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The association of water carriage, water supply and sanitation usage with maternal and child health. A combined analysis of 49 Multiple Indicator Cluster Surveys from 41 countries

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ABSTRACT

Background: Millions of people carry water home from off-plot sources each day and lack improved sanitation. Research on the health outcomes associated with water fetching is limited, and with usage of improved sanitation is inconclusive.

Objectives: To analyse the association of water fetching, unimproved water supplies, and usage of improved sanitation facilities with indicators of women's and children's health.

Methods: 49 Multiple Indicator Cluster Surveys from 41 countries were merged, creating a data set of 2,740,855 people from 539,915 households. Multilevel, multivariable analyses were conducted, using logistic regression for binary outcomes, negative binomial regression for count data and ordinary linear regression for linear data. We adjusted for confounding factors and accounted for clustering at survey, cluster and household level.

Results: Compared to households in which no-one collects water, water fetching by any household member is associated with reduced odds of a woman giving birth in a health care facility (OR 0.88 to 0.90). Adults collecting water is associated with increased relative risk of childhood death (RR 1.04 to 1.05), children collecting water is associated with increased odds of diarrheal disease (OR 1.10 to 1.13) and women or girls collecting water is associated with reduced uptake of antenatal care (β-0.04 to −0.06) and increased odds of leaving a child under five alone for one or more hours, one or more days per week (OR 1.07 to 1.16). Unimproved water supply is associated with childhood diarhhoea (OR 1.05), but not child deaths, or growth scores. When the percentage of people using improved sanitation is more than 80% an association with reduced childhood death and stunting was observed, and when more than 60%, usage of improved sanitation was associated with reduction of diarhhoea and acute undernutrition.

Conclusion: Fetching water is associated with poorer maternal and child health outcomes, depending on who collects water. The percentage of people using improved sanitation seems to be more important than type of toilet facility, and must be high to observe an association with reduced child deaths and diarhhoea. Water access on premises, and near universal usage of improved sanitation, is associated with improvements to maternal and child health.

1. Introduction

Target 6.1 of the UN Sustainable Development Goal on clean water and sanitation is to 'achieve universal and equitable access to safe and affordable drinking water for all', and target 6.2 is to 'achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations', by 2030 (UN, 2015). Equitable or fair access implies that different levels of water supply and sanitation services, or usage of different types of water source and toilet facilities, should not or will not disadvantage specific individuals or households.

In 2017, 785 million people still lacked even a basic drinking water service, defined as one requiring less than a 30 min round trip to fetch water from an improved source. Out of the people lacking a basic service, 206 million people spent over 30 min per round trip to collect water from an improved source (defined as a limited drinking water service) and the remainder relied on unimproved (435 million) or surface water sources (144 million), which most often also require more

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than 30 min to walk to, collect water and return home (WHO and UNICEF, 2019). In the same year, 2 billion people lacked a basic sanitation service (WHO and UNICEF, 2019). Off-plot access to water, even as part of a basic service, commonly requires a household member to complete multiple water fetching trips per day or week, with time spent walking to the source, queuing and physically carrying home enough water filled containers to meet their own needs and the needs of other household members (Evans et al., 2013; Geere, 2015). It therefore creates an immediate challenge to obtaining equitable access in comparison to households with water piped into their home, or which is accessible in the yard. It may also disadvantage individuals tasked with fetching water, usually the poorest women and children in low income regions (UN, 2016; WHO and UNICEF, 2017a, WHO and UNICEF, 2019). Many of these women and children also contend with a complete lack of, or unimproved sanitation facilities, which may further challenge their ability to maintain their own and their families' hygiene, health, safety and dignity (WHO and UNICEF, 2017b).

Different levels of access to safe water and sanitation may impact upon individuals and households through a variety of mechanisms or disease transmission pathways. However, epidemiological evidence of the health benefits of access to safe water and sanitation remains equivocal, at least in Low and Middle-Income Countries. For example, recent large scale multi-country randomised controlled trials have not reported clear associations between improvements in water or sanitation provision and either childhood diarrhoea or indicators of malnutrition (Clasen et al., 2014; Luby et al., 2018; Null et al., 2018). Even when randomised controlled trials of water and sanitation interventions have reported improved health outcomes, concerns were raised that such impact may be explainable largely by reporting bias as a result of lack of blinding of participants and investigators (Hunter, 2009; Schmidt and Cairncross, 2009). Equivocal or unclear findings may also be due to the confounding or mediating effects of other pathways leading to poor health, which have not been evaluated or adequately studied.

One aspect of water supply provision that has not been adequately studied, and may confound or mediate any benefits from improved water supply and sanitation interventions, is the impact that having to carry water home from off the site, or 'off-plot' water sources, may have on public health. Studies suggest that the work of water fetching may directly affect the health and wellbeing of the water carrier because it is associated with pain, fatigue and emotional distress (JA Geere et al., 2010; JL Geere et al., 2010 ; Geere et al., 2018; Wutich and Ragsdale, 2008). Through time and opportunity costs, water fetching might also indirectly lead to poorer health. For example, it might limit uptake of health services (Geere et al., 2018), or a person's capacity to engage with occupations which would otherwise enhance personal and family wellbeing, such as paid employment, vending or caring for young children (Wrisdale et al., 2017).

Because women and girls in the poorest families are most often tasked with fetching water (Geere and Cortobius, 2017; Graham et al., 2016; Hopewell and Graham, 2014; WHO and UNICEF, 2017a), it is likely that a differential burden from different levels of water access and the work of water fetching will become apparent as poorer maternal and child health outcomes (Geere et al., 2018; Pickering and Davis, 2012; Porter et al., 2012; Wang and Hunter, 2010), which might occur through a variety of pathways. For example, the time and energy taken for water carriage might reduce women's opportunities to also spend time and energy attending antenatal clinics (McCray, 2004), and antenatal clinic attendance has been shown to be associated with a woman giving birth in a health care facility (Seraphin et al., 2015). Women who lack social support for household water collection may not feel able to spend time away from home to give birth and recover in a health care facility, particularly if they have very young children to care for (Ono et al., 2013). Improved water supply and sanitation within the home might enable a woman to ask for and receive social support in the perinatal period (Subbaraman et al., 2015), which could then facilitate her access to antenatal care, or to travel to and give birth in a health care facility. Alternatively, communities where people have to fetch their own water may not have heath care facilities, or those that do exist may also lack adequate water supply and sanitation services, which could dissuade women from using them (Bouzid et al., 2018). Furthermore, the energy expenditure required for water carriage might exacerbate under-nutrition. During pregnancy or postnatally, insufficient maternal nutrition may impact upon intrauterine growth or breast feeding, to increase risk of child mortality, or children under five having reduced weight for age (WAZ) and height for age (HAZ) z-scores (Black et al., 2008). Unimproved water supply and low levels of improved sanitation usage may also impact on individuals and households through a variety of mechanisms leading to faecal contamination of the environment and within the home, with subsequent transmission of infectious disease (Clasen et al., 2014).

