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Water, Sanitation and Child Health
Evidence from Subnational Panel Data in 59 Countries

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Abstract

Water, sanitation and hygiene (WASH) investments are widely seen as essential for improving health in early childhood. However, the experimental literature on WASH interventions identifies inconsistent impacts on child health outcomes, with relatively robust impacts on diarrhea and other symptoms of infection, but weak and varying impacts on child nutrition. In contrast, observational research exploiting cross-sectional variation in water and sanitation access is much more sanguine, finding strong associations with diarrhea prevalence, mortality and stunting. In practice, both literatures suffer from significant methodological limitations. Experimental WASH evaluations are often subject to poor compliance, rural bias, and short duration of exposure, while cross-sectional observational evidence may be highly vulnerable to omitted variables bias. To overcome some of the limitations of both literatures, we construct a panel of 442 subnational regions in 59 countries with multiple Demographic Health Surveys. This large subnational panel is used to implement difference-in-difference regressions that allow us to examine whether longer term changes in water and sanitation at the subnational level predict improvements in child morbidity, mortality and nutrition. We find results that are partially consistent with both literatures. Improved water access is statistically insignificantly associated with most outcomes, although water piped into the dwelling predicts reductions in child stunting. Improvements in sanitation predict large reductions in diarrhea prevalence and child mortality, but are not associated with changes in stunting or wasting. We estimate that sanitation improvements can account for just under 10% of the decline in child mortality from 1990-2015.

Keywords: Sanitation; Water; Child Health; Child Mortality
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1. Introduction

The past decade has witnessed a renewed global interest in the health impacts of improved water, sanitation and hygiene (WASH). The Millennium Development Goal (MDG) era saw solid progress in WASH indicators, with almost 2 billion people gaining access to improved water and/or sanitation. However, some 700 million still lack access to improved water, and approximately 2.5 billion people do not use an improved sanitation facility; of these, 1 billion people still practice open defecation (WHO & UNICEF 2014).

The persistence of these problems is a significant public health concern. Human feces are an important reservoir for a range of pathogenic bacteria, as well as soil transmitted helminths (STHs), that can cause diarrhea, environmental enteric disorder (EED), trachoma and other morbidities prevalent in young children (Mara et al. 2010). Diarrhea and EED are also thought to be important determinants of malnutrition in young children (Checkley et al. 2008; Humphrey 2009). Moreover, many of these morbidities, in combination with poor nutrition, often prove fatal if not properly treated, suggesting that poor WASH conditions could be a major underlying risk factor for child mortality (Mara et al. 2010).

Yet, despite several plausible biological pathways, the empirical evidence linking WASH conditions to child health outcomes is both limited and, for some health outcomes, inconsistent. Evidence from cluster randomized control trials (RCTs) and case control studies suggests reasonably strong and consistent impacts of WASH interventions on diarrhea incidence (Fewtrell et al. 2005; Freeman et al. 2017; Wolf et al. 2014) and STH infections (Freeman et al. 2017; Strunz et al. 2014; Ziegelbauer et al. 2012). However, RCT estimates of WASH impacts on child stunting and wasting are often statistically insignificant (Dangour et al. 2013; Freeman et al. 2017). In contrast, observational research typically finds very strong associations with child health and nutrition outcomes. A range of historical studies link reductions in child mortality to WASH improvements in the 19th and early 20th centuries (Cutler and Miller 2005;
Woods, Watterson and Woodward 1989). For 71 contemporary developing countries, a pooled multivariate regression analysis of Demographic Health Survey (DHS) data found that household water and sanitation facilities were strongly associated with lower risk of child mortality, diarrhea and stunting (Fink, Günther and Hill 2011). Various papers by Spears and colleagues also use DHS data to link child mortality, stunting and anemia to toilet use within the broader community, on the grounds that open defecation has negative inter-household externalities on child health (Coffey, Geruso and Spears 2016; Geruso and Spears forthcoming; Spears 2013a). This research also uncovers evidence that open defecation may have more harmful effects in densely populated regions, such as South Asia (Hathi et al. 2017; Spears 2013a).

These different literatures therefore tend to find reasonably strong evidence of WASH impacts on diarrhea, but impacts on child nutrition and mortality outcomes remain uncertain. In practice, both the experimental and observational literatures have important methodological limitations. Several commentaries raise concerns about the quality of the RCT evidence, highlighting issues such as the low adoption of WASH interventions and the short duration of exposure to WASH treatments (Headey 2016; Huda et al. 2012; Schmidt 2014). Yet observational studies also have inherent limitations. Most use repeated cross-sections where WASH exposure is not clearly linked to any specific intervention, and therefore likely to be strongly correlated with a range of confounding factors, including parental knowledge and preferences, cultural norms, local economic development, historical infrastructural investments, governance quality, and environmental factors such as population density (Coffey, Spears and Vyas 2017; Davis 2004; Ndikumana and Pickbourn 2017). Adequately controlling for these inter-household and inter-community differences with cross-sectional survey data is likely to be extremely difficult, if not impossible. As a result, it is difficult to argue that these studies convincingly inform the more policy-relevant question posed by experimental studies: do changes in WASH exposure lead to changes in child health outcomes?
In this study, we use a subnational panel data set constructed from aggregated DHS to address this important policy question. Although the DHS are not a panel of children or households, they are a panel of subnational regions, the smallest geographical unit at which the DHS are representatively sampled. Moreover, DHS data on child health, sanitation and other determinants of child health have been collected within countries in successive DHS waves over relatively long periods of time. These two features allow us to construct a rich subnational panel covering 442 subnational regions in 59 countries with multiple DHS rounds, resulting in approximately 1,500 observations for mortality, diarrhea prevalence, and fever prevalence, and 1,176 observations for stunting and wasting. This data structure has several key advantages.

First and foremost, it permits controls for panel fixed effects, thereby netting out the important time-invariant confounding factors listed above. This means that we estimate difference-in-difference (DID) regressions that control for any non-time varying subnational characteristics, regardless of whether they are observable in the data.

Second, subnational data exploit the growing importance of decentralized governance in developing countries. The importance of state level changes in WASH in India and Nepal has been well documented (Coffey et al. 2016; Coffey et al. 2017; Spears 2013b), but there are many other subnational WASH success stories. In Ethiopia, for example, the SNNP regional government implemented an exceptionally rapid expansion of community-led total sanitation over 2003-05 prior to a national scale-up in 2006 (Bibby and Knapp 2007).

Third, while changes in WASH access are not random in these data, DID regressions restrict endogeneity concerns to time-varying confounding factors, which we may be better able to adequately control for by including time-varying indicators from the DHS and other sources. Moreover, panel data permit us to assess to some extent—by exploring associations between the WASH variables and other likely determinants of child health and through parallel trends exercises—how likely it is that two of the likely sources of potential bias are driving the results.
Finally, in addition to addressing issues of internal validity, the geographical spread of DHS data allows us to speak to important issues of external validity, particularly whether the health benefits of expanded WASH access vary with population density (Hathi et al. 2017) or child age (Alderman and Headey 2018). Our results suggest that changes in subnational sanitation coverage predict sizeable improvements in child morbidity and mortality. A one percentage point increase in sanitation coverage is associated with a decrease in under-5 child mortality of between 0.34 and 0.38 per 1,000 births and a decrease in the prevalence of diarrhea during the two weeks preceding the survey of between 0.056 and 0.12 percentage points. In contrast, we find no statistically significant association between sanitation coverage and stunting or wasting and the association with the prevalence of fever is highly sensitive to the specification used. Combining our estimates with the observed increase in global sanitation coverage between 1990-2015 indicates that changes in sanitation coverage can potentially explain 8.2% of the total observed decline in under-5 mortality over the same period. Unlike sanitation, we find little evidence that increases in access to any improved water source—according to the official definition—are statistically significantly associated with health and nutrition improvements. However, water piped into the dwelling predicts significant reductions in child stunting, suggesting the official definition of “improved water” may need to be revisited.

The remainder of this paper is structured as follows. Section 2 reviews our materials and methods. Section 3 presents our results, and Section 4 concludes.

2. Materials and Methods

2.1 Data

The DHS have now been implemented for approximately three decades and used extensively to analyze the main health outcomes in this study, child mortality, morbidity and nutrition. As a result, many countries have multiple DHS waves, with each wave a cross-section of households rather than a panel. However, because the DHS have complex survey designs to achieve subnational representativeness, they
can be aggregated into a panel of subnational units (states/provinces, districts, ecological zones or simply rural and urban areas). Over time these subnational units have sometimes changed within countries to become more spatially disaggregated, but fortunately DHS STATCOMPILER (USAID and ICF-International 2017) can be used to construct a spatially consistent panel defined by earlier classifications of subnational units. This allows us to construct a panel with multiple rounds that spans relatively long periods of time.¹ Note, however, that the panel is highly unbalanced in the time dimension, both in terms of the number of surveys per country and the time interval between survey (see Table S1 for survey details). Our final dataset is comprised of data from 218 DHS rounds in 59 countries drawn from four major regions/continents (Latin America, Africa, Asia, and Europe and Central Asia), with well over 1000 observations for our main outcomes of interest.

While the subnational STATCOMPILER panel we use is advantageously large and long, a potentially important disadvantage is that it does now allow for flexible age disaggregation in nutrition and health indicators, or allow us to restrict the data used to calculate subnational child mortality rates.² To test sensitivity to these variations we therefore use survey weights to aggregate DHS microdata into two separate subnational panels to examine nutrition and morbidity associations by child age, and to vary the recall period used to estimate the child mortality rates.³ These additional subnational panels cover most of the observations in our main STATCOMPILER dataset, and we show in Supplemental results that the change in sample does not affect our results in any material fashion. Further details of all three subnational panels are provided in Supplement A.⁴

2.1.1 Dependent variables

The primary child health outcomes in our analysis were selected based on the outcomes typically used in the WASH literature summarized in Section 1: the under-5 mortality rate (per 1,000 births) based on a 10-

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¹ The average length between the first and last survey in a country is 14 years, and the average gap between successive surveys is 5 years.
² DHS computes subnational mortality rates using data from the ten years preceding each survey.
³ We thank an anonymous referee for making these suggestions.
⁴ Supplement Table S2 provides the full list of DHS in each of the three data sets.
year recall period, diarrhea prevalence in the previous two weeks, and stunting prevalence (HAZ<-2 standard deviations). We also investigate two secondary outcomes, the results for which are reported in the Appendix: the prevalence of child wasting (weight-for-height Z score< -2 standard deviations), which is often included in experimental and observational studies on WASH; and fever prevalence in the previous two weeks as an additional marker of infections that might be influenced by WASH status.

2.1.2 Drinking water and sanitation variables

A priori, it is not clear which types of WASH technologies matter most for improving specific child health outcomes. Some of the literature cited in Section 1 concludes that more sophisticated WASH technologies have larger health impacts, while others argue that the introduction of basic WASH technologies can yield large benefits. Gunther and Fink (2010) compare and contrast several drinking water and sanitation definitions, including private/public (shared) and technology-based definitions, and Spears (2013a) implicitly argues that the health benefits of moving from open defecation to any form of toilet use (fixed point defecation) is the most critical step on the sanitation ladder because of the primary importance of negative externalities across households. Importantly, our use of subnational data captures both household level effects and community level externalities.

In our main specifications, we first focus on the use of “any toilet” and “any improved water,” where the latter follows the definition of the WHO/UNICEF Joint Monitoring Program (JMP). However, in robustness tests we disaggregate these measures. Sanitation is split into an improved category (flush/pour toilets, pit latrines with a slab or ventilated, composting toilet), and an unimproved category consisting mostly of basic pit latrines. “Any improved water” is disaggregated based on a modification of the technological classification in Gunther and Fink (2010), which distinguishes between “piped to home” (dwelling, yard), “piped to other” (public tap/standpipe, neighbor), and “other improved” as a third category comprised of tubewells/boreholes and protected wells/springs.

2.1.3 Control variables
Our control variables were selected based on an assessment of commonly cited determinants of reductions in diarrhea, stunting and mortality. These consist of subnational DHS-based indicators as well as a series of national level controls for variables not well captured in the DHS, which we sourced from the World Bank (2017). DHS measures include housing characteristics, maternal education, demographic indicators, and health services. At the national level we control for log GDP per capita, cereal yields (a food security proxy), health expenditures as a percent of GDP, foreign aid, urbanization, population, and malaria incidence. In some specifications we also use log population density (people per square km) measured at the subnational level as an interaction variable. This indicator draws on census data compiled by Hathi et al. (2017) supplemented by subnational population density estimates from the GRUMP (2008) database. Summary statistics for the control variables are presented in Supplement Table S3.

2.2 Methods

To estimate the impacts of changes in sanitation and water access on child health we employ sub-national region fixed effects models that take the following form:

\[ H_{i,j,t} = \beta_w W_{i,j,t} + \beta_x X_{i,j,t} + \beta_z Z_{j,t} + \mu_{i,j} + \alpha_t + \gamma_{j,t} + e_{i,j,t} \]  

(1)

In this model \( H \) is a health indicator for subnational unit \( i \) in country \( j \) at time \( t \), \( W \) is a vector of corresponding water and sanitation indicators, \( X \) is a vector of subnational region control variables from the DHS, \( Z \) is a vector of country level control variables, \( \mu_{i,j} \) is a vector of subnational region fixed effects, \( \alpha_t \) is a full set of year fixed effects, and \( \gamma_{j,t} \) are a set of either survey fixed effects or continent-specific linear time trends. We estimate three variations of (1). First, we estimate a naïve fixed effects model that only controls for year fixed effects and the continent-specific time trends. Second, we estimate a model that additionally includes subnational and country-level control variables (\( X \) and \( Z \)). Finally, we estimate a more stringent model that controls for survey fixed effects instead of the continent-specific time trends. The

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5 To ensure that changes in samples driven by the availability of control variables included in \( X \) and \( Z \) are not driving our empirical results, we impute all missing values for the controls to zero and include dummy variables for whether the subnational region had a missing value for a given control variable. We show the results are robust to alternative methods for dealing with missing controls in Section E of the Supplement.
survey fixed effects absorb any variation in a survey year that is common across all subnational regions in the country. This is advantageous in that it absorbs unobservable national level shocks, as well as survey-specific anomalies such as changes in survey timings, which may be important for seasonal indicators such as wasting, diarrhea and fever prevalence. A potential disadvantage, however, is that these fixed effects will also absorb useful and uncontaminated variation in the indicators of interest. For all regressions we estimate and report coefficient p-values based on cluster robust standard errors that allow for arbitrary within-subnational region correlation in the errors.

