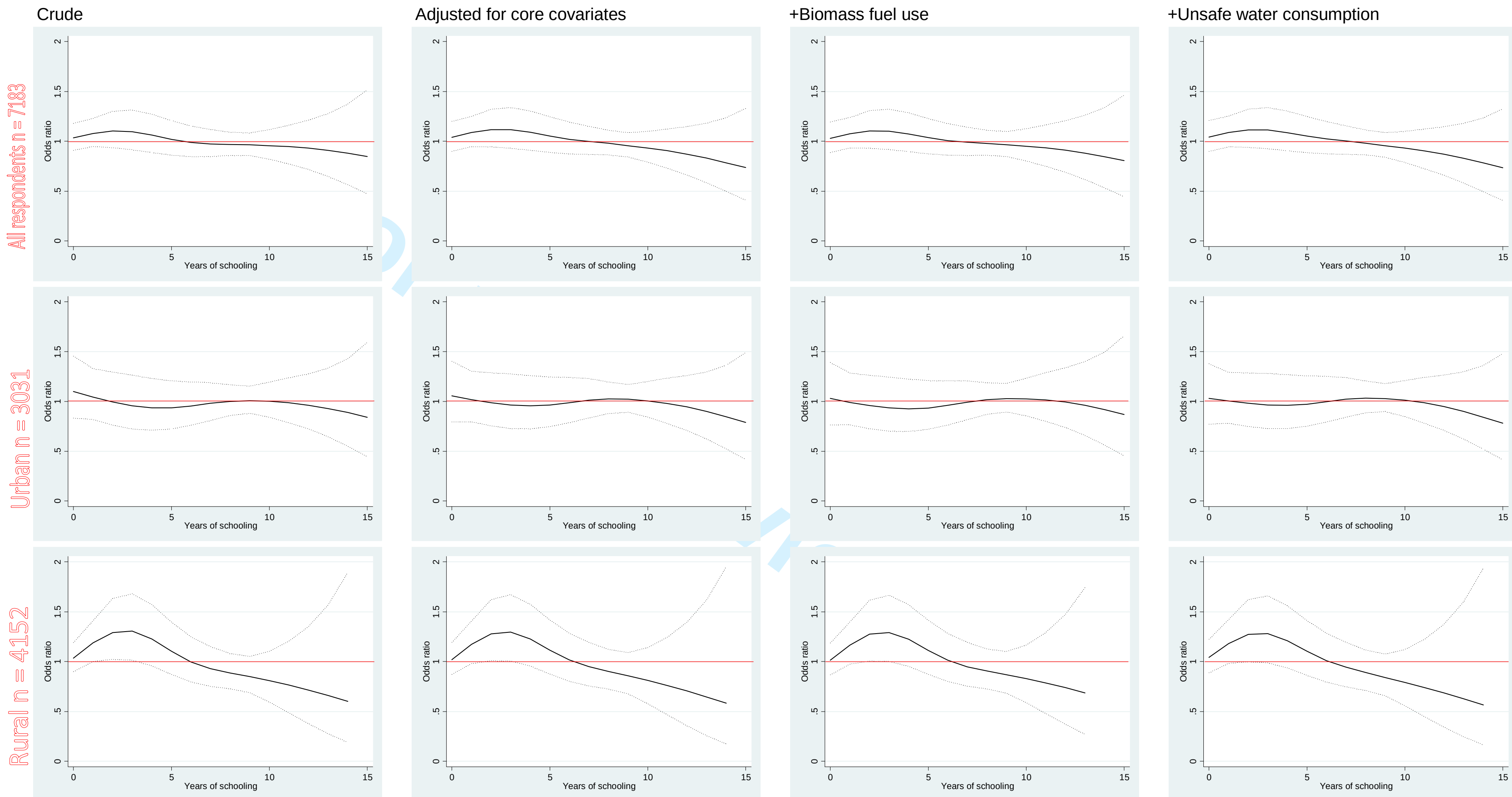

Figure S1. Odds ratios (Solid lines) and their corresponding 95% confidence bands (dotted lines) from generalized additive models (df = 3) regressing lifetime stillbirths on years of maternal schooling.

Table S1. Akaike Information Criterion (AIC) values according to degrees of freedom (df) of GAM fitted models regressing lifetime stillbirths on years of maternal schooling

df	3	4	5	6	7	8
Deviance	3180.14	3178.45	3176.91	3175.77	3174.96	3174.35
AIC	3186.14	3186.45	3186.91	3187.77	3188.96	3190.35

Table S2. Binary logistic regression of lifetime stillbirth experience on maternal education (n=7183)

	Crude OR (95% CI)	Adjusted OR (95% CI)
Education		
None	1.08 (0.73, 1.59)	1.19 (0.78, 1.82)
Lower primary	1.51 (0.98, 2.33)	1.62 (1.04, 2.52)
Upper primary	0.86 (0.53, 1.38)	0.98 (0.60, 1.60)
Some middle/JSS	1.10 (0.69, 1.76)	1.26 (0.78, 2.02)
Completed middle/JSS	1.06 (0.72, 1.58)	1.11 (0.74, 1.65)
Secondary+	1.00	1.00
Age (years)		
<20	0.57 (0.23, 1.42)	0.53 (0.21, 1.35)
20-29	1.00	1.00
30-39	1.95 (1.49, 2.56)	1.94 (1.47, 2.56)
>39	2.38 (1.80, 3.14)	2.37 (1.78, 3.17)
Area of residence		
Urban (City & Town)	1.00	1.00
Rural	0.88 (0.72, 1.08)	0.91 (0.74, 1.13)
Marital status		
Married/ Cohabitation	1.00	1.00
Never married	0.75 (0.47, 1.19)	1.22 (0.74, 1.99)
Divorced/Separated	1.22 (0.90, 1.66)	1.12 (0.82, 1.54)
Widowed	1.14 (0.64, 2.02)	0.92 (0.52, 1.64)
Ethnic group		
Akan	1.00	1.00
Ga/Dangme	0.99 (0.69, 1.41)	0.99 (0.69, 1.41)
Ewe	1.00 (0.75, 1.35)	0.99 (0.74, 1.34)
Guan	0.30 (0.09, 0.95)	0.30 (0.09, 0.95)
Mole – Dagbani	1.17 (0.85, 1.62)	1.17 (0.81, 1.67)
Grussi	0.55 (0.31, 1.00)	0.56 (0.31, 1.04)
Gruma	0.61 (0.36, 1.02)	0.64 (0.37, 1.10)
Hausa	0.83 (0.30, 2.30)	0.90 (0.32, 2.51)
Other	0.80 (0.54, 1.19)	0.83 (0.55, 1.26)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2	Abstract: Methods
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2	Abstract: Methods, Results
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5	Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses	5	Introduction
Methods				
Study design	4	Present key elements of study design early in the paper	5-6	Methods
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-8	Methods
Participants	6	*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6	Eligibility criteria
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8	Assessment of exposure, Outcome of interest, Ascertainment of educational attainment , Covariates
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8	
Bias	9	Describe any efforts to address potential sources of bias	12-14	Validity issues
Study size	10	Explain how the study size was arrived at	5-6	Methods

