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Water, Sanitation and Agriculture Linkages with Health and Nutrition Improvement

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Abstract

In 2010, the United Nations General Assembly recognized access to safe water and sanitation infrastructure a matter of human right. This right is reflected in Sustainable Development Goal 6, whose targets 1 and 2 point to universal access to safe and affordable drinking water and adequate sanitation by 2030, in a gender equitable way. Progress towards these targets has been recorded, building on successes achieved under the previous framework of the Millennium Development Goals (Target 7.c). These positive developments could be expected to spill over to other dimensions of human development, health and nutrition in particular. Yet, progress in either of these dimensions, particularly among young children (SDG target 2.2 on ending all forms of malnutrition), is not commensurate.

In this paper, we advocate for a systemic approach to water management for improved health and nutrition. We focus on rural and peri-urban areas of the developing world, where multi-purpose water systems are particularly relevant. As competition for safe water resources intensifies, it is important to understand the trade-offs between specific uses and their implications for health and nutrition, based on the gender and age of individuals.

We conduct statistical and econometric analyses of secondary, nationally representative data for four countries: Bangladesh, Ethiopia, Ghana and India. These data sets have been routinely used to report on progress toward SDG 6 (availability and sustainable management of water and sanitation for all) and SDG 2 (ending hunger and achieving food security and improved nutrition for all). Our cross-sectional analysis reflects the positive association between access to improved sanitation infrastructure and long-term child nutrition outcomes (height-for-age and weight-for-age). On the other hand, the analysis fails to demonstrate a positive association between access to improved drinking water sources and the same child nutrition indicators.

In the next step, we investigate the associations between multi-use water systems, especially around agricultural activities, and health and nutrition. To that end, we compile data from four household surveys we collected in the same countries, including indicators on the type of irrigation system. The regression analysis of this pooled dataset is complemented by an in-depth, context-specific analysis of behavior around drinking water use and irrigation practices. The analyses reveal a low correlation between water quality at the point of source and water quality at the point of use, drawing attention to behavioral issues around water use. Similarly, the prevalence of open defecation seems much more important to health and nutrition than the existence of sanitation infrastructure. Finally, irrigation is not per se a detrimental factor for drinking water quality or nutrition, but the integration of waste water irrigation in particular needs to be carefully managed in order to avoid adverse nutrition and health effects.

Keywords: multi-purpose water system, sanitation, agriculture, behavior, knowledge, nutrition

JEL Codes: Q15, Q010, Q190, I120

1. Introduction

“Piping” clean water into villages and building toilets for households is necessary for rural health but often not sufficient. Increased food production does not guarantee better nutrition, and even increased income among low income households often does not solve the undernutrition problems comprehensively. Ample research-based evidence reviewed in the section below points at the limitations of these and other mono-causal approaches. Probably, programs to address the nutrition and health deficiencies in low income rural settings need to be studied in a framework that is as complex as the causes of the problems. This paper therefore takes a multidisciplinary and systems approach to identify linkages between water quality and quantity, sanitation and hygiene and agriculture and their implications for investment priorities for better health and nutrition outcomes.

The motivation of the paper lies in the hypothesis that promoting access to safe drinking water and adequate sanitation and hygiene for all (SDG targets 6.1 and 6.2) is necessary, but not sufficient to address the more fundamental goal of water and sanitation (WATSAN) programs: improved health and nutrition for the populations. The key notion behind this hypothesis is that the water and sanitation systems at the household level, particularly in rural areas, cut across different spheres of water use (drinking, cooking, cleaning, personal hygiene, irrigation), with household consumption and production activities as well as hygiene behavior closely intertwined. Our aim is to test this hypothesis and to inform WASH-related policies for improved human health and nutrition.

We try to implement this approach and test this hypothesis in our analysis of existing nationally representative data of rural areas, for which the set of indicators is of course predetermined, and especially in the analysis of our own case studies data. The latter was collected among households in rural and peri-urban settings and focuses on the different facets of their multi-use water systems, hygiene systems, and the links to farming. Notably, it gathers information on the household members’ access to and use of water for agricultural and domestic purposes. The research questions we investigate are:

1. How does improved water and sanitation infrastructure impact on **water quality and hygiene**, in view of household and community behavior?
2. To which extent does access to improved drinking water and sanitation contribute to **improved nutrition and health** (e.g. lower diarrhea prevalence)?
3. How do the complex linkages between water uses in **agriculture** and domestic water uses impact on improved drinking water and sanitation and what are the linkages to nutrition and health?

The specific aim here is to draw out information about agriculture-WATSAN linkages as indirect drivers of health and nutrition outcomes. The comparative analysis of the two data sets helps us to highlight the role of agriculture in WATSAN and to test our working hypothesis that water needs to be considered from a system perspective in order to make further steps toward achieving SDG 2 (zero hunger) and SDG 6 (clean water and sanitation).

This paper builds on a long-term research program carried out at sites in Bangladesh, Ethiopia, Ghana, and India. For each study site, a doctoral dissertation and some other publications are available.[1] These selected countries all face a critical environment with regard to WATSAN, and even WASH (water, sanitation and hygiene), and irrigated agriculture is practiced with clear WATSAN linkages. Research activities were mainly field based at household and community levels. Based on specific criteria, hotspots were selected in the four countries where drinking water, sanitation services, and hygiene conditions are deficient, and where health and nutrition situations are adverse. Spatial aspects of WATSAN-agriculture investments are also considered, as they pose infrastructural and agricultural challenges and require appropriate management and engineering designs, which differ by settings (i.e. in dispersed communities, clustered villages, peri-urban villages, slums at urban peripheries).

Our empirical analysis highlights the relationship between a number of individual-, household- and community-level characteristics and the health and nutrition outcomes of the communities' most vulnerable members: children under five years of age. Children's health and nutrition status is captured by a set of anthropometric indices, namely weight-for-age, weight-for-height and height-for-age z-scores. A child's weight and height is related to the age- and sex-specific median and standard deviation of the WHO Child Growth Standards to derive z-scores, which are used to classify children as underweight, wasted or stunted.[2] In our agriculture and WATSAN context, it is crucial to be able to differentiate short-term and acute versus long-term and permanent impacts of water quality in the production and household water system on health and nutrition outcomes, as partly captured by wasting and stunting indicators, respectively.

Co-variates used in our analysis not only cover the usual socio-economic variables reflecting the composition of the households, their financial resources and the knowledge resources at the disposal of the caregivers, but also focus on identifying the households' type of relationship with the agriculture, water and sanitation system (e.g. irrigating vs non-irrigating

[1] See Hasan (2018) at http://hss.ulb.uni-bonn.de/2018/4988/4988.pdf, Okyere (2018) at http://hss.ulb.uni-bonn.de/2018/4854/4854.pdf, Usman (2017) at http://hss.ulb.uni-bonn.de/2017/4825/4825.pdf, Vangani (2018) at http://hss.ulb.uni-bonn.de/2018/5251/5251.pdf.