3. Results

3.1 Descriptive statistics

Table 1 reports various descriptive statistics for our outcomes and WASH measures (Supplement Table S3 does the same for the control variables, the other potential determinants of the main outcomes that we use as dependent variables in falsification checks, and the age-disaggregated mortality measures, and Supplement Table S4 does the same for the outcomes generated from the aggregated DHS microdata). The second column reports the number of observations by indicator. We have well in excess of 1000 observations for all indicators, with over 1400 observations for mortality and morbidity estimates (a number of DHS do not record nutrition outcomes). The third column reports the intra-country variation in each indicator (the share of total variation within the panel not accounted for by country-level fixed effects) to demonstrate the importance of subnational disaggregation in key variables. Amongst child health outcomes subnational variation accounts for between 36.8% and 67.9% of the total variation. Similarly, there is substantial intra-country variation in the WASH measures, suggesting that there is considerable value to using subnational rather than country level regressions. The other moments (mean, 25th, 50th, and 75th

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6 The potential for survey fixed effects to absorb too much variation in the associations of interest arises from situations in which some regions in a country happen to similar de-meaned values, despite having different levels or trends in the outcomes and WASH indicators.

7 Though allowing for arbitrary within-subnational region correlation in the error terms should be conservative, the results are not sensitive to clustering standard errors at the country-level.

8 Among the subnational control variables there is also important intra-country variation: country fixed effects typically account for just one-third to two-thirds of total variation in these controls.
percentiles) illustrate that there is cross-subnational region variation in the outcomes and WASH indicators, as expected given the highly varied levels of development in the sample. Though not observable in the summary statistic tables, there is also important variation in the outcomes and in WASH coverage over time within subnational regions. The largest improvements in toilet use occurred in the SNNP and Amhara regions of Ethiopia, and various regions in Nepal, Bangladesh and Cambodia. Interestingly, all are well known adopters of Community Led Total Sanitation, which typically focuses on catalyzing construction of simple pit latrines. Cambodia has also seen a rapid expansion in access to improved water, as have several very arid subnational regions in Chad, Burkina Faso, Niger and Kenya that began with very poor access and saw marked improvements in access to improved tubewells. Overall, there appears to be ample variation in water and sanitation access and in the outcomes, creating the opportunity for a quasi-experimental DID analysis.

3.2 Core results

Have these changes in sanitation and water translated into improved child health outcomes? Figures 1 and 2 plot the mortality, diarrhea, stunting, and fever outcomes against sanitation coverage and access to improved water, respectively. For each health outcome, the left panel reports relationships in levels (cross-sectional variation), while the right panel reports these relationships for differences between the earliest completed DHS and the most recent completed DHS in each region (temporal variation). The figures therefore give some insight into the importance of netting out subnational fixed effects through differencing. For sanitation coverage the relationships are generally negative and relatively steep in both levels and differences. However, the relationships between improved water and health outcomes are markedly weaker in differences, suggesting that the levels relationships may be confounded by fixed subnational region-level characteristics.

To investigate these associations more thoroughly, we turn to more rigorous DID models with and without adjustments for time-varying confounders and survey fixed effects. Table 2 displays the results of
these regressions for under-5 mortality, diarrhea, and stunting, while Appendix Table 4 does the same for wasting and fever.

Consistent with Figure 1, the multivariate results in Table 2 continue to suggest there is an important negative relationship between changes in sanitation coverage and changes in child mortality. In the unadjusted model, a one percentage point increase in sanitation coverage is associated with a decrease in the under-5 mortality rate of 0.804 deaths per 1,000 births (p-value <0.001). Adding the extensive set of controls somewhat attenuates the sanitation coefficient, but a meaningfully large and statistically significant relationship remains: a one percentage point increase in sanitation coverage predicts a reduction in under-5 child mortality of 0.381 deaths per 1,000 births (p-value 0.011). Using survey fixed effects in place of the global region trends barely changes the estimate, with a one percentage point increase in sanitation predicted to reduce under-5 mortality by 0.343.

We also find evidence of a statistically significant relationship between sanitation coverage and diarrhea prevalence, albeit with some sensitivity to the inclusion of survey fixed effects. Without controls, a one percentage point increase in sanitation coverage is associated with a decrease in diarrhea prevalence of 0.163 percentage points. Adding controls reduces this association to 0.121, but both estimates have p-values below 0.001. Interestingly, adding survey fixed effects reduces the magnitude of the diarrhea-sanitation association to -0.056, though it remains statistically significant at the 10% level (p-value 0.054). For fever (Table 4 in the Appendix), the estimate from the unadjusted and core models suggest that a one percentage point increase in sanitation coverage predicts a decrease in fever prevalence of 0.193 and 0.163 percentage points (p-values <0.001), respectively. However, adding survey fixed effects decreases the size of the association to -0.042 and renders it statistically insignificantly different from zero (p-value 0.272). One explanation of the sensitivity of the diarrhea and fever results to survey fixed effects is that differences in survey timings explain some of the variation in these indicators as they are more likely to be influenced by seasonality (Carneiro et al. 2010).
The estimated relationship between changes in sanitation coverage and changes in stunting is highly sensitive to the inclusion of time-varying controls. In the unadjusted model, a one percentage point increase in sanitation coverage is associated with a modest decrease in the percentage of children under five who are stunted by 0.06 (p-value 0.049). Adding controls radically reduces the slope and leaves it statistically indistinguishable from zero. Replacing the global region trends with survey fixed effects also results in an association with stunting that is not statistically significantly different from zero. Table 4 in the Appendix also suggests there is no statistically significant relationship between changes in sanitation coverage and changes wasting in any of the models. We interpret this as evidence that the unconditional relationships between changes in sanitation coverage and changes in child stunting are driven by other characteristics correlated with both child stunting and WASH technology.

Estimates of the relationship between changes in access to improved water and the outcomes are shown in the bottom panels of Table 2 and Appendix Table 4. The JMP/WHO indicator of access to improved water sources appears to be a substantially less important predictor of all five health and nutrition outcomes. Only stunting is significantly associated with improved water in the adjusted model without survey fixed effects, but that relationship becomes weaker (coefficient -0.037) and statistically insignificantly different from zero (p-value 0.109) when survey fixed effects are added.

3.3 Extensions to disaggregated water and sanitation measures

As noted above, the existing literature is far from definitive about what type of water and sanitation infrastructures are likely to improve health outcomes. For sanitation, one key debate is whether toilet upgrading is the main driver of health benefits, or whether the basic elimination of open defecation via simple sanitation technologies, such as pit latrines, is paramount. We therefore disaggregate “any sanitation” into improved and unimproved sanitation categories. For water, different sources are perceived to have different levels and sources of pathogenic contaminants, but physical access to water likely also affects the prevalence of handwashing and other hygienic practices—acquiring water from even moderately distant sources dramatically increases the implicit cost of these behaviors—and water
piped to the home could generate important savings of time and effort for households (Devoto et al. 2012; Gross et al. 2018). To reflect potential differences in both contamination levels and access gradients, we therefore disaggregate the JMP/WHO definition of “any improved water” into three categories: piped water to the home/yard, other piped water, and non-piped improved water access.

Results for these more disaggregated measures are reported in Table 3 and Appendix Table 5. We also report the p-value from an F-test of whether there is no difference between each of the associations with the disaggregated WASH measures at the base of all columns.

The results suggest that unimproved sanitation is more robustly associated with under-5 child mortality and the prevalence of diarrhea—for both dependent variables we reject the null of no difference between the associations at the 5% level in specifications with survey fixed effects. While both improved and unimproved sanitation are strongly associated with reductions in under-5 mortality in the models without survey fixed effects, the estimate for improved sanitation is no longer statistically significant at the 10% level when survey fixed effects are included (p-value 0.144). Similarly, the sanitation-diarrhea association with survey fixed effects is only statistically significant for unimproved sanitation, suggesting a one percentage point increase in unimproved sanitation coverage predicts a decrease in the number of children with diarrhea of 0.062 percentage points. We interpret this as evidence that eliminating open defecation via basic (“unimproved”) toilet technologies yields a larger health benefit than toilet upgrading. Neither improved nor unimproved sanitation is statistically significantly associated with stunting or wasting in any of the adjusted models and the associations with fever are eliminated for both sanitation types when survey fixed effects are included.

The bottom panels in Table 3 and Appendix Table 5 conduct the same exercise for the disaggregated water access measures. Some notable differences emerge between water piped to the home and the other two improved water types with respect to the stunting outcome. Across all three stunting specifications, water piped to the home is associated with a statistically significant reduction in stunting, with a one percentage point increase in water piped to the home predicting roughly a 0.1 percentage point decrease
in child stunting in both of the adjusted models. There is no relationship between either of the other two types of improved water sources and stunting. Changes in access to any type of improved drinking water have little association with changes in mortality or fever in the specifications with controls (Appendix Table 5). The relationships between water piped to the home and wasting or diarrhea are sensitive to the specification used, with the wasting association only statistically significant with survey fixed effects and the diarrhea association only statistically significant—and positive—without survey fixed effects. Given the sensitivity of these estimates to the inclusion of survey fixed effects, we are reluctant to draw any strong conclusions.

3.3 Measurement in the subnational panel

The use of subnational region-level DHS data introduces distinct measurement-related advantages and potential issues relative to research using the unit-level microdata. We conduct four checks to gauge whether the use of STATCOMPILER subnational panel data induces problems related to the aggregated measurement of indicators.

In general, we might expect the aggregation of unit-level data to reduce the impact of classical measurement error in both the dependent and independent DHS variables by averaging out idiosyncratic unit-level measurement error. A more significant concern is that the 10-year recall period used to generate subnational mortality rate estimates could result in misclassification errors since WASH status is reported at the time of the survey rather than at the time of death. Moreover, age-disaggregation of the outcomes could be important because children’s immunity to various pathogens is typically lower in infancy and early childhood (Carneiro 2010; Fisher Walker et al. 2012) and the cumulative nature of linear growth (stunting) suggests that stunting-WASH associations could be sensitive to whether children are measured in a period of rapid linear growth; i.e. in utero and the first two years after birth.\(^9\) We therefore explore

\(^9\) Alderman and Headey (2018) provide evidence that stunting associations can be very sensitive to age restrictions in the sampling of child level data.
whether the mortality recall period and the aggregation of outcomes for young and older children substantively impacts the results.

For the mortality results we first use STATCOMPILER data to disaggregate under-5 mortality into perinatal, neonatal, post-neonatal, infant, and mortality between the ages of 1 and 5. The results in Supplement Figure S1 indicates that there is no statistically significant relationship between sanitation coverage and perinatal or neonatal mortality, and that approximately half of the overall predicted reduction in under-5 mortality comes from reductions in post-neonatal mortality (ages 1-11 months) with the other half generated by reductions in the mortality rate among children 1-5 years of age. Supplement Figure S2 does the same for improved water coverage, with none of the associations statistically significantly distinguishable from zero.

We next explore whether the 10-year mortality recall in the STATCOMPILER data is problematic through two checks. First, we restrict the analysis sample to a long panel: retaining just the first and last DHS waves conducted in each subnational region, and requiring that these two waves be at least 10 years apart. This ensures that even the 10-year mortality rate estimates will only use changes in the mortality outcome that occurred during the same period as the changes in WASH coverage, though the loss of two-thirds of the sample inevitably induces imprecision. Supplement Table S5 compares the full panel and long panel results for post-neonatal, infant, child (1-5 years), and under-5 mortality, with p-values from tests of the null hypothesis that there is no difference between the estimates shown at the base of each column. Despite the drastic difference in sample, we can never reject that the full sample and long panel estimates are the same, and the point estimates are qualitatively similar. Associations between the mortality rates and improved water are always close to zero in magnitude and never statistically significantly different from zero for either sample. The similarity in the estimates across the two samples therefore provides some evidence that the 10-year recall is not materially affecting the results.

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10 The results in Figures S1 and S2 are based on specifications with the full set of DHS and country-level controls and global region time trends. The results are unaffected by the inclusion of survey fixed effects in place of the global region trends.
Second, we use DHS microdata and the synthetic cohort life table approach employed by DHS (Rutstein and Rojas 2006) to re-calculate subnational region mortality rates based on 5-year and 1-year recall rather than 10-year recall. This adjustment also adds noise (which is why DHS uses 10-year recall), but if this added measurement error is uncorrelated with the regression error term it should not induce bias.

Supplement Figures S3 and S4 present the point estimates and 95% confidence intervals for the sanitation and improved water access indicators, respectively.\textsuperscript{11} Despite the expected increase in imprecision as the recall period is reduced, the point estimates remain remarkably similar: sanitation coefficients remain negative and frequently are statistically significantly different from zero, while improved water coefficients continue to be close to zero and statistically indistinguishable from zero. This further strengthens the argument that misalignment in the timing of the mortality rates and WASH indicators is not generating meaningful bias in the main WASH-mortality associations.

Finally, we investigate the sensitivity of the morbidity and nutrition results to age disaggregation using the DHS micro data (with appropriate survey weights) to create subnational panels for children 0-23 months and 24-59 months. This entails a sample restriction as the micro surveys and STATCOMPILER surveys do not perfectly align, but we confirm that our main results are robust to this restriction in Supplement Table S6.\textsuperscript{12} Supplement Table S7 reports separate results for children 0-23 and 24-59 months. We find little evidence that the point estimates are sensitive to age restrictions. The sanitation coefficients are always similar in sign, magnitude, and statistical significance. The only difference for the improved water indicator is that the association between improved water and wasting is statistically significant just for the 24-59-month sample, but the difference between the wasting associations is small and not statistically distinguishable from zero. In general, age disaggregation does not materially alter the results.

\textsuperscript{11} The figures display results using the adjusted models with global region time trends without survey fixed effects. The analogous figures that use survey fixed effects instead of global region time trends are extremely similar though less precise in all cases.

