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The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986–2007

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Background Despite continued national and international efforts, access to improved water and sanitation remains limited in many developing countries. The health consequences of lacking access to water and sanitation are severe, and particularly important for child development.

Methods To investigate the associations between child health and access to water and sanitation, we merged all available Demographic and Health Surveys (DHS) with complete birth histories and water and sanitation information. The merged data set of 171 surveys includes information on 1.1 million children under the age of 5 years in 70 low- and middle-income countries over the period 1986–2007. We used logistic models to estimate the effect of water and sanitation access on infant and child mortality, diarrhoea and stunting.

Results Access to improved sanitation was associated with lower mortality (OR = 0.77, 95% CI 0.68–0.86), a lower risk of child diarorhea (OR = 0.87, 95% CI 0.85–0.90) and a lower risk of mild or severe stunting (OR = 0.73, 95% CI 0.71–0.75). Access to improved water was associated with a lower risk of diarrhoea (OR = 0.91, 95% CI 0.88–0.94) and a lower risk of mild or severe stunting (OR = 0.92, 95% CI 0.89–0.94), but did not show any association with non-infant child mortality (OR = 0.97, 95% CI 0.88–1.04).

Conclusions Although our point estimates indicate somewhat smaller protective effects than some of the estimates reported in the existing literature, the results presented in this article strongly underline the large health consequences of lacking access to water and sanitation for children aged <5 years in low- and middle-income countries.

Keywords Water, sanitation, child mortality, diarrhoea, stunting

Introduction

Millennium Development Goal (MDG) 4 calls for a reduction of the Under-5 Mortality Rate by two-thirds between 1990 and 2015. A recent review by Rajaratnam *et al.*[1] suggests that whereas a number of developing countries are on track to achieve MDG-4, many nations, particularly in sub-Saharan Africa, are unlikely to reach the target. Diarrhoea is the second most important cause of under-5 deaths, accounting for an estimated 15% (1.3 million) of such deaths in 2008.[2] The WHO attributed the majority of diarrhoea deaths to unimproved water supply or unimproved sanitation.[3]

Improving water supply and sanitation could thus potentially go a long way towards achieving MDG-4 in many countries. In addition, MDG-7, ensuring environmental sustainability, sets a target specifically related to water and sanitation, aiming for a 50% reduction in the proportion of people without access to safe drinking water and basic sanitation between 1990 and 2015. A mid-period review indicates generally solid progress towards the target for safe drinking water with the notable exception of sub-Saharan Africa; the overall progress made towards adequate sanitation is much weaker.[4] Whereas 83% of the world's population is estimated to have access to improved water supply, only 59% of the population has access to adequate sanitation.[3]

Despite the fact that water and sanitation are seen as central to policies to reduce child mortality (a *Lancet* editorial in 2007 described adequate sanitation as 'the most effective public health intervention the international community has at its disposal'), there have been few comparable studies attempting a more comprehensive analysis of the health benefits of improving drinking water and sanitation in developing countries. A meta-analysis of the impact on diarrhoea morbidity of water supply, water quality and sanitation improvements found only six usable studies of effects of water supply, 15 of water quality, two of sanitation and five of combinations;[5] findings of the meta-analysis were that improved water supply reduced diarrhoea morbidity risk (not explicitly defined in some studies) by 25%, improved water quality by 31%, improved sanitation by 32% and combination interventions by 33%. We have been unable to find comparable meta-studies of the mortality impact of water and sanitation improvement, even though several historical studies suggest that improvements in water and sanitation were instrumental in the declines in infant and child mortality in the 19th and early 20th centuries.[6–11]