Analysis of existing data to establish whether water carriage, adjusted for unimproved water supply and low levels of use of sanitation, is independently associated with poorer maternal and child health outcomes, is an important step prior to further research into which causal pathways operate in specific contexts. Large scale demographic and health surveys (DHS) and Multiple Indicator Cluster Surveys (MICS) are regularly conducted in many countries and have been used to provide data on access to water and sanitation (Graham et al., 2016; Hopewell and Graham, 2014; Sorenson et al., 2011). However, they have not been used to test hypotheses about associations between water fetching, water supply and sanitation use, and the health and wellbeing of household members. We report an analysis of 49 MICS to test the hypotheses that inadequate access to drinking water and low levels of sanitation use are associated with indicators of poorer maternal and child health.

2. Methods

The primary hypotheses were that adverse maternal and child health outcomes are associated with.

1. Having to carry water
2. Use of unimproved drinking water supplies, and
3. Living in communities with low levels of use of improved sanitation

The key variables linked to the primary hypotheses were age and sex of the person in the household identified as usually responsible for collecting water, whether or not people reported use of an improved water supply, category of toilet/latrine usually used in the house and the proportion of homes in a cluster using improved sanitation.

We analysed data on seven health related indicators or outcome measures. The following health outcomes were tested against all three hypotheses.

1. An increase in the risk of child deaths
2. Higher 2 week prevalence of diarrhoea in children under 5 years of age
3. Decreased WHO weight for age z scores (WAZ)
4. Decreased WHO height for age z scores (HAZ)

In addition, the following indicators of health were tested only for having to carry water (hypothesis 1).

5. Reduced likelihood of giving birth in a health care facility (HCF)
6. Reduced uptake of antenatal care
7. Increased likelihood of a child under 5 being left alone for more than 1 h, for one or more days per week

Data sets from 41 countries derived from 49 MICS conducted between 2009 and 14 and with results reported and publicly available in April 2015, were downloaded after obtaining permission from UNICEF,

Table 1
MICs surveys merged for analysis.

Survey Country (region)	Year	N (households)	N (Individuals)	% sample
Afghanistan	2011	13116	101671	3.7
Argentina	2012	23791	89799	3.3
Barbados	2012	2872	8148	.3
Belarus	2012	8284	23650	.9
Belize	2011	4424	17538	.6
Bhutan	2010	14676	68351	2.5
Bosnia and Herzegovina (Roma Settlements)	2012	1544	5864	.2
Bosnia and Herzegovina	2012	5778	20248	.7
Central African Republic	2010	11756	54281	2.0
Chad	2010	16386	88564	3.2
Congo DR	2010	11393	61543	2.2
Costa Rica	2011	5561	21322	.8
Cuba	2011	9183	35454	1.3
Ghana (Accra)	2010–11	1409	4878	.2
Ghana	2011	11925	54228	2.0
Indonesia (Selected Districts of Papua)	2011	2866	12112	.4
Indonesia (Selected Districts of West Papua)	2011	2816	11533	.4
Iraq	2011	35701	238327	8.7
Jamaica	2011	5960	19277	.7
Kazakhstan	2010–11	15800	54316	2.0
Kenya (Mombasa Informal Settlements)	2009	1016	3216	.1
Kenya (Nyanza Province)	2011	6828	30763	1.1
Lao PDR	2012	18843	98440	3.6
Lebanon (Palestinians)	2011	4747	20983	.8
Madagascar (South)	2012	2968	15556	.6
Mauritania	2011	10116	59993	2.2
Moldova	2012	11354	28852	1.1
Mongolia (Khuvsgul Aimag)	2012	1982	6975	.3
Mongolia	2010	10092	35747	1.3
Montenegro	2013	4052	14691	.5
Nepal (Mid and Far Western Regions)	2010	5899	31753	1.2
Nigeria	2011	29077	150810	5.5
Pakistan (Baluchistan)	2010	11612	88427	3.2
Pakistan (Punjab)	2011	95238	599617	21.9
Saint Lucia	2012	1718	4922	.2
Serbia (Roma Settlements)	2014	1743	9014	.3
Serbia	2014	6191	22194	.8
Sierra Leone	2010	11394	66571	2.4
Somalia (North East Zone)	2011	4777	28604	1.0
Somalia (Somaliland)	2011	4808	30777	1.1
South Sudan	2010	9369	55973	2.0
Sudan	2010	14778	83510	3.0
Suriname	2010	7407	28783	1.1
Swaziland	2010	4834	19843	.7
Togo	2010	6039	30948	1.1
Tunisia	2012	9171	38861	1.4
Ukraine	2012	11321	33761	1.2
Vietnam	2011	11614	44831	1.6
Zimbabwe	2014	15686	65336	2.4
Total		539915	2740855	100.0

using the Statistical Package for the Social Sciences (SPSSv22) software. Separate files recording household level variables related to water access, women's health and child health for each survey were merged by creating unique identity numbers for each case in the spreadsheet, derived from survey, cluster, household and individual line numbers. All surveys were then merged producing a total of 2,740,855 people from 539,915 households included in the final data set (Table 1). All dependent (Appendix A) and independent (Appendix B) variables relevant to this study were checked to ensure that value labels were consistent and transformed if necessary prior to merging surveys and in preparation for analysis.

Health indicators or outcomes included in each survey differed and not all households had members who were relevant cases for each indicator, for example only women of child bearing age were asked about birth history, and only those reporting a live birth can provide data on child deaths. Cases with implausible values or missing data for the dependent or any of the independent variables were omitted from the analyses. The independent variable ‘times received antenatal care’ was highly skewed and so we used a square root transformation. Several new variables were created by combining or transforming the original MICS variables (Appendix A, Table A7).

