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Water, Sanitation and Children's Health

Evidence from 172 DHS Surveys

Isabel Günther
Günther Fink

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Abstract

This paper combines 172 Demography and Health Survey data sets from 70 countries to estimate the effect of water and sanitation on child mortality and morbidity. The results show a robust association between access to water and sanitation technologies and both child morbidity and child mortality. The point estimates imply, depending on the technology level and the sub-region chosen, that water and sanitation infrastructure lowers the odds of children to suffering from diarrhea by 7–17 percent, and reduces the mortality risk for children under the age of five by about 5-20 percent. The effects seem largest for modern sanitation technologies and least significant for basic water supply. The authors also find evidence for the Mills-Reincke Multiplier for both water and sanitation access as well as positive health externalities for sanitation investments. The overall magnitude of the estimated effects appears smaller than coefficients reported in meta-studies based on randomized field trials, suggesting limits to the scalability and sustainability of the health benefits associated with water and sanitation interventions.

This paper—a product of the Prospects Group, Development Economics—is part of a larger effort in the group to do forward-looking analyses of development strategies, including strategies for achieving the Millennium Development Goals.. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at isabel.guenther@nadel.ethz.ch and gfink@hsph.harvard.edu.

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Isabel Günther and Günther Fink[*]

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[*] Isabel Günther (the corresponding author): ETH Zürich. Voltastrasse 24, 8092 Zürich, Switzerland,. E-mail: isabel.guenther@nadel.ethz.ch; Günther Fink: Harvard School of Public Health. E-mail: gfink@hsph.harvard.edu.
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1. Background

Diarrheal diseases continue to be a major threat to child health in developing countries around the world. The latest estimates published by the World Health Organization indicate that diarrheal disease is responsible for approximately 800,000 deaths of children under the age of five per year, causing a higher number of under-age-5 deaths than malaria and HIV combined[1] (WHO, 2007).

One of the key factors contributing to the frequency and burden of diarrheal disease is the pronounced lack of water and sanitation in a majority of developing countries (Zwane and Kremer, 2007). According to the United Nations report, more than half of the population in developing countries still lacks access to the most basic form of sanitation (United Nations 2007).[2] Somewhat more progress has been made in the water sector, but 21% of the population in developing countries still does not have access to adequate drinking water (UNDP, 2007/2008). The situation is most severe for Sub-Saharan African countries, where 63% of the population lacks access to basic sanitation and 45% of the population lacks safe drinking water supply (UNDP, 2007/2008).

From a public health perspective, the lack of access to water and sanitation infrastructure is disconcerting. Several studies have documented the significant positive effect of water and sanitation on reducing child diarrhea (for an overview see Esrey et al., 1991; Fewtrell et al., 2005; and Waddington et al., 2009). Moreover, improved water and sanitation has been shown to lower the health risks related to schistosomiasis, trachoma, intestinal helminthes and other water related diseases. In addition, improved water and sanitation is likely to reduce the burden of disease related to other major health issues by reducing the average stress level for the immune system, and thus strengthening the immune response to new infections. This phenomenon has been labeled the Mills-Reincke Multiplier in honor of Hiram Mills and J.J. Reincke, who first noted the health benefits of water-borne disease improvements on other disease-specific mortality rates (Cutler and Miller, 2005; Ewbank and Preston, 1990). Given the large potential

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[1] According to the WHO, Malaria and HIV AIDS caused 584,000 and 184,000 deaths under age 5 in 2002, respectively; the total under-age-5 death burden associated with diarrheal diseases was 841,000.

[2] If flush toilets were considered the sanitation standard to be met, the number of people lacking proper sanitation today would even total 4 billion (Black and Fawcett, 2007).

direct as well as indirect health benefits of water and sanitation infrastructure, it does not come as a surprise that improvements in water and sanitation have been nominated as one of the official targets of the Millennium Development Goals (MDGs). MDG 7 demands that „…*by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation*" shall be reduced by half (MDG7, UNDP, 2007/2008).

From an economic perspective it is easy to see why countries cannot solely rely on market-based solutions for an optimal level of investments in water and sanitation infrastructure. First, with high initial cost and health benefits in the future, individuals with limited access to credit and/or hyperbolic discounting rates will generally under-invest in precautionary health care measures. Second, with disposal of human feces in public areas as a natural alternative to sanitation facilities, social benefits of proper sanitation infrastructure are likely to substantially exceed private benefits. From a welfare perspective, these positive externalities imply that in the absence of government intervention private investment will be sub-optimal. This problem is further aggravated by the fact that health benefits of improved water and sanitation – involving invisible bacteria and parasites – are hard to understand and internalize, especially for populations with little or no formal education.

However, with limited public resources available to most developing countries, the optimal level of public investment in water and sanitation is not obvious, and critically hinges on a comprehensive analysis of the associated health benefits as well as of more broad welfare measures. The same is true for the international financial contributions towards the water and sanitation sectors. Of the US$ 90 billion development aid spent in 2006, only about US $3.9 billion (4.3%) percent were invested in the improvement of water supply and sanitation (OECD). A normative judgment on whether the current international support for Millennium Development Goal 7 is adequate or not certainly also depends on the magnitude of the identifiable health benefits.

Despite the large number of observational and intervention studies on improved water and sanitation supply, a comprehensive empirical evidence base on their private and public health impact is still lacking. A major part of the existing (mainly epidemiological) literature on water and sanitation infrastructure has focused on child diarrhea as an outcome variable for a variety of reasons: first, lower diarrhea prevalence is the most direct presumed effect of improved water and sanitation infrastructure. Second, epidemiological intervention studies in the field are expensive, which limits feasible sample sizes and, as a result, also the statistical power to detect changes in lower frequency events such as short-term mortality. This fact is unfortunate from a policy perspective since reducing diarrhea, unlike combating HIV, malaria and tuberculosis, has not been made an explicit target of the MDGs, and is therefore generally not as high on policy priority lists. The international community is instead highly committed to reducing child mortality (Millennium Development Goal 4). While diarrheal studies provide important information about the immediate health effects of water and sanitation, the link from water and sanitation to child mortality is indirect and cannot directly be derived from estimates on child diarrhea.

Moreover, few studies have explicitly analyzed the health benefits of sanitation infrastructure. The Independent Evaluation Group of the World Bank (2008) postulates in a review of impact evaluations on water supply and sanitation: *"All types of intervention could benefit from further studies, but the most obvious gap is the lack of evidence regarding sanitation...there is a great need to engage in more such studies to support the case – which appears to exist on the basis of limited evidence – for more investment in sanitation."*

In this paper, we aim to fill this evidence gap by combining all available Demography and Health Surveys (DHS) with complete household information into a large international data set that allows us to investigate the relation between water and sanitation and health in a large range of developing country settings over the last 25 years. The Demography and Health Surveys contain an extensive list of household characteristics including access to water and sanitation, and also measures of child morbidity and mortality at the household level. To deal with the large degree of heterogeneity in water and sanitation facilities across countries, we construct three levels of water and sanitation technology, respectively. Following the existing literature, we first analyze diarrhea as the dependent variable, followed by child mortality. Moreover, we analyze both the differences in child health between households with and without access to water and sanitation technologies, as well as differences in child health between rural villages (urban districts) with and without improved infrastructure to account for possible positive health externalities.

Our results imply a significant and positive association between access to water and sanitation technologies and child health. Our point estimates imply, depending on the technology level and the sub-region chosen, that water and sanitation infrastructure lowers the odds of children under-5 to suffering from diarrhea by 7-17%, and reduces the mortality risk for these children by about 5-20%. The highest health benefits are found for modern sanitation technologies, the lowest and least robust for simple water technologies. Consistent with the Mills-Reincke Multiplier, we find water and sanitation mortality effects that cannot fully be explained by reductions in diarrhea; we also find strong evidence for positive spillovers of investments in sanitation technologies.

The paper is structured as follows: a short literature review is given in Section 2. We discuss the data used in Section 3 of the paper, and present our estimation results in Section 4. We conclude with a short summary in Section 5.

2. Literature Review

Three meta-studies have to date summarized the empirical evidence on the health impacts of improved water and sanitation. Esrey et al. (1991) review 144, Fewtrell et al. (2005) 46, and Waddington et al. (2009) 71 studies. All studies compare the benefits of water infrastructure, sanitation infrastructure, water quality treatment and hygiene education using diarrhea as the main indicator of health improvements.

Most of the reviewed articles in the three meta-studies focus on water quality treatment or hygiene education. In contrast, the literature on water and especially sanitation infrastructure is scarce, even though there are some studies that analyze the combined effect. Fewtrell et al. (2005) find only two studies that adequately identify the effects of sanitation infrastructure on child diarrhea. Both papers analyze the impact of a combination of latrine installation and hygiene education and/or improved water supply. The single effect of latrine infrastructure on diarrhea is, hence, not identified in either of these studies. Esrey et al. (1991) identify five, and

Waddington et al. (2009) identify eight studies on sanitation infrastructure. With regard to water infrastructure supply, the picture is not much better: Esrey et al. (1991), Fewtrell et al. (2005), and Waddington et al. (2009) include 22, six and eight articles in their analysis of water infrastructure interventions, respectively.