[2] WHO (2010) provides a short interpretation guide to these indicators. Wasting in children (low weight-for-height) captures acute undernutrition, resulting from insufficient food intake or from infectious diseases such as diarrhea, and is associated with increased risk of death. It can thus be used as an indicator of short-term nutrition and health shocks, which are particularly relevant in the context of WASH studies where infectious diseases can play a big role. Stunting (low height-for-age) in children results from generally poor diets and/or from recurrent infections. It therefore captures chronic nutritional deprivation and is associated with long-term physical and mental development deficiencies that can be transmitted across generations. This indicator clearly links with issues of labor and economic productivity for the households and nations. Underweight (low weight-for-age) is a summary indicator that captures aspects of both chronic and acute undernutrition. Underweight is linked with increased mortality risk for the children and is easily and widely measured.

farmers). As our purpose is to show the need to address WATSAN and WASH issues from a system perspective that includes agricultural water use, further variables are used to control for the traditional measures and goals of water and sanitation programs, such as: improved access to drinking water (in quality and quantity), better hygiene practices, and improved sanitation services.

We focus throughout the paper on identifying associations between the agriculture-WATSAN nexus at the farm level and health and nutrition outcomes for children under five years of age in the surveyed households. To that end, we first present a critical examination of the literature. Second, we attempt to highlight the interlinkages between agriculture and WATSAN using a pooled cross-sectional dataset based on nationally representative Demographic and Health Surveys (DHS) (Bangladesh, 2014; Ethiopia, 2016; Ghana, 2014; India, 2015-16). These datasets or their predecessors have been routinely used to monitor the progress towards the water and sanitation targets of the Millennium Development Goals: access to improved drinking water sources and to improved sanitation. Finally, we complement this analysis with the investigation of a cross-sectional set of comparable data collected under this research program across study sites in the same four countries.

The paper is structured in the following way: section 2 introduces the conceptual framework for health and nutrition analysis in the food, agriculture, and water system and reviews literature on the topic. Section 3 presents the data and descriptive statistics from the two different types of data sources used in this paper and provides basic bivariate analysis. Section 4 introduces the multiple regression analyses to examine some of the associations of interest that were identified in the three research questions above, and finally, section 5 concludes.

2. The agriculture-WATSAN nexus and its linkages with nutrition and health

In many developing countries, especially in rural settings, we find complex interactions of drinking water, sanitation and agriculture: for instance, there are often combined or competing uses of single water sources, for domestic purposes and agriculture. The multipurpose characteristics of water use, especially for irrigation and domestic purposes, pose certain human health and environmental risks, possibly through a trade-off between water quality and quantity (i.e. irrigation provides new water sources for domestic use, but potentially of low quality). In this section, we provide a conceptual framework of the various linkages between nutrition (and health) and the water system at the core of a household's agriculture-WATSAN nexus, including the hygiene elements of the WASH system. We use this framework of the issues at hand to guide our review of existing evidence and the analyses that follow. Figure 1 illustrates how water, sanitation, agriculture, and household situations and their interactions, may impact nutrition, well-being and health. These three sets of outcomes are themselves closely interlinked.

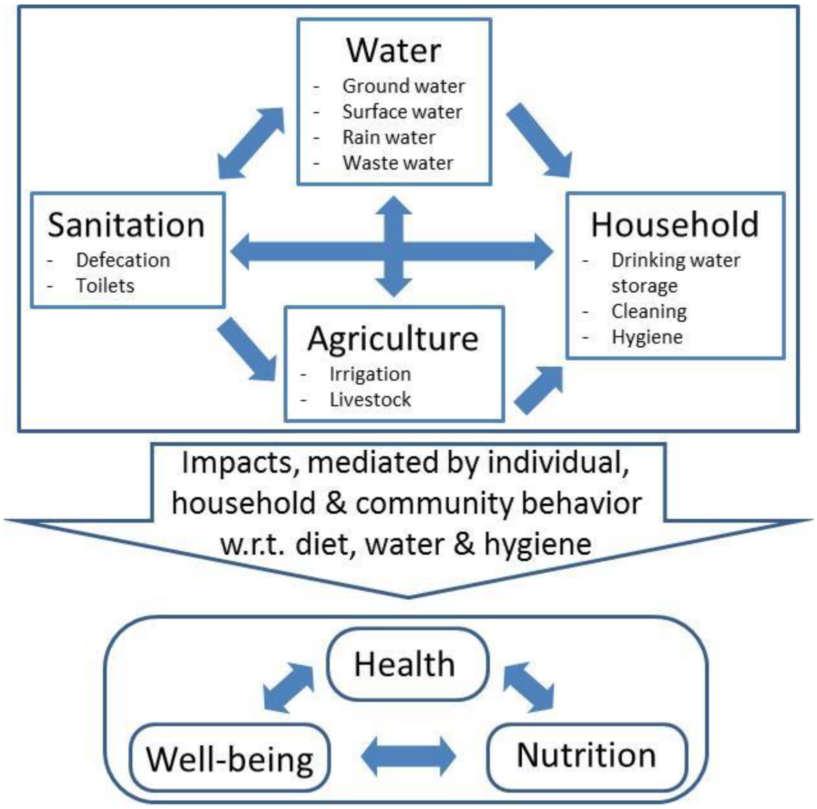

Figure 1: The agriculture-WATSAN System: an integrated framework with health and nutrition links

Source: designed by the authors

2.1 Water linkages

Two aspects around water matter for health and nutrition: quantity and quality. The two are closely connected and combine in determining health and nutrition outcomes. We address them below.

It is well-documented that in traditional settings, it is mostly women and girls who are in charge of the task of fetching water. This often includes traveling long distances and therefore a lot of productive time spent on that activity (WHO/UNICEF 2010). For instance, in Malawi, 87 percent of water fetching duties is taken up by women and 20 percent of the households spend more than an hour for each water collection trip (Sorenson et al. 2011). In rural Ethiopia, adult women are 10 times more likely to collect water for household consumption than adult men and 63 percent of the households need to travel 30 minutes or more for each water collection trip (CSA & ICF International 2012). It was estimated in 2006 that in Sub-Saharan Africa alone, 40 billion working hours are lost each year to collecting water (Blackden & Wodon 2006). Consequently, it is argued that providing an improved water infrastructure would allow women and girls to use the time spent collecting water for income-generating activities, seeking access to health care, schooling, leisure, participating in community activities, and taking care of young children (Ray 2007; Sorenson et al. 2011). These would all directly or indirectly impact health and nutrition outcomes for the women and their families.

Water provided for domestic use should be safe, of sufficient quantity, and from a proximate source with steady supply to maximize health benefits (Johri et al. 2014; Tsegai et al. 2013; Pickering & Davis 2012; OHCHR et al. 2010; Howard & Bartram 2003; van der Hoek et al. 2001; Curtis et al. 1995; Calvo 1994). Carrying heavy water containers over long distances may cause health hazards (Geere et al. 2010; Dufaut 1988). The water used for drinking, cooking, domestic and personal hygiene is more likely to get contaminated if it has to be fetched from a distant source, and the amount consumed may be reduced, with possible negative effects on hygiene (Wright et al. 2004; Howard & Bartram 2003; Calvo 1994). Furthermore, Calvo (1994) observed that women gave priority to proximity rather than to water quality. If fetching water takes less time, women have more time to care for young children and pursue income earning activities (Sorenson et al. 2011; OHCHR et al. 2010; Mpetsheni 2001). For older children, time can be freed up to attend school (OHCHR et al. 2010; Koolwal & van de Walle 2010). Interestingly, in West Africa and particularly in Ghana, gaps in basic services provision were filled by the private-sector sachet water industry (Stoler, 2012). Although the microbiological quality of sachet water remains dubious (Osei et al. 2013), sachets extend water access within low-income urban agglomerations such as urban slums and may thereby potentially lead to health benefits (Stoler et al. 2012).