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8- 9	Statistical analysis
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9	Statistical analysis
		(*b*) Describe any methods used to examine subgroups and interactions		
		(*c*) Explain how missing data were addressed	12	Validity issues
		(*d*) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		
		(*e*) Describe any sensitivity analyses		
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5-6	Methods, Eligibility criteria
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	18, 19	Table 1, Table 2
		(b) Indicate number of participants with missing data for each variable of interest	18, 19	Table 1, Table 2
		Cross-sectional study—Report numbers of outcome events or summary measures	20-21	Table 3, Table 4, Table 5
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	20-21	Table 4, Table 5
		(*b*) Report category boundaries when continuous variables were categorized		
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		

Continued on next page

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		Figure 1
Discussion				
Key results	18	Summarise key results with reference to study objectives	14	Synthesis with previous evidence
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	12-14	Validity issues
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-16	Synthesis with previous evidence, Causal pathways
Generalisability	21	Discuss the generalisability (external validity) of the study results	12	Validity issues
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16	Funding

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Do biomass fuel use and consumption of unsafe water mediate educational inequalities in stillbirth risk? An analysis of the 2007 Ghana Maternal Health Survey

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Do biomass fuel use and consumption of unsafe water mediate educational inequalities in stillbirth risk? An analysis of the 2007 Ghana Maternal Health Survey

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ABSTRACT

Background Numerous studies have explored the association between educational inequalities and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that use of biomass fuels and consumption of unsafe water related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage.

Methods Data from the 2007 Ghana Maternal Health Survey, a nationally representative population-based survey was analyzed for this study. Of the10,370 women aged 15-49 years interviewed via structured questionnaires for the survey, 7183 primi- and multi- parous women qualified for inclusion in the present study.

Results In logistic regression analysis that adjusted for age, area of residence, marital status and ethnicity of women, lower maternal primary education was associated with a 62% (Odds ratio [OR] = 1.62; 95% CI: 1.04, 2.52) increased lifetime risk of stillbirth. Biomass fuel use and consumption of unsafe water mediated 18% and 8% of the observed effects, respectively. Jointly these two exposures explained 24% of the observed effects. The generalized additive modeling revealed a very flat inverted spoon-shaped smoothed curve which peaked at low levels of schooling (2 to 3 years) and confirms the findings from the logistic regression analysis.

Conclusions Our results show that biomass fuel use and unsafe water consumption could be important pathways through which low maternal educational attainment leads to stillbirths in Ghana and similar developing countries. Addressing educational inequalities in developing countries is thus essential for ensuring household choices that curtail environmental exposures, and help improve pregnancy outcomes.

Strengths and limitations of this study

- The study was based on a large and representative sample.
- The education-stillbirth relationship was illustrated in terms of smoothed curves of school-years.
- The exposure assessment method applied has limitations but has been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure.
- Exposure misclassification was possible in the study owing to the inability to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the study participants.

INTRODUCTION

Stillbirth, the intrauterine death of any conceptus at any time during pregnancy,[1] is a major public health concern in developing countries. An estimated 3.2 million stillbirths occurs worldwide annually with 98% of these stillbirths found in developing countries.[2] Important causes of stillbirths globally are asphyxia and infection associated with obstructed or prolonged labour, pre-eclampsia and eclampsia, chorioamnionitis, syphilis, malaria and poor nutritional status.[3] Stillbirth occurrence has been noted to be much higher among ethnic minority, disadvantaged, marginalized and rural populations. [4-6] This observation demonstrates the important role of socioeconomic factors in the etiology of stillbirth.

The risk factors of stillbirth in low-income countries are associated with poverty[7] including solid fuel use and consumption of unsafe water. Many households in developing countries rely on ground and surface water resources due to limited access to pipe-borne water, erratic supply, and high connection and utility charges. These water resources are often polluted by mining and agricultural activities, as well as nearby pit latrines which are also in widespread use in developing countries. Mining activities especially in unregulated mines leads to deposition/leaching of substantial amounts of chemicals such as cyanide and sulfuric acid, and heavy metals into nearby water bodies. Agricultural runoffs also introduce sediments, pesticides, fertilizers and pathogens into water bodies. Pit latrines have also been widely documented to leach microbial and chemical contaminants including coliforms, *Escherichia coli,* fecal streptococci, ammonia, nitrates and nitrites into groundwater resources.[8] Poverty further hampers many households from treating these unwholesome water resources before usage. Solid fuels are also the predominant cooking fuel in developing countries owing to poverty and limited access to clean fuels.[9] Bonjour et al.[10] estimated the proportion of households in Africa and Southeast Asia relying on solid fuels for cooking to be more than 60%. Studies have associated use of solid fuels,[11] and consumption of contaminated drinking water[12-14] with stillbirth and other adverse pregnancy outcomes.

Socioeconomic characteristics including educational attainment are well-documented to have strong effects on health outcomes including pregnancy outcomes. Several studies mostly emanating from high-income countries have explored the relationship between educational attainment and stillbirth but most have failed to elaborate how low educational attainment leads to an increased risk of stillbirth. We hypothesized that household use of biomass fuels and consumption of unsafe water related to low educational attainment could explain the stillbirth burden in Ghana attributable to socioeconomic disadvantage. As noted by Kramer,[15] research that identifies and quantifies the causal pathways and mechanisms through which social disadvantage leads to higher risks of adverse pregnancy outcomes may help to reduce disparities and improve pregnancy outcomes across the entire socioeconomic spectrum.