Esrey et al. (1991) find a 17% reduction in diarrhea induced by improved water supply and a 22% reduction induced by improved sanitation infrastructure. Fewtrell et al. (2005) show a reduction in illness of 25% for water and 32% for sanitation infrastructure. The results are, however, insignificant for water interventions if only diarrhea is considered as the dependent variable. Waddington et al. (2009) report no significant impact on diarrhea morbidity for water supply and a 37 % relative reduction in diarrhea incidence for sanitation infrastructure (but with low precision due to the small number of relevant studies). All 3 meta-studies suggest that the impact of sanitation infrastructure is larger than the health impact of improved water supply. In addition, none of the three studies finds any evidence for complementarities between water and sanitation interventions: the impact of single interventions appears to be similar to the impact of the same interventions in combined programs.

The studies underlying these three meta-studies were mostly based on local case studies and conducted under trial conditions. The only study we could find that directly takes a broader cross-country perspective is an early study by Esrey (1996), who uses eight Demographic and Health Surveys[3] to identify the effects of sanitation on diarrhea. The study finds a reduction of diarrhea of 13-44% for flush toilets and a reduction of diarrhea of 8.5% for latrines. In contrast to the meta-studies discussed above, Esrey (1996) finds complementarities between water and sanitation. He shows that improved water supply has no effect on health if improved sanitation is not present and even if sanitation is present the health benefits of water are reported to be lower than the health benefits of improved sanitation. Esrey's article – undoubtedly one of the most cited works in the filed – is, however, constrained by a rather arbitrary (small) selection of DHS surveys (8 out of the 63 surveys that were already available in 1995).

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[3] The eight surveys used in the study are Bolivia, Burundi, Ghana, Guatemala, Morocco, Sri Lanka, Togo, and Uganda.

In a recent paper, Kremer and Zwane (2007) conclude that the literature on water and sanitation treatment, infrastructure and education still provides only "*...scant evidence and only tenuous consensus on the impact and cost-effectiveness of various environmental health interventions*" when it comes to fighting child diarrhea.

Even less of the literature aims for a comprehensive assessment of water and sanitation infrastructure based on a broader set of health (for example child mortality) and/or welfare (for example income) measures. The only papers attempting a comprehensive cost-benefit analysis were commissioned by the World Health Organization and undertaken by the same authors (e.g. Hutton and Haller, 2004; Hutton, Haller, and Bartram, 2007). Hutton et al. (2007) estimate a lower bound of US$ 5 for each US$ 1 investments in water and sanitation infrastructure. These estimates are, however, based on the assumption that investments in water and sanitation lead to high time savings that can then be used for economic activity (with scarce empirical evidence for water and missing empirical evidence for sanitation infrastructure).

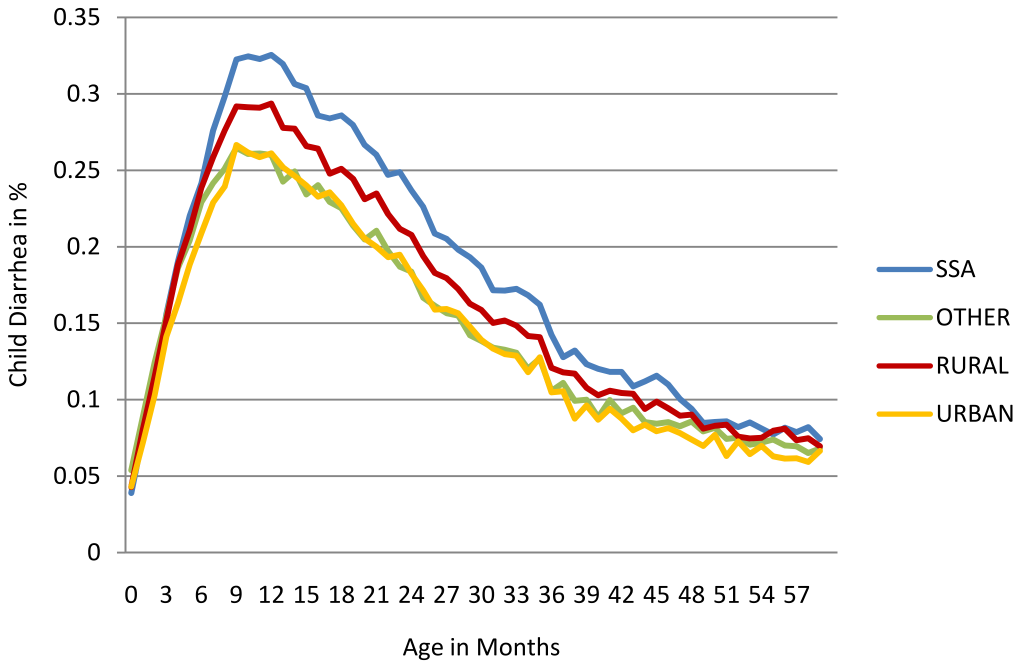
In contrast to the current developing country evidence, the important historical contribution of water and sanitation infrastructure to the secular decline in mortality in Europe and the Americas at the turn of the 19th century appears well documented (e.g. Duffy, 2006; Deaton, 2006; Aiello, Larson, and Sedlak, 2008). Woods, Watterson and Woodward (1988) and Szreter (1988) discuss the critical role of water and sanitation in the historical decline in infant mortality in the late 19th century in England and Wales. Brown (1989) analyzes the surge in sanitation investments in Germany as a response to the devastating cholera epidemic of the 19th century. Cutler and Miller (2005) argue that water and sanitation improvements account for 50% of total, and 75% of child mortality reductions experienced in major US cities throughout the 20th century. Watson (2006) argues that sanitation investment in native Indian reservations was the key driver for the convergence in child health between native Indian and the surrounding populations in the US.

Although some authors have started to draw a parallel between industrialized nations in the 19th century and developing countries in the 21st century (Konteh, 2009), the problem with most of the historical retrospective studies is that causal identification is hard, as a multitude of public health innovations were introduced over the relevant time periods, and detailed historical data is scarce.

3. Data

This paper is built around data from the Demographic and Health Surveys (DHS). Starting in the early 1980s, more than 200 surveys have been conducted in over 70 countries. In this study, we use all standard format surveys that are publicly available and have complete information regarding diarrhea, child mortality, and access to sanitation and water infrastructure. This leaves us with a total of 172 surveys in 70 countries as summarized in Table A.1 in the Appendix.

Figure 1: Child diarrhea



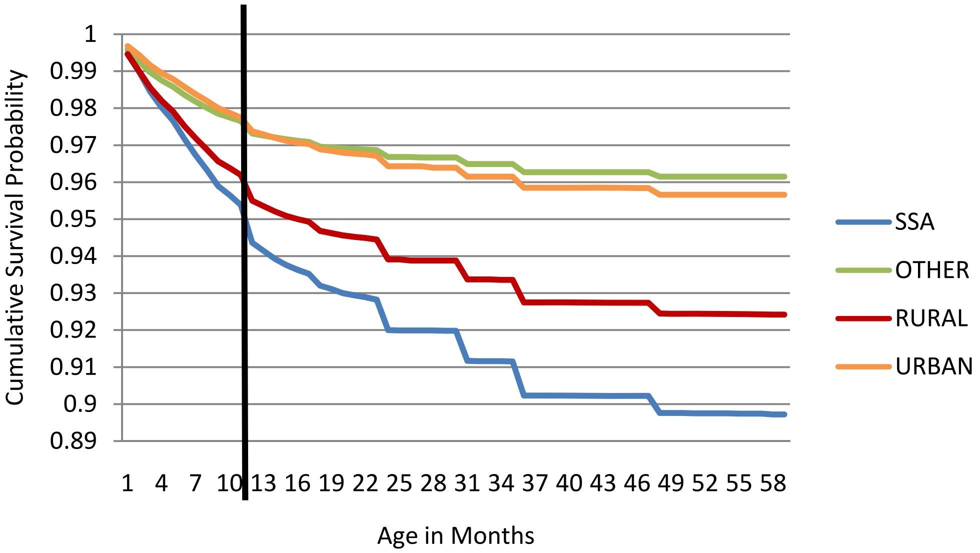
In line with most of the existing literature, the first dependent variable we use in our analysis is child diarrhea. Most DHS surveys ask female respondents whether any of their children under the age of 5 had diarrhea over the two weeks preceding the interview. As Figure 1 illustrates, the likelihood of a child being reported with diarrhea rapidly increases with age early on, and peaks at 11 -15 months of age in both rural and urban areas. As Figure 1 also illustrates, the likelihood of mothers reporting a diarrhea episode for the child also appears significantly larger in Sub-Saharan Africa and rural areas.

The second variable of interest we analyze in this paper is child mortality. We restrict the mortality data to the five-year time window prior to the interview because we aim to link child mortality to water and sanitation infrastructure observed at the time of the interview. Given the censored nature of our data, we hence estimate the determinants of under-5 mortality using a survival model.