\textsuperscript{12} We note that there are two modest differences: the stunting-improved water association declines from -0.042 (p-value 0.064) to -0.023 (p-value 0.388) and the wasting-improved water association increases from 0.009 (p-value 0.563) to 0.039 (p-value 0.021). Still, the results suggest that the age-disaggregated associations in the microdata sample are likely to be good estimates of what the age-specific associations would be in the full sample.
3.4 Tests for parameter heterogeneity

The impacts of WASH improvements on child health could systematically differ with other characteristics. We investigate two specific forms of parameter heterogeneity identified as being important in the existing literature. First, there may be non-linearities in the relationships, particularly if WASH coverage generates externalities. For example, some studies suggest that reductions in open defecation do not yield substantial benefits until sanitation coverage has reached a sufficiently high level (Headey et al. 2015; Andres et al., 2017; Jung, Lou and Cheng 2017). To examine whether there are non-linearities in the WASH associations we categorize each of the WASH access measures into indicators for whether regions were in one of nine or ten equal sized categories: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, or 90-100% (no region has 0-10% access to improved water access). Supplement Figures S5-S12 display coefficient estimates and 95% confidence intervals for the outcomes when using the binned sanitation and improved water access indicators. The results, which should be interpreted as changes in the outcome relative to regions with 0-10% sanitation coverage or 10-20% access to improved water, support the linear-in-parameters specifications in Table 2 for both WASH technologies.

Second, it has long been argued that sanitation may have larger health impacts in more densely populated areas. Haiti et al. (2017) present the first extensive evidence of this relationship using cross-sectional variation in open defecation and the log of subnational population density to predict changes in infant mortality and child HAZ. We estimate an analogous interaction, with the difference being that we are implicitly estimating the impacts of changes in sanitation conditional upon initial population density. Supplement Table S8 presents these results from the adjusted models with global region time trends.13 Similar to Haithi et al. (2017), we find evidence that the association between child HAZ and sanitation coverage is increasing in population density, although the main coefficient on “any sanitation” is sufficiently negative that the association between sanitation coverage and HAZ only turns positive around

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13 Estimates with survey fixed effects are nearly identical to the results without survey fixed effects.
the 90th percentile of population density. Hence, these results suggest that sanitation improvements result in modest improvements in HAZ in the highest density regions, about half of which are predominantly urban areas. The sanitation-density interactions for the other health outcomes of interest generally have an unexpected sign, suggesting lower sanitation impacts in higher density areas. Overall, then, the results do not provide strong support to results reported in Hathi et al. (2017).

3.5 Assessing Identifying Assumptions

Supplement D provides a detailed description of specifications that investigate the associations between the WASH variables and other likely determinants of the main outcomes and prior trends assessments; we use these exercises to explore the possibility that the main estimates may be driven by unobserved time-varying determinants of the outcomes or variation in the outcomes that chronologically precedes the observed changes in WASH coverage. The results of these specification checks, which are presented in Supplement Tables S9, S10, and S11, offer suggestive evidence that these two potential sources of bias are unlikely to be driving the main results. Sanitation does not predict significant variation in any of the nine other likely determinants of the main outcomes, and we fail to reject any of the null hypotheses that future sanitation coverage predicts current values of the child health and nutrition outcomes. We find a statistically significant association between improved water access and one of the nine potential determinants of the main outcomes (the likelihood of vitamin A supplementation), and there is some evidence that decreases in under-5 mortality may be associated with future increase in access to improved water access. This latter finding suggests that the mortality-improved water association in Table 2 may be downward biased.

There is some uncertainty as to whether these checks are sufficiently strong to identify evidence of bias (see Supplement D for a discussion), but the results are broadly encouraging insofar as there are few signs of obvious bias, particularly for the sanitation associations.
3.6 Estimating the impacts of sanitation improvements on child mortality over the Millennium Development Goal era (1990-2015)

To help put our main empirical results in context, we combine the observed changes in sanitation between 1990-2015 with the coefficients for under-5 mortality from Table 2 to estimate the fraction of the observed reduction in under-5 child mortality between 1990-2015 that can potentially be explained by sanitation improvements. Globally, sanitation coverage was estimated to increase from 76% to 87% over 1990-2015 (WHO & UNICEF 2015), while under-5 mortality fell from 93 to 42 per 1,000 births (UNICEF 2017). The coefficient on sanitation coverage in the core under-5 mortality regression from Table 2 suggests that this 11-percentage point increase in sanitation coverage would reduce under-5 mortality by 4.19 deaths per 1,000 births;\(^{14}\) explaining approximately 8.2% of the total observed reduction in under-5 mortality between 1990 and 2015. Thus, sanitation investments appear to have played a critical role in global efforts to reduce child mortality.

4. Discussion

WASH investments are widely viewed as an integral component of improving child health outcomes in developing countries. However, experimental evaluations of WASH interventions have not always uncovered strong evidence of impacts, particularly on child nutrition outcomes, and are also potentially subject to methodological limitations related to short timeframes, poor compliance and limited external validity. These evaluations are never statistically powered to assess precise mortality impacts. Instead, many researchers have resorted to observational analyses that exploit cross-sectional variation in water and sanitation access. Although such studies generate useful suggestive evidence, cross-sectional estimates may be significantly biased by omitted time-invariant factors, offer few rigorous means of gauging that bias, and do not directly address the question of whether historical changes in WASH coverage typically lead to improvements in health outcomes.

\(^{14}\) The predicted reduction is 3.77 if we use the estimates from specification with survey fixed effects.
In this study, we pursue a DID analysis to address some of the limitations in both the experimental and observational literatures. The subnational panel of DHS data used herein allows us to explore longer term changes in WASH access in a broad swathe of countries, to purge regressions of important time-invariant sources of bias, to conduct a range of extensions and robustness tests, and to conduct several falsification exercises.

At the same time, the data and methods used in this paper are subject to limitations. Despite passing most falsification checks, we cannot definitively rule out biases from time-varying omitted variables, which would caution against drawing overly strong causal inferences from these results. Our estimates are also somewhat imprecise, and are therefore subject to uncertainty in a quantitative sense. We discuss and explore potential measurement issues with the dependent variables, but another source of imprecision is measurement error in the DHS WASH indicators. Sanitation indicators in the DHS are not ideal since toilet ownership does not always equate to toilet use, or to appropriate disposal of children’s stools, although the fact that we find significant and relatively large coefficients on sanitation for two of the outcomes perhaps suggests that attenuation bias is not an overwhelming problem for sanitation. Perhaps of greater concern is that “improved” water infrastructure could be a poor proxy for latent water quality in microbial sense. For example, piped water systems that lack regular and consistent water flow may become breeding grounds for pathogenic bacteria (Klasen et al. 2012). Hence there is likely to be important heterogeneity in the quality of piped water across countries that we cannot observe. Still, the statistically significant association between water piped into the home and stunting – and the insignificant coefficients on improved water not piped into the home – suggests that the costs associated with collecting water outside the home may have especially harmful impacts on child welfare even with heterogeneity in water quality (Gross et al. 2018).

Another limitation is that our WASH indicators solely focus on hardware measures. Improving hygiene, however, is also likely to require significant behavioral changes that are not well recorded in the DHS and similar surveys. Formal education and adult literacy programs have been shown to be associated with
both health knowledge and child health more broadly (Glewwe 1999; Kovsted et al. 2003; Blunch 2013; Blunch 2017), and it may be that this kind of soft knowledge complements the availability of improved WASH hardware.

Bearing these caveats in mind, many of our results are quite consistent with the experimental WASH literature. The importance of sanitation for reducing the prevalence of diarrhea accords closely to findings from both the experimental literature (Fewtrell et al. 2005; Freeman et al. 2017; Wolf et al. 2014) and the observational literature (Fink et al. 2011). Also consistent with much of the experimental literature is the lack of any statistically significant association between changes in sanitation and changes in child stunting and wasting (Dangour et al. 2013; Freeman et al. 2017).\footnote{Pickering et al. (2015) is one notable exception.} There are plausible biological explanations for a relatively weak relationship between sanitation and stunting. While some cohort studies do find that diarrhea episodes may contribute to stunting (Checkley et al. 2008), others find that significant catch-up growth occurs after diarrhea episodes, thereby limiting long run impacts on linear growth (Richard et al. 2014). Another recent line of research speculates that animal feces may be an important contributor to EED and stunting (Mbuya and Humphrey 2016; Headey and Hirvonen 2016; Headey et al. 2017), an exposure unlikely to be influenced by conventional WASH hardware.

Despite disappointing evidence regarding sanitation’s impacts on child nutrition, we find relatively strong associations with child morbidity and mortality. We estimate that sanitation improvements have accounted for just under 10\% of the decline in child mortality from 1990-2015. This is a significant contribution, although since approximately 1 billion people still practice open defecation, further investments in sanitation are still very much needed.
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# Tables

## Table 1: Summary statistics for child health outcomes and key WASH indicators

|                      | Obs  | Within-country variation (%)\(^a\) | Mean | 25th | 50th | 75th |
|----------------------|------|-----------------------------------|------|------|------|------|
| **Outcomes\(^b\)**   |      |                                   |      |      |      |      |
| Under 5 mortality rate (per 1,000 live births) | 1,497 | 39.0                              | 93.8 | 51.0 | 81.0 | 125.0 |
| Children with diarrhea | 1,547 | 55.6                              | 18.8 | 13.0 | 18.0 | 23.9 |
| Children stunted      | 1,208 | 40.1                              | 35.0 | 25.2 | 35.0 | 44.9 |
| Children with fever   | 1,606 | 67.9                              | 29.8 | 21.9 | 29.1 | 37.3 |
| **WASH Measures\(^b\)** |      |                                   |      |      |      |      |
| Households with any sanitation | 1,548 | 40.0                              | 71.9 | 53.3 | 81.2 | 94.7 |
| Households with improved toilet | 1,548 | 63.8                              | 31.2 | 4.0  | 22.8 | 51.5 |
| Households with unimproved toilet | 1,548 | 53.8                              | 40.7 | 10.6 | 37.3 | 67.5 |
| Households with improved water source | 1,612 | 50.9                              | 71.7 | 58.3 | 74.8 | 88.3 |
| Households with any piped water source | 1,612 | 36.0                              | 28.0 | 10.1 | 21.5 | 41.0 |
| Households with non-piped improved water source | 1,612 | 45.6                              | 43.7 | 28.9 | 42.8 | 56.8 |

**Notes:**

a. This indicator reports the share of total variation in the subnational panel explained by intra-country variation. It is equal to 100 minus the R-squared coefficient from a regression of each variable against country-level fixed effects.

b. These variables are all sourced from DHS STATcompiler (USAID and ICF-International 2017), which disaggregates variables at subnational units that we standardize across multiple DHS rounds.
Table 2: DID regressions of child health outcomes against sanitation and improved water

|                         | Under 5 Mortality |          | Diarrhea          |          | Stunting          |          |
|-------------------------|-------------------|----------|-------------------|----------|-------------------|----------|
|                         | (1)               | (2)      | (3)               | (4)      | (5)               | (6)      |
| Panel A                 |                    |          |                    |          |                    |          |
| Households with any sanitation | 0.804*** | 0.381** | -0.343** | 0.163*** | -0.121*** | -0.056* |
|                         | [0.000]           | [0.011]  | [0.026]           | [0.000]  | [0.054]           | [0.049]  |
| R-squared (within)      | 0.602             | 0.686    | 0.815             | 0.196    | 0.254             | 0.481    |
| N                       | 1,401             | 1,401    | 1,401             | 1,451    | 1,451             | 1,451    |
| Region Fixed Effects    | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |
| Time Controls           | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |
| Full Controls           | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |
| Survey Fixed Effects    | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |
|                         |                    |          |                    |          |                    |          |
| Panel B                 |                    |          |                    |          |                    |          |
| Households with improved water | 0.269** | -0.048 | -0.118             | -0.021   | 0.016             | 0.028    |
|                         | [0.013]           | [0.642]  | [0.326]           | [0.335]  | [0.467]           | [0.263]  |
| R-squared (within)      | 0.589             | 0.683    | 0.807             | 0.144    | 0.237             | 0.494    |
| N                       | 1,479             | 1,479    | 1,479             | 1,515    | 1,515             | 1,515    |
| Region Fixed Effects    | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |
| Time Controls           | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |
| Full Controls           | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |
| Survey Fixed Effects    | ✓                 | ✓        | ✓                 | ✓        | ✓                 | ✓        |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Table 3: Panel A, DID regressions of child health outcomes against disaggregated sanitation indicators

|                              | Under 5 Mortality | Diarrhea | Stunting |
|------------------------------|-------------------|----------|----------|
|                              | (1)               | (2)      | (3)      | (4) | (5) | (6) | (7) | (8) | (9) |
| Households with improved sanitation | -0.654***        | -0.318** | -0.233   | -0.160*** | -0.120*** | -0.024 | -0.069** | -0.012 | 0.03 |
|                               | [0.000]           | [0.036]  | [0.144]  | [0.000] | [0.000] | [0.438] | [0.036] | [0.734] | [0.403] |
| Households with unimproved sanitation | -0.813***       | -0.385*** | -0.366** | -0.164*** | -0.121*** | -0.062** | -0.060* | -0.015 | 0.011 |
|                               | [0.000]           | [0.010]  | [0.018]  | [0.000] | [0.000] | [0.035] | [0.052] | [0.672] | [0.730] |
| R-squared (within)            | 0.608             | 0.687    | 0.816    | 0.197 | 0.254 | 0.484 | 0.436 | 0.516 | 0.679 |
| N                             | 1,401             | 1,401    | 1,401    | 1,451 | 1,451 | 1,451 | 1,193 | 1,193 | 1,193 |
| P-value: Improved = Unimproved | 0.000             | 0.081    | 0.021    | 0.774 | 0.922 | 0.009 | 0.439 | 0.834 | 0.223 |
| Region Fixed Effects          | ✓                 | ✓        | ✓        | ✓     | ✓     | ✓     | ✓     | ✓     | ✓     |
| Time Controls                 | ✓                 | ✓        | ✓        | ✓     | ✓     | ✓     | ✓     | ✓     | ✓     |
| Full Controls                 | ✓                 | ✓        | ✓        | ✓     | ✓     | ✓     | ✓     | ✓     | ✓     |
| Survey Fixed Effects          | ✓                 | ✓        | ✓        | ✓     | ✓     | ✓     | ✓     | ✓     | ✓     |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Table 3: Panel B, DID regressions of child health outcomes against disaggregated improved water indicators

|                      | Under 5 Mortality | Diarrhea | Stunting |
|----------------------|-------------------|----------|----------|
|                      | (1)               | (2)      | (3)      | (4)      | (5)      | (6)      | (7)      | (8)      | (9)      |
| Households with water piped to dwelling/yard | -0.437***         | -0.157   | -0.199   | -0.01    | 0.076*** | 0.026    | -0.142*** | -0.107*** | -0.101*** |
|                      | [0.002]           | [0.270]  | [0.153]  | [0.688]  | [0.009]  | [0.406]  | [0.000]  | [0.003]  | [0.001]  |
| Households with other piped water          | -0.503***         | -0.14    | -0.123   | -0.027   | 0.02     | 0.045    | -0.077**  | -0.032    | -0.018    |
|                      | [0.001]           | [0.303]  | [0.506]  | [0.456]  | [0.583]  | [0.223]  | [0.022]  | [0.314]  | [0.597]  |
| Households with non-piped improved water    | -0.146            | -0.006   | -0.089   | -0.022   | 0.004    | 0.023    | -0.079*** | -0.031    | -0.02     |
|                      | [0.192]           | [0.954]  | [0.484]  | [0.306]  | [0.847]  | [0.389]  | [0.001]  | [0.188]  | [0.461]  |
| R-squared (within)       | 0.595             | 0.684    | 0.807    | 0.144    | 0.244    | 0.494    | 0.469     | 0.543     | 0.706     |
| N                     | 1,479             | 1,479    | 1,479    | 1,515    | 1,515    | 1,515    | 1,176     | 1,176     | 1,176     |
| P-value: Piped to home = Other piped       | 0.662             | 0.903    | 0.664    | 0.637    | 0.097    | 0.604    | 0.072     | 0.058     | 0.021     |
| P-value: Piped to home = Non-piped         | 0.002             | 0.114    | 0.288    | 0.581    | 0.002    | 0.902    | 0.006     | 0.011     | 0.008     |
| P-value: Other piped = Non-piped           | 0.015             | 0.257    | 0.837    | 0.883    | 0.601    | 0.513    | 0.945     | 0.978     | 0.968     |
| Region Fixed Effects       | ✓                 | ✓        | ✓        | ✓        | ✓        | ✓        | ✓         | ✓         | ✓         |
| Time Controls              | ✓                 | ✓        | ✓        | ✓        | ✓        | ✓        | ✓         | ✓         | ✓         |
| Full Controls              | ✓                 | ✓        | ✓        | ✓        | ✓        | ✓        | ✓         | ✓         | ✓         |
| Survey Fixed Effects       | ✓                 | ✓        | ✓        | ✓        | ✓        | ✓        | ✓         | ✓         | ✓         |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Figures