Methods

We use data from a set of broadly comparable nationally representative household surveys carried out in 70 developing countries since 1986 to produce a systematic evaluation of the relation between household access to adequate water and sanitation and child health. Although the cross-sectional nature of the data used complicates matters when it comes to the (causal) interpretation of the estimated effects, the main advantage of the approach chosen in this paper lies in its geographical and temporal scope: rather than measuring the short-term and *local* effects of water and sanitation programmes in the geographically focused and closely controlled environments typically studied (see Fewtrell *et al*.[5] for an overview), we explore household-level variation in a wide array of institutional, geographical and socioeconomic settings to quantify the average child health improvements associated with changes in water and sanitation access in developing countries. In addition to their broad coverage, the main advantage of working with data from the DHS is that they allow us not only to analyse child diarrhoea as the most commonly used measure of child health related to water and sanitation, but also to look at child mortality and stunting as two alternative child health indicators. Whereas the relevance of child mortality appears obvious, it seems plausible that continued exposure to diarroheal diseases will also manifest itself in a child's physical development. Conditional on the same housing, family and nutrition conditions, we expect children lacking access to adequate water and sanitation to suffer more frequently from bouts of diarrhoea as well as other water and sanitation-related diseases, and, as a consequence, to develop more slowly relative to their age cohort. Accordingly, we interpret the height-for-age measure used in our analysis as an indicator for the child's cumulative exposure to health hazards, and use it to identify the medium- to long-term effects of lacking access to water and sanitation on child development.

The data analysed in this article are from the Demographic and Health Surveys (DHS), which are nationally representative household surveys largely financed by the United States Agency for International Development and implemented by Macro International in collaboration with national statistical agencies (see http://www.measuredhs.com/ for further information). In all, a total of 173 standard DHS surveys were conducted in 71 low- and middle-income countries between 1986 and 2007, with a rather comprehensive geographical coverage as illustrated in Figure 1. Two surveys, Ecuador 1987 and Cambodia 2005, were dropped from our analysis due to lack of information on access to water, leaving a sample of 1.1 million children in 171 surveys across 70 countries.

For our purposes, the key pieces of information collected by the DHS surveys are the full birth history for every woman in the sample (whereas, in general, DHS use nationally representative sampling for all women aged 15–49 years, some countries, such as Bangladesh, restrict the sampling frame to ever-married women), information about the health of each child and information from the household questionnaire, which contains data on the household's access to water and sanitation, as well as on a large set of potentially confounding household characteristics. The DHS survey questionnaire asks household respondents about the 'main source' of drinking water as well as the toilet facility members of the households 'usually use'. Members of the households may thus have access to other water sources or types of sanitation which we cannot observe in the survey data.

The birth history files provide information on child mortality; each woman is asked for the date of birth

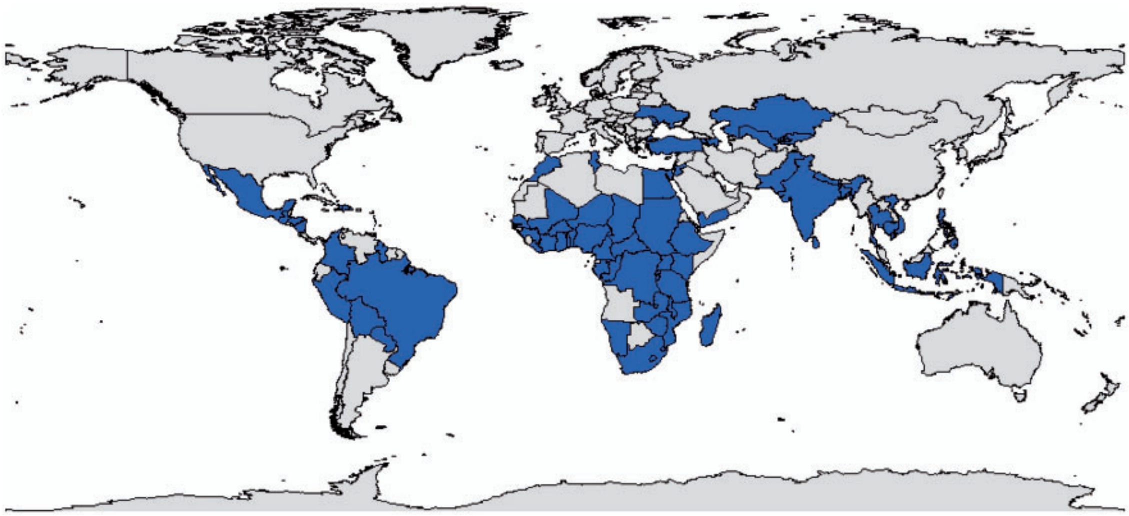

Figure 1 Seventy countries that conducted at least one Demographic and Health Survey for which data on household access to water and sanitation are available