We do not include children who were born more than 5 years before the respective DHS survey. Including older children would have the advantage of (i) increasing statistical power and (ii) reducing the problem of right censoring. The main shortcoming of extending the time period under consideration is, however, that the link between the information on current household characteristics and child mortality becomes weaker. Even within a five year period, water and sanitation infrastructure is likely to change for a fraction of households, which would be an argument for restricting the analysis to an even shorter time period (e.g. 12 months prior to the survey interviews). However, this would yield a very small number of child deaths and would therefore make the empirical identification of the relevant effects difficult. The five year horizon chosen in this paper was deemed long enough to achieve sensible mortality estimates, while still being short enough to avoid major shifts in water and sanitation infrastructure at the household level.

As Figure 2 shows, child death under age 5 is mostly concentrated in the first 12 months of children's life. The cumulative survival functions fall sharply between birth and the age of 12 months and then flatten out, with relatively few deaths occurring between the 3rd and the 5th year of children's life. Similar to the plotted diarrhea rates in Figure 1, and as expected, large differences in levels can be found between Sub-Saharan Africa and other regions of the world as well as between urban and rural households.

Figure 2: Child Survival



The main explanatory variables of interest are the use of water and sanitation infrastructure. The classification of sanitation varies substantially across time and countries in the DHS surveys: some surveys focus on the distinction between private and public facilities, while others focus on the location (in or outside the house) or the exact type of the facility (e.g., ventilated vs. non-ventilated latrines). In total we found over 400 different sanitation codes in the DHS surveys. Water categories were even more heterogeneous, with over 500 different codes across all DHS surveys.[4] Similar to sanitation infrastructure some DHS surveys contain very detailed information, distinguishing between multiple technologies and between private versus public water access, whereas several surveys only report very broad categories of unimproved versus improved water sources, with no indication whether the water point is private or shared.

To abstract from these classification differences across countries and time we divide water and sanitation in three different groups following some relatively simple coding rule as illustrated in column 2 of Table 1. In our initial approach we divide water and sanitation in “technology classes”. We define all latrines as “basic” sanitation technology, and flush toilets as “advanced” sanitation technology. With respect to water, we regard boreholes and any kind of protected and unprotected wells and springs as “basic” water technology, while we classify piped

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[4] A detailed list of all water and sanitation infrastructure categories in the DHS, as well as a suggestion to recode them, and as done in this paper, is available from the authors by request.

connections (in the household or through public standpipes) as “advanced” technology water supply. Open defecation and surface water is the reference category in all estimations and is considered as lack of access to any water and sanitation infrastructure.

This definition is slightly different from the WHO definition of improved and unimproved water and sanitation (WHO, 2009), which is used by the Joint Monitoring Programme (JMP) for Water Supply and Sanitation by the WHO and UNICEF[5] (see column 1 of Table 1). The reason for this difference is simple: a large number of DHS surveys does neither distinguish between protected and unprotected wells, springs and boreholes nor distinguish between private and public flush toilets and latrines. Since we are not primarily interested in identifying the more subtle differences between individual technologies (e.g. between ventilated and non-ventilated latrines or between protected and unprotected wells), we choose a slightly more broad classification, which allows us to estimate the equation of interest across a large number of countries and time, without the need the make any assumptions (see next paragraph). Moreover, we want to explicitly differentiate between surface water and simple water technologies and open defecation and simple sanitation technologies to analyze if already simple - and according to the WHO definition still “unimproved” - sanitation and water technologies are associated with improved child health.

To investigate the degree to which the specific coding rule chosen affects our result, we analyze an alternative definition in a second step, where we follow the official definition of the WHO of improved and unimproved water and sanitation as closely as possible (see column 3 of Table 1). Whenever it was not clear from the data whether a spring or well or a latrine was improved or not had to make the assumption that it is unimproved.

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[5] See http://www.wssinfo.org/.

Table 1: Water and Sanitation Definitions

	(1) JMP/WHO	(2) Technology	(3) Improved/ Unimproved	(4) Private/ Public
	WATER CATEGORIES			
Piped water into dwelling/yard/plot	improved	piped	improved	private
Public tap or standpipe	improved	piped	improved	public
Tubewell or borehole	improved	well	improved	public
Protected dug well - private	improved	well	improved	private
Protected dug well - public	improved	well	improved	public
Protected spring	improved	well	improved	excluded
Unprotected spring	unimproved	well	unimproved	excluded
Unprotected dug well-private	unimproved	well	unimproved	private
Unprotected dug well-public	unimproved	well	unimproved	public
Tanker-truck / Bottled water	unimproved	excluded	excluded	excluded
Surface water	unimproved	surface	surface	surface
	SANITATION CATEGORIES			
Flush toilet/sewer system/septic tank	improved	flush	improved	private
Flush/pour flush to pit latrine	improved	latrine	improved	private
Ventilated improved pit latrine	improved	latrine	improved	private
Pit latrine with slab	improved	latrine	improved	private
Special case	improved	excluded	excluded	excluded
Shared flush toilet	unimproved	flush	improved	public
Shared latrine	unimproved	latrine	unimproved	public
Pit latrine without slab	unimproved	latrine	unimproved	private
Hanging toilet or hanging latrine	unimproved	latrine	unimproved	private
Flush/pour flush to elsewhere	unimproved	latrine	unimproved	private
Bucket	unimproved	open	open	open
No facilities or bush or field	unimproved	open	open	open

Notes: *Detailed categorization is available from the authors by request.*

In a last specification, and only for a selected number of surveys, we distinguish between public and private water and sanitation access (see column 4, Table 1). Public water access implies on average a longer distance to the household and hence longer transport and storage times, and is thus likely to reduce the water quality consumed in comparison to private access to the same technology. Similarly, public sanitation can– for example, due to free-rider problems - be expected to be less hygienic than private toilets. For water access, the distinction between private and public access is explicitly coded in most surveys; surveys where no difference between private and public water access is made are not used for this part of our analysis. For sanitation, few surveys explicitly asked whether a latrine or flush toilet was used by several or only one household. In general, we assume toilets to be private, and only recode them as public when sharing with other household is explicitly stated.

One advantage of the approach chosen in this paper is that it allows us to estimate the effect of improved sanitation and improved water access on child morbidity as well as on child mortality across a large number of countries using the same methodology. As water and sanitation are often competing for the same resources (WHO/UNICEF, 2000; Clark and Gundry, 2004), having a broad comparison of their marginal impact seems desirable both from a scientific and from a policy perspective.

One obvious limitation of the analysis presented in this paper is that we are not able to directly measure the quality of water. Because of inadequate water transportation or water storage, water that is clean at the source can be contaminated at the point of use. For an overview of an extensive literature on this issue see Wright et al. (2004) or Kremer et al. (2007). The water technology measures used in this paper are also likely to represent both water quantity and water quality. A similar concern applies when it comes to interpreting our coefficients on sanitation. Policies targeted at sanitation improvements in developing countries are often implemented in conjunction with hygiene education programs, so that the observed sanitation effects may to some degree reflect underlying behavioral change rather than the true infrastructure effect itself.

The estimates presented in this paper should thus be viewed as total impact estimates associated with access to basic or advanced water and sanitation technologies. While some may view the inability to disentangle the various channels through which water and sanitation infrastructures affect health outcomes as a short-coming, the total impact is likely the key variable of interest when it comes to evaluating the costs and benefits for such interventions from a policy perspective (Whittington et al., 2008).

Table 2 summarize the prevalence of water and sanitation infrastructure (following the technological definition discussed before in Table 1, column 2) for children in the DHS surveys for the 1990s and the 2000s for all those countries where we have at least one survey in each period. Since we constrain the countries listed in Table 2 to countries with at least one survey in the 1990s and 2000s, not all surveys and countries used in our estimation are represented here.[6] It is furthermore worth noting that these statistics deviate from official WHO statistics not only due

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[6] See Appendix, Table A1 for a complete list of countries and surveys.

to the differences in water and sanitation definitions, but also because of the sample domain which is restricted to children under the age of five.