We must also stress that access to close and improved water sources (as per JMP definitions) might be a necessary element of improved health and nutrition but by no means is it sufficient. Indeed, Johri et al. (2014) found that water was contaminated in a majority of households although over 97% of the households had access to so-called improved drinking water sources, and proved that access to safe drinking water may well coexist with high levels of child mortality and morbidity. Hasan and Gerber (2016) found that access to piped water can have limited impacts if supply is constrained in time or quantity.

2.2 Agriculture linkages

Groundwater and surface water are the main sources of water for domestic purposes and irrigation. Irrigation agriculture, its outputs and spillover effects resulting from irrigation schemes and infrastructure, can have positive and negative effects on nutrition and health for the farm households and the surrounding communities.

We start here with positive impacts. In water-scarce areas, agriculture can produce a greater diversity and quantity of foods if irrigated, providing higher and more stable food supplies throughout the year. This is likely to result in improved food security and higher energy, protein and micronutrient intakes, through improved availability of and access to diverse food and diets, with positive nutrition and health effects (Burney et al. 2013; Namara et al. 2005). These but also effects from cash income from irrigated agriculture are well-documented in Africa (Domenech & Ringler 2013, Domenech 2015). Evidence from Kenya, for example, shows higher energy intakes and lower chronic malnutrition in children in communities with access to irrigation as compared to communities without access (Kirogo et al. 2007). Increased production may also benefit famers' health indirectly by creating opportunities for diversification of livelihoods that allows for better nutrition and higher incomes (von Braun et al. 1989), potentially leading to better health care services and use. Furthermore, irrigation water is often used for non-agricultural purposes, including domestic uses such as food preparation, gardening, laundering and personal hygiene. In areas with inadequate drinking water supply, irrigation water can also be used as drinking water (van Der Hoek et al. 2001; van Der Hoek et al. 1999). Despite the critical quality of irrigation water, van der Hoek et al. (2002) argue that water quantity is more important than water quality as it reduces the prevalence of hygiene-related diseases.

On the negative side however, there are risks associated with irrigation in agriculture, especially in areas prone to waterborne diseases. Agricultural practices such as water harvesting techniques, irrigation canals, ponds, tanks or dams may in fact increase the incidence of disease by serving as breeding grounds for waterborne diseases, for example, malaria and infection with bacteria and helminth infestation (Amacher et al. 2004; Asayehegn 2012; Asenso-Okyere et al. 2012; Ersado 2005; Fobil et al. 2012; Hawkes & Ruel 2006; Keiser et al. 2005; Kibret et al. 2010; Kibret et al. 2009), especially if irrigation schemes are not managed carefully (Domenech & Ringler 2013; Ghebreyesus et al. 1999; Yewhalaw et al. 2009; Peters & Pasvol 2002). Malaria causes an abnormal breakdown of red blood cells and other responses to infection that may result in life-threatening anemia. The accumulation of malaria parasites in the placenta may result in intrauterine growth retardation, premature birth and low birth-weight, maternal and infant anemia, and infant mortality (Peters & Pasvol 2002; Crawley 2004). Some studies indicate that postnatally, malaria increases the risk of stunting in children and that stunted growth is also associated with more severe malaria-related anemia (Verhoef et al. 2002; Nyakeriga et al. 2004; Kang et al. 2013). In Ethiopia, water-related diseases and malaria are prevailing in irrigated areas and in small-scale schemes where canal water is used for domestic purposes (FAO 2005b). However, this must not necessarily be the case when increased income from irrigated agriculture is used by households for protection against such diseases, for example, by buying insecticide-treated nets. Mutero et al. (2006) showed that effect in Tanzania.

The use of wastewater for irrigation poses additional risks to human health. In India, for example, using wastewater as an input for production has emerged as a strategy to deal with scarce fresh water resources while ensuring food security. Wastewater has become an important resource for agricultural production particularly in increasingly urbanized and water scarce states (Vangani 2018). While utilizing wastewater for agriculture has benefits in terms of boosted income and reduced dependence on artificial fertilizers, it poses environmental and health risks to humans when used in untreated form. In India, over 220 million children are in need of deworming (WHO 2014) and up to 10 percent of the developing world is affected. Intestinal worms are largely a disease of people exposed to untreated wastewater or food grown on it. The Mezquital Valley in central Mexico is a classic example of the usage of untreated sewage for crop irrigation causing significant diarrhea and intestinal worm infections (Cifuentes et al. 1993). The presence of pathogens in fruits and vegetables grown on wastewater-irrigated fields (Steele & Odumeru 2004) negatively affects the health of households, and possibly even neighboring communities. Studies on wastewater and its impact on health have found higher rates of morbidity in the wastewater irrigated villages when compared to control villages (Gupta 2005; Srinivasan & Reddy 2009).

Moreover, the quality and quantity of groundwater for domestic uses may also be affected by irrigation activities that reduce the quality and availability of water within irrigated areas (Horgby & Larson 2013; van Der Hoek et al. 1999; Vangani 2018). Fertilizer, pesticides, and other chemical compounds that are applied in intensified agriculture may be released into surface water or leach into groundwater. In Ghana, for example, pesticides, high concentrations of nitrate and phosphate and salt in groundwater were reported in agricultural areas (FAO 2005a). They may not only affect the water resources, but also food safety and the health environment in general (WHO 2011; Domenech & Ringler 2013; Tsegai et al. 2013), with linkages with stunting and cognitive development (Grandjean et al. 2006). The same holds true for contaminants from irrigation water and for pathogens originating from untreated wastewater, human waste, or livestock (Raja et al. 2015; Srinivasan & Reddy 2009; WHO & UNICEF 2006; Usman et al. 2018a; Klous et al. 2016; FAO 2013), with negative effects on children’s physical and mental development and performances (Guillette et al. 1998; Grandjean et al. 2006).

Another possible negative side effect of more productive, irrigated agriculture would be an increased workload of women that leaves less time for child care (Kennedy 1994). As the opportunity cost of time rises, mothers may spend more time with paid work, which could have a negative impact on their caring capacity and child health outcomes (Miller & Urdinola 2010).

Finally, it is worth noting that water may be contaminated with arsenic, which occurs naturally in groundwater in certain areas, or with salts and heavy metals from industrial effluents (WHO 2011; Raja et al. 2015). For instance, groundwater significantly contributes to the daily human intake of arsenic in Bangladesh since it is the major source of water for drinking, cooking and irrigation (Joseph et al. 2015; Hasan & Gerber 2017). Ideally, water for drinking, cooking and personal hygiene will be treated if necessary before being provided to the households, or directly at point of use (POU) in the households. Irrigation water is usually withdrawn from the source without further treatment (Tsegai et al. 2013).

2.3 Sanitation linkages

A functioning sanitation system, meaning that it completes its mission of removing pathogens and bacteria present in human faeces from the environment, helps to protect water resources from contamination (Tsegai et al. 2013). It may also provide interesting by-products: treated human waste as manure for agriculture, or treated wastewater, which still contains nutrients and organic matter. Such examples of resource recovery and re-use can generate productivity gains in agriculture that could be realized without endangering health, the health environment or food safety through exposure to fecal pathogens (WHO 2006; Niwagaba 2009; Domenech & Ringler 2013).