(month and year) of each live-born child, the child's sex, whether the child is still alive and (if the child has died) the age at death (in days if in the first month, in months if between months 1 and 24, and in years thereafter). These data make it possible to locate child deaths both in time and by age. In addition to the analysis of the relationship between water and sanitation and child mortality, we also examine two measures of morbidity among children under the age of 5 years collected as part of the DHS: whether the child had diarrhoea in the 2 weeks preceding the survey, and growth retardation (stunting). A child is stunted if its height is $\geqslant$2SDs below the international standard height tables for a child of that age; our stunted category thus includes both mildly and severely stunted children (following a change in the WHO guidelines, the growth standards used in the DHS were changed in 2005; the resulting changes in the stunting categorization are small).

Our main explanatory variables of interest are access to drinking water and sanitation. Most socioeconomic variables in the DHS are standardized in the recode files prior to the public data dissemination. This is, however, not true for the water and sanitation variables, where different categories are used not only across countries, but also across surveys for the same country. In the merged data set, there are 422 different categories for toilet facility, and 556 different categories for the household's source of drinking water. To guarantee comparability of the water and sanitation variables across countries and time, we have constructed categorical variables, dividing both water source and toilet facility access into broad classes of presumed 'quality' (the DHS surveys do not contain detailed information about water and sanitation quality; it should generally be true, however, that better water and sanitation technology is associated with improved water and hygiene conditions). Since we want to differentiate explicitly between types or qualities of water and sanitation infrastructure, we follow a coding similar to the sanitation ladder proposed by the WHO/UNICEF Joint Monitoring Program (JMP), which is slightly more complex than the dichotomous improved vs unimproved water and sanitation definition originally suggested by the WHO.

Water source quality was coded as poor if the primary source of water was surface water such as rivers, lakes or standing rainwater. The water source was coded as of intermediate quality if the primary source was below the surface, such as all springs, boreholes, standpipes, wells and dug wells but not part of a public piped system. Lastly, water source quality was coded as high if the household reported direct access to piped water or bought drinking water from vendors. Even though it is clearly possible that in some cases water from intermediate quality sources may be less contaminated than water from public piped systems or vendors (especially in the case of deep boreholes), the main presumption of the chosen categorization is that better technology leads, on average, to higher quality water.

Following the same logic, we divided toilet facilities into three broad categories of different presumed 'quality': poor if the household reported no access to any toilet facilities; intermediate if the household reported access to a basic or improved latrine; and high if the household had access to a flush toilet. A full list of the categories and classifications is available as a web appendix.

In addition to these key variables, we have included several control variables: the sex and age of the child, whether the child was the result of a multiple birth, the education of the mother and her partner, usual type of place of residence, the number of household residents over the age of 5 years, household ownership of specified assets, and whether the mother has a health card for the child (for the child health outcomes only). DHS surveys collect information on a long list of household assets, the composition of which varies substantially across time and country; we selected ownership of three assets, radio, television and bicycle, which were the ones most consistently used. The inclusion of a longer list of assets would have substantially reduced sample size without adding much to the explanatory power of the models.

We run logistic regressions using the Stata© 10 software package with five different child health measures as dependent variables: neonatal mortality (the probability of dying in the first month of life), post-neonatal mortality (the probability of dying between the 1st and 13th month of life, conditional on surviving to 1 month), the probability of dying between the ages of 13 months and 5 years, conditional on surviving to the age of 1 year, the probability of having diarrhoea in the 2 weeks before the survey, and the probability of being stunted. It should be noted that whereas the stunting and diarrhoea (as reported by the mother) variables and many of the control variables reflect information at the time of the interview, the child mortality variables reflect mortality over the 5-year period preceding the survey covered in the child recode file. All the regressions control for child characteristics (sex, whether one of a multiple birth and age for the analyses of mortality between the ages of 1 and 5 years, diarrhoea and stunting).