Table 2: Water and Sanitation Prevalence in the 1990s and the 2000s

	1990s				**2000s**			
	well	**piped**	**latrine**	**flush**	**well**	**piped**	**latrine**	**flush**
Bangladesh	0.891	0.037	0.467	0.250	0.886	0.073	0.625	0.263
Benin	0.564	0.111	0.142	0.000	0.481	0.365	0.290	0.001
Bolivia	0.206	0.598	0.309	0.229	0.144	0.740	0.380	0.240
Burkina Faso	0.712	0.256	0.369	0.010	0.715	0.148	0.252	0.009
Cameroon	0.235	0.468	0.389	0.090	0.507	0.156	0.848	0.053
Chad	0.817	0.066	0.336	0.004	0.647	0.254	0.375	0.030
Colombia	0.054	0.917	0.040	0.864	0.099	0.776	0.023	0.834
Dom. Republic	0.044	0.728	0.557	0.261	0.073	0.669	0.656	0.190
Egypt, Arab Rep.	0.211	0.789	0.672	0.206	0.050	0.950	0.630	0.365
Ghana	0.339	0.287	0.616	0.042	0.524	0.332	0.573	0.046
Haiti	0.210	0.643	0.571	0.039	0.563	0.353	0.515	0.012
India	0.615	0.340	0.125	0.190	0.542	0.422	0.211	0.330
Indonesia	0.667	0.173	0.437	0.195	0.678	0.211	0.275	0.408
Kenya	0.240	0.279	0.765	0.060	0.348	0.298	0.668	0.094
Madagascar	0.460	0.223	0.346	0.034	0.366	0.359	0.557	0.026
Malawi	0.535	0.335	0.756	0.038	0.752	0.152	0.822	0.017
Mali	0.771	0.198	0.718	0.007	0.722	0.225	0.748	0.018
Morocco	0.478	0.455	0.107	0.415	0.371	0.577	0.106	0.648
Mozambique	0.589	0.294	0.415	0.031	0.620	0.197	0.512	0.019
Namibia	0.320	0.485	0.064	0.221	0.191	0.728	0.117	0.274
Nepal	0.577	0.347	0.133	0.016	0.548	0.381	0.195	0.210
Nicaragua	0.391	0.526	0.639	0.116	0.578	0.301	0.554	0.126
Niger	0.663	0.309	0.231	0.020	0.679	0.306	0.251	0.025
Nigeria	0.373	0.305	0.610	0.102	0.594	0.167	0.617	0.093
Pakistan	0.395	0.540	0.133	0.367	0.589	0.375	0.206	0.456
Peru	0.259	0.595	0.325	0.299	0.082	0.812	0.334	0.439
Philippines	0.393	0.598	0.243	0.547	0.459	0.522	0.127	0.691
Rwanda	0.505	0.269	0.928	0.014	0.516	0.289	0.955	0.009
Senegal	0.554	0.416	0.512	0.090	0.465	0.521	0.489	0.244
Tanzania	0.443	0.297	0.808	0.012	0.481	0.354	0.760	0.021
Uganda	0.644	0.132	0.825	0.027	0.755	0.117	0.835	0.007
Vietnam	0.639	0.147	0.543	0.162	0.641	0.199	0.528	0.259
Zambia	0.351	0.441	0.468	0.228	0.529	0.256	0.646	0.081
Zimbabwe	0.559	0.313	0.325	0.224	0.587	0.313	0.346	0.249
Country Average	**0.462**	**0.380**	**0.439**	**0.159**	**0.494**	**0.379**	**0.471**	**0.200**

The differences in water and sanitation prevalence and facility standards across countries and regions are remarkable. In some countries, like Egypt, almost all children had access to an at least basic water technology already in the 1990s. In contrast, in other countries, like Kenya and Cameroon, still in the mid 2000s over 30 percent of children did not have access to even basic water technologies.[7] The same holds for sanitation: some countries, such as Rwanda had achieved almost complete sanitation coverage by the 1990s, while in other countries, such as Benin and Niger, less than half of the children in our sample had access to any kind of sanitation technology even in the 2000s. Moreover, while flush toilets is the major sanitation technology in some countries (such as in Colombia and the Philippines), the prevalence of such modern facilities is almost non-existing in other countries (such as Rwanda and Uganda).

Water and sanitation access appear to have improved in our sample on average over the last decade, but the average increase is modest with only about 3 percentage points for basic water technologies, 0 percentage points for advanced (piped) water technologies, 3 percentage points for basic sanitation and 4 percentage points for modern sanitation facilities. In some countries the percentage of children having access to sanitation has even deteriorated (for example Burkina Faso or Colombia). In general, access to sanitation is much lower than the access to water infrastructure. Finally, the prevalence of advanced technologies is still low. In the last survey round, only 20 % of children had access to a flush toilet and only 40% had access to piped water. In general, improvements seem to be based on the basic rather than on the advanced technology level.

Figure 3 shows unconditional cross-tabulations of diarrhea and child mortality rates for each water and sanitation technology level (not controlled for any covariates). The overall gradient is as expected: child morbidity and mortality are substantially lower for children with access to more advanced water and sanitation technologies.[8]

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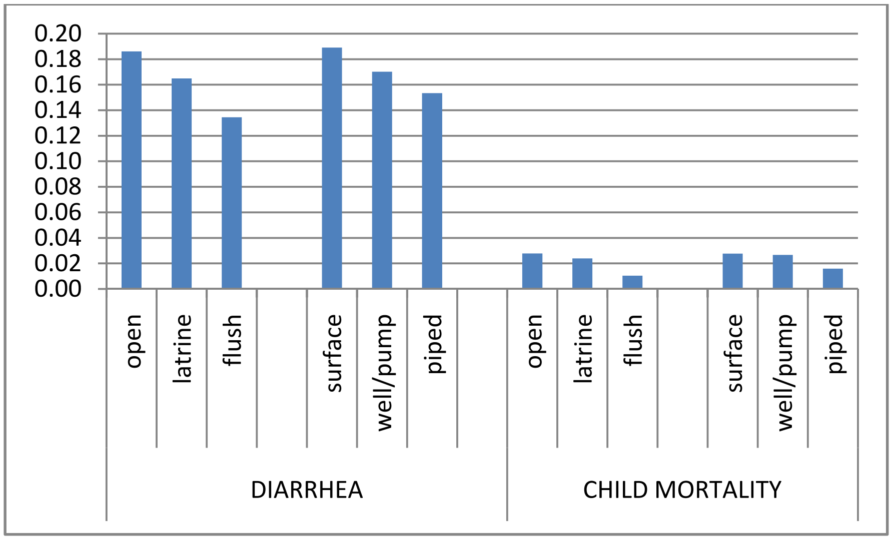
[7] Note that our estimates somewhat overestimate the access to improved water as we count unprotected wells and springs as an improved water source (see previous section for explanation).

[8] Note that child mortality rates in Figure 3 are much smaller than officially published figures on under-5 child mortality. While in general mortality rates up to the age of five for a pre-defined period are reported, Figure 3 shows the 12 months survival probability (one prior to the survey interview) for all children under the age of 5.

Figure 3: Correlation Water, Sanitation and Children's Health



4. Empirical Specification and Results

4.1 Empirical Specification

The general equation we estimate is given by

$$CV_{icjt} = \alpha_{11} + \beta_{11} Latrine_{icjt} + \beta_{12} Flush_{icjt} + \gamma_{11} Pump_{icjt} + \gamma_{12} Piped_{icjt} + \delta_1 X_{icjt} + c_{jt} + e_{icjt} \tag{1}$$

where *CV is* the child variable of interest. *Latrine* is the basic sanitation technology indicator (household having access to a private or public latrine), *Flush* is the indicator for access to a flush toilet, *Pump* and *Piped* is households' access to pump/well/spring or piped water, respectively, and *X* is a matrix of additional control variables (see the following paragraph). *i* is the household index, *c* is the cluster index[9], *j* is the (sub-national) regional index, and *t* the index of the survey year.

Since health preferences and budget constraints are likely to be correlated with both child health as well as with sanitation and water infrastructure, we include a wide set of control

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[9] In general within the DHS surveys, in rural areas clusters are villages and districts in urban areas.

variables in our empirical specifications: education and age of the mother, marital status of the mother, household size, urban or rural residence and various assets of the household to proxy for income or socioeconomic status. DHS surveys do not contain any direct information about the income or consumption of households. To overcome this lack of data we have to include several assets to approximate a household's permanent income level. The assets we use in our final specification are electricity, radio, TV, bicycle and fridge as well as the material used to construct the house of residence. Since the available assets differ widely across countries and time, the selected assets were chosen to reach a maximum of included assets on the one and of included DHS surveys on the other hand.

In addition, we control for various child level characteristics that might have an influence on children's morbidity and mortality and are standard in the literature: age and gender of the child, whether the child is the first born child, the length (in month) to the preceding birth if he or she is not the first born, and whether he or she is/was breast-fed. For diarrhea we further include whether the child was vaccinated against measles to control for household preferences for improved health. We also use vaccination in a control specification for child mortality but not in our main specification. The problem with vaccination is first, that it is usually not recorded for children that have died. Second, if children died at a very young age they never had the opportunity to get vaccinated. We could use the vaccination status of living siblings to approximate the vaccination status of dead children. But for several households we only have one child in our sample, where such a procedure is not feasible.

In all of our specifications, we also control for the survey year and regional (sub-national) or country fixed effects, to avoid potential biases from time-specific local unobservables, correlated with both water and sanitation and our health outcomes of interest. The DHS surveys recode on average 10 regions per year and country. We adjust our standard errors for clustering in the DHS surveys.

For the specification of child diarrhea, we furthermore include the month of interview in addition to the survey year. Several studies have shown that diarrhea shows high seasonal fluctuations (for example Chambers et al., 1979; Molbak et al., 1994, Curriero et al., 2001). In general diarrhea incidence is higher during the rainy than during the dry season. To be sure not to confuse seasonal with infrastructure effects we control for the month of the interview within a country.

Last, complementing the estimation of the direct health benefit of children's access to water and sanitation technologies, we also attempt to estimate potential positive health externalities, especially with regard to sanitation. A lack of access to improved sanitation is frequently associated with disposal of human feces in public spaces. Therefore, improvements in sanitation are also likely to the benefit of neighboring households. As a result, the true benefits of sanitation may be captured more accurately on a more aggregate village or city district level than at the household level.