Access to sanitation is also a precondition for a clean, sanitary environment, since people do not have to practice open defecation owing to lack of alternatives. Improved sanitation thus protects humans from exposure to pathogens and limits the strong negative neighborhood effects of open defecation (Geruso & Spears 2015), thus benefitting health (UNICEF & WHO 2006; Fink et al. 2011; Hathi et al. 2017; Coffey & Geruso 2015; Hammer & Spears 2013; Spears 2012) as well as cognitive development in children (Spears & Lamba 2015). School sanitation that offers safety and privacy to students is important for promoting school enrollment and attendance, in particular of adolescent girls (Adukia 2016; OHCHR et al. 2010). Yet although sanitation facilities are necessary, they are not sufficient for a sanitary environment if harmful behaviors do not change. This applies for example with regard to the disposal of children’s stools (Majorin et al. 2014; Usman et al. 2018b) and culturally and socially engrained open defecation (Ramani et al. 2017; Coffey et al. 2014; Curtis et al. 2000).

On the other hand, there is much evidence of the negative impacts of an inexistent or malfunctioning sanitation infrastructure. Kumar and Vollmer (2013) analyze nationally representative data for India and find a 2.2 percentage point reduction in diarrhea among under-five children living in households with improved sanitation infrastructure. A similar study in Nepal by Bose (2009) showed an even larger reduction of 11 percentage points among younger children under the age of two. Access to improved sanitation was found to be associated with a 13 percent lower risk of child diarrhea and a 27 percent lower risk of mild to severe stunting in an analysis of data from 171 Demographic and Health Surveys for 70 countries that were collected over the period 1986-2007 (Fink et al. 2011). Barreto et al. (2007) conducted a study in Brazil on the effect of city-wide sanitation programs focusing mainly on the promotion of sewerage connections and conscientious use of the system and find a 21 percent reduction in diarrhea.

Other studies also highlight the importance of a systematic solution to sanitation problems. Indeed, households with improved sanitation are still exposed to high levels of pathogens from fecal material if their neighbors have no improved sanitation (Baker & Ensink 2012; Root 2001). Similarly, intervention studies assessing the effectiveness of a rural sanitation intervention within the context of the Government of India's Total Sanitation Campaign (Clasen et al. 2014; Patil et al. 2014) show no improvement in child health in the intervention villages with latrines Diarrhea rates in these studies are virtually the same between the intervention and control groups, and so is the prevalence of infection with parasitic worms and child malnutrition.

A large body of scientific literature presents empirical evidence that the lack of access to improved WASH services is a cause of poor child health (e.g. Bose 2009; Checkley et al. 2004; Esrey 1996; Günther & Fink 2010; Jalan & Ravallion 2003; Kumar & Vollmer 2013). The empirical evidence base showing that lack of these services, especially a lack of sanitation services, is a cause of child malnutrition is also growing and has received renewed attention in recent years.

The necessity for systemic investigations and solutions is further illustrated by studies showing that inadequate water and sanitation (WATSAN) environments, with insufficient water supply and sanitation, are a large risk for communities and are responsible for high disease incidence, in particular of diarrhea and infectious diseases. A wide range of empirical studies show that improvements in WATSAN services lead to better health outcomes, as measured by less diarrhea, improved child growth, reduction in parasitic infections, skin diseases, trachoma, and lower rates of morbidity and mortality (Checkley et al. 2004; Esrey 1996; Esrey et al. 1991; Fenn et al. 2012; Günther & Fink 2010; Jalan & Ravallion 2003). Systematic reviews to assess the impact of inadequate water and sanitation services on diarrheal disease in low and middle-income settings have shown that overall improvements in drinking water and sanitation were associated with a decreased risk of diarrhea (Fink et al. 2011; Kumar & Vollmer 2013; Waddington and Snilstveit 2009; Wolf et al. 2014). The gravity of the problem is illustrated by figures from Ethiopia, where 70 percent of diarrheal diseases and 60 percent of the country's disease burden are mainly attributed to poor WASH environments (Federal Ministry of Health [FMoH] 2005). Similarly, in a cohort study in peri-urban Peru, Checkley et al. (2003) show that children in households with poor water source, sanitation and water storage had about 54 percent more diarrheal morbidity compared to their counterparts with the best conditions. Furthermore, children in households with small storage facilities had 28 percent more diarrhea cases than their counterparts in households with large storage facilities. Therefore, there is a strong case that interventions which improve WATSAN environments and reduce infectious disease incidence break the cycle and result in better child nutrition through direct and indirect pathways (Fenn et al. 2012; Guerrant et al. 2008; Lin et al. 2013; Prüss-Üstün & Corvalán 2006; Spears 2013). Since malnutrition is a multidimensional problem, it requires multi-sectoral interventions from improving agriculture, health, water, sanitation and household infrastructure to improving care and feeding practices (Gulati et al. 2012).

Finally, in addition to the manifold general health and nutrition benefits, empirical evidence has been presented for the positive impact of an improved WATSAN environment on female health and participation in the economy. A gender-sensitive perspective is important since women and girls are especially affected by problematic WATSAN environments. Empirical evidence suggests an increase in female school enrollment through the provision of sanitation facilities by over 15 percent (IRC 2007; UN Water 2008).

2.4 Household behavior linkages

Beyond systemic and infrastructure considerations, much of the WATSAN-agriculture nexus and its impacts on health and nutrition boil down to attitudes and behavior within the households. Here we consider two spheres of human behavior that matter particularly in this context: drinking water and its handling, and health and hygiene practices.

Drinking water

Unsafe drinking water is considered one of the major causes of diarrhea (Zwane & Kremer 2007). Therefore, ensuring access to safe drinking water substantially improves child health in terms of reduced risk of diarrheal diseases (Esrey et al. 1990; Fewtrell et al. 2005; Overbey 2008). The scientific literature puts a focus on the impact of access to piped water connections by households, and substantial benefits for child health could be shown (Bukenya & Nwokolo 1991; Mangyo 2008). Furthermore, it can be shown that positive impacts on health outcomes are substantially greater in the case of in-house water connections compared with other improved public water sources (Bartram & Cairncross 2010; Curtis et al. 1995). This is due to contamination of drinking water in the source-to-mouth chain. In fact, it is widely found that even water from improved sources is frequently contaminated during water collection, transportation and storage in the household because of improper handling (Rufener et al. 2010; Shields et al. 2015; Wolf et al. 2014; Wright et al. 2004). Therefore, some argue that water treatment at the POU is more effective than improving water at sources. A systematic meta-analysis of 33 studies conducted by Clasen et al. (2007) showed that using flocculation or disinfection at POU is more effective in minimizing the risk of diarrhea than water source improvements. Various studies also emphasize the role of storage behavior on water quality at the POU (Clasen & Bastable 2003; Crampton & Aid 2005; McGarvey et al. 2008; Rufener et al. 2010; Baker et al. 2013). A systematic review suggested that treating water with chlorine tablets at the POU reduces not only the risk of Escherichia coli (E. coli) contaminating storage water but also the risk of child diarrhea significantly in developing countries (Arnold & Colford 2007). The empirical evidence on the link between water transport and storage containers and health outcomes is sparse, but one recent study in Benin found that improved water storage and containers are associated with both a reduction in E. coli colony count in water and a lower incidence of self-reported diarrheal diseases (Günther & Schipper 2013).