SPSS data files were uploaded to MLwiN (v3.01) software (Charlton et al., 2017) to conduct multilevel, multivariable regression analyses of the associations between the key independent variables and maternal and child health outcomes. Where the dependent variable was binary we used logistic regression, where count data we used negative binomial regression and where linear we used ordinary linear regression (Appendix B, table B.8). We conducted four-level analyses in which individual survey respondents (level 1) were nested in households (level 2), which were nested in ‘clusters’ (level 3: a number of households randomly selected from within an enumeration area, or segment of an enumeration area of the survey), which were nested in surveys (level 4: country and/or surveyed region within a country). Our research aim was to determine the effect of the four key household level variables on health outcomes, as described above. Maternal and child health varies between countries, geographic areas or ‘clusters’ within countries and households (Black et al., 2008; Dangour et al., 2013; Goudet et al., 2015). It is therefore likely that contextual factors existing at these levels, but not represented by questions included in MIC surveys and therefore variables in the data set, could be associated with the health outcomes of interest. It is also likely that within clusters, respondents are more similar than people from different clusters, due to shared characteristics and contextual factors. Therefore, the four-level analyses allowed for random effects due to unmeasured contextual factors associated with the clusters in which an individual was situated (at household, enumeration cluster and survey level), and correlations within clusters (individuals within clusters are likely to be more similar than those from different clusters), and adjusted for the effects of individual and household level variables included as covariates in the models (factors known or hypothesised to be associated with the outcomes). To check the robustness of the models we ran fixed effects models for each outcome with country as an explanatory variable. We obtained similar results, but with the random effects models having slightly more conservative parameter estimates and a smaller deviance value indicating a better fit of the models (Appendix C). The analyses enabled us to provide an estimate of the independent association of four key modifiable household level variables with the maternal and child health outcomes of interest in this study.

3. Results

Table 1 (and Appendix A, Table A1-6) list the 49 surveys included in this analysis. The results of the seven regression analyses are shown in Tables 2 and 3. Table 2 shows the results of the regression analyses for child mortality, diarrhoea, and WHO WAZ and HAZ scores. Table 3 shows the results of regression analyses for likelihood of giving birth in a health care facility, uptake of antenatal care, and likelihood of leaving a child under five years of age alone for one or more hours, one or more days per week.

Relative risk of child death was greater in households that fetched water (Table 2). In households where women carried the water the relative risk of child death was 1.05 (95% confidence intervals 1.02–1.08). Where men carried the water, the risk was similar (1.04, 95%CI 1.00–1.07). Where children primarily collected water, there was no increased risk of death. Using an unimproved drinking water source was not independently associated with increased risk of child death. Living in a household where members did not usually use a flush toilet was associated with 9–12% greater relative risk of child death than living in a household where members usually used flush toilets. However, there was little obvious difference in mortality rates between those households using non-flush improved sanitation, unimproved sanitation or practicing open defecation. As the percentage of households in a cluster using improved sanitation increased in communities, the association with child deaths declined. Those children born into communities with $>$ 90% improved sanitation usage were 12% less likely to die than those born into communities with $\leq$20% usage (Fig. 1).

An increase in the odds of a child under five years of age being reported to have had diarrhoea in the previous two weeks (10–13%) was associated with children collecting water, but not with adults collecting water, when compared to households in which no one collects water (Table 2). Using unimproved drinking water supply compared to improved drinking water supply was associated with an increase in the odds of diarrhoea by 5%. Use of an improved or unimproved toilet and open defecation in comparison to a flush toilet was also associated with an increase in the odds of diarrhoea, with improved toilets associated with a greater comparative increase (16%) than unimproved toilets (11%) or open defecation (5%). Improved sanitation usage was associated with the odds of childhood diarrhoea reducing by 8%, 13% and 21% in the $>$ 60–80, $>$ 80–90 and $>$ 90% categories of coverage respectively (Fig. 2).

A small decrease in children's WHO WAZ scores, which indicate acute undernutrition, was associated with water carriage performed by women, men or boys when compared to non-water fetching households (Table 2). No association was observed between WAZ scores and use of an improved compared to unimproved water supply. The use of non-flush toilets (improved or unimproved) or open defecation compared to flush toilets, was associated with a decrease in WHO WAZ scores. A gradual increase in WAZ score was associated with each higher level of improved sanitation coverage beyond 60% (Fig. 3).

No association between children's WHO HAZ scores, which indicate childhood stunting, and household water fetching or improved water supply was observed (Table 2). Use of non-flush toilets (improved or unimproved) or open defecation compared to flush toilets was associated with a decrease in HAZ scores, and when more than 80% of people within a cluster used improved sanitation an association with increased HAZ scores was observed (Fig. 4).

Water fetching was associated with reduced odds of a woman giving birth in a health care facility (10–12% reduction), compared to non-water fetching households, with little difference according to the age and gender of the person responsible for collecting water (Table 3). A reduction in uptake of antenatal care was observed in households where a girl or woman usually collected water, however, when men or boys usually collected water, the odds ratio for antenatal care uptake was not significantly different from that of women living in non-water fetching households (Table 3). The odds of a child under five years of age being left alone for an hour or more, on one or more days of the week, was increased in households where a woman or female child was responsible for collecting water, but not in those where a man or boy collects water, when compared to households where no one collects water (Table 3).

4. Discussion

We believe that ours is the first study to utilize data from a large number of MICS, and analyse the relationships between water carriage, use of improved drinking water and sanitation, and maternal and child health. We have been able to control for a range of possible confounding factors and allow for random effects at the household, cluster and survey level. We have found that having to carry water home is independently associated with a range of adverse child and maternal health outcomes. In comparison to households where no one must collect and carry water, adults carrying water is associated with increased risk of child death, children carrying water with increased odds of childhood diarrhoea, and adults or boys carrying water with reduced WHO WAZ scores. Women of water fetching households are less likely to give birth in a health care facility, and women or girls collecting water, is associated with reduced antenatal care up-take and children under five being much more likely to be left alone at home. In addition, we report the largest study to date on the associations between toilet facility usage and percentage of households using improved sanitation within a cluster, with a range of health outcomes. Our findings suggest that health benefits are associated with a high percentage of households within a geographic area using improved sanitation. More than 60% usage is associated with reduced diarrhoea and acute undernutrition, and more than 80% usage is associated with reduction of the more severe outcomes of childhood death and stunting. This evidence supports the view that to be effective, WaSH interventions should aim toward sanitation provision and usage for all, and provision of safe water on premises.