We relied on data from the 2007 Ghana Maternal Health Survey,[16] a nationally representative population-based survey that collected comprehensive information at both the household and individual woman's level on maternal health issues including pregnancies, stillbirths, abortions and miscarriages, and maternal deaths in the country.

METHODS

Data from the 2007 Ghana Maternal Health Survey (GMHS)[16] was analyzed for this study. GMHS was a nationally representative population-based survey that collected comprehensive information on maternal health and mortality in the country to provide baseline information for the Reducing Maternal Morbidity and Mortality (R3M) program initiated in three regions (Greater Accra, Eastern, Ashanti) of Ghana in 2006. The survey design of GMHS involved the selection of 1600 primary sampling units (clusters) from the 10 administrative regions of the country, across urban and rural areas. The primary sampling units consisted of wards or sub-wards drawn from the 2001 Population Census.

Data collection was carried out in two phases with data for the present study deriving from the second phase. In the second phase, 400 clusters were randomly selected from the

1600 clusters with a long household questionnaire administered in 10,858 households (response rate, 98.8%) randomly selected from these clusters. These households were selected independently from the 227,715 households identified in the first phase (from the 1600 clusters) for profiling maternal deaths. Also in the second phase, a women's questionnaire was administered to 10,370 women age 15-49 (response rate, 97.6%) identified from the 10,858 households. The long household questionnaires collected information on the demographic and socioeconomic characteristics of members of the households sampled whereas the women's questionnaire gathered information on a wide range of maternal health-related issues including live births, stillbirths, abortions and miscarriages, and utilization of health services in relation to these events.

To be eligible for inclusion in the present study, a woman must have given birth at least once (i.e. primi- and multi- parous women). Of the 10,370 women aged 15-49 years, 7183 (69.3%) primi- and multi- parous women were eligible for the present study.

A flowchart of the survey sampling procedure and mothers included in the present study is depicted in figure 1.

Ascertainment of educational attainment

In the women's questionnaire, respondents were asked whether they have ever attended school and if they answered "yes" they were further asked about the highest level of school they attended, and the highest grade they completed at that level. Maternal education was treated both as a continuous and categorical variable in the analysis.

In treating maternal educational attainment as a continuous variable, we combined the information obtained from mothers who reported ever attending school into years of schooling (1 to 15 years). Mothers who never attended school were ranked zero on this scale.

The following levels of maternal education were applied in the analysis: none, lower primary (1 to 4 years of schooling), upper primary (5 to 6 years of schooling), some middle/junior high school (JHS) (7 to 8 years of schooling), completed middle school/JHS (9 years of schooling), secondary/senior high school (SHS) (10 to 12 years of schooling), and higher (≥13 years of schooling).

Assessment of exposure

Maternal exposure to household air pollution (HAP) was assessed by the type of fuel used by households for cooking. This information was obtained from the long household questionnaire. In this questionnaire, household heads were asked *"What type of fuel does your household mainly use for cooking?"* Mothers living in households using electricity, liquefied petroleum gas (LPG) and natural gas served as the reference category with those residing in households using charcoal, firewood and straw/shrubs/grass representing the exposed category. Kerosene, a non-solid fuel but with uncertainties about its cleanliness was excluded from the reference category. Very few households used coal/lignite, a non-biomass fuel for cooking and were thus excluded from the analysis.

Maternal exposure to contaminated drinking water was ascertained by the type of drinking water sources of the household. This information was also obtained from the long household questionnaire in which household heads were asked *"What is the main source of drinking water for members of your household?"* Mothers residing in households using piped and bottled/sachet water served as the reference category with those living in households sourcing water from surface (rivers, streams, lakes, dams, ponds etc.) and ground (wells, boreholes) waters representing the exposed categories. Mothers in households using spring water, rainwater and tanker water were excluded from the analysis because of the small number of household using these water resources.

Outcome of interest

The outcome of interest was lifetime experience of stillbirth (yes vs. no) among primi- and multi-parous women. This information was extracted from the women's questionnaire where mothers were asked whether they have ever given birth in late pregnancy (7 months or more) to a dead child and if they answered "yes", they were further asked about the number of stillbirths they have had in their lifetime.

Covariates

The following core potential confounders were adjusted for in the analysis: area of residence (urban, rural), age of woman, marital status and ethnicity.

Ethical consideration

The GMHS was conducted under the scientific and technical supervision of the Ghana Statistical Service and Ghana Health Service. The MEASURE DHS project at Macro International, Calverton, Maryland, USA approved the survey and provided technical assistance. Informed consent was obtained from all the participants before the interview.

Statistical analysis

We first described the education-stillbirth relationship in terms of relative risk by educational categories using logistic regression (PROC LOGISTIC). PROC LOGISTIC was used to estimate the effects of maternal education on the risk of stillbirth (yes, coded 1 vs. no, coded 0) in a woman's lifetime, and to also establish whether a gradient in the risk exists. The analysis was adjusted for the core potential confounders.

We performed a causal pathway analysis using the difference method[17] to establish the independent and joint mediating effect of biomass fuel use and consumption of unsafe drinking water in the observed educational differences in stillbirth risk. In brief, after controlling for the core confounders, biomass fuel use and unsafe water consumption were further independently and jointly added to the adjusted model with the mediation fractions computed using the formula below:

$$\frac{OR_{adjusted} - OR_{mediation}}{1 - OR_{adjusted}} \times 100\%$$

where $OR_{adjusted}$ is the odds ratio in the adjusted model and $OR_{mediation}$ is the odds ratio in the independent and joint mediation models.

We next illustrated the education-stillbirth relationship in terms of cubic smoothing splines using generalized additive modeling (GAM) with three degrees of freedom (df). Three df was chosen after fitting six separate models (df = 3, 4, 5, 6, 7 and 8) and identifying the model with 3df to have the best fit. The Akaike Information Criterion (AIC) was used to evaluate goodness of fit of the models fitted. AIC was estimated using the formula below:

$$\text{AIC} = D(\theta) + 2p$$

where $D(\theta)$ is the deviance and p is the number of parameters (df) in the model. The model with the smaller AIC value was deemed a better fit. The AIC values are presented in Table S1.