Health and hygiene behavior

Besides necessary infrastructure improvements in water and sanitation environments, proper hygiene behavior is of great importance. The two issues are interlinked, for instance, reducing water collection time directly increases water availability, which may translate into more bathing and washing (Cairncross & Cuff 1987). In particular, the frequency of handwashing is highly correlated with the quantity of water available to households (Cairncross 1997; Curtis et al. 2000; Gilman et al. 1993).

Yet, regardless of infrastructure or water availability, hygiene behavior directly impacts health and nutrition. Changing people's poor hygiene behavior is, however, very complex. It requires people to change their long-held habits, which have been shaped by cultural, religious and socio-economic factors. Schools can educate their students about adequate health and hygiene behaviors. Behavior change messages are hoped to improve the health environment on the long run and also in the short term if students act as agents of change in their families (Okyere et al. 2017; Malek et al. 2016).

Although educating people to change their behavior is a complex task with an uncertain outcome, Curtis et al. (2000) suggested that hygiene interventions can be successful if a few behaviors that have the greatest potential health impacts are targeted and promoted. For instance, interventions promoting handwashing, and safe water storage and handling practices can produce significant health gains. Providing sufficient and clean water is crucial.

A growing body of evidence focuses on hygiene behavior and its impacts: It shows that handwashing with water and soap at critical times, that is, after stool disposal or defecation, and before preparing food or eating, can help to avoid the spread of water-related diseases and has the greatest success in achieving health impacts. Handwashing with soap was shown to reduce diarrhea incidence by up to 48 percent (Curtis & Cairncross 2003; Cairncross et al. 2010). Similar evidence was presented by Hill et al. (2004) showing that handwashing interventions achieved a median reduction in diarrhea incidence by 35 percent. In a randomized controlled trial in urban Pakistan, Luby et al. (2006) found that intensive handwashing promotion could reduce diarrhea incidence by 51 percent. Luby et al. (2005) also analyzed the effect of handwashing with soap on the incidence of pneumonia and diarrheal diseases and found strong supporting evidence: In households that received the intervention, diarrhea incidence was reduced by 53 percent and pneumonia incidence by 50 percent in under-five children.

Another important hygiene behavior relates to the keeping of animals in domestic environments. The presence of animals in or near the house influences the exposure to pathogens - that is, viruses, bacteria, and parasites (Usman et al. 2018a; Klous et al. 2016; FAO 2013). Especially livestock and poultry-farming households are at risk of fecal water and food contamination through improper hygiene. Several studies found that households keeping their poultry and livestock inside their houses or in the vicinity show an increase in stunting in children under five (George et al. 2015; Headey et al. 2017; Headey & Hirvonen 2016). Evidence from former rural Zaire (now the Democratic Republic of the Congo) makes a case for promoting handwashing and safe disposal of human and animal excreta. It was shown that this results in an 11 percent reduction in diarrhea morbidity (Haggerty et al. 1994).

2.5. Interlinkages between well-being, health and nutrition outcomes

Insufficient household food security, lack of caring capacity, or an unhealthy environment can rapidly push a child into a vicious cycle of inadequate dietary intake and deteriorating health and nutrition status. We review here some of the evidence on the linkages between nutrition–health and well-being, which includes future human capital prospects.

Malnutrition increases the risk of infections. Lack of dietary energy and protein and certain micronutrient deficiencies result in impaired functioning of the immune system and damage to mucous membranes. Barriers against infection are no longer intact, and resistance to pathogens is weakened. The risk of infection rises, and a poor nutritional status prior to infection prolongs the duration and aggravates the severity of the infectious disease. Loss of appetite is a frequent consequence of infection, which in turn reduces dietary intake. Children that are temporarily or chronically malnourished are more likely to suffer in particular from diarrheal and other infections (UNICEF 2013). Black et al. (2008) even found that severely undernourished children (weight-for-age) are ten times more likely to die from diarrhea compared to the average. Malnutrition increases both the frequency and the duration of diarrheic events (Preidis et al. 2011).

On the other hand, infections increase the risk of malnutrition. Physiological changes specific to many infectious diseases are energy-consuming fever and catabolism of body protein that enhance the need for dietary energy and protein, as well as malabsorption that leads to loss of nutrients (Tomkins & Watson 1989). Exposition of children to fecal coliforms can lead to intestinal infections and subsequent chronic inflammation of the gastrointestinal tract. It prevents the normal absorption of macro- and micronutrients leading to malnutrition (Guerrant et. al. 2008). Thus, infections can be both a cause and consequence of undernutrition (Reinhardt & Fanzo 2014). Diarrhea features prominently among the diseases related to unsafe WASH. Diarrhea leads to poor absorption and ability to retain nutrients and often causes worsening nutritional status (Briend 1990; Checkley et al. 2008; Checkley et al.

2003; Dewey & Mayers 2011; Patwari 1999; Schorling et al. 1990; Ulijaszek 1996). A study in India found that diarrheal diseases caused by poor sanitation accounted for 25 percent of stunting in children up to 24 months (Checkley et al. 2008). The incidence of diarrhea rises at about six months of age when complementary foods are introduced at the beginning of the weaning period. Food hygiene – that is, ensuring that food and utensils do not become contaminated - is critical during this period, although an increase in exposure to diarrheal pathogens cannot be totally avoided.

In the short term, the vicious cycle of insufficient dietary intake and illness may result in poor nutrition and health outcomes (morbidity, mortality, disability). In the long term, children either fully recover to grow into healthy adults or they suffer from persistent impairment with intergenerational consequences, such as reduced adult height and lower cognitive ability (UNICEF 2013). Further, reviews of studies have shown that the risk of a child becoming stunted increases with the incidence of diarrhea (Tomkins & Watson 1989; Reinhardt & Fanzo 2014), thus drawing attention to the long-term, human capital (and well-being) consequences of diarrhea incidence as a shorter-term health condition. Other studies also show the interlinkages between nutrition and WASH and their associated impacts on educational outcomes. Poor WASH affects school attendance and academic performance of school-age children (UNICEF 2006; Dreibelbis et al. 2013). Malnutrition is associated with poor academic performance and school absenteeism (Brown et al. 2013a, Lorntz et al. 2006; Kvestad et al. 2015; Guerrant et al. 2013).

2.6 Confounding factors

Naturally, the impact pathways described above are not the only ones which are relevant in the analysis of the agriculture-WASH nexus for health and nutrition. In particular, they are somewhat mediated by a large set of confounding factors in various fields (socio-economic, including education and income, environmental, etc.) and at different scales (national, community, households). We review here some additional literature linked to such confounding factors of importance.

A sound health environment is critical to prevent and cure infections. It should include access to enough and safe water, adequate sanitation, quality health care services, and environmental safety, including shelter. The type of dwelling and the actual garbage collection have an impact on the health environment (Smith & Haddad 2000; Reinhardt & Fanzo 2014) and on health and nutrition (Vangani 2018). By definition, food safety is considered part of food security (FAO 1996); however, with regard to the agriculture-water-sanitation nexus, food safety can better be discussed in the context of the health environment. Food safety may be compromised in the course of agricultural production, or during food preparation if hygiene practices are inadequate or the water or cooking utensils are contaminated (Hasan & Gerber 2017).