Of note in our study, is that whilst use of unimproved water supply, an indicator of water quality, was not associated with risk of childhood death, the need for an adult to collect water from an off-plot source was independently associated with an increased risk of child death. When adults must fetch water, it is likely that in many households children are left unsupervised for the time it takes to walk to a water source, wait in a queue for water and return. Unsupervised children may be at more risk of death from accidental injury, or simply from reduced parental

Table 2
Risk of childhood death, odds of diarrhoea affecting a child under 5 years of age in the previous 2 weeks, and regression parameters for WHO weight for age and height for age z-scores by socio-economic characteristics, demographic variables, water supply, sanitation type, sanitation usage and water carriage.

Independent Variable	Child death RR (95% CI)	p-value	Diarrhoea OR (95% CI)	p-value	WAZ β (95% CI)	p-value	HAZ β (95% CI)	p-value
Fixed part of model								
Person collecting water								
No one	1.00		1.00		0		0	
Male child (< 15 years)	0.99 (0.94, 1.05)	0.828	1.13 (1.02, 1.25)	0.022	−0.05 (−0.09, −0.01)	0.021	−0.03 (−0.09, 0.02)	0.185
Man (15 + years)	1.04 (1.00, 1.07)	0.051	0.98 (0.92, 1.05)	0.602	−0.03 (−0.05, −0.01)	0.012	−0.02 (−0.05, 0.01)	0.139
Female child (< 15 years)	1.00 (0.95, 1.04)	0.871	1.10 (1.02, 1.20)	0.016	−0.00 (−0.04, 0.03)	0.857	−0.01 (−0.05, 0.03)	0.582
Woman (15 + years)	1.05 (1.02, 1.08)	0.001	1.05 (1.00, 1.10)	0.069	−0.02 (−0.04, −0.00)	0.028	−0.01 (−0.03, 0.01)	0.345
Water supply								
Improved	1.00		1.00		0		0	0.729
Unimproved	1.00 (0.98, 1.03)	0.926	1.05 (1.01, 1.10)	0.014	0.02 (0.00, 0.03)	0.055	0.00 (−0.02, 0.02)	
Toilet facility								
Flush toilet	1.00		1.00		0		0	
Other improved	1.10 (1.07, 1.13)	< 0.001	1.16 (1.10, 1.22)	< 0.001	−0.03 (−0.05, −0.01)	0.003	−0.10 (−0.12, −0.07)	< 0.001
Unimproved	1.12 (1.08, 1.16)	< 0.001	1.11 (1.04, 1.18)	0.002	−0.03 (−0.06, −0.01)	0.021	−0.09 (−0.12, −0.06)	< 0.001
Open defecation	1.09 (1.06, 1.13)	< 0.001	1.05 (0.99, 1.11)	0.147	−0.06 (−0.08, −0.04)	< 0.001	−0.08 (−0.11, −0.05)	< 0.001
Improved sanitation usage [c]								
≤20	1.00		1.00		0		0	
> 20 to 40	1.02 (0.98, 1.06)	0.323	0.96 (0.90, 1.03)	0.281	−0.02 (−0.05, 0.01)	0.186	−0.04 (−0.07, −0.00)	0.032
> 40 to 60	1.01 (0.97, 1.05)	0.776	0.93 (0.86, 1.00)	0.056	−0.01 (−0.04, 0.02)	0.441	−0.02 (−0.05, 0.02)	0.368
> 60 to 80	0.98 (0.93, 1.02)	0.251	0.92 (0.86, 1.00)	0.046	0.04 (0.01, 0.07)	0.007	0.03 (−0.00, 0.07)	0.079
> 80 to 90	0.92 (0.87, 0.97)	0.001	0.87 (0.79, 0.95)	0.002	0.07 (0.03, 0.10)	< 0.001	0.07 (0.03, 0.11)	0.001
> 90	0.88 (0.85, 0.93)	< 0.001	0.79 (0.73, 0.86)	< 0.001	0.08 (0.05, 0.12)	< 0.001	0.07 (0.03, 0.10)	< 0.001
Wealth index								
Poorest	1.00		1.00		0		0	
Second	0.96 (0.94, 0.99)	0.004	0.91 (0.87, 0.95)	< 0.001	0.08 (0.06, 0.10)	< 0.001	0.08 (0.06, 0.10)	< 0.001
Middle	0.89 (0.87, 0.91)	< 0.001	0.82 (0.78, 0.85)	< 0.001	0.16 (0.14, 0.18)	< 0.001	0.16 (0.14, 0.18)	< 0.001
Fourth	0.81 (0.78, 0.84)	< 0.001	0.77 (0.73, 0.81)	< 0.001	0.25 (0.23, 0.27)	< 0.001	0.27 (0.25, 0.30)	< 0.001
Richest	0.66 (0.63, 0.68)	< 0.001	0.62 (0.58, 0.66)	< 0.001	0.44 (0.42, 0.47)	< 0.001	0.49 (0.46, 0.51)	< 0.001
Education of household head								
Primary/none	1.00		1.00		0		0	
Secondary +	0.85 (0.83, 0.86)	< 0.001	0.89 (0.86, 0.92)	< 0.001	0.11 (0.10, 0.12)	< 0.001	0.13 (0.12, 0.15)	< 0.001
Area								
Urban	1.00		1.00		0		0	
Rural	0.99 (0.97, 1.02)	0.663	0.92 (0.88, 0.97)	0.001	0.02 (0.00, 0.04)	0.036	0.01 (−0.01, 0.03)	0.476
Sex of household head								
Male	1.00		1.00		0		0	
Female	0.99 (0.97, 1.01)	0.424	0.99 (0.94, 1.03)	0.495	0.06 (0.04, 0.07)	< 0.001	0.05 (0.04, 0.07)	< 0.001
Sex of child								
Male	n/a		1.00		0		0	
Female	n/a		0.92 (0.90, 0.94)	< 0.001	0.06 (0.05, 0.07)	< 0.001	0.08 (0.07, 0.09)	< 0.001
Age in years [a,b]	1.02 (1.02, 1.02)	< 0.001	0.75 (0.74, 0.76)	< 0.001	−0.08 (−0.08, −0.08)	< 0.001	−0.17 (−0.18, −0.17)	< 0.001
β_0 (S.E.)	−3.08 (0.10)		−1.71 (0.13)		−0.72 (0.09)		−0.72 (0.09)	
Random part of model								
Country level variance (S.E.)	0.34 (0.08)		0.60 (0.14)		0.33 (0.08)		0.25 (0.06)	
Cluster level variance (S.E.)	0.17 (0.01)		0.58 (0.02)		0.10 (0.00)		0.12 (0.00)	
Household level variance (S.E.)	0.28 (0.03)		1.23 (0.03)		0.26 (0.01)		0.27 (0.01)	
Individual level variance (S.E.)	0.78 (0.03)		1.00 (0.00)		0.98 (0.01)		1.47 (0.01)	