GAM allowed maternal education to be applied as a continuous variable (school-years), thereby increasing statistical power and enabling a better illustration of the predictor-risk relationship. Possible nonlinearities in the maternal education data were explored by performing chi square test of nonlinearity. We stratified the curve fitting by urban and rural residence to ascertain whether there exist any marked differences.

SAS version 9.3 was used to perform all the analysis with the exception of the generalized additive modeling which was performed with Stata 12.0.

RESULTS

The characteristics of the study population are presented in Tables 1 and 2. Close to one-third (31.9%) of the respondents were within the age group 20-39 years. More than half (68.6%) of the women reported being married with very few (6.4%) reporting that they have never been married. Close to half (46.3%) of the study population were resident in the R3M regions (Greater Accra, Eastern and Ashanti) with 19% of the women living in the three northern regions (Northern, Upper East, Upper West). More than half (58%) of the respondents were rural dwellers with about 17% of the respondents identified as city dwellers. Majority of the women (75%) were Christians with Muslims making up about 16% of the study respondents. Close to half (46%) of the women were Akans. Close to one-third (32.3%) of the respondents had no formal education with only 2.1% of the women educated up to the tertiary level or higher.

Biomass fuel, notably charcoal and firewood were the dominant cooking fuels of respondent's households with 91% of households using these fuels. LPG was used by 8% of the respondent's households. Whereas among highly educated mothers, LPG was the dominant fuel used (69%), among uneducated (77%) and primary educated (64%) mothers firewood was the fuel mostly used. Piped water (40%) and well/borehole (41%) were the dominant drinking water sources of the respondents. About 5% and 11% of the respondents used bottled/sachet and surface water, respectively. Secondary (59%) and highly (64%) educated mothers patronized piped water mostly. A quarter of highly educated mothers used bottled/sachet water. Among uneducated mothers, 53% accessed well/borehole water resources with 26% using piped water. Among primary and some middle school/JHS educated women, the proportion using piped and well/borehole water resources were about the same.

The gravidity status and lifetime stillbirth experience of the women interviewed are presented in Table 3. About 14% of the respondents were primigravida. About 6% of the respondents reported experiencing stillbirth in their lifetime with a small proportion (13%) of them experiencing this occurrence more than once. Uneducated mothers and mothers who

completed middle/JHS recorded the highest proportion of lifetime stillbirths; 32% and 26%, respectively.

Table 4 and S2 present the odds ratios (OR) for the association between maternal education and lifetime stillbirth experience calculated from logistic regression. Lower primary education was associated with a statistically significant 62% (OR = 1.62, 95% CI: 1.04, 2.52) increased risk of stillbirth in a lifetime after adjustment for the core covariates. Biomass fuel use and unsafe water consumption mediated 17.7% and 8.1% of the observed association of lower primary education on lifetime stillbirth risk. In the joint model, the mediation fraction was 24.2%. No consistent educational gradient was observed.

Figure S1 depicts the smoothed curves for odds ratio of stillbirth in a lifetime in relation to maternal years of schooling. Among all mothers, a very flat inverted spoon-shaped smoothed curve was observed. The odds ratio of lifetime stillbirth increased slightly away from the reference level up to about 2.5 years of schooling, and declined slowly afterwards with further schooling . The 95% confidence band was generally wide especially towards the tail end of the smoothed curve. Among rural dwellers, a more pronounced inverted spoon-shaped smoothed curve was observed. Among urban dwellers, an s-shape smoothed curve with a generally wide 95% confidence band over the whole range of the maternal schooling years was observed.

For all study participants (p = 0.4166), and urban dwellers (p = 0.6003), the nonlinearity chi-square was not statistically significant. Among rural dwellers, the nonlinearity chi-square was borderline significant (p = 0.0558) thereby indicating possible departure from linearity. In the model adjusting for the mediating effect of biomass fuel use, the decrease in the odds ratio of lifetime stillbirth after 6.5 years of schooling was very gentle. In the model adjusting for the mediating effect of unsafe water consumption, no appreciable change in the smoothed curve was observed and possibly confirms the small mediation fraction estimated in the logistic regression.

DISCUSSION

We found lower maternal primary education to be associated with a 62% (Odds ratio [OR] = 1.62; 95% CI: 1.04, 2.52) increased lifetime risk of stillbirth. Biomass fuel use and consumption of unsafe water mediated 18% and 8% of the observed effects, respectively. Jointly these two exposures explained 24% of the observed effects. The generalized additive modeling revealed a very flat inverted spoon-shaped smoothed curve which peaked at low levels of schooling (2 to 3 years) and confirms the findings from the logistic regression modeling.

Validity issues

Selection bias was minimized in the study owing to the population-based nature of the GMHS survey and the high response rate (97.6%) achieved. Also the standardized data collection instruments and procedures of DHS surveys including the present, and the extensive training of interviewers guarantees the collection of reliable information from survey participants. On the issue of missing data, of the variables of interest concerned (education, marital status, ethnic group, cooking fuel type, drinking water source), the proportion of respondents with missing data was very low (< 0.04%).

Educational attainment is a strong determinant of future employment and income,[18,19] and certainly has implications for maternal health and pregnancy outcomes. The potential for outcome measurement bias is reduced in our study even though the outcome of interest was subjectively reported by the respondents. This is because stillbirth is a very traumatic experience that every mother with such an experience can vividly recollect.

Exposure to HAP and drinking water contaminants was assessed based on the primary cooking fuels and main drinking water sources of maternal households. There are limitations with the exposure assessment method applied but they have been widely used in environmental epidemiological studies and shown to be very good proxy measures of exposure. There is nonetheless the potential for exposure misclassification in the study with the direction of bias unclear. It was impossible to ascertain whether cooking fuel choices and drinking water sources of the households remained relatively stable throughout the pregnancies of the mothers interviewed. Regarding cooking fuel choices, it is often the case of households transitioning to fuels higher up the energy ladder with improved socioeconomic conditions and back to their traditional fuels as conditions deteriorate. With regards to drinking water sources, except in situations where communities have been connected to pipe-borne water, household water sources traditionally remain the same irrespective of improvement in socioeconomic conditions. It is possible that households connected to pipe-borne water after years of relying on ground and surface water resources will report use of pipe-borne water as their main drinking water source. This information bias, however, would rather underestimate the true effect.