Figure 1: Scatter Plots and Slope Coefficients for Primary Outcomes and Sanitation Coverage: Levels and differences

Panel A: Under-5 Mortality in Levels

Panel B: Under-5 Mortality in Differences

Panel C: Diarrhea Prevalence in Levels

Panel D: Diarrhea Prevalence in Differences
Notes: Differences refer to the change in an indicator from the first survey round available to the last round available while levels plots use data from the median survey year available for each region. Slope coefficients from linear regressions are reported in the legend of each panel. *, ** and *** denote significance at the 10%, 5% and 1% level respectively. Source: DHS STATcompiler (USAID and ICF-International 2017).
Figure 2: Scatter Plots and Slope Coefficients for Primary Outcomes and Improved Water Coverage: Levels and differences

Panel A: Under-5 Mortality in Levels

Panel B: Under-5 Mortality in Differences

Panel C: Diarrhea Prevalence in Levels

Panel D: Diarrhea Prevalence in Differences
Panel E: Stunting in Levels

Panel F: Stunting in Differences

Panel G: Fever Prevalence in Levels

Panel H: Fever Prevalence in Differences

Notes: Differences refer to the change in an indicator from the first survey round available to the last round available while levels plots use data from the median survey year available for each region. Slope coefficients from linear regressions are reported in the legend of each panel. *, ** and *** denote significance at the 10%, 5% and 1% level respectively. Source: DHS STATcompiler (USAID and ICF-International 2017).
Appendix (to be included in the manuscript)

Table 4: WASH Technology, Wasting, and Fever

|                      | Wasting |     |     |     |     | Fever |
|----------------------|---------|-----|-----|-----|-----|-------|
|                      | (1)     | (2) | (3) | (4) | (5) | (6)   |
| **Panel A**          |         |     |     |     |     |       |
| Households with any sanitation | -0.017  | -0.023 | -0.025 | -0.193*** | -0.163*** | -0.042 |
| R-squared (within)   | 0.199   | 0.309 | 0.527 | 0.426 | 0.511 | 0.691 |
| N                    | 1,187   | 1,187 | 1187 | 1521 | 1521 | 1521  |
| Region Fixed Effects | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |
| Time Controls        | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |
| Full Controls        | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |
| Survey Fixed Effects | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |
| **Panel B**          |         |     |     |     |     |       |
| Households with improved water | -0.003  | 0.009 | 0.012 | -0.023 | 0.025 | -0.007 |
| R-squared (within)   | 0.234   | 0.33  | 0.319 | 0.412 | 0.51  | 0.693 |
| N                    | 1,170   | 1,170 | 1170 | 1574 | 1574 | 1574  |
| Region Fixed Effects | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |
| Time Controls        | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |
| Full Controls        | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |
| Survey Fixed Effects | ✓       | ✓    | ✓    | ✓    | ✓    | ✓     |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values are reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Table 5: Disaggregated WASH Technology, Wasting, and Fever

|                                | Wasting     |              |              | Fever      |              |              |
|--------------------------------|-------------|--------------|--------------|------------|--------------|--------------|
|                                | (1)         | (2)          | (3)          | (4)        | (5)          | (6)          |
| Households with improved sanitation | -0.006      | -0.019       | -0.015       | -0.197***  | -0.172***    | -0.023       |
|                                | [0.808]     | [0.439]      | [0.577]      | [0.000]    | [0.000]      | [0.599]      |
| Households with unimproved sanitation | -0.018      | -0.024       | -0.027       | -0.192***  | -0.162***    | -0.047       |
|                                | [0.386]     | [0.288]      | [0.286]      | [0.000]    | [0.000]      | [0.222]      |
| R-squared (within)             | 0.202       | 0.309        | 0.528        | 0.426      | 0.511        | 0.692        |
| N                              | 1,187       | 1,187        | 1,187        | 1,521      | 1,521        | 1,521        |
| P-value: Improved = Unimproved  | 0.170       | 0.592        | 0.224        | 0.743      | 0.442        | 0.344        |
| Region Fixed Effects           | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |
| Time Controls                  | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |
| Full Controls                  | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |
| Survey Fixed Effects           | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |
| Households with water piped to dwelling/yard | -0.016      | -0.017       | -0.039*      | -0.026     | 0.054        | -0.015       |
|                                | [0.390]     | [0.416]      | [0.090]      | [0.553]    | [0.227]      | [0.710]      |
| Households with other piped water | -0.018      | -0.003       | -0.007       | -0.091*    | -0.009       | -0.021       |
|                                | [0.434]     | [0.882]      | [0.792]      | [0.085]    | [0.867]      | [0.662]      |
| Households with non-piped improved water | 0.007      | 0.018        | -0.008       | -0.001     | 0.028        | 0.001        |
|                                | [0.644]     | [0.254]      | [0.665]      | [0.965]    | [0.413]      | [0.981]      |
| R-squared (within)             | 0.237       | 0.334        | 0.532        | 0.414      | 0.511        | 0.694        |
| N                              | 1,170       | 1,170        | 1,170        | 1,574      | 1,574        | 1,574        |
| P-value: Piped to home = Other piped | 0.931       | 0.561        | 0.233        | 0.212      | 0.211        | 0.9          |
| P-value: Piped to home = Non-piped | 0.1        | 0.03         | 0.109        | 0.508      | 0.446        | 0.637        |
| P-value: Other piped = Non-piped | 0.188      | 0.281        | 0.972        | 0.059      | 0.426        | 0.637        |
| Region Fixed Effects           | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |
| Time Controls                  | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |
| Full Controls                  | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |
| Survey Fixed Effects           | ✓           | ✓            | ✓            | ✓          | ✓            | ✓            |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values are reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Online Supplement

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Supplement A. Description of datasets and additional summary statistics

We use three subnational panels in this study. Our main data set comes from the online DHS STATCOMPILER data: https://www.statcompiler.com/en/. STATCOMPILER provides nationally and subnationally representative data for most of the standard indicators collected in the DHS. In some countries the subnational units change over time, but STATCOMPILER typically reports both the more recent and more disaggregated subnational units as well more aggregated older subnational units to allow for comparisons over a longer period of time in each country. In all cases we use the longer and more aggregated subnational units to increase the time dimension of our data. Details of the STATCOMPILER dataset are provided in Table S1.

In addition to our main dependent variables and explanatory WASH variables, we also use DHS data on a range of other common determinants of health and nutrition outcomes, and supplement subnational DHS data with country-level data of relevance from the World Development Indicators (World Bank 2017). DHS measures include housing characteristics (electricity, finished floors), maternal education (the percent of women with at least some secondary schooling), demographic indicators (total fertility rate, median birth interval), and health services used in the preceding three years (live births with no antenatal care, live births that took place in a health facility). At the national level we control for economic growth (log GDP per capita), cereal yields (a food security proxy measured as the log of kg per hectare), total health expenditures as a percent of GDP, foreign aid flows (the log of total official development aid per capita), urbanization (percent of total population in urban areas), the log of total population, and malaria incidence (per 1,000 population at risk). Descriptive statistics for these additional controls are reported in Supplement Table S3.

Two important limitations of the STATCOMPILER data are that the subnational data are not reported for children of different ages and the mortality estimates at the subnational level use a 10-year recall period to ensure there is sufficient information. To overcome these limitations, we also use multi-country micro level DHS data collated by the authors. These micro data cover most of the surveys used in
STATCOMPILER but not all. Supplement Table S2 lists the DHS included in the main analysis, the DHS included in the microaggregated sample for the nutrition and morbidity outcomes (“DHS-Nutrition” column), and the DHS included in the microaggregated sample for the mortality outcomes (“DHS-Mortality”). Table S5 in Supplement B further shows that our main STATCOMPILER-based results are robust to restricting the sample to the smallest micro data-based sample. Summary statistics for the main variables of interest in these microaggregated DHS datasets are reported in Table S4 below.
Table S1: Wave and Region Counts by Country for the main STATCOMPILER dataset

| Country                     | Number of DHS Waves | Earliest Year | Most Recent Year | Number of Sub-National Regions |
|-----------------------------|---------------------|---------------|------------------|--------------------------------|
| Angola                      | 2                   | 2006          | 2011             | 4                              |
| Armenia                     | 3                   | 2000          | 2010             | 11                             |
| Bangladesh                  | 7                   | 1993          | 2014             | 6                              |
| Benin                       | 4                   | 1996          | 2011             | 6                              |
| Bolivia                     | 4                   | 1994          | 2008             | 11                             |
| Brazil                      | 1                   | 1996          | 1996             | 6                              |
| Burkina Faso                | 3                   | 2003          | 2014             | 13                             |
| Burundi                     | 2                   | 2010          | 2012             | 5                              |
| Cambodia                    | 4                   | 2000          | 2014             | 16                             |
| Cameroon                    | 4                   | 1991          | 2011             | 5                              |
| Chad                        | 3                   | 1996          | 2014             | 2                              |
| Colombia                    | 5                   | 1990          | 2010             | 5                              |
| Comoros                     | 2                   | 1996          | 2012             | 3                              |
| Congo Democratic Republic   | 2                   | 2007          | 2013             | 11                             |
| Cote d'Ivoire               | 4                   | 1994          | 2011             | 2                              |
| Dominican Republic          | 6                   | 1991          | 2013             | 14                             |
| Egypt                       | 7                   | 1992          | 2014             | 4                              |
| Eritrea                     | 2                   | 1995          | 2002             | 6                              |
| Ethiopia                    | 3                   | 2000          | 2011             | 11                             |
| Gabon                       | 2                   | 2000          | 2012             | 5                              |
| Ghana                       | 5                   | 1993          | 2014             | 8                              |
| Guatemala                   | 2                   | 1995          | 1998             | 7                              |
| Guinea                      | 3                   | 1999          | 2012             | 5                              |
| Guyana                      | 2                   | 2005          | 2009             | 2                              |
| Haiti                       | 3                   | 2000          | 2012             | 10                             |
| Honduras                    | 2                   | 2005          | 2011             | 20                             |
| India                       | 3                   | 1992          | 2005             | 26                             |
| Indonesia                   | 6                   | 1991          | 2012             | 27                             |
| Jordan                      | 5                   | 1997          | 2012             | 3                              |
| Kazakhstan                  | 2                   | 1995          | 1999             | 5                              |
| Kenya                       | 5                   | 1993          | 2014             | 8                              |
| Kyrgyz Republic             | 2                   | 1997          | 2012             | 2                              |
| Lesotho                     | 3                   | 2004          | 2014             | 10                             |
| Liberia                     | 4                   | 2007          | 2013             | 6                              |
| Madagascar                  | 4                   | 1992          | 2008             | 6                              |
| Malawi                      | 6                   | 1992          | 2014             | 3                              |
| Mali                        | 5                   | 1995          | 2015             | 4                              |
| Moldova                     | 1                   | 2005          | 2005             | 4                              |
| Morocco                     | 2                   | 1992          | 2003             | 7                              |
| Country       | Count | Start Year | End Year | Observations |
|--------------|-------|------------|----------|--------------|
| Mozambique   | 3     | 1997       | 2011     | 11           |
| Namibia      | 3     | 2000       | 2013     | 12           |
| Nepal        | 4     | 1996       | 2011     | 5            |
| Nicaragua    | 2     | 1998       | 2001     | 17           |
| Niger        | 4     | 1992       | 2012     | 6            |
| Nigeria      | 5     | 1999       | 2013     | 6            |
| Pakistan     | 3     | 1990       | 2012     | 3            |
| Peru         | 9     | 1991       | 2012     | 4            |
| Philippines  | 5     | 1993       | 2013     | 17           |
| Rwanda       | 6     | 1992       | 2014     | 5            |
| Senegal      | 8     | 1992       | 2014     | 4            |
| Sierra Leone | 2     | 2008       | 2013     | 4            |
| Tanzania     | 6     | 1991       | 2011     | 9            |
| Togo         | 2     | 1998       | 2013     | 5            |
| Turkey       | 3     | 1993       | 2003     | 5            |
| Uganda       | 4     | 1995       | 2011     | 4            |
| Vietnam      | 2     | 1997       | 2002     | 10           |
| Yemen        | 3     | 1991       | 2013     | 2            |
| Zambia       | 5     | 1992       | 2013     | 9            |
| Zimbabwe     | 4     | 1994       | 2010     | 10           |