To detect positive externalities, Glaeser et al. (2002) and Graham and Hahn (2005) proposed to compare the coefficient of the variable of interest at the individual level with the same coefficient at higher levels of aggregated data. In our specific setting here this implies that positive spill-over effects of sanitation can be inferred from larger coefficients estimated at the cluster relative to the household level (Glaeser et al., 2002; Graham and Hahn, 2005). We therefore estimate two equations:

$$CV_{icjt} = \alpha_1 + \beta_1 impSan_{icjt} + \gamma_1 impWat_{icjt} + \delta_1 X_{icjt} + \nu_{jt} + e_{icjt} \qquad (2)$$

$$\overline{CV}_{cjt} = \alpha_2 + \beta_2 \overline{impSan}_{cjt} + \gamma_2 \overline{impWat}_{cjt} + \delta_2 \overline{X}_{cjt} + \nu_{cjt} \qquad (3)$$

We first estimate the same equation as in equation (1), but for interpretational reasons only distinguish between surface water and open defecation and the use of any water and sanitation technology, respectively. In a second step, we average over observations *i* within a cluster *c* and run the regression on the village and city district sample means. If there are no positive externalities $\beta_1 = \beta_2$. In the presence of positive externalities the ratio (β_2 / β_1) should be larger than one. In that case we can cautiously conclude about positive externalities of sanitation infrastructure, with public health benefits of sanitation exceeding private health benefits. We follow the same calculation for access to water technologies. For the derivations and limitations of this approach see e.g. Graham and Hahn (2005).

We apply simple ordinary least squares (OLS) and Logit regression models for the binary variable of child diarrhea and a Weibull survival model for under-5 child mortality. We estimate both Logit regressions and simple OLS for the following reason: Because of limitations in computational power, we could only control for country-year fixed effects in the Logit and survival model. Our computational power is unfortunately not sufficient to estimate a Logit or survival model with the originally planned more than 1500 regional (sub-national) fixed effects. As a robustness check, we therefore also estimated simple OLS regressions with regional in comparison to country fixed effects in Appendix A2. The results of the regional (sub-national) and country fixed effects regressions are very similar. The 95% confidence intervals of the estimated coefficients of the two specifications overlap to a large extend (see Appendix A2).

4.2 Empirical Results

Table 3 shows our main results for child diarrhea. In column (1) of Table 3 we show the impact of improved water and sanitation technologies on child morbidity for the full sample, while we stratify the sample in rural and urban areas, respectively, in columns (2) and (3), and in Sub-Saharan African countries and other developing countries in columns (4) and (5). We analyze urban and rural households separately to get an idea of the impact of population density on the correlation between inadequate water, sanitation and health. We analyze Sub-Saharan African countries separately to other developing countries to get a better understanding of the situation in the countries that are lacking most behind MDG 4 (child health) and MDG 7 (water and sanitation infrastructure). For better comparison with the survival model of child mortality and for easy interpretation, all results are shown in odds ratios.

Table 3: Child diarrhea

	(1)	(2)	(3)	(4)	(5)
	total	rural	urban	SSA	OTHER
Latrine	0.929 ***	0.919 ***	0.924 ***	0.930 ***	0.933 ***
Conf. Int.	*(0.911, 0.949)*	*(0.898, 0.941)*	*(0.880, 0.968)*	*(0.900, 0.957)*	*(0.906, 0.960)*
Flush	0.871 ***	0.898 ***	0.828 ***	0.843 ***	0.859 ***
Conf. Int.	*(0.844, 0.899)*	*(0.850, 0.942)*	*(0.780, 0.872)*	*(0.792, 0.897)*	*(0.827, 0.893)*
Well/pump	0.925 ***	0.927 ***	0.882 ***	***0.989***	0.855 ***
Conf. Int.	*(0.901, 0.950)*	*(0.900, 0.954)*	*(0.809, 0.963)*	***(0.956, 1.023)***	*(0.817, 0.888)*
Piped	0.927 ***	0.927 ***	0.906 **	0.947 **	0.900 ***
Conf. Int.	*(0.900, 0.956)*	*(0.896, 0.960)*	*(0.833, 0.987)*	*(0.913, 0.9969*	*(0.857, 0.935)*
Female	0.902 ***	0.900 ***	0.906 ***	0.906 ***	0.898 ***
Age	0.977 ***	0.977 ***	0.976 ***	0.979 ***	0.975 ***
First born	0.929 ***	0.940 ***	0.914 ***	0.947 ***	0.912 ***
Birth interval	0.999 ***	0.999 ***	1.000 *	0.999 ***	0.999 ***
Vaccinated	1.238 ***	1.233 ***	1.259 ***	1.289 ***	1.182 ***
Educ. mother	0.981 ***	0.984 ***	0.977 ***	0.971 ***	0.985 ***
Age mother	0.959 ***	0.967 ***	0.947 ***	0.962 ***	0.956 ***
Age squared	1.001 ***	1.000 ***	1.001 ***	1.000 ***	1.001 ***
Mother married	0.924 ***	0.946 ***	0.880 ***	0.942 ***	0.890 ***
Household size	1.003 ***	0.999	1.010 ***	1.006 ***	0.998
Electricity	0.974 **	1.012	0.947 ***	0.874 ***	1.024
Radio	0.924 ***	0.935 ***	0.912 ***	0.928 ***	0.929 ***
TV	0.948 ***	0.971 *	0.916 ***	0.941 ***	0.945 ***
Fridge	0.888 ***	0.934 ***	0.882 ***	1.003	0.855 ***
Bike	0.984 *	0.961 ***	1.013	0.954 ***	0.998
Urban	yes	no	no	yes	yes
Country	yes	yes	yes	yes	yes
Year	yes	yes	yes	yes	yes
Season	yes	yes	yes	yes	yes
Observations	753239	503165	250074	332115	421124

*Notes: Logit Model. Reported coefficients are odds ratios. Year-country fixed effects. ***: p<0.01, **: p<0.05, *: p<0.10 Robust standard errors are clustered at the cluster level. For year-regional (sub-national) fixed effects estimations see Appendix A.2. Conf. Int.: 95% confidence interval. The left out category in all specifications is surface water and open defecation.*

A point estimate of 0.929 for latrines in column (1) implies that basic sanitation lowers the relative probability (odds) of diarrhea by about 7 % in comparison to children without access to any sanitation technology. According to our estimates, flush toilets would lower the odds of diarrhea by about 13 % and any kind of water technology by about 7 %. For reductions in odds of around 10%, the absolute risk reductions are very similar, which makes odds ratio easier to interpret.[10] We observe the highest positive effect of water and sanitation infrastructure on children's health in urban areas and Sub-Saharan Africa (SSA) for flush toilets. According to our estimates children in households with access to a flush toilet in those sub-groups show about 17% lower odds for diarrhea when compared to children using open defecation. Our control variables show the expected direction.

In line with the reviewed meta-studies, we find that improved sanitation has a somewhat higher positive effect on diarrhea than water infrastructure. In contrast to previous studies, the effect we estimate for sanitation is, however, significant smaller: about half of the previously reported estimates on improved sanitation, which showed reductions in diarrhea between 20% and 30%. While one may interpret our lower coefficients as evidence of measurement (attenuation) bias, an at least equally likely explanation is that the short-term effects typically observed in localized controlled trials should be expected to fade out over time as the quality of water and sanitation infrastructure deteriorates in the absence of external maintenance and support.

Last, all sub-samples show a considerable and statistically significant difference between basic and advanced sanitation technologies, whereas we cannot find a remarkable difference for basic and more advanced water infrastructure. This last finding was already previously stated by Esrey (1996). Cairncross and Kolsky (1997), however, challenge the former study both on data quality and methodological grounds, arguing that pushing towards the highest possible sanitation standards *"could lead to the unwarranted rejection of affordable low-cost sanitation for the poor in developing countries."* We did our best to be very careful in our statistical estimation, including as many as possible control variables[11] and 172 DHS surveys. The difference we find between simple and more advanced sanitation technologies is smaller than in the study of Esrey (1996), but still seems to be statistically significant. This, however, does not automatically mean – as presumed by Cairncross and Kolsky (1997) – that flush toilets are necessarily the first best

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[10] For example, a 13% percent reduction in the odds implies a reduction of diarrhea from 19% (e.g. for open defecation, see Figure 3) to 16.8 %, which is equal to an 11.5% reduction in diarrhea risk. The odds for 0.19 are 0.19/0.81=0.235. A reduction of 13% in the odds of 0.235 leads to odds of 0.202, which transfers into a diarrhea risk of 0.168 (0.202=0.168/0.832).

[11] Most importantly, note that piped water was controlled for in all specifications, which means that flush toilets do not pick up the effect of piped water into the household.

policy choice. With the general very high costs of sewage systems, low-cost sanitation might still come out to be the better option to invest in to achieve the maximum of diarrhea reduction given a fixed budget.