The study adjusted for the effect of age of respondent, marital status, area of residence (urban vs. rural) and ethnicity. We had no information on the smoking status of the mothers, but in Ghana only few women smoke. The 2008 Ghana Demographic and Health Survey[20] estimated the proportion of women smoking cigarettes and other tobacco products to be 0.4%. Maternal smoking can therefore not be considered as a serious threat to validity in this study. We were unable to examine the confounding effect of prenatal and intrapartum care, maternal nutrition and anthropometry as well as malaria and sexually transmitted infections. However, with regards to infections it has been suggested by Silver et al.[21] that they are more clearly associated with early stillbirth (20 weeks) than with late stillbirth (after 28 weeks). With the GMHS survey ascertaining stillbirths with a cut-off point of 7 or more months, we can assume that the associations reported are not likely to be confounded by maternal infections.

Synthesis with previous evidence

Our study adds to the weight of evidence emanating mostly from high-income countries[22-26] on the adverse perinatal effects of low maternal educational attainment. We found lower primary education to be associated with a 62% increased risk of lifetime stillbirth. The smoothing curves also peaked at low levels of schooling (2 to 3 years) and declined with further schooling. A multi-country study[27] conducted in six low-income and one middle-income countries reported a 40% (RR=1.4; 95% CI: 1.2, 1.5) increased risk of stillbirth with no formal maternal schooling. Two recent population-based studies conducted in rural Ghana,[28,29] however, found no association between maternal education and stillbirth. Ha et al.[28] reported a small and statistically insignificant increased odds of antepartum and intrapartum stillbirth with no formal and primary maternal education. Engmann et al.[29] reported a much higher increased odds of stillbirth with no formal (OR=1.47; 95% CI: 0.94, 2.29) and primary/JHS (OR=1.48, 95% CI: 0.95, 2.30) maternal education. These associations were also not statistically significant. A systematic review and meta-analysis of the available evidence on the major risk factors for stillbirth in high-income countries[26] found low educational attainment (<10 years of schooling) to be associated with 70% (OR=1.7; 95% CI: 1.4, 2.0; n=5) increased odds of stillbirth. The findings of our study are consistent with the findings of McClure et al.[27] and Flenady et al.[26]

Causal pathways

Medical care has been mentioned as the route through which education leads to inequality in stillbirth from placental abruption and cord compression.[30] Suboptimal care including delayed recognition of medical problems or poor management has been noted to contribute to a significant proportion of stillbirths.[31] Delayed access of prenatal care services owing to ignorance is very common in developing countries. Also common in developing countries is the inability of mothers to apply the nutritional and health messages received during prenatal visits for improved maternal and fetal health. This situation arises as a result of lack of education or low educational attainment of mothers. According to Galobardes et al.,[32] education may affect an individual's cognitive functioning and enable him/her to access appropriate health services, to better communicate with healthcare workers, and to be more receptive to health education messages. Stephansson et al.[33] have also suggested that, the socioeconomic differences in the risk of stillbirth can be attributed to social differences in seeking care for signs of pathological pregnancy such as reduced fetal movements.

In developing countries, besides access and utilization of health services, there are other important pathways through which low educational attainment impacts on perinatal outcomes. Our study is the first to explore the mediating role of environmental factors in the maternal education - stillbirth relationship. Biomass fuel use and unsafe water consumption explained about 18% and 8% of the observed effects of low maternal educational attainment on lifetime stillbirth risk. Jointly, they mediated almost a quarter (24%) of the observed effect. A study in Ghana found the effects of low educational attainment on average birth weight to be substantially (62%) mediated by biomass fuel use.[34] Studies in Ghana,[35,36] Ethiopia,[37,38] Cameroun[39] and Kenya[40] have reported educational attainment to be an important determinant of cooking fuel choices of households.

We must mention that the mediation fraction reported is likely to be overestimated and should be interpreted with caution. This is because prenatal and intrapartum care, maternal nutrition and other social factors which we were unable to control in the analysis are associated with educational attainment just as much as fuel and drinking water choices. It is thus possible biomass fuel use and unsafe water consumption are essentially a proxy for these confounding variables and biasing the causal effect away from null as a result.

CONCLUSIONS

In conclusion, we provide evidence that in Ghana and similar developing countries, biomass fuel use and unsafe water consumption could be important pathways through which low maternal educational attainment leads to stillbirths. Women with no formal or low education should therefore receive extra care and support, and be alerted to household environmental risks to their pregnancies during prenatal visits. This recommendation could help curb the high stillbirth occurrence in developing countries. According to Goldenberg et al.,[41] each geographical area must understand the local causes of stillbirth, and the contexts in which they occur to enable prevention strategies to be developed and implemented.

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Authors contribution AKA conceived and designed the study, and performed the data analysis with guidance from SN and JJKJ. AKA wrote the manuscript with SN and JJKJ reviewing drafts for intellectual content. All authors read and approved the final version.

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Competing interests None declared.

Ethics approval The Ghana Maternal Health Survey was approved by the Ghana Statistical Service, Ghana Health Service and MEASURE DHS.

Data sharing statement No additional data are available.