Source: DHS STATcompiler (USAID and ICF-International 2017).
| Country      | Year | DHS-Nutrition | DHS-Mortality |
|-------------|------|---------------|--------------|
| Angola      | 2006 | 0             | 1            |
| Angola      | 2011 | 0             | 1            |
| Armenia     | 2000 | 1             | 1            |
| Armenia     | 2005 | 1             | 1            |
| Armenia     | 2010 | 1             | 1            |
| Bangladesh  | 1993 | 0             | 1            |
| Bangladesh  | 1996 | 1             | 1            |
| Bangladesh  | 1999 | 1             | 1            |
| Bangladesh  | 2004 | 1             | 1            |
| Bangladesh  | 2007 | 1             | 1            |
| Bangladesh  | 2011 | 1             | 1            |
| Bangladesh  | 2014 | 1             | 1            |
| Benin       | 1996 | 1             | 1            |
| Benin       | 2001 | 1             | 1            |
| Benin       | 2006 | 1             | 1            |
| Benin       | 2011 | 1             | 1            |
| Bolivia     | 1994 | 1             | 1            |
| Bolivia     | 1998 | 1             | 1            |
| Bolivia     | 2003 | 0             | 1            |
| Bolivia     | 2008 | 1             | 1            |
| Brazil      | 1996 | 1             | 1            |
| Brazil      | 1986 | 0             | 0            |
| Burkina Faso| 2003 | 0             | 0            |
| Burkina Faso| 2010 | 0             | 0            |
| Burkina Faso| 2014 | 0             | 0            |
| Burundi     | 2010 | 0             | 1            |
| Burundi     | 2012 | 0             | 1            |
| Cambodia    | 2000 | 1             | 1            |
| Cambodia    | 2005 | 0             | 1            |
| Cambodia    | 2010 | 0             | 1            |
| Cambodia    | 2014 | 0             | 1            |
| Cameroon    | 1991 | 0             | 1            |
| Cameroon    | 1998 | 0             | 1            |
| Cameroon    | 2004 | 1             | 1            |
| Cameroon    | 2011 | 1             | 1            |
| Chad        | 1996 | 0             | 1            |
| Chad        | 2004 | 1             | 1            |
| Chad        | 2014 | 0             | 1            |
| Colombia    | 1986 | 0             | 0            |
| Country               | Year | Row 1 | Row 2 |
|-----------------------|------|-------|-------|
| Colombia              | 1990 | 0     | 1     |
| Colombia              | 1995 | 1     | 1     |
| Colombia              | 2000 | 1     | 1     |
| Colombia              | 2005 | 1     | 1     |
| Colombia              | 2010 | 1     | 1     |
| Comoros               | 1996 | 1     | 1     |
| Comoros               | 2012 | 1     | 1     |
| Congo Democratic Republic | 2007 | 1     | 1     |
| Congo Democratic Republic | 2013 | 1     | 1     |
| Cote d'Ivoire         | 1994 | 1     | 1     |
| Cote d'Ivoire         | 1998 | 1     | 1     |
| Cote d'Ivoire         | 2005 | 0     | 1     |
| Cote d'Ivoire         | 2011 | 1     | 1     |
| Dominican Republic    | 1986 | 0     | 0     |
| Dominican Republic    | 1991 | 0     | 1     |
| Dominican Republic    | 1996 | 1     | 1     |
| Dominican Republic    | 1999 | 0     | 1     |
| Dominican Republic    | 2002 | 1     | 1     |
| Dominican Republic    | 2007 | 1     | 1     |
| Dominican Republic    | 2013 | 1     | 1     |
| Egypt                 | 1988 | 0     | 0     |
| Egypt                 | 1992 | 0     | 1     |
| Egypt                 | 1995 | 0     | 1     |
| Egypt                 | 2000 | 1     | 1     |
| Egypt                 | 2003 | 1     | 1     |
| Egypt                 | 2005 | 1     | 1     |
| Egypt                 | 2008 | 1     | 1     |
| Egypt                 | 2014 | 1     | 1     |
| Eritrea               | 1995 | 0     | 0     |
| Eritrea               | 2002 | 0     | 0     |
| Ethiopia              | 2000 | 1     | 1     |
| Ethiopia              | 2005 | 1     | 1     |
| Ethiopia              | 2011 | 1     | 1     |
| Gabon                 | 2000 | 0     | 1     |
| Gabon                 | 2012 | 0     | 0     |
| Ghana                 | 1988 | 0     | 0     |
| Ghana                 | 1993 | 0     | 1     |
| Ghana                 | 1998 | 0     | 1     |
| Ghana                 | 2003 | 1     | 1     |
| Ghana                 | 2008 | 1     | 1     |
| Ghana                 | 2014 | 0     | 1     |
| Guatemala             | 1987 | 0     | 0     |
| Country            | Year  | Column1 | Column2 |
|--------------------|-------|---------|---------|
| Guatemala          | 1995  | 1       | 1       |
| Guatemala          | 1998  | 1       | 1       |
| Guinea             | 1999  | 1       | 1       |
| Guinea             | 2005  | 1       | 1       |
| Guinea             | 2012  | 1       | 1       |
| Guyana             | 2005  | 0       | 1       |
| Guyana             | 2009  | 1       | 1       |
| Haiti              | 2000  | 1       | 1       |
| Haiti              | 2005  | 1       | 1       |
| Haiti              | 2012  | 1       | 1       |
| Honduras           | 2005  | 1       | 1       |
| Honduras           | 2011  | 1       | 1       |
| India              | 1992  | 1       | 1       |
| India              | 1998  | 1       | 1       |
| India              | 2005  | 1       | 1       |
| Indonesia          | 1991  | 0       | 1       |
| Indonesia          | 1994  | 0       | 1       |
| Indonesia          | 1997  | 0       | 1       |
| Indonesia          | 2002  | 0       | 1       |
| Indonesia          | 2007  | 0       | 1       |
| Indonesia          | 2012  | 0       | 1       |
| Jordan             | 1997  | 1       | 1       |
| Jordan             | 2002  | 1       | 1       |
| Jordan             | 2007  | 1       | 1       |
| Jordan             | 2009  | 1       | 1       |
| Jordan             | 2012  | 1       | 1       |
| Kazakhstan         | 1995  | 1       | 1       |
| Kazakhstan         | 1999  | 1       | 1       |
| Kenya              | 1989  | 0       | 0       |
| Kenya              | 1993  | 1       | 1       |
| Kenya              | 1998  | 1       | 1       |
| Kenya              | 2003  | 1       | 1       |
| Kenya              | 2008  | 1       | 1       |
| Kenya              | 2014  | 0       | 1       |
| Kyrgyz Republic    | 1997  | 1       | 1       |
| Kyrgyz Republic    | 2012  | 1       | 1       |
| Lesotho            | 2004  | 0       | 1       |
| Lesotho            | 2009  | 0       | 1       |
| Lesotho            | 2014  | 0       | 1       |
| Liberia            | 2007  | 0       | 0       |
| Liberia            | 2009  | 0       | 0       |
| Liberia            | 2011  | 0       | 0       |
| Liberia            | 2013  | 0       | 0       |
| Country   | Year | Value 1 | Value 2 |
|-----------|------|---------|---------|
| Madagascar| 1992 | 1       | 1       |
| Madagascar| 1997 | 1       | 1       |
| Madagascar| 2003 | 1       | 1       |
| Madagascar| 2008 | 1       | 1       |
| Madagascar| 2011 | 0       | 1       |
| Madagascar| 2013 | 0       | 0       |
| Malawi    | 1992 | 1       | 1       |
| Malawi    | 2000 | 1       | 1       |
| Malawi    | 2004 | 0       | 1       |
| Malawi    | 2010 | 1       | 1       |
| Malawi    | 2012 | 0       | 1       |
| Malawi    | 2014 | 0       | 1       |
| Mali      | 1987 | 0       | 0       |
| Mali      | 1995 | 1       | 1       |
| Mali      | 2001 | 0       | 1       |
| Mali      | 2006 | 1       | 1       |
| Mali      | 2012 | 1       | 1       |
| Mali      | 2015 | 0       | 1       |
| Moldova   | 2005 | 1       | 1       |
| Morocco   | 1987 | 0       | 0       |
| Morocco   | 1992 | 1       | 1       |
| Morocco   | 2003 | 1       | 1       |
| Mozambique| 1997 | 1       | 1       |
| Mozambique| 2003 | 0       | 1       |
| Mozambique| 2009 | 0       | 0       |
| Mozambique| 2011 | 1       | 1       |
| Namibia   | 2000 | 1       | 1       |
| Namibia   | 2006 | 1       | 1       |
| Namibia   | 2013 | 1       | 1       |
| Nepal     | 1996 | 1       | 1       |
| Nepal     | 2001 | 1       | 1       |
| Nepal     | 2006 | 1       | 1       |
| Nepal     | 2011 | 0       | 0       |
| Nicaragua | 1998 | 1       | 1       |
| Nicaragua | 2001 | 1       | 1       |
| Niger     | 1992 | 0       | 1       |
| Niger     | 1998 | 1       | 1       |
| Niger     | 2006 | 1       | 1       |
| Niger     | 2012 | 1       | 1       |
| Nigeria   | 1999 | 0       | 0       |
| Nigeria   | 2003 | 1       | 1       |
| Nigeria   | 2008 | 1       | 1       |
| Country     | Year 1  | Year 2  | Year 3  |
|------------|---------|---------|---------|
| Nigeria    | 2010    | 0       | 1       |
| Nigeria    | 2013    | 1       | 1       |
| Nigeria    | 2015    | 0       | 1       |
| Pakistan   | 1990    | 1       | 1       |
| Pakistan   | 2006    | 0       | 1       |
| Pakistan   | 2012    | 1       | 1       |
| Peru       | 1986    | 0       | 0       |
| Peru       | 1991    | 1       | 1       |
| Peru       | 1996    | 1       | 1       |
| Peru       | 2000    | 1       | 1       |
| Peru       | 2004    | 0       | 0       |
| Peru       | 2007    | 1       | 1       |
| Peru       | 2009    | 1       | 1       |
| Peru       | 2010    | 1       | 1       |
| Peru       | 2011    | 1       | 1       |
| Peru       | 2012    | 1       | 1       |
| Philippines| 1993    | 0       | 1       |
| Philippines| 1998    | 0       | 1       |
| Philippines| 2003    | 0       | 1       |
| Philippines| 2008    | 0       | 1       |
| Philippines| 2013    | 0       | 1       |
| Rwanda     | 1992    | 1       | 1       |
| Rwanda     | 2000    | 1       | 1       |
| Rwanda     | 2007    | 1       | 1       |
| Rwanda     | 2010    | 0       | 1       |
| Rwanda     | 2013    | 0       | 1       |
| Rwanda     | 2014    | 0       | 1       |
| Senegal    | 1986    | 0       | 0       |
| Senegal    | 1992    | 1       | 1       |
| Senegal    | 1997    | 0       | 1       |
| Senegal    | 2005    | 1       | 1       |
| Senegal    | 2006    | 0       | 1       |
| Senegal    | 2008    | 0       | 1       |
| Senegal    | 2010    | 1       | 1       |
| Senegal    | 2012    | 1       | 1       |
| Senegal    | 2014    | 0       | 1       |
| Sierra Leone| 2008  | 1       | 1       |
| Sierra Leone| 2013 | 1       | 1       |
| Tanzania   | 1991    | 0       | 0       |
| Tanzania   | 1996    | 1       | 1       |
| Tanzania   | 2003    | 0       | 0       |
| Tanzania   | 2004    | 1       | 1       |
| Tanzania   | 2007    | 0       | 1       |
| Country     | Year 1 | Year 2 | Year 3 |
|-------------|--------|--------|--------|
| Tanzania    | 2010   | 1      | 1      |
| Tanzania    | 2011   | 0      | 1      |
| Togo        | 1988   | 0      | 0      |
| Togo        | 1998   | 1      | 1      |
| Togo        | 2013   | 0      | 1      |
| Turkey      | 1993   | 1      | 1      |
| Turkey      | 1998   | 1      | 1      |
| Turkey      | 2003   | 0      | 1      |
| Uganda      | 1988   | 0      | 0      |
| Uganda      | 1995   | 1      | 1      |
| Uganda      | 2000   | 1      | 1      |
| Uganda      | 2006   | 1      | 1      |
| Uganda      | 2011   | 1      | 1      |
| Vietnam     | 1997   | 0      | 1      |
| Vietnam     | 2002   | 0      | 1      |
| Yemen       | 1991   | 1      | 1      |
| Yemen       | 1997   | 0      | 0      |
| Yemen       | 2013   | 1      | 1      |
| Zambia      | 1992   | 1      | 1      |
| Zambia      | 1996   | 0      | 1      |
| Zambia      | 2001   | 1      | 1      |
| Zambia      | 2007   | 1      | 1      |
| Zambia      | 2013   | 1      | 1      |
| Zimbabwe    | 1988   | 0      | 0      |
| Zimbabwe    | 1994   | 1      | 1      |
| Zimbabwe    | 1999   | 1      | 1      |
| Zimbabwe    | 2005   | 1      | 1      |
| Zimbabwe    | 2010   | 1      | 1      |
| Table S3: Additional Summary Statistics for Analysis Sample | Obs | Within-country variation (%) | Mean | 25th | 50th | 75th |
|----------------------------------------------------------|-----|------------------------------|------|------|------|------|
| **Other Potential Determinants of the Main Outcome**<sup>b</sup> |     |                              |      |      |      |      |
| Breastfed within 1 hour of birth                         | 1382| 52.2                         | 47.0 | 32.8 | 48.2 | 61.8 |
| Received all 8 basic vaccinations                        | 1523| 51.6                         | 59.0 | 44.9 | 62.3 | 75.7 |
| Received no vaccinations                                 | 1514| 68.3                         | 8.6  | 1.5  | 4.5  | 11.0 |
| Pregnant women: slept under bednet last night            | 499 | 44.8                         | 39.3 | 16.5 | 36.6 | 61.4 |
| Pregnant women: slept under ITN last night               | 499 | 52.5                         | 29.2 | 6.0  | 24.8 | 47.1 |
| Children under 5: slept under bednet last night         | 504 | 43.6                         | 39.5 | 16.9 | 37.7 | 60.3 |
| Children under 5: slept under ITN last night            | 504 | 52.5                         | 29.3 | 5.8  | 25.1 | 49.0 |
| Women took SP/Farsider during pregnancy                 | 418 | 50.9                         | 37.1 | 6.3  | 31.3 | 64.5 |
| Children 6-59 mo: Received vitamin A in last 6 mo.      | 644 | 30.6                         | 56.2 | 38.8 | 60.5 | 74.2 |
| **DHS Control Variables**<sup>b</sup>                   |     |                              |      |      |      |      |
| Women with some secondary education                      | 1621| 30.7                         | 38.6 | 17.4 | 34.8 | 56.5 |
| Households with electricity                             | 1575| 33.5                         | 47.2 | 12.4 | 44.8 | 80.0 |
| Households with finished floors                         | 1591| 50.6                         | 46.4 | 21.2 | 43.5 | 71.7 |
| Total fertility rate 15-44                               | 1644| 32.8                         | 4.1  | 2.9  | 3.9  | 5.3  |
| Median birth interval (months)                           | 1639| 51.6                         | 36.3 | 31.2 | 34.4 | 39.2 |
| Place of delivery: Health facility                      | 1567| 46.2                         | 53.1 | 28.9 | 52.2 | 78.1 |
| No antenatal care                                        | 1587| 44.6                         | 15.1 | 2.9  | 7.1  | 19.4 |
| **WDI Control Variables**<sup>c</sup>                   |     |                              |      |      |      |      |
| Ln Cereal Yield (kg/ha)                                  | 1636| N/A                          | 7.5  | 7.1  | 7.4  | 7.9  |
| Ln GDP per capita (US$)                                  | 1640| N/A                          | 6.7  | 6.0  | 6.7  | 7.2  |
| Total health expenditure (% of Total GDP)                | 1404| N/A                          | 5.3  | 4.0  | 5.0  | 6.1  |
| Ln Total ODA per capita (US$)                            | 1636| N/A                          | 3.1  | 2.3  | 3.6  | 4.1  |
| Urban population (% of total)                            | 1640| N/A                          | 39.0 | 26.1 | 37.6 | 48.4 |
| Ln Total Population                                      | 1640| N/A                          | 17.1 | 16.0 | 16.7 | 18.2 |
| Malaria cases per 1,000 at risk                          | 267 | N/A                          | 176.9| 29.8 | 105.9| 207.0|
| **Other DHS Characteristics**<sup>bd</sup>              |     |                              |      |      |      |      |
| Child Height-for-age Z                                   | 1091| 43.6                         | -1.4 | -1.8 | -1.4 | -1.0 |
| Region population density (people per sq. km)            | 1644| 92.8                         | 541.6| 35.2 | 92.7 | 291.0|
| Children with any anemia                                | 646 | 24.5                         | 59.1 | 46.0 | 59.6 | 72.2 |
| **Mortality Rates**<sup>b</sup>                         |     |                              |      |      |      |      |
| Perinatal (per 1,000 pregnancies)                       | 1062| 57.5                         | 30.8 | 21.0 | 29.0 | 39.0 |
| Neonatal (per 1,000 live births)                        | 1499| 52.8                         | 30.8 | 20.0 | 29.0 | 39.0 |
| Post-Neonatal (per 1,000 neonatal survivors)             | 1497| 50.4                         | 30.1 | 15.0 | 27.0 | 40.0 |
| Infant (per 1,000 live births)                           | 1497| 48.7                         | 61.0 | 39.0 | 57.0 | 77.0 |
| Child (1-5 yrs) (per 1,000 1 year-olds)                  | 1497| 34.3                         | 35.9 | 11.0 | 25.0 | 51.0 |
Note:

a. This indicator reports the share of total variation in the subnational panel explained by intra-country variation. It is equal to 100 minus the R-squared coefficient from a regression of each variable against country-level fixed effects.
b. These variables are all sourced from DHS STATcompiler (USAID and ICF-International 2017), which disaggregates variables at subnational units that we standardize across multiple DHS rounds.
c. These variables are all sourced from the World Bank’s (2017) World Development Indicators.
d. Regional level population density data is sourced from Hathi et al. (2017) and the GRUMP (2008) database.
e. Calculated using DHS microdata and DHS survey weights.
Table S4: Summary Statistics for Dependent Variables in the Age-Disaggregated DHS data

| Obs | Within-country variation (%) | Mean | 25th | 50th | 75th |
|-----|------------------------------|------|------|------|------|
| **Microdata Age-Disaggregated Outcomes** | | | | | |
| Children with diarrhea (under 2) | 938 | 57.6 | 21.7 | 15.3 | 21.1 | 27.8 |
| Children with diarrhea (3 to 5) | 938 | 71.8 | 11.9 | 7.5 | 10.6 | 15.3 |
| Children stunted (under 2) | 931 | 40.5 | 28.6 | 19.4 | 28.3 | 37 |
| Children stunted (3 to 5) | 931 | 36.6 | 41.3 | 27 | 41.5 | 55.2 |
| Children with fever (under 2) | 921 | 62.6 | 30.2 | 20.6 | 29.1 | 39 |
| Children with fever (3 to 5) | 921 | 68.1 | 24.2 | 15.9 | 22.8 | 31.4 |
| Children wasted (under 2) | 925 | 37.7 | 11.1 | 4.6 | 9.5 | 16.1 |
| Children wasted (3 to 5) | 925 | 44.9 | 6 | 1.7 | 4.4 | 8.6 |
| **Microdata Mortality Rates** | | | | | |
| Post-Neonatal mortality rate (5-year data) | 1,467 | 60.8 | 26.5 | 12.4 | 22.8 | 36.1 |
| Post-Neonatal mortality rate (1-year data) | 1,467 | 71.4 | 28.1 | 10.2 | 23 | 40.2 |
| Infant mortality rate (5-year data) | 1,467 | 58.9 | 54 | 33.1 | 49.5 | 71.7 |
| Infant mortality rate (1-year data) | 1,467 | 68.1 | 56.2 | 28.7 | 52.9 | 78.1 |
| Child mortality rate (5-year data) | 1,467 | 40.9 | 31.2 | 8.9 | 21.3 | 42.7 |
| Child mortality rate (1-year data) | 1,467 | 48.5 | 34.7 | 7.7 | 22 | 50.3 |
| Under 5 mortality rate (5-year data) | 1,467 | 48 | 82.8 | 42.5 | 71.5 | 111.4 |
| Under 5 mortality rate (1-year data) | 1,467 | 53.5 | 88.2 | 41.5 | 76.1 | 123.5 |

Note:

a. This indicator reports the share of total variation in the subnational panel explained by intra-country variation. It is equal to 100 minus the R-squared coefficient from a regression of each variable against country-level fixed effects.
b. These variables are all sourced from DHS STATcompiler (USAID and ICF-International 2017), which disaggregates variables at subnational units that we standardize across multiple DHS rounds.
c. These variables are all sourced from the World Bank’s (2017) World Development Indicators.
d. Regional level population density data is sourced from Hathi et al. (2017) and the GRUMP (2008) database.
e. Calculated using DHS microdata and DHS survey weights.

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values are reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Supplement B: Disaggregating by age and limiting the mortality recall window

The main text only considers the relationship between WASH access and under-5 mortality. However, the DHS data permit us to disaggregate under-5 mortality into mortality rates for more narrowly defined age groups. Specifically, we separately estimate the relationship between sanitation coverage and perinatal (deaths between 22 weeks gestation and one week post-partum), neonatal (first month after birth), post-neonatal (1-11 months), infant (0-11 months), and child mortality (12-59 months). Though we do not interpret the age-specific mortality relationships as being driven purely by differences in sanitation coverage at that age—accumulated exposure to open defecation at earlier life stages is likely to influence later mortality—the pattern we observe in the age-specific mortality associations may help to shed light on the potential mechanisms driving the overall sanitation-mortality link.

Figure S1 displays age-disaggregated sanitation-mortality relationships (with 95% confidence intervals) from estimating the core model with continent-specific time trends. We find no statistically significant association between sanitation coverage and either perinatal or neonatal mortality. Given that, on average, perinatal and neonatal mortality rates are higher than those measured later in infancy and childhood, the small point estimates and lack of a statistically significant association is particularly notable. Beginning with post-neonatal mortality, we estimate a statistically significant relationship between sanitation coverage and all the remaining mortality measures. Half of the overall predicted reduction in under-5 mortality appears to be from reductions in post-neonatal mortality (1-11 months), with the other half coming from a reduction in the mortality rate among children 1-5 years of age.

Figure S2 displays the same results for the access to improved water measure. We are never able to reject that the association between improved water and mortality is statistically significantly different from zero, reinforcing the lack of a statistically significant association between improved water and the aggregate under-5 mortality measure show in Table 2.
Figure S1: Sanitation and age-disaggregated mortality using STATCOMPILER

Note: Figure presents the point estimates and 95% confidence intervals for the sanitation coverage indicator and different measures of fetal and early childhood mortality. Perinatal mortality covers the period between 22 weeks gestation and 1 week post-partum, neonatal mortality includes mortality during the first month, post-neonatal mortality covers 1-11 months, infant mortality includes deaths between birth and 12 months, child (1-5 years) includes deaths between 12 and 60 months, and under five mortality includes all deaths before 60 months. Confidence intervals are based on Huber-White robust standard errors clustered at the subnational region level. Source: DHS STATcompiler (USAID and ICF-International 2017).
Figure S2: Improved Water and age-disaggregated mortality using STATCOMPILER

Note: Figure presents the point estimates and 95% confidence intervals for the improved water indicator and different measures of fetal and early childhood mortality. Perinatal mortality covers the period between 22 weeks gestation and 1 week post-partum, neonatal mortality includes mortality during the first month, post-neonatal mortality covers 1-11 months, infant mortality includes deaths between birth and 12 months, child (1-5 years) includes deaths between 12 and 60 months, and under five mortality includes all deaths before 60 months. Confidence intervals are based on Huber-White robust standard errors clustered at the subnational region level. Source: DHS STATcompiler (USAID and ICF-International 2017).
Figure S3: Sanitation and mortality with limited recall periods

Note: Figure presents the point estimates and 95% confidence intervals for the sanitation coverage indicator with different restrictions on the years of data used to calculate the mortality rates. “All” results reproduce the adjusted models with global region time trends using ten years of data, the “5yr” results restrict the data to just the five years immediately preceding each DHS, and the “1yr” results restrict the data to just the year preceding each DHS. Dots represent point estimates and the shaded bars display the 95% confidence intervals based on standard errors clustered at the subnational region level. Source: Demographic Health Surveys (various years).
Figure S4: Improved water and mortality rate with limited recall periods

Note: Figure presents the point estimates and 95% confidence intervals for the improved water access indicator with different restrictions on the years of data used to calculate the mortality rates. "All" results reproduce the adjusted models with global region time trends using ten years of data, the "5yr" results restrict the data to just the five years immediately preceding each DHS, and the "1yr" results restrict the data to just the year preceding each DHS. Dots represent point estimates and the shaded bars display the 95% confidence intervals based on standard errors clustered at the subnational region level. Source: Demographic Health Surveys (various years).
Table S5: WASH technology and mortality: Full sample and first and last wave results

| Mortality Rate | Post-Neonatal | Infant | Child (1-5 years) | Under 5 |
|---------------|---------------|--------|-------------------|---------|
|               | Full panel    | First & last wave | Full panel    | First & last wave | Full panel    | First & last wave |
|               | (1)           | (2)     | (3)               | (4)     | (5)               | (6)           | (7)               | (8)               |
| Panel A       |               |         |                   |         |                   |               |                   |                   |
| Households with any sanitation | -0.164** | -0.149 | -0.213** | -0.359 | -0.200** | -0.260* | -0.381** | -0.567* |
|               | [0.024]       | [0.289] | [0.042]           | [0.102] | [0.021]           | [0.094]       | [0.011]           | [0.061]           |
| R-squared     | 0.56          | 0.791   | 0.596             | 0.823   | 0.645             | 0.863         | 0.686             | 0.875             |
| N             | 1401          | 537     | 1401              | 537     | 1401              | 537           | 1401              | 537               |
| P-value: Coeff. are Equal | 0.899 | 0.375   | 0.637             | 0.42    |                   |               |                   |                   |
| Region Fixed Effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Full Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Panel B       |               |         |                   |         |                   |               |                   |                   |
| Households with improved water | -0.032 | 0.009 | -0.029 | 0.053 | -0.026 | 0.026 | -0.048 | 0.078 |
|               | [0.468]       | [0.945] | [0.660]           | [0.781] | [0.681]           | [0.869]       | [0.642]           | [0.783]           |
| R-squared     | 0.559         | 0.789   | 0.593             | 0.814   | 0.639             | 0.85          | 0.683             | 0.866             |
| N             | 1479          | 574     | 1479              | 574     | 1479              | 574           | 1479              | 574               |
| P-value: Coeff. are Equal | 0.702 | 0.613   | 0.703             | 0.601   |                   |               |                   |                   |
| Region Fixed Effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Full Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: “Full” columns replicate the main estimates from adjusted DID regressions with global region time trends. “Long” columns show the analogous estimates when limiting the sample to the first DHS and the last DHS for each subnational region and requiring that these DHS waves be at least ten years apart. The “P-value: Coeff are Equal” row displays p-values from tests of the null hypothesis that there is no difference between the estimates for the “Full” and “Long” samples. *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017) from various years and countries.
Table S6: WASH technology and child health: STATCOMPILER and aggregated DHS results

| Sample                        | STATCOMPILER (1) | Micro aggregated (2) | STATCOMPILER (3) | Micro aggregated (4) | STATCOMPILER (5) | Micro aggregated (6) | STATCOMPILER (7) | Micro aggregated (8) |
|-------------------------------|------------------|----------------------|------------------|----------------------|------------------|----------------------|------------------|----------------------|
| **Panel A**                   |                  |                      |                  |                      |                  |                      |                  |                      |
| Households with any sanitation| -0.121***        | -0.100***            | -0.015           | -0.017               | -0.163***        | -0.119**             | -0.023           | -0.019               |
| [0.000]                       | [0.004]          | [0.674]              | [0.663]          | [0.000]              | [0.020]          | [0.295]              | [0.531]          |                      |
| R-squared (within)            | 0.254            | 0.447                | 0.516            | 0.45                 | 0.511            | 0.648                | 0.309            | 0.306                |
| N                             | 1,451            | 926                  | 1,193            | 919                  | 1,521            | 917                  | 1,187            | 913                  |
| Region Fixed Effects          | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    |
| Time Controls                 | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    |
| Full Controls                 | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    |
| **Panel B**                   |                  |                      |                  |                      |                  |                      |                  |                      |
| Households with improved water| 0.016            | 0.023                | -0.042*          | -0.023               | 0.025            | 0.062                | 0.009            | 0.039**              |
| [0.467]                       | [0.407]          | [0.064]              | [0.388]          | [0.446]              | [0.146]          | [0.563]              | [0.021]          |                      |
| R-squared (within)            | 0.237            | 0.449                | 0.538            | 0.455                | 0.51             | 0.648                | 0.33             | 0.305                |
| N                             | 1,515            | 938                  | 1,176            | 931                  | 1,574            | 921                  | 1,170            | 925                  |
| Region Fixed Effects          | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    |
| Time Controls                 | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    |
| Full Controls                 | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    | ✓                | ✓                    |