Note: Number of women reporting child deaths once individuals with missing data excluded = 299, 084 (86.6% of original MICs data), households = 274 145, clusters = 26519, MIC surveys = 40.
Number of women reporting diarrhoea affecting child under 5 years of age in the previous 2 weeks, once individuals with missing data excluded = 290, 176 (78.8% of original MICs data), households = 190 641, clusters = 27 030, MIC surveys = 43.
Number of WHO WAZ scores once individuals with missing data excluded = 230, 406 (84.8% of original MICs data), households = 154 742, clusters = 24 367, MIC surveys = 36.
Number of WHO HAZ scores once individuals with missing data excluded = 217, 210 (80.2% of original MICs data), households = 148 670, clusters = 24, 262, MIC surveys = 36.
RR, relative risk; OR, odds ratio; β, regression parameter; WHO WAZ, World Health Organisation weight for age z-score; WHO HAZ, World Health Organisation height for age z-score; β_0, Y intercept; S.E. = standard error.
[a] For children dead 'age' = age of mother.
[b] For diarrhoea, HAZ and WAZ 'age' = age of child.
[c] % with improved sanitation within cluster.

care when it is needed, for example during illness or when they are very young. In Ethiopia, Gibson and Mace (2006) found that when women's work of water fetching was substantially reduced because of access to tap stands much closer to home, the monthly risk of child death was 50% lower among children of the women with access to the new taps. They suggested that the increase in child survival was most likely due to increased quantity and improved quality of water available for household use, but also greater opportunities for mothers to care for their young children. If the association observed in our study was due to a larger quantity of water being available in non-water fetching households, it is difficult to explain why adults, but not children collecting water, who would be likely to carry even less water than adults, should be associated with an increase in the child death rate. Whilst the increase in risk is not as large as that associated with being in the higher three wealth quintiles, in countries where the under 5 mortality is high a 5% increase in risk independently associated with a modifiable risk

Table 3
Odds of a woman giving birth in a health care facility, uptake of antenatal care and odds of leaving a child under 5 alone > 1 h on 1 or more days per week by socio-economic characteristics, demographic variables and water carriage.

Independent variable	Birth in a health care facility OR (95% CI)	P value	Times received antenatal care β (95% CI)	P value	Child left alone OR (95% CI)	P value
Fixed part of model						
Person collecting water						
No one collects water	1.00		0		1.00	
Male child (< 15)	0.88 (0.79, 0.99)	0.032	−0.02 (−0.07, 0.02)	0.285	0.99 (0.91, 1.08)	0.878
Adult man (15 + years)	0.90 (0.84, 0.96)	0.001	−0.01 (−0.04, 0.01)	0.29	0.98 (0.93, 1.05)	0.605
Female child (< 15)	0.89 (0.82, 0.98)	0.015	−0.06 (−0.09, −0.03)	< 0.001	1.16 (1.08, 1.25)	< 0.001
Adult woman (15 + years)	0.89 (0.84, 0.93)	< 0.001	−0.04 (−0.05, −0.02)	< 0.001	1.07 (1.02, 1.13)	0.003
Wealth index						
Poorest	1.00		0		1.00	
Second	1.33 (1.27, 1.40)	< 0.001	0.06 (0.05, 0.08)	< 0.001	1.02 (0.97, 1.06)	0.459
Middle	1.76 (1.67, 1.85)	< 0.001	0.12 (0.10, 0.13)	< 0.001	1.02 (0.97, 1.07)	0.496
Fourth	2.34 (2.21, 2.48)	< 0.001	0.15 (0.14, 0.17)	< 0.001	0.99 (0.93, 1.04)	0.58
Richest	3.74 (3.47, 4.03)	< 0.001	0.25 (0.23, 0.27)	< 0.001	0.90 (0.85, 0.97)	0.003
Education of household head						
Primary/none	1.00		0		1.00	
Secondary +	1.22 (1.18, 1.27)	< 0.001	0.05 (0.04, 0.06)	< 0.001	0.99 (0.95, 1.02)	0.427
Area						
Urban	1.00		0		1.00	
Rural	0.84 (0.80, 0.87)	< 0.001	−0.05 (−0.07, −0.04)	< 0.001	1.08 (1.02, 1.14)	0.01
Sex of household head						
Male	1.00		0		1.00	
Female	1.15 (1.10, 1.21)	< 0.001	0.02 (0.00, 0.03)	0.012	1.02 (0.98, 1.07)	0.298
Age in years[a]	0.99 (0.99, 1.00)	< 0.001	0.001 (0.00, 0.002)	0.004	1.44 (1.42, 1.45)	< 0.001
β_0 (S.E.)	1.61 (0.43)		2.33 (0.08)		−4.12 (0.26)	
Random part of model						
Country level variance (S.E.)	7.22 (1.63)		0.25 (0.06)		2.78 (0.62)	
Cluster level variance (S.E.)	0.26 (0.01)		0.07 (0.00)		0.87 (0.02)	
Household level variance (S.E.)	0.00 (0.00)		0.06 (0.01)		0.30 (0.02)	
Individual level variance (S.E.)	1.00 (0.00)		0.19 (0.01)		1.00 (0.00)	

Note: Number of women reporting place of birth 100, 505 (85.4% of original MICs data), households = 95 890, clusters = 22 784, MIC surveys = 44.
Number of women reporting times received antenatal care 52, 696 (80.0%), households = 50 689, clusters = 14 904, MIC surveys = 40.
Number of women reporting whether a child under 5 years of age is left alone for an hour or more, on 1 or more days per week = 228, 307 (84.9%), households = 154 705, clusters = 21 617, MIC surveys = 43.
OR, odds ratio; β, regression parameter; β_0, Y intercept; S.E., standard error.
[a] For birth in health care facility and uptake of antenatal care, 'age' = age of woman, for child left alone, 'age' = age of child.