FIGURE LEGEND

Figure 1 Flowchart of the survey sampling procedure and mothers included in present study

Table 1 Demographic and background characteristics of the study respondents (n=7183)

Characteristic	No. (%)
Age (years)[1]	
<20	247 (3.4)
20-29	2293 (31.9)
30-39	2713 (37.8)
>39	1930 (26.9)
Marital status[2]	
Married	4925 (68.6)
Cohabitation	878 (12.2)
Never married	457 (6.4)
Divorced/Separated	721 (10.0)
Widowed	200 (2.8)
Missing	2 (0.03)
Region of residence	
Western	569 (7.9)
Central	642 (8.9)
Greater Accra	1071 (14.9)
Volta	590 (8.2)
Eastern	1084 (15.1)
Ashanti	1173 (16.3)
Brong Ahafo	684 (9.5)
Northern	637 (8.9)
Upper East	409 (5.7)
Upper West	324 (4.5)
Area of residence[3]	
City	1249 (17.4)
Town	1782 (24.8)
Rural	4152 (57.8)
Education	
None	2316 (32.3)
Lower Primary (1 - 4 years of schooling)	789 (11.0)
Upper Primary (5 - 6 years of schooling)	801 (11.2)
Some Middle/JSS (7 - 8 years of schooling)	699 (9.7)
Completed Middle/JSS (9 years of schooling)	1941 (27.0)
Secondary/SSS (10 - 12 years of schooling)	485 (6.8)
Higher (≥13 years of schooling)	151 (2.1)
Missing	1 (0.01)
Religion	
Christian	5364 (74.7)
Moslem	1142 (15.9)
Traditional/Spiritualist	284 (4.0)
Other	5 (0.1)
No religion	385 (5.4)
Missing	3 (0.04)
Ethnic group[4]	
Akan	3303 (46.0)
Ga/Dangme	624 (8.7)
Ewe	985 (13.7)
Guan	155 (2.2)
Mole – Dagbani	683 (9.5)
Grussi	341 (4.8)
Gruma	416 (5.8)
Hausa	77 (1.1)
Other	597 (8.3)
Missing	2 (0.03)

Covariates: [1]Age group 20-29 years, [2]Married/cohabitation, [3]Urban (City & town), and [4]Akan served as reference category

Table 2 Cooking fuel choices and drinking water sources of study respondents households (n = 7182)

	None n (%)	**Lower primary n (%)**	**Upper primary n (%)**	**Some Middle/JSS n (%)**	**Completed Middle/JSS n (%)**	**Secondary/ SSS n (%)**	**Higher n (%)**	**Total N (%)**
Type of cooking fuel								
Electricity	1 (0.04)	1 (0.13)	0 (0.00)	0 (0.00)	2 (0.10)	3 (0.62)	4 (2.65)	11 (0.15)
LPG	14 (0.60)	24 (3.04)	29 (3.62)	30 (4.29)	232 (11.95)	158 (32.58)	104 (68.87)	591 (8.23)
Natural gas	1 (0.04)	1 (0.13)	0 (0.00)	1 (0.14)	3 (0.15)	0 (0.00)	1 (0.66)	7 (0.10)
Kerosene	0 (0.00)	0 (0.00)	2 (0.25)	1 (0.14)	7 (0.36)	0 (0.00)	0 (0.00)	10 (0.14)
Coal/Lignite	0 (0.00)	0 (0.00)	1 (0.12)	0 (0.00)	0 (0.00)	1 (0.21)	0 (0.00)	2 (0.03)
Charcoal	492 (21.24)	256 (32.45)	334 (41.70)	267 (38.20)	872 (44.93)	221 (45.57)	34 (22.52)	2476 (34.48)
Firewood	1789 (77.25)	504 (63.88)	433 (54.06)	397 (56.80)	819 (42.19)	100 (20.62)	8 (5.30)	4050 (56.39)
Straw/Shrub/Grass	18 (0.78)	0 (0.00)	2 (0.25)	1 (0.14)	0 (0.00)	1 (0.21)	0 (0.00)	22 (0.31)
No cooking	0 (0.00)	3 (0.38)	0 (0.00)	2 (0.29)	5 (0.26)	1 (0.21)	0 (0.00)	11 (0.15)
Missing	1 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	2 (0.03)
Source of drinking water								
Piped water	606 (26.17)	290 (36.76)	325 (40.57)	276 (39.48)	959 (49.41)	287 (59.18)	97 (64.24)	2840 (39.54)
Well/Borehole	1232 (53.19)	330 (41.82)	312 (38.96)	296 (42.34)	671 (34.57)	88 (18.14)	16 (10.59)	2945 (41.00)
Spring	72 (3.11)	16 (2.02)	18 (2.24)	15 (2.14)	24 (1.24)	2 (0.42)	0 (0.00)	147 (2.04)
Surface water	356 (15.37)	112 (14.20)	98 (12.23)	70 (10.01)	122 (6.29)	13 (2.68)	1 (0.66)	772 (10.75)
Rainwater	9 (0.39)	4 (0.51)	6 (0.75)	6 (0.86)	24 (1.24)	3 (0.62)	0 (0.00)	52 (0.72)
Tanker truck	8 (0.35)	10 (1.27)	4 (0.50)	1 (0.14)	9 (0.46)	4 (0.82)	0 (0.00)	36 (0.50)
Bottled/Sachet water	32 (1.38)	27 (3.42)	38 (4.74)	35 (5.01)	130 (6.70)	88 (18.14)	37 (24.50)	387 (5.39)
Other	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	1 (0.01)
Missing	1 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	2 (0.03)

The education category had one missing value

Table 3 Gravidity status and lifetime stillbirth experience of study respondents classified by maternal education

	None n (%)	Lower primary n (%)	Upper primary n (%)	Some middle/JSS n (%)	Completed middle/JSS n (%)	Secondary/ SSS n (%)	Higher n (%)	Total N (%)
Gravidity								
Primigravida								1029 (14.3)
Multigravida								6154 (85.7)
Lifetime stillbirth experience								
No	2183 (32.3)	727 (10.8)	764 (11.3)	658 (9.7)	1831 (27.1)	458 (6.8)	144 (2.1)	6766 (94.2)
Yes	133 (31.9)	62 (14.9)	37 (8.9)	41 (9.8)	110 (26.4)	27 (6.5)	7 (1.7)	417 (5.8)
No. of stillbirths in lifetime								
One	114 (31.3)	54 (14.8)	30 (8.2)	37 (10.2)	99 (27.2)	23 (6.3)	7 (1.9)	364 (87.3)
Two or more	19 (35.9)	8 (15.1)	7 (13.2)	4 (7.6)	11 (20.8)	4 (7.6)	0 (0.0)	53 (12.7)