Since access to water and sanitation is clearly not randomly assigned to households covered in nationally representative household surveys such as the DHS, simple correlations between water and sanitation access and health outcomes are likely to overstate the causal effect of the former on the latter. It seems reasonable to expect that wealthier households, households with more health knowledge and households with stronger health preferences are more likely not only to invest privately in water and sanitation, but also to make an effort to use publicly provided infrastructure. To reduce the selection or omitted variable bias generated by the correlation between water and sanitation access and these factors to a minimum, we run regressions with controls for parental educational attainment (separate intercepts for primary, secondary and tertiary education), urban residence, household size in terms of numbers of household members aged ⩾5 years, and household ownership of durable goods as a proxy of the household's long-term income.[12] In an attempt to also control for parental health knowledge and preoccupation with child health we also include an indicator variable for whether the mother has a health card for the child in the child health regressions (stunting and diarrhoea regressions only since health card information is not available for deceased children).

Last, we include survey-fixed effects to control for unobserved country and time-period characteristics specific to a particular survey, which means that we can also exclude country-level differences in income and health as well as infrastructure policies as potential confounders.

The generic logistic model we estimate is given by

$$\ln\left(\frac{p_{ijk}}{1-p_{ijk}}\right) = \beta_0 + \beta_1 Wat_j + \beta_2 San_j + \chi C_{ijk} + \delta_j H_j + \kappa S_k + \varepsilon_{ijk}$$

where p_{ijk} is a dichotomous outcome for child i in household j in DHS survey k, Wat_j is the type of water access of household j, San_j is the toilet facility of household j, C_{ijk} is a vector of child characteristics, H_j is a vector of household physical and human capital variables and S_k is a survey dummy. Standard errors are adjusted for the complex survey design used in the DHS by clustering the standard errors at the survey cluster level.

Results

Table 1 shows descriptive statistics across the entire pooled data set. Information about basic child characteristics as well as water and sanitation is available for 1 113 517 children under the age of 5 years. Twelve per cent of children in the sample live in households with surface water as the primary drinking water source, whereas 45% have access to a spring or well and 43% live in households with a high quality water source. The lack of access to intermediate and high-quality sanitation is even more pronounced: 34% of children in our sample have no access to any toilet facility at all, whereas 43% have access to some intermediate quality and only 23% have access to high quality sanitation.

With regard to the health outcomes, approximately 30 out of 1000 children die in the 1st month of life, and about the same percentage in the subsequent 12 months; a fewer 10 per 1000 die between the ages of 13 and 59 months. It should be noted that the probability of death of children between 13 and 59 months of age does not correspond to the standard mortality measure (${}_{47}q_{13}$), since we include all children under the age of five years independent of their age at the point of the survey as long as they survive the 1st year of their life. Accordingly, the age fixed effects in our empirical specifications represent both changes in mortality over time and differential mortality risk exposure durations across cohorts. As explained in further detail in the notes to Table 1, information on child diarrhoea and height was only collected in 80% and 60% of the surveys, respectively. Mothers reported a diarrhoeal episode in the 2 weeks prior to the survey interview for 17% of children with available diarrhoea information. With regard to growth retardation, a staggering 33% of all children