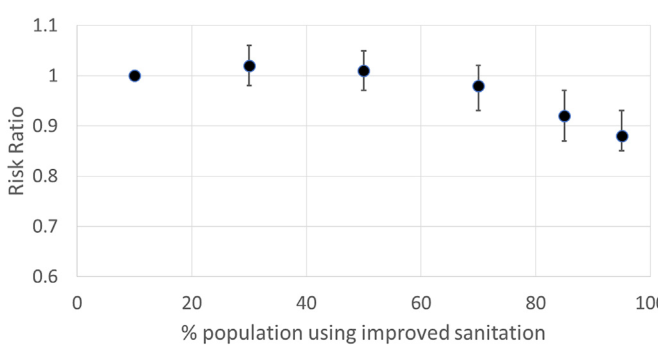

Fig. 1. Relative risk of child mortality by percentage of population using improved sanitation (reference category ≤20% using improved sanitation) Model: negative binomial regression. Covariates: wealth index, education of household head, urban/rural area, sex of household head, age of mother, improved/unimproved water supply, toilet facility, coverage (%) improved sanitation usage, and person collecting water.

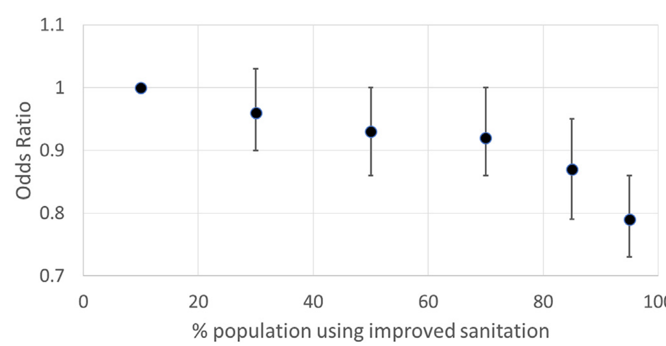

Fig. 2. Odds ratio for childhood diarrhoea by percentage of population using improved sanitation (reference category ≤20% using improved sanitation) Model: logistic regression. Covariates: wealth index, education of household head, urban/rural area, sex of household head, sex of child, age of child, improved/unimproved water supply, toilet facility, coverage (%) improved sanitation usage, and person collecting water.

factor is potentially important. For example our data set includes two surveys from Somalia conducted in 2011, when the under 5 mortality rate for the whole country was reported to be 153.5 deaths/1000 live births or 15.4% (UNICEF, 2019).

Compared to flush toilets, the use of any other type of toilet or open defecation was associated with increased risk of child death. Non-flush toilets of any type had higher relative risk than open defecation, indicating that they may have no benefit or create even greater risk of harm to young children than open defecation. This could occur if toilets are unhygienic, structurally unsafe for a small child to use, or situated in locations which are unsafe for children under five to access (Govender, 2014). Inequitable sanitation access within geographic areas, even where only 20% of households use unimproved sanitation or open defecation, was not significantly associated with a reduction in the risk of child death. This indicates that even a small percentage of households using unimproved sanitation may lead to increased disease transmission through person to person contact or environmental contamination.

The increased odds (10–13%) of children under five having

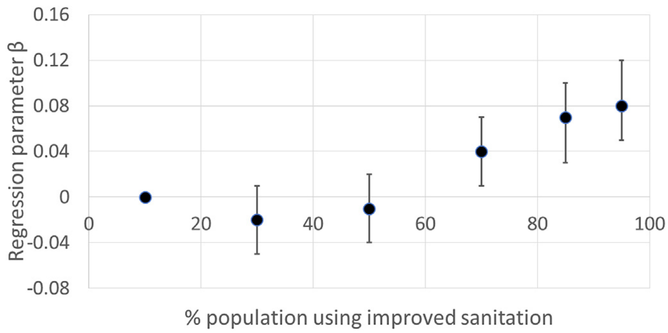

Fig. 3. WHO weight for age z-score by percentage of population using improved sanitation (reference category ≤20% using improved sanitation) Model: linear regression. Covariates: wealth index, education of household head, urban/rural area, sex of household head, sex of child, age of child, improved/unimproved water supply, toilet facility, coverage (%) improved sanitation usage, and person collecting water.

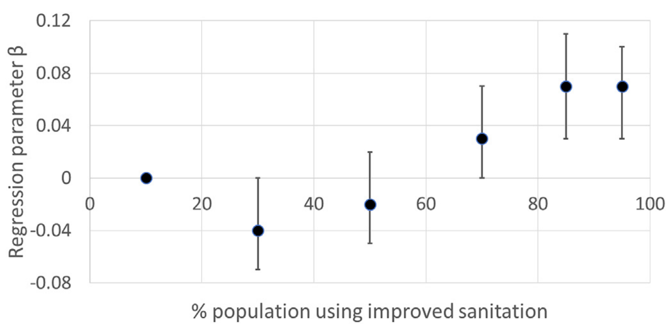

Fig. 4. WHO Height for age z-score by percentage of population using improved sanitation (reference category ≤20% using improved sanitation) Model: linear binomial regression. Covariates: wealth index, education of household head, urban/rural area, sex of household head, sex of child, age of child, improved/unimproved water supply, toilet facility, coverage (%) improved sanitation usage, and person collecting water.

diarrhoea in households where children fetch water compared to households that do not, could simply reflect differing water quality from different source types as reported by Esrey (1996), and that children fetching water away from their home are more likely to be using an unimproved source, and therefore at more risk of diarrheal disease through consumption of contaminated drinking water. However, our analysis adjusted for the 5% increase in diarrhoeal risk from using an unimproved water supply. Furthermore, if use of an unimproved water source were the only reason for the observed association, one would not expect to see significant increases in diarrhoeal disease when children but not when adults collect water, after adjusting for differences in household toilet facilities and sanitation usage. It is known that water quality can deteriorate after collection from a shared source and during storage (Diouf et al., 2014; Jagals et al., 2003) and it's possible that children may be less likely or able to maintain hygienic practices, such as handwashing or cleaning containers adequately prior to refilling them. They may also be more likely to play in or drink untreated water at the source point than adults, and therefore more vulnerable to water borne disease.

Our results showed borderline significance of an association between a woman fetching water and increased risk of diarhhoea (RR 1.05, p = 0.067), whilst men showed no significant association with any increased risk of diarhhoea (0.98, p = 0.602) compared to non-water fetching households. It is possible that by fetching water, adults, and particularly men, may bring larger quantities of water to the house, either because they are simply stronger (Marras et al. 2002, 2003; Stemper et al., 2008) and therefore able to carry more water, or because they are more likely to use equipment or vehicles to collect more water (Geere, 2015). Men are also more likely to collect water when it is located closer to home, and women when it is located further away, such that men may collect larger quantities of water due to proximity of the supply point (WHO and UNICEF, 2017a). A larger quantity of water may enable all household members to improve cleanliness and hygiene practices such as handwashing to reduce the incidence of diarrhoea (Esrey et al., 1989; Hunter et al., 2010). By fetching water, an adult man or woman may also enable other family members, particularly other women but also children, to have more time and energy to engage in household management and chores, including hygiene practices related to washing, cooking and cleaning (Domenech et al., 2012; Rao et al., 2007; Zolnikov and Blodgett Salafia, 2016).