Table 4: Child mortality

	(1)	(2)	(3)	(4)	(5)
	total	rural	urban	SSA	OTHER
Latrine	0.954 ***	0.952 ***	0.936 **	***0.999***	0.867 ***
Conf. Int.	*(0.920, 0.982)*	*(0.921, 0.982)*	*(0.874, 0.999)*	*(0.965, 1.035)*	*(0.825, 0.911)*
Flush	0.862 ***	0.826 ***	0.839 ***	***0.972***	0.794 ***
Conf. Int.	*(0.813, 0.913)*	*(0.752, 0.907)*	*(0.766, 0.918)*	*(0.893, 1.059)*	*(0.734, 0.860)*
Well/pump	0.955 ***	0.927 ***	***1.056***	0.940 ***	***1.004***
Conf. Int.	*(0.922, 0.988)*	*(0.894, 0.962)*	***(0.929, 1.200)***	*(0.903, 0.979)*	***(0.926, 1.059)***
Piped	0.885 ***	0.894 ***	0.884 *	0.871 ***	0.906 ***
Conf. Int.	*(0.847, 0.924)*	*(0.851, 0.940)*	*(0.777, 1.006)*	*(0.824, 0.920)*	*(0.829, 0.962)*
Female	0.983	1.001	0.926 ***	0.978 *	0.996
First born	0.593 ***	0.583 ***	0.626 ***	0.676 ***	0.467 ***
Birth interval	0.988 ***	0.986 ***	0.993 ***	0.989 ***	0.986 ***
Breast fed	0.326 ***	0.323 ***	0.327 ***	0.421 ***	0.256 ***
Educ. mother	0.944 ***	0.952 ***	0.931 ***	0.959 ***	0.926 ***
Age mother	0.916 ***	0.927 ***	0.892 ***	0.932 ***	0.885 ***
Age squared	1.001 ***	1.001 ***	1.002 ***	1.001 ***	1.002 ***
Mother married	0.797 ***	0.842 ***	0.709 ***	0.811 ***	0.793 ***
Household size	0.945 ***	0.939 ***	0.959 ***	0.954 ***	0.910 ***
Electricity	0.851 ***	0.829 ***	0.905 ***	0.857 ***	0.850 ***
Radio	1.006	1.001	1.002	0.993	1.009
TV	0.888 ***	0.901 ***	0.881 ***	0.867 ***	0.930 ***
Fridge	0.826 ***	0.871 ***	0.846 ***	0.929	0.794 ***
Bike	1.030 **	1.041 **	0.991	1.044 ***	1.033
Urban	yes	no	no	yes	yes
Country	yes	yes	yes	yes	yes
Year	yes	yes	yes	yes	yes
Season	yes	yes	yes	yes	yes
P	0.708	0.710	0.703	0.766	0.604
Observations	796219	533905	262314	365515	430704

*Notes: Weibull Survival Model. Reported coefficients are hazard ratios. Year-country fixed effects. ***: p<0.01, **: p<0.05, *: p<0.10. Robust standard errors are clustered at the cluster level. Conf. Int.: 95% confidence interval. The left out category in all specifications is surface water and open defecation.*

In Table 4 we repeat the regressions shown in Table 3, but use child mortality, rather than diarrhea morbidity as the dependent variable. We estimate a survival model for under-5 mortality. The dependent variable in these regressions is hence an indicator variable which equals one if a child born within the 5 last years has died prior to the survey interview. In contrast to the previous table that reported the odds ratio of a logistic model, the reported coefficients of the survival model are hazard ratios. This means that a significant coefficient smaller than one means that the risk of dying in any given month until the age of five is reduced by about 1 minus the estimated coefficient. In other words, hazard ratios are the ratio between the probability to die with water and sanitation infrastructure relative to the probability to die without improved water and sanitation infrastructure.

Again, simple improved water access has only a small positive impact on child mortality, with a reduction of child mortality risk of about 5 % that is not even always statistically significant. Flush toilets and piped water seem to have a significant effect on reducing under-5 mortality. Flush toilets reduce the hazard rate or the risk of dying between the age of 0 and 5 by about 14 to 20 percent, and piped water by about 10 to 13 percent, depending on the sub-sample considered. Hence, and similar to diarrhea incidence, flush toilets seem to have a somewhat larger effect on child mortality than piped water. Surprisingly, although being very robust in all other sup-samples and specifications, a worrying result is that - at least until now – access to sanitation technologies does not seem to improve child mortality in Sub-Saharan African countries, even though effects on morbidity are significant; further research will be needed to better understand this result.

Last, since we find that the percentage reduction in child mortality is about equal to the reduction in diarrhea incidence (given the same water and/or sanitation technology and the same sub-sample), our results indicate that the mortality reduction is larger than a pure reduction in diarrhea incidence would indicate. Doing a quick back-of-the-envelope-calculation, we find on average strong support of the Mills-Reincke Multiplier. For example, if we assume that the effect of basic sanitation (latrine) was the same on diarrhea mortality than on diarrhea morbidity, child mortality should only be reduced by about 1 %. Diarrhea accounts for about 16% of total child mortality (WHO, 2007) and we estimated a reduction of about 7 % diarrhea incidence for basic sanitation. Hence, child mortality should only be reduced by about 1% (0.07 * 0.16), and not by about 4.5% as estimated and shown in Table 4 (column 1).

One possible explanation for this result is that improved water and sanitation infrastructure has a larger impact on the severity than on the incidence of diarrhea. Another explanation could be that water and sanitation infrastructure does not only decrease the number of children that die from diarrhea but also from other water related diseases (e.g. various worm infections). In addition, according to the Mills-Reincke Multiplier, a lower incidence of diarrhea also prevents child mortality from other diseases by strengthening the immune system of children.

In a next step we estimate two further specifications with different definitions of improved and unimproved water and sanitation access (see Table 1 and Table 5). First, improved water and sanitation are defined in line with the WHO/UNICEF definitions, where improved latrines (e.g. ventilated pit latrines) are counted as improved, but simple latrines as unimproved sanitation and where improved wells and springs (i.e. covered or protected) are counted as an improved but uncovered wells and springs are counted as an unimproved water source. We still keep open defecation and surface water separate, considering it as the lowest water/sanitation quality, whereas in the WHO/UNICEF definition no difference is made between open defecation and simple latrines and between surface water and traditional water sources (Table 1).

Second we distinguish whether the infrastructure is privately or publicly used (see again Table 1). It could well be that the water quality at the point of use (and hence its health impact) does not depend on the "extracting" technology but rather depends on whether the source is privately used or shared with other households. A private water source is usually closer to the household with less contamination during transport and storage. Similarly, the health impact of sanitation infrastructure might also increase if sanitation is only used by a single household, since free-rider problems of cleaning and hence hygienic maintenance might be less problematic than for public latrines and/or flush toilets.

Using the WHO/UNICEF classifications, our results do not change much, except that traditional latrines do not seem to have any impact on child mortality and that the impact of improved sanitation, including both flush toilets and modern latrines, is less than the health impact of flush toilets only (Table 5). Hence, even "unimproved" sanitation and water technologies have a positive (even if small) health impact and seem to be an improvement to surface water and open defecation. According to our estimates, it is therefore not clear why simple technologies and the total lack of technologies are often both classified as unimproved water and/or sanitation. Moreover, it seems that there is not a statistical significant difference of the impact of various water technologies on child diarrhea, independent of where we make the technology cut-off (according to our or the WHO definition). The big difference seems to be whether households use surface water (left-out category) or ground water (extracted by simple or more advanced technologies).

Table 5: Classifications and Positive Externalities

	child diarrhea				**child mortality**		
	odds ratio	**95% confidence interval**			**hazard ratio**	**95% confidence interval**	
	Technological Classification						
Latrine	0.929***	0.911	0.949		0.954***	0.927	0.982
Flush	0.871***	0.844	0.899		0.861***	0.813	0.913
Well	0.925***	0.901	0.950		0.954***	0.922	0.988
Piped	0.927***	0.900	0.956		0.884***	0.847	0.924
Observations	753,239				796,219		
	WHO/UNICEF Classification						
Basic sanitation	0.937***	0.918	0.958		0.962	0.917	1.010
Improved sanitation	0.886***	0.863	0.910		0.949***	0.917	0.982
Basic water	0.937***	0.911	0.964		0.948***	0.913	0.984
Improved water	0.917***	0.893	0.943		0.873***	0.833	0.926
Observations	753,239				796,219		
	Private/Public Classification						
Public sanitation	1.006	0.975	1.038		0.967**	0.939	0.996
Private sanitation	0.916***	0.895	0.938		0.869***	0.833	0.908
Public water	0.927***	0.902	0.953		0.955***	0.921	0.991
Private water	0.861***	0.834	0.889		0.924***	0.890	0.921
Observations	595,661				630,320		
	Household Level						
Latrine/flush	0.922***	0.904	0.941		0.942***	0.916	0.970
Well/piped	0.926***	0.903	0.951		0.940***	0.909	0.972
Observations	753,239				796,219		
	Cluster level						
Latrine/flush	0.837***	0.779	0.901		0.782***	0.727	0.841
Well/piped	0.958	0.879	1.043		1.017	0.934	1.109
Observations	61,605				83,745		

*Notes: Logit Model for diarrhea and Weibull Survival Model. Odds ratios and hazard ratios are reported. Year-country fixed effects. The set of control variables used in the estimation are identical to the ones specified in Table 3 and 4. For more details on the classifications see Table 1. The left out category in all specifications is surface water and open defecation.*** $p<0.01$, ** $p<0.05$, * $p<0.10$. Robust standard errors underlying confidence intervals are clustered at the cluster level.*

The analysis of private versus public access to water and/or sanitation technologies yields some additional interesting results. Whereas we found little difference between various water technologies, the gap is considerable and significant if we look at private versus public water access (independent of the water technology). Private access to any water technology decreases the relative likelihood of diarrhea by about 14%, whereas the odds of diarrhea are reduced by only about 7% if the household uses a public pipe and/or a public well/borehole. The same holds for households that share toilets with several other households: There is no significant impact of access to a public latrine/flush toilet on child diarrhea, and the effect on child mortality is only 3.3%, whereas private sanitation facilities reduce the odds of diarrhea by 10% and the likelihood of dying before the age of 5 by 13%.