Table 1 Descriptive characteristics [mean (SD) or *n* (Proportion)] by subsample

Characteristics	Full sample ($n = 1\,198\,558$)	Complete household information ($n = 887\,400$)	Child health and household information ($n = 567\,011$)
Water and sanitation, *n* (%)			
Intermediate quality water source	511 779 (0.45)	432 891 (0.49)	258 607 (0.46)
High quality water source	485 033 (0.43)	350 302 (0.39)	242 958 (0.43)
Intermediate quality sanitation	489 889 (0.43)	382 343 (0.43)	239 420 (0.42)
High quality sanitation	260 226 (0.23)	177 314 (0.20)	124 840 (0.22)
Child characteristics, *n* (%)			
Child is female	587 708 (0.49)	435 290 (0.49)	279 266 (0.49)
Child is multiple birth	30 332 (0.03)	22 950 (0.03)	12 137 (0.02)
Child age <1 year	261 917 (0.22)	193 268 (0.22)	127 436 (0.22)
Child age ⩾1 year, < 2 years	255 362 (0.21)	190 533 (0.21)	126 644 (0.22)
Child age ⩾2 years, < 3 years	252 705 (0.21)	190 229 (0.21)	121 264 (0.21)
Child age ⩾3 years, <4 years	223 465 (0.19)	164 809 (0.19)	101 198 (0.18)
Child age ⩾4 years, <5 years	205 109 (0.17)	148 601 (0.17)	90 469 (0.16)
Child health, *n* (%)			
Neonatal mortality	37 724 (0.03)	28 565 (0.03)	
Mortality 1–12 months	39 733 (0.03)	30 009 (0.03)	
Mortality 13–59 months	15 386 (0.01)	12 094 (0.01)	
Diarrhoea	177 152 (0.17)	129 246 (0.16)	95 760 (0.17)
Stunted	238 101 (0.33)	196 630 (0.35)	196 159 (0.35)
Parental education, *n* (%)			
Mother no education	456 304 (0.38)	366 253 (0.41)	234 947 (0.41)
Mother primary education	416 716 (0.35)	292 147 (0.33)	183 987 (0.32)
Mother secondary education	269 597 (0.22)	190 786 (0.21)	123 407 (0.22)
Mother tertiary education	55 695 (0.05)	38 254 (0.04)	24 670 (0.04)
Partner no education	322 389 (0.29)	273 515 (0.31)	171 956 (0.30)
Partner primary education	388 831 (0.35)	293 469 (0.33)	185 870 (0.33)
Partner secondary education	327 257 (0.29)	254 890 (0.29)	165 797 (0.29)
Partner tertiary education	86 343 (0.08)	65 566 (0.07)	43 388 (0.08)
Other household characteristics			
Household members age >5 years, mean (SD)	5.16 (3.34)	5.11 (3.31)	5.08 (3.21)
Mother's age group, mean (SD)	3.30 (1.38)	3.31 (1.38)	3.30 (1.37)
Female head of houshold, *n* (%)	145 176 (0.13)	106 204 (0.12)	70 349 (0.12)
Household owns radio, *n* (%)	655 046 (0.57)	501 976 (0.57)	327 267 (0.58)
Household owns TV, *n* (%)	390 707 (0.34)	275 766 (0.31)	185 643 (0.33)
Household owns bike, *n* (%)	328 153 (0.29)	275 196 (0.31)	174 474 (0.31)
Child has health card, *n* (%)	832 523 (0.76)	613 735 (0.75)	439 019 (0.77)

Diarrhoea information not available in the Egypt 1988, Guyana 2005, Indonesia 1987, Turkey 2003 and Ukraine 2007 surveys. Height for age data not collected in the following surveys: Bangladesh 1993, Brazil 1991, Colombia 1990, Dominican Republic 1999, Guyana 2005, Indonesia 1987, Indonesia 1991, Indonesia 1994, Indonesia 1997, Indonesia 2002, Kenya 1989, Liberia 1986, Pakistan 2006, Peru 1986, Philippines 1993, Philippines 1998, Philippines 2003, Senegal 1997, South Africa 1998, Sudan 1990, Ukraine 2007, Vietnam 1997, Vietnam 2002.

in the combined DHS sample were classified as stunted. It should be noted that all statistics displayed in Table 1 represent unweighted sample averages.

Table 2 shows the associations of drinking water source and type of toilet facility and mortality risks in the neonatal, post-neonatal and child age ranges. For each outcome variable, we show the results of two models: a reduced model which includes only water and sanitation as well as child characteristics and survey fixed effects (columns 1, 3 and 5), and a full specification which includes parent and household characteristics to reduce endogeneity concerns as discussed above (columns 2, 4 and 6). Higher quality toilet facilities appear protective for all age ranges of children, except for intermediate quality facilities on the mortality risks for children aged 13–59 months. For all age ranges high quality sanitation seems to be more protective than intermediate quality latrines, in the specification with and without the full set of confounders. The addition of mother and household characteristics lowers the estimated protective effects of water and sanitation for all three age groups. Nevertheless, the estimated effects are substantial even with the full set of controls: children living in a household with high quality toilet infrastructure have a mortality risk which is some 15–23% lower than that of children living in households with no toilet facility. The result that higher quality facilities are more protective than intermediate technologies also appears plausible.