Table 4 Binary logistic regression of lifetime stillbirth experience on maternal education (n=7183)

Education	**Unadjusted**	**Adjustment for:**			
		Model 1: Core covariates[1]	**Model 2: +**Biomass fuel use	**Model 3: +**Unsafe water consumption	**Model 4: +**Biomass fuel use and unsafe water consumption
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
None	1.08 (0.73, 1.59)	1.19 (0.78, 1.82)			
Lower primary	1.51 (0.98, 2.33)	1.62 (1.04, 2.52)	1.51 (0.95, 2.41)	1.57 (1.00, 2.47)	1.47 (0.92, 2.37)
Upper primary	0.86 (0.53, 1.38)	0.98 (0.60, 1.60)			
Some middle/JSS	1.10 (0.69, 1.76)	1.26 (0.78, 2.02)			
Completed middle/JSS	1.06 (0.72, 1.58)	1.11 (0.74, 1.65)			
Secondary+	1.00	1.00	1.00	1.00	1.00

[1]Core covariates were age of mother, marital status, area of residence and ethnic group
Mediation fractions: Lower primary education (Biomass fuel: 17.7%; Unsafe water: 8.1%; Joint: 24.2%)

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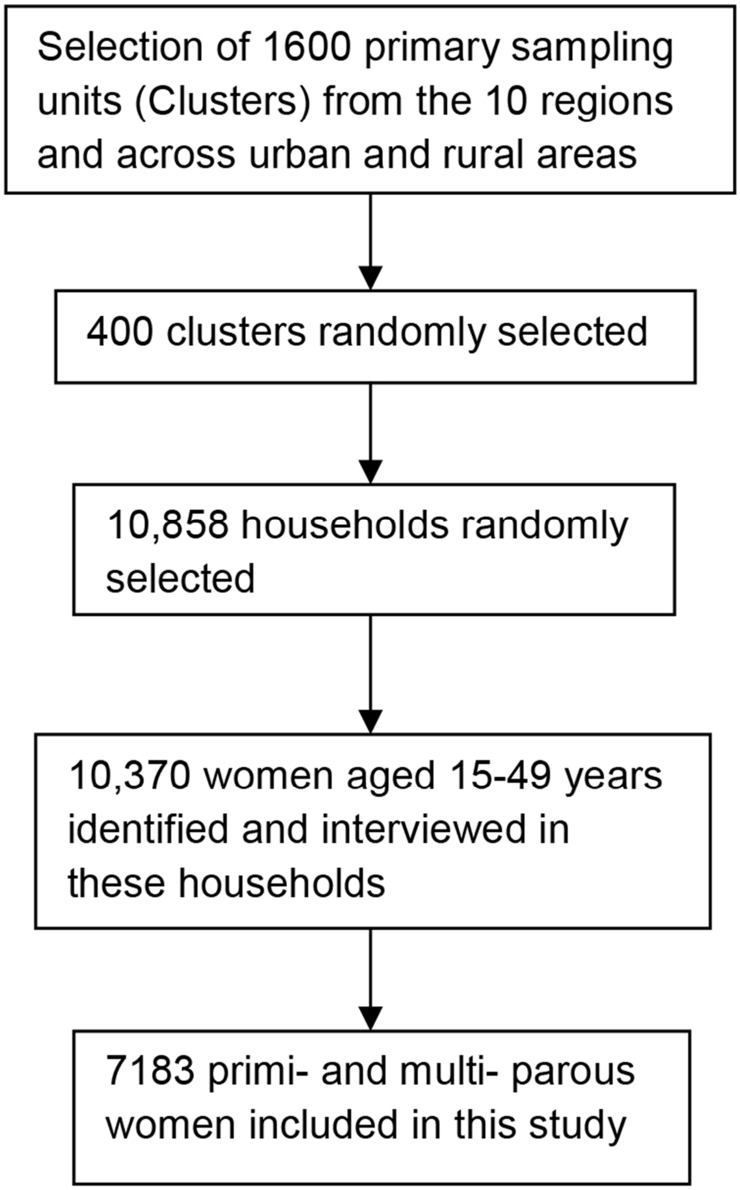

Figure 1. Flowchart of the survey sampling procedure and mothers included in present study

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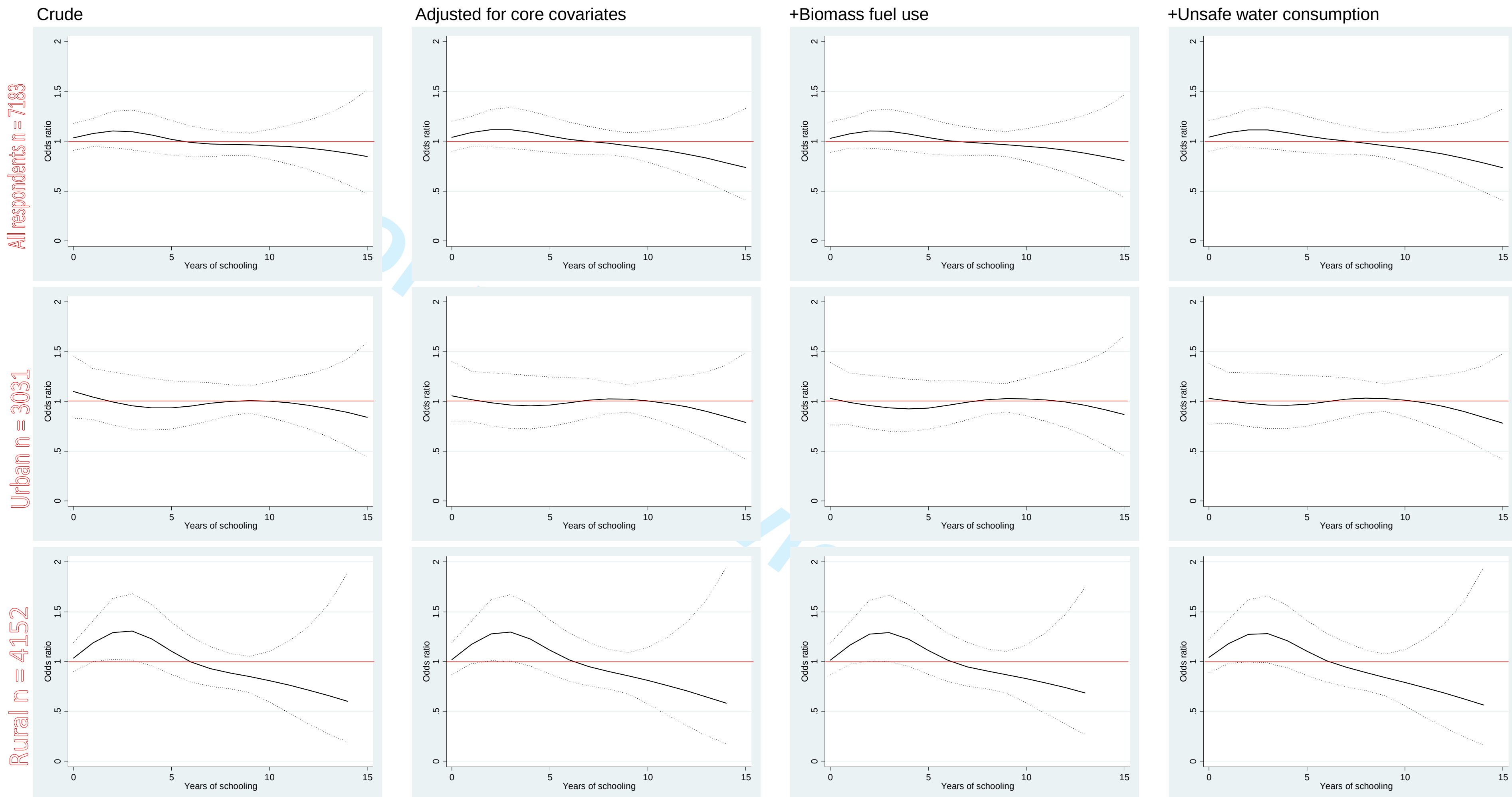