In a final step, we try to get some indication whether positive externalities of water and sanitation infrastructure exist (Table 5, last two rows). The approach we follow is described in Section 4.1: if coefficients on access to water and sanitation technologies estimated at the cluster level are significantly larger than coefficients estimated at the household level, positive externalities might be prevalent. Households would hence not only benefit from their personal access to water and sanitation infrastructure but also from their neighbors' use of these technologies. According to our estimates, and for the case of both child diarrhea and mortality, it seems that the impact of access to sanitation is more than twice as large at the cluster as at the household level. This means that if villages or urban districts switch from open defection to some form of improved sanitation technology, the health improvement for the children is larger than the sum of the individual household effects. The last row of Table 5 also shows that similar results do not apply for water access, highlighting the important differences in health spillovers when it comes to comparing investments in water and sanitation technologies.

4.3 Discussion

Our estimation results in Table (3), (4) and (5) indicate

(1) that the impact of water and sanitation infrastructure on child mortality is larger than its effects driven by reductions in diarrhea, highlighting the importance of the Mills-Reincke

Multiplier when it comes to evaluating the health benefits of water and sanitation investments;

(2) that there are large positive health externalities of improved sanitation (but not for improved water infrastructure), implying that the need for public interventions should be larger in the realm of sanitation than when it comes to providing access to improved water technologies;

(3) that the access to water and sanitation infrastructure on health is considerably larger if only used by the household and not shared with other households, which certainly puts some extra pressure on public water and sanitation budgets;

(4) that even simplest water and sanitation technologies (officially often classified as unimproved water and sanitation access) show a modest but significant positive impact on children's health;

(5) that the estimated impact of sanitation on diarrhea is significantly smaller than suggested by previous studies in the area but that the impact of water infrastructure on children's health is still smaller and less significant than the impact of sanitation technologies.

This last point (5) certainly needs some further discussion. The first question is why we find lower effects of sanitation than the existing studies which found reductions in diarrhea that are double our estimates. The second question is why we find (but this time in line with other studies) that the impact of water technologies on children's health is smaller than the impact of improved access to sanitation.

We have four explanations for the first question. First, previous larger studies use a smaller set of controls, which may have induced a positive omitted variable bias in some of the reported observational studies, which we may have - at least partially - removed in our more tightly specified model. Second, when it comes to comparing the results of large-scale observational studies to local controlled trials, context and sustainability clearly make a difference. Individual studies designed mainly for the purpose of evaluating sanitation infrastructure are likely to find larger effects due to the fact that technologies were newly introduced and closely monitored. Large positive health impacts of water and sanitation in the short term are likely to weaken over time in the absence of proper maintenance and due to general infrastructure deterioration. In contrast, our estimates are not intervention based and do hence – as well as other cross-sectional studies – estimate more medium to long-term effects of sanitation. Moreover, interventional studies can better control for the actual use of infrastructure whereas our study should rather be seen as a measure of the impact of the access to certain water and sanitation technologies. Infrastructure that is reported in the DHS surveys by households may or may not be used by all family members or all of the time.

Third, epidemiological studies often analyze the health impact of village interventions, where entire villages switch from poor to improved sanitation coverage. In contrast, in our main specification we compare the differences in child health of households with to households without access to improved sanitation. If positive health externalities of improved sanitation exist, as our estimates in Table 5 imply, epidemiology studies include those positive externalities whereas this is not taken up by a study at the household level. Our cluster level estimates in Table 5, do indeed show effects of sanitation more closely in magnitude to the once estimated in previous studies.

Last, in a cross-sectional study based on data sets not specifically designed to estimate the impact of water and sanitation infrastructure on child morbidity, misclassification of infrastructure is more likely than in epidemiological studies, which will mechanically bias the estimated coefficients towards zero. While it is hard to quantify the exact magnitude of this effect, the main reason for choosing the simplest possible coding rules, i.e. dividing water and sanitation access into three broad classes, was to keep the likelihood of miscoding as small as possible. While one may argue whether or not one type of latrine is better than another one, it is hard to argue that latrines are on average not better than having no toilet at all. Thus, while there clearly is some degree of miscoding in the data, we argue that the fraction of the total variance generated by this kind of error is likely small relative to the true variation observed in the underlying variables.

Similar to other studies, we find that the impact of simple and improved water technologies is somewhat smaller than the impact of sanitation infrastructure. This result certainly does not question the importance of water quality for health, but questions the relevance of improved water infrastructure without improved hygiene conditions. This hypothesis is supported by our estimates on private versus shared water access (Table 5), where we show significant differences in health impacts between private and public water access. Several studies have shown the large positive impact of water treatment at point of use, which directly improves water quality. In contrast, wells or public standpipes do often not lead to improved water quality, given the "traditional" water transport and storage in most developing countries.[12] In contrast, it appears that sanitation infrastructure, although we cannot control for quality and complementary improved hygiene behavior, has a somewhat larger impact on children's health. One possible explanation is that sanitation infrastructure with low (hygienic) conditions is not used by the population whereas this is not the case for modern water infrastructure, which is used in any case for convenience and time savings.

Another reason for the relatively strong results on sanitation may be the more direct link between private action and preferences and technological choice. While water access if often provided through communities, toilets generally require some degree of private initiative and investment. The observed households with improved sanitation might thus be the self-selected group of respondents with sufficiently high preference for health and/or better hygienic practices and/or higher income to invest in improved sanitation. While we tried to control for this income and health knowledge and preference effect by controlling for maternal education, household structure and assets as well as child vaccination practices, we are clearly not able to completely rule out residual selection or omitted variable bias concerns.[13]

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[12] We also interacted sanitation and water infrastructure in a further specification. We did not find any significant results indicating that complementarities between water and sanitation technologies do not exist.

[13] As a small robustness check, to analyze the effect of (omitted) income on the estimated coefficients on sanitation, we estimated the model as presented in Table 3 and 4 again, but first without any assets, then with some basic assets, then with all assets used in the final specification in this paper, and in a last step with additional assets (which reduces the sample size considerably). We observe that the estimated effects decrease significantly when we move from no to few assets, but do not change much when we move from few assets to more assets. Moreover, the observed changes are not considerably larger for sanitation technologies relative to water technologies. Estimation results of these specifications are available from the authors on request.

5. Summary and Conclusion

In this paper, we use a comprehensive data set from more than 70 developing countries over the period from 1986 to 2008 to identify the effect of different technologies of improved water and sanitation on child morbidity and mortality in rural and urban areas, with a particular focus on Sub-Saharan African countries. This is – to our knowledge – the first study that has attempted to combine a large number of population based surveys to estimate a global average treatment effect of water and sanitation infrastructure.

The results of this study show that the potential health benefits generated by improvement in water and sanitation infrastructure are considerable. On average, and for the total sample, we find that access to advanced water and sanitation technologies reduces the odds of suffering from diarrhea among children under five by 7.3 and 12.9 percent, respectively, and also find substantial and similar reductions in the under-5 mortality risk, which indicates the existence of the Mills-Reinke Multiplier. In addition to these reductions in health risk at the household level we also find strong evidence for positive health spillovers of access to improved sanitation at the village and urban district level, which we do not find for access to water infrastructure.

In the light of the results presented in this paper the current focus of international donors on water infrastructure appears slightly surprising. One reason for this preference is certainly the additional (and often large) time savings - and hence economic benefits - that come along with improved water infrastructure that are less clear for sanitation infrastructure. From an individual economic perspective, gaining access to improved water may seem preferable to gaining access to improved sanitation. From a public health perspective, however, sanitation infrastructure should in our opinion receive more attention, as the private health benefits to sanitation seem to be at least equal to the benefits of water infrastructure, while the social health spillovers are likely substantially larger.

Optimal policy clearly does not only depend on the marginal health benefit, but also on the respective policy cost. This aspect will be the focus of a second part of this research project, where we provide a detailed analysis of the cost-benefit ratios of different technologies for achieving MDG 7 and MDG 4.