Somewhat contrary to the historical evidence (Cutler and Miller[6] argue that the health improvements generated by investment in sanitation infrastructure are small when compared with the improvements generated by centralized water supply), the results for water access are less clear-cut. Once we control for parental and household characteristics, water access appears beneficial only for children aged between 1 month and 1 year. In this group, however, the effect of high quality water appears as large as the effect of high quality sanitation, and similar magnitudes also emerge for the intermediate categories.

Table 3 shows the associations of drinking water source and type of toilet facility and indicators of child health for surviving children. The dependent variables are indicator variables for the child having had an episode of diarrhoea in the 2 weeks before the survey, and for the child being stunted, respectively. As before, we show results for a reduced model, which excludes parental and household characteristics in columns 1 and 3, and the results of a model including all confounders in columns 2 and 4. Once again, all models include controls for child characteristics and survey fixed effects.

Our results imply that access to both water and sanitation have positive effects on child health. Once all other household characteristics are controlled for, children in households with access to a high quality water source have 8% and 9% lower odds of diarrhoea and of being stunted relative to children in households with low quality water access, with intermediate quality falling somewhere in between for both outcomes. The point estimates for sanitation are substantially larger. The results from the models including all control variables displayed in columns 2 and 4 of Table 3 suggest that children in households with access to high quality sanitation have 13% lower odds of suffering from diarrhoea in the short run, and nearly 27% lower odds of being stunted; the reductions in stunting for intermediate quality sanitation (12%) are about half as large.

This analysis of the associations between child health outcomes and source of household drinking water supply and type of toilet suggests strongly

Table 2 Source of water and type of toilet facility and child mortality

	Neonatal mortality		**Mortality 1–12 months**		**Mortality 13–59 months**	
	(1)	(2)	(3)	(4)	(5)	(6)
Intermed. quality water	1.03	1.067	0.89	0.88	1.00	1.04
	(0.99–1.07)	(1.01–1.10)	(0.85–0.92)	(0.85–0.92)	(0.95–1.06)	(0.98–1.11)
High quality water	0.89	0.97	0.72	0.81	0.80	0.97
	(0.86–0.93)	(0.92–1.02)	(0.69–0.75)	(0.77–0.85)	(0.75– 0.86)	(0.88–1.04)
Intermed. quality sanitation	0.84	0.90	0.81	0.92	0.84	0.97
	(0.82–0.87)	(0.87–0.93)	(0.78–0.83)	(0.89–0.95)	(0.80–0.88)	(0.92–1.02)
High quality sanitation	0.70	0.85	0.55	0.83	0.49	0.77
	(0.68–0.74)	(0.81–0.90)	(0.52–0.58)	(0.78–0.88)	(0.45–0.54)	(0.68–0.86)
Household characteristics	No	Yes	No	Yes	No	Yes
Observations	1 113 517	887 440	843 235	671 882	586 258	466 782

Coefficient estimates displayed are odds ratios, 95% confidence intervals in parentheses. Standard errors are clustered at the survey cluster level. All specifications include survey fixed effects and controls for child sex and multiple births. Columns 2, 4 and 6 also control for mother's educational attainment, mother's 5-year age group, urban residence, household size, household assets as well as partner's educational attainment.