Care means providing time, attention and support to meet the needs of others. Trade-offs in time allocation occur naturally if mothers and other caregivers are responsible for collecting water from distant sources. Caring capacity requires knowledge, for example about proper breastfeeding and complementary feeding practices for young children, hygiene and health-seeking behaviors. To adequately care for others, the caregiver needs control of resources and autonomy in decision-making as well as physical and mental health. Because mothers usually take care of their children, gender roles, the division of labor in the household and women's workload affect caring capacity. Adequate care for pregnant and lactating mothers is also a crucial factor for child nutrition (Smith & Haddad 2000; Reinhardt & Fanzo 2014). The caring capacity of adults is greater if they are healthier, and school-age children are able to attend school more regularly if they have fewer sick days. Household food security may also benefit from adult household members being economically more productive and from lower expenses on health care. Better health of adults and older children also improves the health environment of young children because their exposure to pathogens is reduced.

In the long term, improved school enrollment and attendance will result in greater educational achievement. Adults with higher education will be better equipped to take care of their children and have better income-earning opportunities. Higher future incomes from agricultural or non-agricultural labor can have positive effects on household food security, impacting another underlying determinant of child health and nutrition outcomes (UNICEF 2013; Reinhardt & Fanzo 2014).

3. Descriptive statistics and description of the study areas

This section first presents the nationally representative data for the four case study countries: Bangladesh, Ethiopia, Ghana and India. This provides the necessary platform for a general discussion around WATSAN, health and nutrition indicators often used and referred to in the international development discourse, and SDG targets 6.1 and 6.2 in particular. Next, we introduce our case study settings in the same four countries, where household surveys were conducted for the purpose of analyzing health and nutrition outcomes from the perspective of the agriculture-WATSAN linkages, including elements of WASH (i.e. hygiene behavior). The settings and water systems vary greatly across the four study sites where the data was collected. Each study site was indeed selected with a specific purpose in mind within the agriculture-WATSAN nexus. Consequently, the variation among water system characteristics offers a contrasted perspective on the agriculture-WATSAN linkages and their impacts on health and nutrition. These water systems are briefly described and the descriptive statistics extracted from the pooled case studies data discussed. The compilation of data generated by the specific surveys around the common denominator of agriculture-WATSAN linkages helps us to draw out the guiding elements of our multivariate analysis.

3.1 National survey data

The four study countries have recent data from nationally representative samples that can be compared with our pooled case studies data (collected between 2013 and 2015): the Demographic and Health Survey (DHS) data for Ethiopia (2016), Ghana (2014), India (2015-16) and Bangladesh (2014). The major difference between the DHS data and our own survey data is naturally that the former are nationally representative (for both rural and urban areas). Since this paper focuses on the agriculture-WATSAN linkages and thus on households either active in or living next to agricultural activities (rural and peri-urban), we excluded urban households in the analysis of the DHS data. Table 1 presents the summary statistics (mean and standard errors) of the variables used in the analysis. We analyze the full samples of the rural households in the DHS data for this table, except for child-related variables, which are computed only for the sample of children under five years.

The sampling weights of the respective surveys produce coefficient estimates that represent the entire rural population of each study country after urban households have been omitted. When pooling the data sets, the sampling weights need to be adjusted to take into account the large variation in the sizes of the populations that are represented by the samples from the four study countries. If this is not done, the results of the multivariate analysis will be driven by the associations found in the Indian data set, since India has by far the largest population among the study countries. To prevent this problem and account for the sampling weights obtained from the DHS program for each country, we divide the sampling weight by the share of each country's rural population in the total rural population that is represented by all four samples. By means of this approach, the estimates account for within-country sampling weights, while each study country is weighed equally in the pooled data set.

Table 1: Summary statistics for the four national data sets (DHS, rural areas)

Variables	Pooled	Ghana	Ethiopia	Bangladesh	India
Farm - Yes=1	0.627	0.586	0.862	0.485	0.526
	(0.007)	(0.021)	(0.009)	(0.010)	(0.002)
Livestock ownership - Yes=1	0.719	0.546	0.877	0.763	0.597
	(0.006)	(0.017)	(0.008)	(0.012)	(0.002)
Distance to water (min. per round trip)	19.57	19.23	43.59	4.27	7.34
	(0.816)	(0.823)	(2.231)	(0.371)	(0.058)
Improved water source - Yes=1	0.779	0.691	0.565	0.970	0.888
	(0.009)	(0.024)	(0.023)	(0.010)	(0.002)
Water on premises –Yes=1	0.387	0.117	0.058	0.744	0.581
	(0.009)	(0.012)	(0.011)	(0.016)	(0.002)
Sanitation categories					
Improved	0.235	0.085	0.030	0.436	0.366
Not improved	0.450	0.626	0.583	0.516	0.093
Open defecation	0.315	0.288	0.388	0.047	0.541
HH size	4.567	3.895	4.893	4.514	4.692
	(0.025)	(0.081)	(0.049)	(0.035)	(0.006)
Education level HH head					
None	0.443	0.317	0.623	0.386	0.375
Primary	0.257	0.170	0.308	0.302	0.203
Secondary	0.249	0.450	0.046	0.237	0.370
Higher	0.051	0.064	0.022	0.075	0.052
Gender child (<5 y.o.a) - Female=1	0.486	0.476	0.493	0.481	0.483
	(0.005)	(0.014)	(0.008)	(0.015)	(0.002)
Age child (<5 y.o.a), months	29.13	28.17	28.39	29.85	30.24
	(0.144)	(0.540)	(0.252)	(0.253)	(0.050)
Total number of children (<5 y.o.a) per	1.764	1.892	1.854	1.464	1.868
household	(0.018)	(0.046)	(0.034)	(0.023)	(0.005)
Diarrhea - Yes=1	0.100	0.123	0.121	0.057	0.096
(children <5 y.o.a., over 14 days)	(0.004)	(0.013)	(0.007)	(0.008)	(0.001)
Underweight - Yes=1	0.288	0.129	0.243	0.350	0.385
(children <5 y.o.a.)	(0.005)	(0.011)	(0.009)	(0.011)	(0.002)
Wasting - Yes=1	0.134	0.057	0.103	0.151	0.214
(children <5 y.o.a.)	(0.003)	(0.009)	(0.006)	(0.007)	(0.002)
Stunting - Yes=1	0.379	0.222	0.397	0.381	0.416
(children <5 y.o.a.)	(0.006)	(0.014)	(0.011)	(0.011)	(0.002)
Weight-for-age Z-score	-1.361	-0.852	-1.210	-1.580	-1.659
(children <5 y.o.a.)	(0.016)	(0.036)	(0.028)	(0.027)	(0.005)
Weight-for-height Z-score	-0.711	-0.291	-0.508	-0.940	-1.056
(children <5 y.o.a.)	(0.016)	(0.037)	(0.031)	(0.026)	(0.005)
Height-for-age Z-score	-1.513	-1.131	-1.489	-1.634	-1.605
(children <5 y.o.a.)	(0.021)	(0.044)	(0.044)	(0.029)	(0.007)
Survey year		2014	2016	2014	2015-16
Number of children	194,277	3,280	7,711	4,696	178,540
Number of households	454,247	5,896	11,418	11,370	425,563

Notes: Linearized standard errors are in parentheses and were computed using the svy command.
Source: Authors' calculation using DHS data.