Notes: “Stat compiler” columns replicate the main results from Tables 2 and S5 from the adjusted DID regressions for each outcome with global region time trends. “Micro aggregated” columns show the corresponding estimates when the DHS Nutrition microdata sample is used to calculate the value for each outcome for all subnational region years in the data. *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values reported in brackets. Source: DHS and DHS STATcompiler (USAID and ICF-International 2017) from various years and countries.
Table S7: WASH technology, child health, and age disaggregation

| Sample: | Diarrhea | Stunting | Fever | Wasting |
|---------|----------|----------|-------|---------|
|         | Under 2  | Age 2-5  | Under 2 | Age 2-5 | Under 2 | Age 2-5 | Under 2 | Age 2-5 |
|         | (1)      | (2)      | (3)    | (4)     | (5)      | (6)    | (7)      | (8)     |

**Panel A**

Households with any sanitation

|                      | (1)     | (2)     | (3)     | (4)     | (5)     | (6)     | (7)     | (8)     |
|----------------------|---------|---------|---------|---------|---------|---------|---------|---------|
|                      | -0.109** | -0.096*** | -0.071 | -0.040 | -0.111** | -0.113** | -0.003 | -0.03   |
| R-squared (within)   | 0.322   | 0.427   | 0.29    | 0.606   | 0.635   | 0.591   | 0.241   | 0.238   |
| N                    | 926     | 926     | 919     | 919     | 917     | 917     | 913     | 913     |
| Region Fixed Effects | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       |
| Time Controls        | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       |
| Full Controls        | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       |

**Panel B**

Households with improved water

|                      | (1)     | (2)     | (3)     | (4)     | (5)     | (6)     | (7)     | (8)     |
|----------------------|---------|---------|---------|---------|---------|---------|---------|---------|
|                      | 0.056   | 0.000   | -0.027  | -0.003  | 0.061   | 0.059   | 0.030   | 0.041** |
| R-squared (within)   | 0.325   | 0.43    | 0.296   | 0.608   | 0.635   | 0.591   | 0.24    | 0.238   |
| N                    | 938     | 938     | 931     | 931     | 921     | 921     | 925     | 925     |
| Region Fixed Effects | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       |
| Time Controls        | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       |
| Full Controls        | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       | ✔️       |

Notes: "Under 2" columns show estimates from adjusted DID regressions with global region time trends using the value of the outcome calculated just using children under twenty-four months of age at the time of the survey. "Age 2-5" columns show the analogous estimates with outcomes calculated using children between the ages of twenty-four and fifty-nine months at the time of the survey. *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values reported in brackets. Source: DHS data from various years and countries.
Supplement C. Testing for parameter heterogeneity

As an extension to the main results, we categorize each of the WASH access measures into indicators for whether regions were in one of nine or ten equal sized categories—0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, or 90-100%—based on the percent of surveyed households in the region who reported having sanitation or access to an improved water source. There are only nine categories for access to improved water as we never observe any region with below 10% improved water access in the data. Including the full set of WASH category indicators—excluding the bottom category (0 to 10% for sanitation coverage and 10-20% for access to improved water)—relaxes the assumption that the relationship between the child health outcomes and WASH technologies is linear. This enables us to assess whether the non-linear relationships uncovered in several recent papers between sanitation and child health outcomes are relevant for our data (Headey et al. 2015; Andres et al., 2017; Jung, Lou and Cheng 2017). Supplement Figures S5-S12 display coefficient estimates and 95% confidence intervals for the outcomes when using the binned sanitation and improved water access indicators.

The results, which should be interpreted as changes in the outcome relative to regions with 0-10% sanitation coverage or 10-20% access to improved water, support the linear-in-parameters specifications in Table 2 for both WASH technologies. For all three of the outcomes for which we find a statistically significant association in Table 2 (mortality, diarrhea, fever), the figures suggest treatment effects are increasing in absolute value as sanitation coverage increases across categories. Consistent with the lack of an association for stunting and wasting, the figures for these outcomes identify flat gradients between sanitation coverage categories and the outcomes. Similarly, the association between access to improved water and child health outcomes is flat and the 95% confidence intervals never exclude zero. Therefore, for both WASH technologies, there is no evidence of non-linearities in our region-level panel.
Figure S5: Sanitation Coverage Categories and Under-5 Mortality

Figure S6: Sanitation Coverage Categories and Diarrhea Prevalence
Figure S7: Sanitation Coverage Categories and Stunting

Figure S8: Sanitation Coverage Categories and Fever Prevalence
Figure S9: Improved Water Access Categories and Under-5 Mortality

![Graph showing the relationship between improved water access categories and under-5 mortality.](image)

Figure S10: Improved Water Access Categories and Diarrhea Prevalence

![Graph showing the relationship between improved water access categories and diarrhea prevalence.](image)
Figure S11: Improved Water Access Categories and Stunting

Figure S12: Improved Water Access Categories and Fever Prevalence
Table S8: Sanitation, Population Density and Child Health Outcomes

|                      | Under 5 Mortality | Diarrhea | Stunting | Fever | Height-for-age | Infant Mortality |
|----------------------|-------------------|----------|----------|-------|----------------|-----------------|
|                      | (1)               | (2)      | (3)      | (4)   | (5)            | (6)             |
| Households with any sanitation | -0.766**          | -0.210*** | 0.088    | -0.377*** | -0.008**       | -0.330          |
|                       | [0.018]           | [0.002]  | [0.161]  | [0.000] | [0.015]       | [0.145]         |
| Households with any sanitation*ln Population Density | 0.093             | 0.022    | -0.024   | 0.053** | 0.001**       | 0.028           |
|                       | [0.139]           | [0.145]  | [0.101]  | [0.015] | [0.035]       | [0.511]         |
| R-squared             | 0.687             | 0.256    | 0.519    | 0.515  | 0.539         | 0.597           |
| N                    | 1,401             | 1,451    | 1,193    | 1,521  | 1,080         | 1,401           |
| Region Fixed Effects  | ✓                 | ✓        | ✓        | ✓      | ✓             | ✓               |
| Time Controls         | ✓                 | ✓        | ✓        | ✓      | ✓             | ✓               |
| Full Controls         | ✓                 | ✓        | ✓        | ✓      | ✓             | ✓               |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values are reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Supplement D: Assessing Identifying Assumptions

Although the list of control variables included in the adjusted models is extensive, there is a residual concern that subnational regions exhibiting significant progress on WASH access may be making improvements in other areas relevant to child health. We assess whether the estimates from Eq. (1) are likely to be driven by omitted variable bias from unobserved time-varying factors and whether the observed changes in outcomes chronologically precede the changes in WASH access through two exercises. For the first we replace the main outcomes, $H$, with a series of health behaviors ($H^c$) not included in $Z$. Under two key assumptions discussed in more detail below, the coefficient on the WASH measures provides information about the likelihood that the main associations are driven by changes in the health behaviors or in other unobserved characteristics that are strongly correlated with the health behaviors. The second assessment examines the parallel trends assumption implicit in DID models. In our context this assumption implies that, after conditioning on controls, subnational areas that experience accelerated changes in WASH access would have had similar changes in the outcome variables in the absence of WASH accelerations. For countries with several treatment periods we can explore the plausibility of this assumption by examining whether past changes in the health outcomes predict subsequent changes in WASH coverage (Goldsmith-Pinkham, Sorkin and Swift 2017). Recovering a null estimate for these relationships boosts the credibility of the identifying assumptions by suggesting that any associations between WASH coverage and the outcomes occur in the chronologically expected order (e.g. the changes in outcomes do not precede the changes in WASH coverage).

Though neither specification check provides a broad assessment of the identifying assumptions, they offer some evidence regarding two of the more likely sources of potential bias. These exercises are described in more detail below.

Alternative Outcomes: Other Potential Determinants of the Main Outcomes
For the first specification check we replace the main dependent variables $H$ with a series of health behaviors not included in $Z$. To provide useful information about the identifying assumptions, the health behaviors we use as outcomes in these exercises ($H^C$) should be variables that are not directly impacted by the WASH improvements but that appropriately reflect broader improvements in healthcare and that we expect to be strongly predictive of the main outcomes of interest. For these checks we re-estimate equation (1), but after replacing the main outcomes with the health behaviors we view as likely to be predictive of the main outcomes:

\[
H^C_{i,j,t} = \beta_W W_{i,j,t} + \beta_X X_{i,j,t} + \beta_Z Z_{j,t} + \mu_{i,j} + \alpha_t + \gamma_{j,t} + e_{i,j,t}
\]

(2)

By assumption there should be no direct association between $W_{i,j,t}$ and $H^C_{i,j,t}$ and there should be a strong relationship between $H^C_{i,j,t}$ and the main outcomes. Thus, rejecting that $\beta_W$ are equal to zero suggests it is less likely that there are unobserved time-varying characteristics that are driving the results in (1) as the main outcomes, the variables included in $H^C_{i,j,t}$, and other unobserved determinants of the main outcomes should be correlated with one another.

With continuous and typically non-zero right-hand-side variables of interest, pre-treatment values of the main outcomes—which would be ideal variables to include in $H^C_{i,j,t}$—are not available. Instead, we select outcomes that we expect to be strongly related to the outcomes of interest but that should be unaffected by region-level changes in WASH coverage (Imbens and Rubin 2015): indicators of exposure to child health and nutrition interventions, such as improved initial breastfeeding practices (to capture exposure to nutritional interventions), vaccination coverage (generic child health interventions), malaria prevention and treatment indicators, and vitamin A supplementation. We note that some of these indicators are only measured for a sub-sample of observations. We do not show results for other measures of breastfeeding (e.g. median duration exclusive breastfeeding) as it seems unlikely that these would not directly be affected by changes in the WASH indicators. This is especially true for the improved water access indicator, as
households may view breastfeeding and improved water as substitutes. Supplement Table S2 shows summary statistics for all the variables in $H_{i,j,t}^C$.

While we feel the variables selected are likely to satisfy both conditions for these checks, we acknowledge that the assumption the $H_{i,j,t}^C$ outcomes are not affected by the WASH indicators after conditioning on subnational region fixed effects and the other controls is ultimately untestable. Rejecting the null hypothesis of no association between the WASH indicators and a variable in $H_{i,j,t}^C$ could therefore reflect likely bias in the main estimates or simply the possibility that changes in WASH access directly affect the alternative outcome and the main outcomes of interest, for example because households alter these behaviors in response to perceived changes in the risk of adverse health shocks resulting from the variation in WASH access.\textsuperscript{16} Similarly, while there is ample evidence linking the outcomes in $H_{i,j,t}^C$ to the child health and nutrition outcomes, a failure to reject the null of no relationship between $H_{i,j,t}^C$ and one of the WASH indicators could be more likely to occur if there is attenuation bias from measurement error in the WASH variables or if an insufficient sample size critically reduces statistical power.

Despite these potential issues, our view is that these specifications provide useful information about the plausibility that there are no unobserved time-variant determinants of the main outcomes that are correlated with changes the WASH measures in the main outcome equations. If the above conditions are met—so that the variables included in $H_{i,j,t}^C$ do not respond to the changes in perceived health risk generated by variation in WASH access—but both changes in these variables and changes in WASH access are correlated with other unobserved determinants of the main outcomes (e.g. preferences for child health and nutrition outcomes), then we should expect to find positive relationships between WASH coverage and $H_{i,j,t}^C$ when we estimate equation (2).

\textsuperscript{16} We thank an anonymous referee for pointing this out.
Supplement Tables S9 and S10 present the results of estimating (2) based on adjusted models with the global region time trends. For none of the three outcomes in Table S9 (early initiation of breastfeeding, vaccination coverage) do we estimate a statistically significant association with sanitation coverage. The relationships between sanitation coverage and the malaria and vitamin A supplementation outcomes (reported in Supplement Table S10) are similarly never statistically significantly different from zero, though the sample sizes are restricted by the limited availability of these outcomes in the DHS data. Across all 9 outcomes in $H_{i,j,t}$, we therefore never estimate a statistically significant relationship with sanitation coverage. These checks therefore suggest that there is little association between changes in sanitation coverage and changes in the other determinants of the child and nutrition outcomes included in $H_{i,j,t}$.

The analogous estimates for access to improved water are shown in the bottom panels of Tables S9 and S10. Access to improved water is statistically significantly associated with just one of the 9 measures—the likelihood that children 6-59 months of age received a vitamin A supplement during the six months preceding the survey—for which the point estimate on the improved water access measure is negative. As with the analogous checks for sanitation, we therefore estimate little evidence that changes in improved water access are statistically significantly related to other likely determinants of the main outcomes.

Parallel Trends Assessment

The second specification check we implement is a prior trends assessment that examines the parallel trends assumption implicit in DID models. In our context this assumption implies that, after conditioning on controls, subnational areas that experience accelerated changes in WASH access would have had similar changes in the outcome variables in the absence of WASH accelerations. For countries with several treatment periods we explore the plausibility of this assumption by examining whether past changes in the health outcomes predict subsequent changes in WASH coverage (Goldsmith-Pinkham, Sorkin and Swift 2017). Phrased another way, with continuous (and typically non-zero) right-hand-side variables of interest,
this amounts to exploring whether the changes in the outcomes preceded the changes in WASH coverage in the data. Recovering a null estimate for these relationships between past changes in health outcomes and future changes in WASH access boosts the credibility of the identifying assumptions by suggesting that the changes in the outcomes and the changes in WASH coverage occur in the chronologically expected order.

The conditional version of this test – as described in Goldsmith-Pinkham et al. (2017) – takes the residuals \( \tilde{H}_{i,j,t} \) from equation (1) and estimates them as a function of sanitation coverage in the next wave:

\[
\tilde{H}_{i,j,t} = \beta W_{i,j,t+1} + \mu_{i,j} + \alpha_{t+1} + \gamma_{j,t+1} + u_{i,j,t}
\]  

(3)

along with controls for subnational fixed effects, a full set of survey-year dummies for the later DHS wave being used, and either DHS fixed effects or continent-specific trends for the later survey. Because the prior trends assessment focuses on exploring whether the temporal sequencing between the WASH measures and outcomes is appropriate, we use the under-5 mortality rate estimated using just the five years of data preceding each survey. The results are not sensitive to this choice.