Figure S1. Odds ratios (Solid lines) and their corresponding 95% confidence bands (dotted lines) from generalized additive models (df = 3) regressing lifetime stillbirths on years of maternal schooling.

Table S1. Akaike Information Criterion (AIC) values according to degrees of freedom (df) of GAM fitted models regressing lifetime stillbirths on years of maternal schooling

df	3	4	5	6	7	8
Deviance	3180.14	3178.45	3176.91	3175.77	3174.96	3174.35
AIC	3186.14	3186.45	3186.91	3187.77	3188.96	3190.35

Table S2. Binary logistic regression of lifetime stillbirth experience on maternal education (n=7183)

	Crude OR (95% CI)	Adjusted OR (95% CI)
Education		
None	1.08 (0.73, 1.59)	1.19 (0.78, 1.82)
Lower primary	1.51 (0.98, 2.33)	1.62 (1.04, 2.52)
Upper primary	0.86 (0.53, 1.38)	0.98 (0.60, 1.60)
Some middle/JSS	1.10 (0.69, 1.76)	1.26 (0.78, 2.02)
Completed middle/JSS	1.06 (0.72, 1.58)	1.11 (0.74, 1.65)
Secondary+	1.00	1.00
Age (years)		
<20	0.57 (0.23, 1.42)	0.53 (0.21, 1.35)
20-29	1.00	1.00
30-39	1.95 (1.49, 2.56)	1.94 (1.47, 2.56)
>39	2.38 (1.80, 3.14)	2.37 (1.78, 3.17)
Area of residence		
Urban (City & Town)	1.00	1.00
Rural	0.88 (0.72, 1.08)	0.91 (0.74, 1.13)
Marital status		
Married/ Cohabitation	1.00	1.00
Never married	0.75 (0.47, 1.19)	1.22 (0.74, 1.99)
Divorced/Separated	1.22 (0.90, 1.66)	1.12 (0.82, 1.54)
Widowed	1.14 (0.64, 2.02)	0.92 (0.52, 1.64)
Ethnic group		
Akan	1.00	1.00
Ga/Dangme	0.99 (0.69, 1.41)	0.99 (0.69, 1.41)
Ewe	1.00 (0.75, 1.35)	0.99 (0.74, 1.34)
Guan	0.30 (0.09, 0.95)	0.30 (0.09, 0.95)
Mole – Dagbani	1.17 (0.85, 1.62)	1.17 (0.81, 1.67)
Grussi	0.55 (0.31, 1.00)	0.56 (0.31, 1.04)
Gruma	0.61 (0.36, 1.02)	0.64 (0.37, 1.10)
Hausa	0.83 (0.30, 2.30)	0.90 (0.32, 2.51)
Other	0.80 (0.54, 1.19)	0.83 (0.55, 1.26)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2	Abstract: Methods
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2	Abstract: Methods, Results
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5	Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses	5	Introduction
Methods				
Study design	4	Present key elements of study design early in the paper	5-6	Methods
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-8	Methods
Participants	6	*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6	Eligibility criteria
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8	Assessment of exposure, Outcome of interest, Ascertainment of educational attainment , Covariates
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8	
Bias	9	Describe any efforts to address potential sources of bias	12-14	Validity issues
Study size	10	Explain how the study size was arrived at	5-6	Methods

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8- 9	Statistical analysis
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9	Statistical analysis
		(*b*) Describe any methods used to examine subgroups and interactions		
		(*c*) Explain how missing data were addressed	12	Validity issues
		(*d*) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		
		(*e*) Describe any sensitivity analyses		
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5-6	Methods, Eligibility criteria
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	18, 19	Table 1, Table 2
		(b) Indicate number of participants with missing data for each variable of interest	18, 19	Table 1, Table 2
		Cross-sectional study—Report numbers of outcome events or summary measures	20-21	Table 3, Table 4, Table 5
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	20-21	Table 4, Table 5
		(*b*) Report category boundaries when continuous variables were categorized		
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		

Continued on next page

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		Figure 1
Discussion				
Key results	18	Summarise key results with reference to study objectives	14	Synthesis with previous evidence
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	12-14	Validity issues
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-16	Synthesis with previous evidence, Causal pathways
Generalisability	21	Discuss the generalisability (external validity) of the study results	12	Validity issues
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16	Funding

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.