As seen in Table 1, there are clear differences across regions and countries. First, the water infrastructure is typically more developed in Bangladesh and India as compared to Ethiopia and Ghana: For the two Asian countries, distance to the water source (measured in travel time, to account for the actual drudgery of getting the water) is several orders of magnitude lower, but the shares of rural households having access to the source of drinking water in their premises or having access to an improved drinking water source (as per WHO guidelines[3]) are 45 to 70 and 20 to 40 percentage points higher, respectively, than for the two African countries. From the sanitation perspective, the picture is more complex: Ethiopia and Ghana show very low coverage of improved sanitation (below 10%), a majority of households with access to unimproved sanitation and around a third of the households practicing open defecation; Bangladesh has a very low prevalence of open defecation (less than 5%) combined with an almost even access to improved and unimproved sanitation infrastructure; in India the majority of households practice open defecation, whilst sanitation infrastructure is mostly of the improved form.[4] Finally, regarding the health and nutrition outcome variables for children below the age of five, we can see that Ethiopia, Bangladesh and India do not show large differences with regard to the prevalence of stunting, and that Ghana fares better than the three other countries in all categories except for the prevalence of diarrhea among children under five years of age. Interestingly, Bangladesh and India have lower diarrhea prevalence but higher wasting (low weight for height) prevalence, although the latter is a typical indicator of "short term" malnutrition.

In Table 2 we focus on the possible linkages between agriculture, sanitation and health using the nationally representative surveys. The association between the prevalence of diarrhea and a household either a) being predominantly a farming household or b) holding livestock in or around the house is not consistently significant across the four countries. Keeping in mind that (stated) diarrhea prevalence over relatively short periods of time (14 days in this case) is known to be a rather inconsistent indicator (due to e.g. seasonality effects and reporting bias) and that longitudinal data would be preferable, we can report that across the four countries, this indicator shows no clear conclusive association with living in a farming household or with the presence of livestock in or around the house. The hypothesis behind these associations is that contact with animals, dung and/or potentially contaminated irrigation water would worsen the children's exposure to pathogens, E. coli in particular, leading to higher diarrhea prevalence.[5] This hypothesis is weakly confirmed only for farm households in India (for farm households in Ghana and livestock holding households in Ethiopia, this association is not statistically significant). So one cannot generally associate farming activities with increased

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[3] See https://www.who.int/water_sanitation_health/monitoring/jmp04_2.pdf, accessed on January 31st 2019.

[4] Please note these figures are as per the years of the national survey data. Much progress on access to improved sanitation has been achieved since, if not on the behavioral side of the sanitation equation. Also, note that the WHO definitions of "improved" and "not improved" sanitation are applied here, with one exception: "improved" facilities that are shared by several households are classified as "not improved".

[5] The common fecal indicator bacterium Escherichia coli (E. coli) is generally used to measure the efficacy of drinking water treatment in removing bacterial pathogens responsible for enteric diseases. We use the same indicator throughout the different case study analyses presented in this paper: The presence of E. coli in drinking water, as indicator of the presence of thermotolerant fecal coliforms. Various techniques were used to determine the count level of E. coli per 100 ml of water, all performed in laboratory settings by trained scientists.

risk of child diarrhea. This does not mean the pathways do not exist, but that at least they might be mitigated by other factors. For instance, it could be that rural but non-farm households are typically poorer (or richer) than farming households, a mitigating factor that is not captured in the two-way associations of Table 2, or that neighborhood effects play a role.

Table 2: Rural national diarrhea prevalence in the past 14 days by agricultural activities (% under 5 children)

	Farming		Livestock		All
	Yes	No	Yes	No	Households
Ghana	13.02	12.84	12.17	14.19*	12.91
Ethiopia	11.78	13.32	12.14	10.71	12.01
India	9.81	9.29*	9.52	9.64***	9.56
Bangladesh	4.77	6.52***	5.42	6.63	5.69

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01. We performed a Wald test adjusted for the survey design.

Similarly in Table 3 we examine the association between WATSAN variables and the prevalence of diarrhea among children. The WATSAN indicators cover: a) access to improved water sources, b) having water directly on the premises, and c) the category of the sanitation infrastructure. Only in Bangladesh does the access to better water infrastructure (i.e. improved or on the premises) seem to pay dividends in restricting the prevalence of diarrhea among children. The results are more intuitive with respect to sanitation: better infrastructure mostly decreases the prevalence of diarrhea. One exception applies: the case of unimproved sanitation versus open defecation in Ethiopia, where no infrastructure (open defecation) might be better than unimproved (largely shared) sanitation. These are potentially signs of behavioral problems around shared sanitation or of a problem of pathogenic concentration implied by the infrastructure. Generally, this points to the fact that improved water infrastructure in itself is not solving the health and nutrition conundrum, whilst sanitation infrastructure shows more effect, whilst also pointing at behavioral issues (open defecation is practiced also by people with access to sanitation infrastructure).

Table 3: Rural national diarrhea prevalence in the past 14 days by WATSAN characteristics (% under 5 children)

	Improved water		Water on premises		Sanitation		
	Yes	No	Yes	No	Improved	Not improved	Open defecation
Ghana	14.43	9.20***	13.56	12.85	7.19	12.28	15.04*
Ethiopia	12.44	11.56	13.11	11.97	6.12	12.74	11.45**
India	9.74	8.09***	10.01	8.89***	8.54	9.54	10.10***
Bangladesh	5.66	6.71**	5.36	6.65*	4.72	6.32	7.83**

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01 (For the sanitation variable we use the F-test, thus reporting if any of the three categories is significantly different from any of the two others)

The pathogenic pathways incurred by either living in a farm household and/or keeping livestock are also investigated with respect to potential effects on stunting. We report here stunting only, as the anthropometric indicator of longer term nutritional and health issues. The numbers in Table 4 suggest that only farming and livestock-holding households in Ethiopia are significantly worse-off, all other categories show insignificant differences or negative associations between farming or livestock and stunting (i.e. reduced prevalence).

Table 4: Rural national prevalence of stunting by agricultural activities (% under 5 children)

	Farming		Livestock		All
	Yes	No	Yes	No	Households
Ghana	23.13	20.90	23.45	20.05	22.24
Ethiopia	40.54	35.20**	39.95	37.96	39.77
India	40.57	42.76***	42.02	40.93***	41.62
Bangladesh	32.33	43.27***	38.77	35.97	38.14

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01. We performed a Wald test adjusted for the survey design.

The picture is equally inconclusive with respect to the association between water infrastructure and the three anthropometric indicators in Table 5. Access to improved drinking water sources is associated with lower prevalence of wasting in Ethiopia, India and Bangladesh. For the other indicators, the association is insignificant or positive (access associated with higher prevalence, which is counter-intuitive, in India). Having water on the premises has a clearer negative association with the prevalence of stunting, underweight or wasting, across several countries (all significant associations have the expected direction). However, this variable, which cumulates the benefits of access to an improved water source and lessened issues associated with longer distance and time to transport water to the household (e.g. contamination during transport, care time and drudgery effects, etc.), can potentially also contain a strong correlation with income and education, more so than the WHO improved water indicator. Finally, access to improved sanitation infrastructure seems to be consistently associated with lower prevalence of stunting and underweight: the prevalence almost systematically increases along the gradient from improved to unimproved and to no infrastructure (open defecation). The association with the shorter term malnutrition indicator of wasting is less consistent along the same gradient. As in Table 3, behavioral issues around community sanitation and hygiene practices are hidden within such associations.