Appendix:

A.1 Country list, survey years and observations

#	Country	Year	Obs.	#	Country	Year	Obs.
1	Angola	2006	1420	87	Lesotho	2004	3568
2	Armenia	2000	1669	88	Liberia	1986	3180
3	Armenia	2005	1366	89	Liberia	2006	5562
4	Azerbaijan	2006	1956	90	Liberia	2008	4111
5	Bangladesh	1993	3845	91	Madagascar	1992	4901
6	Bangladesh	1996	6169	92	Madagascar	1997	3670
7	Bangladesh	1999	6808	93	Madagascar	2003	5272
8	Bangladesh	2004	6897	94	Malawi	1992	4481
9	Bangladesh	2007	5545	95	Malawi	2000	11584
10	Benin	1996	2586	96	Malawi	2004	10744
11	Benin	2001	5150	97	Mali	1987	3199
12	Benin	2006	15790	98	Mali	1995	5992
13	Bolivia	1989	2479	99	Mali	2001	12776
14	Bolivia	1993	3432	100	Mali	2006	14081
15	Bolivia	2003	9943	101	Mexico	1987	3759
16	Burkina Faso	1992	5646	102	Moldova	2005	1406
17	Burkina Faso	1998	5692	103	Morocco	1987	4432
18	Burkina Faso	2003	10416	104	Morocco	1992	5029
19	Burundi	1987	3799	105	Morocco	2003	5899
20	Cambodia	2000	6834	106	Mozambique	1997	4061
21	Cameroon	1991	3271	107	Mozambique	2003	9853
22	Cameroon	1998	2126	108	Namibia	1992	3842
23	Cameroon	2004	6147	109	Namibia	2000	3622
24	CAR	1994	2792	110	Namibia	2006	4781
25	Chad	1996	6557	111	Nepal	1996	4355
26	Chad	2004	5031	112	Nepal	2001	6534
27	Colombia	1986	2247	113	Nepal	2006	5461
28	Colombia	1990	3361	114	Nicaragua	1997	8160
29	Colombia	1995	4983	115	Nicaragua	2001	4492
30	Colombia	2000	4611	116	Niger	1992	6162
31	Colombia	2004	13492	117	Niger	1998	4433
32	Comoros	1996	1112	118	Niger	2006	9009
33	Congo, Dem. Rep.	2007	8619	119	Nigeria	1990	7560
34	Congo, Rep.	2005	4337	120	Nigeria	1999	3380
35	Cote d'Ivoire	1994	3968	121	Nigeria	2003	5500
36	Cote d'Ivoire	1998	1831	122	Pakistan	1990	6204
37	Dominican Republic	1986	3283	123	Pakistan	2006	8520
38	Dominican Republic	1991	3861	124	Paraguay	1990	3758
39	Dominican Republic	1996	3673	125	Peru	1986	2820
40	Dominican Republic	1999	381	126	Peru	1991	7919
41	Dominican Republic	2002	6202	127	Peru	1996	15739
42	Dominican Republic	2007	4799	128	Peru	2000	12708
43	Egypt, Arab Rep.	1988	8047	129	Peru	2003	1937
44	Egypt, Arab Rep.	1992	8453	130	Philippines	1993	8796
45	Egypt, Arab Rep.	1995	11024	131	Philippines	1998	7713
46	Egypt, Arab Rep.	2000	10820	132	Philippines	2003	6567
47	Egypt, Arab Rep.	2003	6218	133	Rwanda	1992	5313
48	Egypt, Arab Rep.	2005	12790	134	Rwanda	2000	7796
49	Egypt, Arab Rep.	2008	9981	135	Rwanda	2005	8509

50	Ethiopia	1992	10493		136	Senegal	1986	4230
51	Gabon	2000	4009		137	Senegal	1992	5549
52	Ghana	1988	4081		138	Senegal	1997	6880
53	Ghana	1993	2179		139	Senegal	2005	10310
54	Ghana	1998	3273		140	South Africa	1998	4840
55	Ghana	2003	3752		141	Sri Lanka	1987	3887
56	Ghana	2008	2800		142	Sudan	1989	5538
57	Guatemala	1987	4112		143	Swaziland	2006	2676
58	Guatemala	1995	9601		144	Tanzania	1991	7797
59	Guatemala	1998	4653		145	Tanzania	1996	6689
60	Guinea	1999	3063		146	Tanzania	1999	2961
61	Guinea	2005	6131		147	Tanzania	2004	8056
62	Guyana	2005	702		148	Thailand	1987	3379
63	Haiti	1994	1865		149	Togo	1988	2685
64	Haiti	2000	6487		150	Togo	1998	3902
65	Haiti	2005	5430		151	Trinidad&Tobago	1987	1790
66	Honduras	2005	8551		152	Tunisia	1988	3831
67	India	1992	47833		153	Turkey	1993	3489
68	India	1998	32765		154	Turkey	1998	3181
69	India	2005	47075		155	Turkey	2003	3871
70	Indonesia	1987	4870		156	Uganda	1988	4891
71	Indonesia	1991	14027		157	Uganda	1995	5666
72	Indonesia	1994	16281		158	Uganda	2000	6702
73	Indonesia	1997	16744		159	Uganda	2006	8024
74	Indonesia	2002	14116		160	Ukraine	2007	1153
75	Indonesia	2007	16043		161	Uzbekistan	1996	1300
76	Jordan	1990	1827		162	Vietnam	1997	1774
77	Jordan	1997	6267		163	Vietnam	2002	1286
78	Jordan	2002	5460		164	Yemen, Rep.	1991	6889
79	Jordan	2007	8572		165	Zambia	1992	6270
80	Kazakhstan	1995	789		166	Zambia	1996	7118
81	Kazakhstan	1999	1186		167	Zambia	2001	6643
82	Kenya	1988	6468		168	Zambia	2007	6015
83	Kenya	1993	5934		169	Zimbabwe	1988	3206
84	Kenya	1998	3443		170	Zimbabwe	1994	2422
85	Kenya	2003	5430		171	Zimbabwe	1999	3475
86	Kyrgyz Republic	1997	1117		172	Zimbabwe	2005	5070

Table A.2 Child diarrhea – OLS, Regional and Country Fixed Effects

	total		SSA		OTHER	
	regional fixed	country fixed	regional fixed	country fixed	regional fixed	country fixed
Latrine	-0.0073***	-0.0099***	-0.0082***	-0.0112***	-0.0065***	-0.0083***
Conf. Int.	*(-0.0101,-0.0045)*	*(-0.0126,-0.0071)*	*(-0.0124,-0.0041)*	*(-0.0153,-0.0070)*	*(-0.0102,-0.0028)*	*(-0.0120,-0.0047)*
Flush	-0.0134***	-0.0157***	-0.0184***	-0.0228***	-0.0147***	-0.0168***
Conf. Int.	*(-0.0172,-0.0096)*	*(-0.0195,-0.0119)*	*(-0.0266,-0.0101)*	*(-0.0306,-0.0148)*	*(-0.0191,-0.0102)*	*(-0.0212,-0.0123)*
Well/pump	-0.0098***	-0.0114***	***-0.0042***	***-0.0020***	-0.0161***	-0.0217***
Conf. Int.	*(-0.0135,-0.0061)*	*(-0.0227,-0.0076)*	***(-0.0090,0.0004)***	***(-0.0070,0.0028)***	*(-0.0218,-0.0102)*	*(-0.0276,-0.0158)*
Piped	-0.0088***	-0.0112***	-0.0093***	-0.0071**	-0.0096***	-0.0155***
Conf. Int.	*(-0.0129,-0.0047)*	*(-0.0124,-0.0070)*	*(-0.0151,-0.0035)*	*(-0.0131,-0.0011)*	*(-0.0157,-0.0035)*	*(-0.0216,-0.0094)*
Female	-0.0132***	-0.0134***	-0.0139***	-0.0140***	-0.0127***	-0.0128***
Age	-0.0029***	-0.0028***	-0.0029***	-0.0029***	-0.0028***	-0.0028***
First born	-0.0070***	-0.0093***	-0.0057**	-0.0077***	-0.0079***	-0.0108***
Birth interval	-0.0000***	-0.0000***	-0.0000***	-0.0001***	-0.0000	-0.0000***
Vaccinated	0.0249***	0.0231***	0.0353***	0.0325***	0.0153***	0.0146***
Educ. Mother	-0.0018***	-0.0022***	-0.0029***	-0.0039***	-0.0013***	-0.0015***
Age mother	-0.0058***	-0.0061***	-0.0050***	-0.0061***	-0.0065***	-0.0062***
Age squared	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
Married	-0.0148***	-0.0114***	-0.0133***	-0.00763***	-0.0170***	-0.0177***
HH size	0.0001	0.0002**	0.0004**	0.0008***	-0.0003*	-0.0002
Electricity	-0.0034**	-0.0037**	-0.0126***	-0.0174***	0.0009	0.0029
Radio	-0.0092***	-0.0104***	-0.0089***	-0.0116***	-0.0083***	-0.0083***
TV	-0.0055***	-0.0063***	-0.0059**	-0.0061**	-0.0064***	-0.0071***
Fridge	-0.0118***	-0.0128***	-0.0016	0.0017	-0.0151***	-0.0177***
Bike	-0.0012	-0.0017	-0.0076***	-0.0062***	0.0022	-0.0003
Urban	yes	yes	yes	yes	yes	yes
Country		yes		yes		yes
Region	yes		yes		yes	
Year	yes	yes	yes	yes	yes	yes
Season	yes	yes	yes	yes	yes	yes
Observations	753239	753239	332115	332115	421124	421124

*Notes: OLS Model. Reported coefficients are marginal effects. Year-regional fixed effects. ***: p<0.01, **: p<0.05, *: p<0.10 Robust standard errors are clustered at the cluster level.*

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