The association of an increased risk of diarrhoea with use of both improved and unimproved toilets, but not with open defecation, when compared to use of flush toilets is surprising. However, 'improved' toilets may not be used by all household members and may not remain functional over time (Clasen et al., 2014), and for these or other reasons may not be effective in preventing faecal contamination of water supplies or the environment (Patil et al., 2014). For example, the difficulties of cleaning, maintaining and emptying 'improved' toilets in which faecal matter is essentially stored near to homes, but not flushed away by water, might mean that it is hard to prevent disease transmission from person to person contact or environmental contamination. Certainly, many latrines, even improved latrines, are not maintained in a hygienic state with faecal smearing especially around the pit (Nakagiri et al., 2015; Simiyu et al., 2017; Sonego and Mosler, 2014). It is highly likely that such filthy latrines add to the risk of enteric pathogens.

Our findings that more than 60% coverage of households using improved sanitation in associated with a significant reduction of childhood diarrhoeal disease, might explain the lack of effectiveness of sanitation programmes reported in the literature. For example Clasen et al. (2014) found that a rural sanitation programme in India, which resulted in a mean 63% of households in the intervention villages having a latrine, had only 11 of 50 intervention villages with ≥50% functional latrine coverage at follow up. The programme was not effective in reducing exposure to faecal contamination or childhood diarrhoea and the authors felt that insufficient coverage and use of latrines were the most plausible explanations for their findings. Their findings are similar to those reported by others in India where there was no difference in household or source levels of *E. coli* contamination between intervention and control groups, and only 41% improved sanitation coverage was achieved in the intervention group (Patil et al., 2014). In Kenya, Null et al. (2018) also found no effect of interventions including improved sanitation on childhood diarhhoea. Whilst adherence to interventions which included improved sanitation was high in their study (78–82% of households), only 33–37% of the same households safely disposed of children's faeces. However, Luby et al. (2018) found that children receiving sanitation, handwashing, nutrition, and combined interventions (but not drinking water chlorination) had less reported diarrhoea. In their study adherence indicated by a functional latrine was very high (96–97%). Further support for this observation that community improved sanitation coverage and usage is more important than individual toilet ownership comes from a recent meta-regression analysis conducted by the World Health Organization (Wolf et al., 2018). This reported larger reductions in diarrhoea in those studies that achieved very high to 100% coverage. Another recent study from Mali also provides strong evidence for this observation (Harris et al., 2017).

Energy expenditure due to the work of water fetching may be important for nursing mothers, and if it affects breast feeding behaviour, might influence childhood nutrition and therefore children's weight for age (WAZ) or height for age (HAZ) scores (Goudet et al., 2015; Keino et al., 2014). WAZ and HAZ scores indicate acute undernutrition and chronic undernutrition or 'stunting' respectively (Dangour et al., 2013). Despite this potential effect, we found a significant but only small reduction in mean WAZ score in water fetching households associated with adults or boys collecting water, and did not find any association of water fetching with HAZ scores. In contrast to our findings of little to no effect, Gibson and Mace (2006) found that in an area of rural Ethiopia, children under 5 of women with access to water points which reduced the distance and time to fetch water, had significantly increased risk of being malnourished and stunted compared to children of women fetching water in the same area prior to the installation of labour saving taps. They proposed that reduced energy expenditure on water collection supported an observed increase in birth rate (OR 3.78, $p = 0.009$), which as a consequence, meant that smaller, low birth-weight babies were coming to full term and surviving early childhood. Inconsistent findings between studies such as ours and that reported by Gibson and Mace, might be due to contextual factors mediating the effects of water carriage on maternal health and therefore childhood growth.

Others have reported the energy costs of fetching water as moderate to high (Rao et al., 2007) and highlighted that the energy expenditure required for water fetching may become important in ‘food-scarce’ environments (Domenech et al., 2012). Several other studies also reported fatigue and tiredness affecting water carriers (JA Geere et al., 2010; JL Geere et al., 2010; Hemson, 2007; Porter et al., 2012; Zolnikov and Blodgett Salafia, 2016), and one study (Evans et al., 2013) reported that people who carried water had significantly less (40 min) ‘inactivity’ time (defined as sleep, resting or watching television) than those who did not carry water. Therefore, whilst findings from a range of studies indicate that the energy expenditure of water fetching may impact detrimentally on pregnant women and mothers, and that reducing the work of water carriage is likely to benefit them, other factors related to maternal or child nutritional intake (Luby et al., 2018; Stewart et al., 2018) and availability of family planning services (Dangour et al., 2013) may determine whether any impact on perinatal or maternal health leads to further impacts on under five weight for age and stunting. We were not able to include any indicators of food intake, nutritional status, feeding programs, birth rates or illness affecting mothers in the analyses, and therefore cannot exclude other possible confounding factors which may have influenced our results.

Dangour et al. (2013) conducted a meta-analysis including 4627 children and found no evidence of an effect of WaSH interventions on WAZ score (mean difference 0.05; 95% CI -0.01 to 0.12) and a borderline statistically significant but small effect of WaSH interventions on HAZ score (mean difference 0.08; 95% CI 0.00 to 0.16). The recent study by Clasen et al. (2014) focusing on a sanitation intervention in India found evidence for small increases in WAZ scores in villages with coverage of ≥50% and households with functional latrines, but no effect on HAZ scores. Our findings that any type of sanitation other than a flush toilet was associated with reduced WAZ and HAZ scores, together with the association of > 60% improved sanitation usage to achieve increased WAZ sores and > 80% usage to achieve increased HAZ scores, support Clasen et al.,’s (2014) recommendations to aim for full latrine coverage and use, and to end open defecation. However, in studies conducted in Kenya (Null et al., 2018), Bangladesh (Luby et al., 2018) and India (Patil et al., 2014), WaSH interventions alone did not improve child growth, and did not add to the improvements observed with nutrition interventions. In our analysis of observational surveys, the effects of water fetching, water supply and sanitation usage were small in comparison to the effects of wealth, which may enable families to secure enough food to optimize maternal and child nutrition. Overall this suggests that sufficient nutrition is of key importance (Black et al., 2008), which may explain why WaSH interventions alone are insufficient to achieve meaningful improvements in childhood growth.