Table 3 Source of water and type of toilet facility and child health

	Diarrhoea in past 2 weeks		Stunted (height < median–2SD)	
	(1)	(2)	(3)	(4)
Intermediate water quality	0.92	0.92	0.92	0.97
	(0.90–0.95)	(0.90–0.95)	(0.90–0.94)	(0.95–0.99)
High water quality	0.87	0.91	0.69	0.92
	(0.85–0.89)	(0.88–0.94)	(0.67–0.71)	(0.89–0.94)
Intermediate quality sanitation	0.89	0.92	0.72	0.88
	(0.87–0.90)	(0.90–0.94)	(0.71–0.73)	(0.87–0.90)
High quality sanitation	0.74	0.87	0.41	0.73
	(0.72–0.76)	(0.85–0.90)	(0.40–0.42)	(0.71–0.75)
Household characteristics	No	Yes	No	Yes
Observations	989 188	796 557	686 414	567 011

Coefficient estimates displayed are odds ratios, 95% confidence intervals in parentheses. Standard errors are clustered at the survey cluster level. All specifications include survey fixed effects and controls for child age, sex and multiple births. Columns 2, 4 and 6 also control for mother's education level, mother 5-year age group, urban residence, household size, household assets, partner's educational attainment, child age in years and for whether the mother holds a health card for the child at the time of the interview.

protective effects, particularly for high quality toilets. The effects of high quality sanitation are similarly large for child mortality and child morbidity outcomes, are robust to the inclusion of controls for human and physical capital of the household and do not seem to vary markedly by age of the child. The effects of high quality water access on child mortality are a bit more nuanced and protective effects result only for children between the ages of 1 and 12 months. This result is consistent with the notion that the period of highest risk of poor quality water coincides with weaning, which generally happens before the child's first birthday. The effects of improved water supply on child morbidity outcomes are robust to the inclusion of controls for human and physical capital of the household and of similar magnitude for both diarrhoea episodes and stunting risk.

One of the most robust findings in analyses of factors associated with child health and mortality risks is a persistent and large protective effect of maternal (and to a lesser extent partner) education.[13,14] The magnitude of the water and sanitation effects shown in our analysis can thus be appreciated by comparing coefficients of the water and sanitation variables with the coefficients in the same models of various levels of maternal and paternal (or partner) education. Table 4 shows coefficients for four categories of maternal and paternal education (the omitted category is no education) for the five outcome variables studied; the results in all cases are of course controlling for parental and household characteristics. As would be expected from the literature, maternal education is strongly protective for all the outcomes and the protective effect increases with the level of education. In general, the protective effect of maternal education on mortality is smallest in the neonatal period and increases with age range of child, tends to be smaller on diarrhoea risk than on mortality and is very similar between mortality and stunting. Patterns for partner education are broadly similar to those for the mother, but generally smaller.

Relative to the point estimates obtained for maternal education, the protective effect of an intermediate or high quality toilet tends to fall somewhere between the protective effect of primary and secondary education and high quality toilet is more protective than partner secondary education. Effects of improved water supply are generally smaller than those of maternal primary education, but those of high quality water generally exceed the effects of partner primary education.

Discussion

Although the results presented in this article present some rather strong evidence of the protective effect of water and sanitation, some caveats are in order. First, whereas we include a large set of parental and home environment controls in our main specification to reduce the risk of confounding, we cannot completely rule out residual correlations between unobservable household or child characteristics and both our child health and water and sanitation variables. If these unobservable characteristics happen to reduce the risk of poor health outcomes, and also to positively correlate with our water and sanitation variables, we might overestimate the effects of water and sanitation even in our fully specified model. Second, given the medium-term approach chosen in our stunting and mortality regressions, one may wonder if parental water and sanitation choice may respond to observed health outcomes. Whereas it seems rather implausible