We show results from two slightly different versions of equation (3). In the first, to ensure the sample remains constant when estimating the residuals used in (3), we code the next survey year \((t + 1)\) to be 0 and impute the WASH measure to its year \(t\) level for the last wave in each region. The year \(t + 1\) fixed effects, which therefore partial out the impact of the imputed values for the last available year, ensure that these observations do not directly impact the coefficients of interest; they are used only to estimate the residuals, through their contribution to the estimated relationship between WASH coverage and the outcomes within each year. The second method only uses data on the outcomes when the next DHS survey for that subnational region is also observed. Thus, the last DHS wave for each subnational region is not used when estimating (3). In practice, the results to not change regardless of which method is used.

While the prior trends exercise is a useful assessment of one threat to the interpretation of the main estimates, there are several caveats that are important to mention. First, the parallel trends exercise does
not provide a broad appraisal of the identifying assumptions. That is, though the failure to reject the null hypotheses of no relationships between changes in the outcomes and future changes in the WASH measures would suggest that the changes in outcomes are not likely to temporally precede the changes in WASH measures, it does not necessarily provide evidence about the likelihood that unobserved time-varying confounders are driving the associations between WASH access and the main outcomes.

Second, by relying on the subnational region DID specification to generate residuals in each period, the prior trends exercise is susceptible to unobserved time-varying sources of bias. If the predicted residuals are biased, then the subsequent associations between the predicted residuals and future WASH coverage may similarly be affected.

Third, because we do not observe future WASH for the last DHS wave, we either drop this wave from the sample used to measure the association between the current value of the outcomes and future WASH coverage or we code it to zero and we include a dummy variable for whether the value was missing. In both cases, we effectively lose one observation per subnational region. This implies that we have, on average, 3.6 DHS waves per subnational region in our data. While the main estimates are unaffected by limiting the sample to the first and last waves for each subnational region, between which the autocorrelation in the outcomes is likely to be substantially smaller (and therefore the bias due to the incidental parameters problem is also likely to be smaller), this could be more problematic when we use the shorter panel available for the prior trends assessment.

Supplement Table S11 presents the results of the conditional parallel trend test for the five child health outcomes and both WASH technology measures. Panel A displays the results for sanitation when we discard the last DHS for each region and therefore do not impute the values of future sanitation coverage and Panel B shows the results when the last DHS is included in the sample and future sanitation coverage is imputed to its value in the previous wave. Panel C and Panel D do the same for the access to improved water indicator.
Panel A uncovers no evidence that changes in the outcomes precede changes in sanitation coverage. The smallest of the five p-values is 0.310 and the point estimates are of varying signs—the estimates for under-5 mortality and wasting are positive—and small in magnitude relative to the main estimates. Panel B similarly finds no statistically significant associations between future sanitation coverage and current values of the five outcomes, with p-values ranging from 0.386 (for wasting) to 0.934 (for stunting). The point estimates are generally smaller than in Panel A and, again, are of differing signs. Both Panel A and Panel B therefore support the idea that changes in sanitation coverage are not preceded by changes in the outcomes of interest.

Panels C and D suggest there are also limited associations between future access to improved water and current diarrhea, stunting, fever, or wasting: p-values for these four outcomes range from marginally statistically insignificant (0.102 for the fever outcome when missing values for future improved water access are imputed) to nearly one (0.985 for stunting when the last DHS for each region is omitted). However, in Panel C we find a statistically significant (p-value 0.060) and negative association between future access to improved water and current under-5 mortality. While the estimate for under-5 mortality in Panel D is slightly smaller in magnitude (-0.204 as compared to -0.280) and not statistically significantly different from zero at the 10% level (p-value 0.134), both coefficients seem to suggest there may be negative trends in under-5 mortality in areas that subsequently experience increases in access to improved water. If anything, this indicates that the associations between access to improved water and under-5 mortality shown in Panel B of Table 2—which were not statistically significantly different from zero—may be more negative than the true relationship between these two variables.
Table S9: WASH Technology and Breastfeeding and Vaccination Behavior

|                      | Early Breastfeeding (<1hr) | All 8 Vaccinations | No Vaccinations |
|----------------------|----------------------------|--------------------|-----------------|
| Panel A              | (1)                        | (2)                | (3)             |
| Households with any sanitation | 0.111                      | 0.095              | -0.050          |
| [0.148]              | [0.113]                     | [0.241]            |
| R-squared (within)   | 0.419                      | 0.507              | 0.529           |
| N                    | 1,237                      | 1,345              | 1,345           |
| Region Fixed Effects | ✓                          | ✓                  | ✓               |
| Time Controls        | ✓                          | ✓                  | ✓               |
| Full Controls        | ✓                          | ✓                  | ✓               |

Panel B

|                      | Early Breastfeeding (<1hr) | All 8 Vaccinations | No Vaccinations |
|----------------------|----------------------------|--------------------|-----------------|
| Households with improved water | 0.085                      | 0.032              | 0.054           |
| [0.101]              | [0.465]                     | [0.103]            |
| R-squared (within)   | 0.537                      | 0.542              | 0.548           |
| N                    | 1,288                      | 1,423              | 1,419           |
| Region Fixed Effects | ✓                          | ✓                  | ✓               |
| Time Controls        | ✓                          | ✓                  | ✓               |
| Full Controls        | ✓                          | ✓                  | ✓               |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values are reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
| Panel A | Pregnant Women | Children Under 5 | Women with a live birth during past 2 years | Children 6-59 Months |
|--------|----------------|------------------|------------------------------------------|---------------------|
|        | Slept under bednet last night | Slept under insecticide treated bednet last night | Slept under bednet last night | Slept under insecticide treated bednet last night |
|        | (1) | (2) | (3) | (4) |
| Households with any sanitation | 0.09 | 0.045 | 0.088 | -0.009 | -0.09 | 0.146 |
| [0.679] | [0.821] | [0.646] | [0.961] | [0.689] | [0.285] |
| R-squared (within) | 0.753 | 0.817 | 0.790 | 0.847 | 0.919 | 0.795 |
| N | 412 | 412 | 416 | 416 | 366 | 609 |
| Region Fixed Effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Full Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

| Panel B | Pregnant Women | Children Under 5 | Women with a live birth during past 2 years | Children 6-59 Months |
|--------|----------------|------------------|------------------------------------------|---------------------|
|        | Slept under bednet last night | Slept under insecticide treated bednet last night | Slept under bednet last night | Slept under insecticide treated bednet last night |
|        | (1) | (2) | (3) | (4) |
| Households with improved water | -0.022 | -0.085 | 0.027 | 0.001 | 0.008 | -0.225*** |
| [0.870] | [0.531] | [0.821] | [0.993] | [0.938] | [0.006] |
| R-squared (within) | 0.753 | 0.817 | 0.790 | 0.847 | 0.919 | 0.805 |
| N | 410 | 410 | 414 | 414 | 366 | 602 |
| Region Fixed Effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Full Controls | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Notes: *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values are reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
### Table S11: WASH Technology, Child Health Outcomes and Prior Trends

|                  | Under 5 Mortality | Diarrhea | Stunting | Fever | Wasting |
|------------------|-------------------|----------|----------|-------|---------|
|                  | (1)               | (2)      | (3)      | (4)   | (5)     |
| Future households with any sanitation | 0.107             | -0.04    | -0.032   | -0.032 | 0.006   |
|                  | [0.475]           | [0.310]  | [0.475]  | [0.608] | [0.867] |
| R-squared (within) | 0.093             | 0.043    | 0.103    | 0.064  | 0.073   |
| N                | 991               | 1042     | 842      | 1069   | 842     |

**Panel A**

- **Region Fixed Effects**: ✓ ✓ ✓ ✓ ✓
- **Time Controls**: ✓ ✓ ✓ ✓ ✓
- **Full Controls**: ✓ ✓ ✓ ✓ ✓

Missing Future Sanitation Imputed

### Panel B

|                  | Under 5 Mortality | Diarrhea | Stunting | Fever | Wasting |
|------------------|-------------------|----------|----------|-------|---------|
|                  | (1)               | (2)      | (3)      | (4)   | (5)     |
| Future households with any sanitation | 0.08              | -0.017   | -0.003   | -0.03 | -0.019  |
|                  | [0.537]           | [0.614]  | [0.934]  | [0.535] | [0.386] |
| R-squared (within) | 0.065             | 0.031    | 0.06     | 0.053  | 0.036   |
| N                | 1395              | 1451     | 1193     | 1521   | 1187    |

**Panel B**

- **Region Fixed Effects**: ✓ ✓ ✓ ✓ ✓
- **Time Controls**: ✓ ✓ ✓ ✓ ✓
- **Full Controls**: ✓ ✓ ✓ ✓ ✓

Missing Future Sanitation Imputed

### Panel C

|                  | Under 5 Mortality | Diarrhea | Stunting | Fever | Wasting |
|------------------|-------------------|----------|----------|-------|---------|
|                  | (1)               | (2)      | (3)      | (4)   | (5)     |
| Future households with improved water | -0.280*           | 0.001    | -0.034   | -0.013 | -0.021  |
|                  | [0.060]           | [0.985]  | [0.219]  | [0.752] | [0.413] |
| R-squared (within) | 0.112             | 0.054    | 0.119    | 0.062  | 0.083   |
| N                | 1010              | 1085     | 805      | 1112   | 805     |

**Panel C**

- **Region Fixed Effects**: ✓ ✓ ✓ ✓ ✓
- **Time Controls**: ✓ ✓ ✓ ✓ ✓
- **Full Controls**: ✓ ✓ ✓ ✓ ✓

Missing Future Improved Water Imputed

### Panel D

|                  | Under 5 Mortality | Diarrhea | Stunting | Fever | Wasting |
|------------------|-------------------|----------|----------|-------|---------|
|                  | (1)               | (2)      | (3)      | (4)   | (5)     |
| Future households with improved water | -0.204            | -0.01    | -0.004   | -0.057 | -0.029  |
|                  | [0.137]           | [0.697]  | [0.862]  | [0.102] | [0.120] |
| R-squared (within) | 0.063             | 0.035    | 0.065    | 0.049  | 0.04    |
| N                | 1435              | 1515     | 1176     | 1574   | 1170    |

**Panel D**

- **Region Fixed Effects**: ✓ ✓ ✓ ✓ ✓
- **Time Controls**: ✓ ✓ ✓ ✓ ✓
- **Full Controls**: ✓ ✓ ✓ ✓ ✓

Missing Future Improved Water Imputed

**Notes:** *, ** and *** refer to significance at the 10%, 5% and 1% levels. P-values are reported in brackets. Source: DHS STATcompiler (USAID and ICF-International 2017).
Supplement E. Sensitivity of results to alternative treatment of missing data

Our main results deal with the problem of missing control variables by imputing all missing values to zero and including an indicator variable for whether the value for each control was imputed for the regions in our data. We do this to preserve all available information while ensuring our sample sizes do not change because of variables other than those directly involved in one of the relationships of interest: the outcomes and WASH indicators. Though an extensive literature in statistics and the social sciences suggests this approach may lead to misleading estimates when missing data is determined by individual, household or enumerator characteristics, in our data the missing data are produced by an entirely different process. Specifically, missing data are directly determined by whether the DHS program or the World Bank elect to collect data on different indicators in a country-year. For instance, data for the malaria prevalence indicator control—the only variable in our data that is missing for more than 11% of the sample—are only available after 1999 and data for the total health expenditures as a percent of total GDP indicator—the only other control that is missing for more than 5% of the sample—is only available after 1994. Similar processes drive the missing rates for all the other controls.

While we feel our treatment of missing controls is appropriate given the reasons for missing data, we can show that our results are robust to alternative methods for dealing with the missing values. Unfortunately, multiple imputation—the most appropriate way of dealing with missing data—is not feasible in our context because when a DHS characteristic is not available, the likely correlates of that control are often also missing, and there is no variation within a country in the availability of a characteristic. Instead, we calculate estimates under two different ways of dealing with missingness: dropping the two control variables with greater than 5% missing rates—the malaria prevalence control and the total health expenditure as a percent of total GDP—and conducting complete case analysis (without including the two most frequently missing controls).
Figure S13 shows the result of this exercise for sanitation coverage while Figure S14 does the same for access to improved water. To help put the estimates under alternative methods into context, we also show the estimates from our main specifications.

For all three methods, Figure S13 displays the point estimates and 95% confidence intervals for all five outcomes. We use an M to label the main results, an NC to represent the estimates after dropping the two controls with >5% missingness rates, and a CC to represent the estimates from a complete case analysis after dropping the same two controls. For none of the five outcomes are our conclusions sensitive to the method we use to deal with missing data. Point estimates are nearly identical across the three plots for each outcome and 95% confidence intervals either do not include zero (for mortality, diarrhea, and fever) or always include zero (for stunting and wasting). Similarly, Figure S14 finds no important differences in the estimated relationship between access to improved water and the five outcomes between the three methods. Confidence intervals always include zero for the four outcomes excluding stunting and the stunting point estimate similar across the three scenarios, though the confidence interval for stunting under the complete case method does expand to include zero. Taken together, Figures S13 and S14 strongly support the idea that our method for dealing with missing controls is not importantly affecting estimates of the relationships of interest for sanitation.
Figure S13: Outcome Associations with Sanitation Coverage and Treatment of Missing Data

Note: Figure presents the point estimates and 95% confidence intervals for the sanitation coverage indicator under different methods of dealing for missing control variables. M represents the primary empirical results, where we impute all missing control variables to zero and include an indicator for whether each control variable was missing. NC follows the same procedure as M, but drops the WDI malaria prevalence indicator and the total expenditures as a percent of total GDP indicator (the only variables with >5% missingness) as controls. CC does complete case analysis after excluding the WDI malaria prevalence indicator and the health expenditures as a percent of total GDP as controls. Dots represent point estimates and the shaded bars display the 95% confidence intervals. Source: DHS STATcompiler (USAID and ICF-International 2017).
Figure S14: Outcome Associations with Improved Water and Treatment of Missing Data

Note: Figure presents the point estimates and 95% confidence intervals for the access to improved water indicator under different methods of dealing for missing control variables. M represents the primary empirical results, where we impute all missing control variables to zero and include an indicator for whether each control variable was missing. NC follows the same procedure as M, but drops the WDI malaria prevalence indicator and the total expenditures as a percent of total GDP indicator (the only variables with >5% missingness) as controls. CC does complete case analysis after excluding the WDI malaria prevalence indicator and the health expenditures as a percent of total GDP as controls. Dots represent point estimates and the shaded bars display the 95% confidence intervals. Source: DHS STATcompiler (USAID and ICF-International 2017).