We found that being from a water fetching household was associated with a reduction in the likelihood of a woman giving birth in a health care facility, but with little difference according to who was responsible for collecting water in the household. Ono et al.’s (2013) findings in Western Kenya indicate that decisions about giving birth at home or in a health care facility are complex, may differ according to which family member provides support with water fetching, and is significantly influenced by other factors in addition to social support. These are similar to our findings that wealth, higher education level of the household head, rural location and sex of the household head had the largest odds ratios associated with place of birth. However, our study provides evidence that as a modifiable risk factor, providing water on premises may independently increase the odds of women giving birth in health care facilities, which may be particularly important for women from lower socio-economic groups living in rural areas.

We found that uptake of antenatal care is likely to be lower for women from water fetching households, when a woman or girl is responsible for collecting water. This supports the findings of McCray (2004) who conducted a cross sectional survey of mothers of a child aged 12–23 months, from 327 randomly selected households in Kwazulu Natal, South Africa. They found that if a woman reported fetching water to be a daily activity affected by making a trip to the clinic, she was twice as likely to utilize prenatal care services at a low level, than an average level. Their conclusion was that making water more easily accessible would facilitate access to health care facilities for antenatal care (McCray, 2004). The added perspective from our research, is that where the location of a water source is not likely to change during a woman's pregnancy, help from her husband or sons to fetch water might enable her to receive antenatal care more times, because there was no decrease in uptake of antenatal care when men or boys collect water, compared to up-take of antenatal care in non-water fetching households. This suggests that by fetching water for household use, men and boys can make an important contribution to their family's health, as increased utilisation of antenatal care has been shown to be associated with better maternal and child health outcomes (Lincetto et al., 2006).

The association of an increased odds that a child under five is left alone for more than 1 h, for one or more days per week when women or girls collect water, highlights the challenges of providing child care and supervision when water is not accessed on premises. Qualitative research has highlighted the ‘Hobson's choice’ that carers face when they must obtain water from off-plot sources, and then choose to either leave their child alone, or take (often carrying) the child with them along what may be an unsafe route (JA Geere et al., 2010; Schatz and Gilbert, 2014; Wrisdale et al., 2017). The lack of change in the odds that a child is left alone when a man or boy collects water may indicate that the woman in the household is relieved of a task which would require her to leave children alone, and that she utilises the additional time to engage in household tasks that allow her to be with her children. When a woman collects water, it is possible that in some households, there may not be another adult at home and available to supervise children. It is also possible that even when living at home, men will prioritise time for income generating or other activities which take place away from home over child minding, and assume that a woman will manage to combine child minding with water fetching.

4.1. Limitations

MIC surveys are cross-sectional studies, which therefore prevent us from being able to confirm causal relationships between variables. The use of completed MICs questionnaires also limits the extent to which we were able to control for bias or confounding in our analyses. The variable ‘person collecting water’ is indicated by mutually exclusive response categories for the question ‘who usually goes to this source to collect the water for your household?’ A response option is not available to indicate that multiple people collect water. Therefore data from households where water carriage is performed by multiple people, for example as work shared by women and children, might introduce bias and have a mediating or confounding effect on the association between the person usually carrying water and the outcomes observed in this study. However, this is likely to reduce the strength of association observed and so our findings may underestimate the association. Time spent finding a place for open defecation (WSP, 2018) might have been a confounding factor affecting the relationship between water fetching and place of birth, up-take of antenatal care, and leaving a child alone. However, inadequate sanitation has been estimated to have much greater economic impacts through direct health costs such as premature death, diarhhoea and stunting than through time costs (WSP, 2018), and it is likely that fetching water for the household is much more time consuming than finding a place to defecate. Several of the outcome variables rely on self-reported information which may introduce reporting bias, however, outcomes such as number of children who have died are likely to be well remembered by respondents, with little gain to be had from intentional misreporting. Considering these limitations, the associations we observed remain plausible, unlikely to have occurred by chance, are strong in some analyses and consistent with the results of other studies, with some evidence of a 'dose-response' relationship for sanitation coverage (Bonita et al., 2006). Therefore, whilst our study cannot demonstrate causal relationships because the data lacks a clear temporal relationship with exposure preceding outcome, and the possibility of bias and confounding cannot be eliminated, it does contribute to the body of evidence supporting causal relationships between the predictor and outcome variables we analysed (Bonita et al., 2006). Further longitudinal cohort studies are required to allow firmer judgements on causation to be made.

The data set included a large number of studies from different countries, which were not conducted at the same time. However, the studies were all conducted within a five year timespan (2009–2014), and utilizing data from all 49 MICS of 41 countries which were available in April 2015 maximizes the generalizability of our results, and the relevance of our findings to global health. The surveys were not designed to specifically test the hypotheses which we have tested, however MICS and DHS data sets from multiple countries conducted at different times have been used to generate descriptive statistics (Graham et al., 2016; Hopewell and Graham, 2014; Sorenson et al., 2011) and to analyse associations between improved water supplies and sanitation usage and incidence of childhood diarrhoea, height and weight (Esrey, 1996). Utilizing a large set of surveys from different countries may increase the risk of variation in study design across surveys, however MICS are conducted after training enumerators to use standardized data collection tools and methods, and with population sampling which is either nationally representative, or representative of a target group or region within a country (UNICEF, 2017). The variables used for analysis in this study were checked and transformed if necessary to ensure that they had identical response options and value labels before data sets were merged for analyses.

5. Conclusion

Data from 49 surveys in 41 countries indicate that the work of fetching water when it is not located in the home or yard is associated with poorer maternal and child health outcomes. Our study is the first to report associations between maternal and child health and the age and gender of the person responsible for collecting water. Water fetching by any household member is associated with reduced odds of a woman giving birth in a health care facility. Adults collecting water is associated with increased risk of childhood death, children collecting water with increased risk of diarrheal disease and women or girls collecting water, with reduced uptake of antenatal care and increased odds of leaving a child under five alone for an hour or more, one or more days per week. We have found that sanitation usage must reach high levels to be associated with a reduction of childhood death and diarrhoea. Our results demonstrate that water access on premises, and high levels of improved sanitation usage, are associated with improvements in maternal and child health and safety.

Acknowledgements and declaration of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2019.08.007.

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