Table 4 Child health and parental education

	Neonatal mortality (1)	Mortality 1–12 months (2)	Mortality 13–59 months (3)	Diarrhoea (4)	Stunted (5)
Mother primary	0.92	0.90	0.89	1.02	0.85
	(0.89–0.96)	(0.87–0.93)	(0.84–0.94)	(1.00–1.04)	(0.83–0.86)
Mother secondary	0.83	0.63	0.58	0.91	0.62
	(0.79–0.87)	(0.50–0.67)	(0.53–0.64)	(0.88–0.93)	(0.61–0.64)
Mother tertiary	0.67	0.41	0.39	0.73	0.40
	(0.61–0.75)	(0.35–0.48)	(0.28–0.40)	(0.70–0.77)	(0.38–0.42)
Partner primary	0.99	0.92	0.94	1.00	0.95
	(0.96–1.03)	(0.88–0.95)	(0.89–98)	(0.98–1.03)	(0.93–0.97)
Partner secondary	0.91	0.81	0.80	0.96	0.79
	(0.87–0.95)	(0.77–0.85)	(0.75–0.85)	(0.94–0.98)	(0.77–0.81)
Partner tertiary	0.85	0.61	0.64	0.86	0.67
	(0.79–0.92)	(0.55–0.67)	(0.53–0.75)	(0.82–0.89)	(0.64–0.69)
Observations	887 440	671 882	466 782	796 557	567 011

Coefficient estimates displayed are odds ratios, 95% confidence intervals in parentheses. Standard errors are clustered at the survey cluster level. All specifications include the water and sanitation variables, survey fixed effects and controls for child age, sex and multiple births as well as mother's education level, mother 5-year age group, urban residence, household size, household assets, partner's educational attainment, child age in years and, for the child health outcomes, whether the mother holds a health card for the child at the time of the interview.

that parents decide to invest in water and sanitation in response to a single bout of diarrhoea, it may well be possible that continued observation of children being sick or, even more so, experiencing a child death in the family (potentially attributable to poor water and sanitation) may induce parents to change their primary access point. To the extent that this was true, we would underestimate the true effects of water and sanitation, as parents with particularly bad health records self-select into the high quality water and sanitation groups. Last, and maybe most importantly, there is clearly some noise in the coding of our water and sanitation variables. As discussed before, our water and sanitation variables are only proxies of the actual conditions faced by children in the household, so that both water and sanitation quality are likely to be measured with substantial error in our data set; the resulting attenuation bias skews the expected distribution of estimates towards zero, leading to an expected underestimation of the true magnitudes. Whereas it is hard to quantify, and even harder to rule out, these potential biases in any observational study, the direction of the overall bias does not appear obvious in the analysis presented here. The fact that our point estimates indicate effects that are somewhat less protective than those found in randomized trials (see, e.g. Fewtrell *et al.*[4]) is not entirely surprising, and may be interpreted as evidence for decreasing marginal impacts of water and sanitation investment as programmes are scaled up and have to be sustained over time. The fact that estimation results appear highly consistent across health measures and strictly increase with the quality of water and sanitation infrastructure can be viewed as further evidence for the robustness of the presented results and their implications regarding the health effects of water and sanitation investment.

Conclusion

We analyse the associations of water and sanitation with child health indicators across 70 countries and 171 household surveys conducted as part of the DHS. Controlling for as many potentially confounding characteristics of the child, the mother and the household as possible, we find strongly protective effects of high quality toilet facilities for neonatal, post-neonatal and child mortality risks, as well as for risks of episodes of diarrhoea and for stunting; in magnitude, the effects fall somewhere between the protection offered by primary and secondary maternal education. Benefits of high quality water are in general smaller, but for mortality appear most strongly in the risk period between 1 month and 1 year in which weaning is most likely to occur.

Improved water and sanitation are targets for MDG-7, as well as potentially contributing to achievement of MDG-4. However, a mid-term assessment found that progress on water and especially sanitation was not sufficient to reach the MDG-7 target in most sub-Saharan African countries, where 64% of households do not have access to basic sanitation, and 42% lack safe drinking water.[3] Of the US$ 90 billion of development aid disbursed by international donors in 2006, US$ 3.9 billion (4.3%) was invested in the improvement of water supply and sanitation.[15] The evident benefits of (particularly) improved sanitation, the area which has lagged most, make a renewed thinking about investments in such projects an urgent priority.

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KEY MESSAGES

- The protective effects of access to improved water and sanitations are large.
- Our results based on over 1 million children suggest that access to high quality sanitation reduces the odds of child diarrhoea, stunting and mortality by 13%, 27% and 23%, respectively.
- Given the still limited access to improved water and sanitation in many developing countries, the potential health improvements achievable by water and sanitation investment appear substantial.

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