Globally, the national level bivariate analyses point to the fact that access to improved drinking water sources and to drinking water on the household premises are (inconsistently) associated with lower prevalence of child malnutrition in the expected direction, but not with lower prevalence of child diarrhea. Access to sanitation infrastructure has a much clearer association with decreased prevalence of child malnutrition and decreased prevalence of child diarrhea. A closer look at these associations in a multivariate analysis is necessary to sharpen our analysis.

Table 5: Rural national prevalence of undernutrition by WATSAN characteristics (% under 5 children)

	Improved water		Water on premises		Sanitation		
	Yes	No	Yes	No	Improved	Not improve d	Open defecation
Stunting							
Ghana	23.25	19.71	21.59	22.31	18.68	19.61	26.66**
Ethiopia	39.45	40.10	33. 981	40.00	33.61	37.53	43.40***
India	41. 96	38.78***	40.36	43.52***	31.70	36.48	47. 57***
Bangladesh	37.99	43.15	35.02	46.97***	31.55	42.93	42.80***
Underweight							
Ghana	13.60	11.24	12.25	13.00	9.08	12.46	14.26
Ethiopia	24.58	24.83	22.36	24.80	18.25	22.02	28.93***
India	38. 51	38.36	35.96	42.32***	28.51	32.73	44.57***
Bangladesh	34.86	39.30	32.29	42.61***	29.52	38.55	44.65***
Wasting							
Ghana	5.50	6.29	5.50	6.30	3.83	6.00	5.65
Ethiopia	9.69	10.95	9.69	10.95	9.69	9.27	11.77*
India	21.13	23.73***	19.82	22.13***	18.95	18.97	23.07***
Bangladesh	15.12	17.38	15.12	17.38	15.42	14.53	21.71*

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01. We performed a Wald test adjusted for the survey design.

On the other hand, we hypothesized that due to multiple water uses in a farm household, the contamination of drinking water with pathogens and E. coli in particular is more likely and thus farm operations could be associated with a higher prevalence of child diarrhea. This hypothesis is not consistently verified at this stage across the four countries (only in India), whilst we observe that farming and keeping livestock are associated with higher prevalence of child stunting only in Ethiopia.

3.2 Water, sanitation and agriculture systems at the study sites in Bangladesh, Ethiopia, Ghana and India

Before presenting the pooled data from the case study sites in Bangladesh, Ethiopia, Ghana and India, it needs to be highlighted that the WATSAN systems differ a lot between these locations. This diversity is a general feature of WATSAN systems and suggests that there are limitations of any one-size-fits all programmatic approaches to address the water and sanitation issues as stipulated in the SDGs. For each of the study sites, a rough depiction of the system is presented below. While these charts demonstrate the differences between the four sites and appear already quite complex, it is important to point out that within each of the sites further diversity of systems exists, which cannot be fully captured by such charts.

In Bangladesh (Figure 2), the analysis focuses mostly on rural households in one region (North-West) where piped water services have been delivered to a large number of households under a public scheme. Due to high water extraction, the groundwater level is low throughout the region. This fact, combined with the pervasive arsenic contamination of groundwater in Bangladesh, means that deep tube wells are necessary to access clean drinking water, which is costly. The scheme thus aims at securing access to potable and safe water for the households, pumped by the publicly operated deep tube wells from the region's groundwater resources and distributed to households, for a small fee, by means of a pipe and water tower network. Regional and national authorities expected this infrastructure to deliver benefits in terms of reduced diseases, an assumption that the data help to test from an infrastructure perspective and from a behavioral perspective. Figure 2 illustrates the typical cycle of the WATSAN system in the study area. Groundwater is the main source of drinking water and irrigation water for the households, and irrigation is practiced by 62% of the households. Water from other sources (e.g. the village pond) can also be used for various purposes. Concurrent use of several water resources for different purposes and/or during different times of the years is common, especially as piped water is not always available. WATSAN and irrigation are also interlinked as on-site sanitation is practiced among all rural households. Although open defecation has almost been eradicated in Bangladesh as a whole, slightly less than 20% of households in the study area reported practicing it, thus the potential for contamination of the village ponds and of the other open water bodies (e.g. rivers) exists.

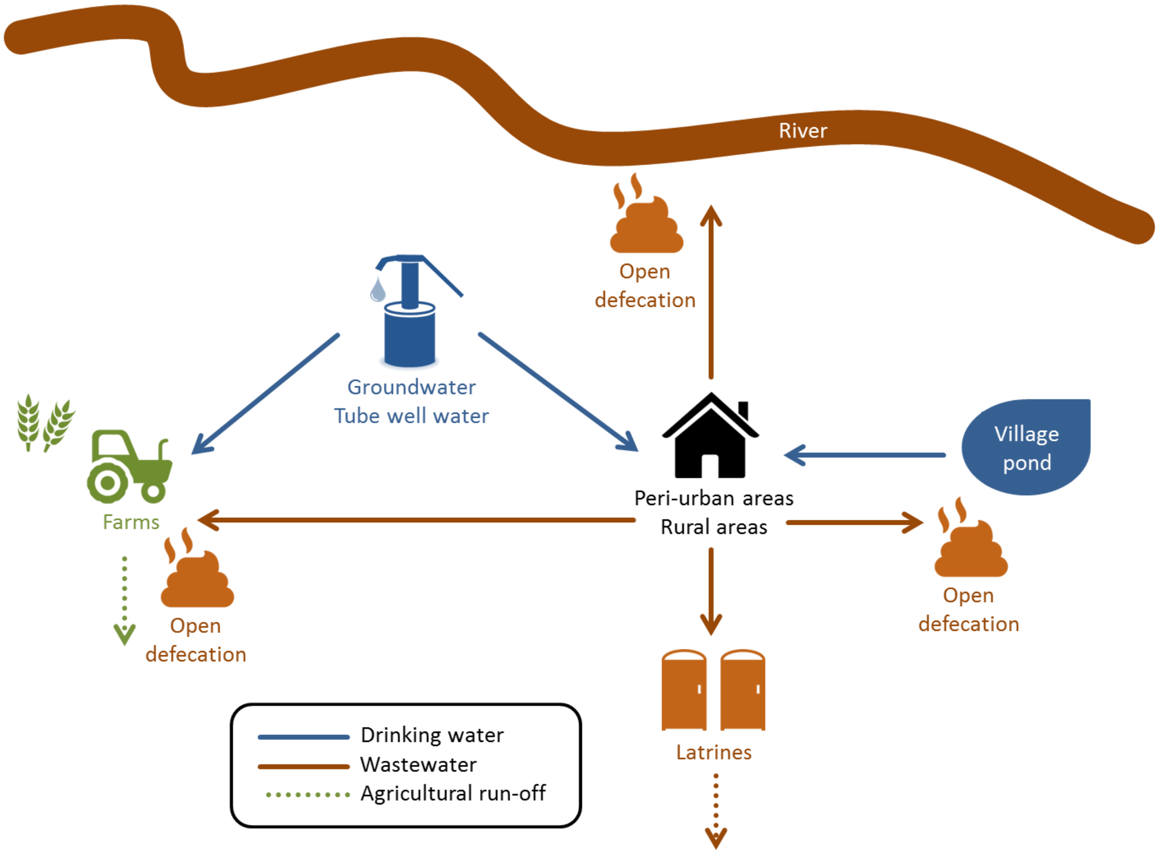

Figure 2: WATSAN system for the case study site in Bangladesh

Source: Designed by Samantha Antonini, logos source-Creative Commons license available at http://creativecommons.org/licenses/by/3.0/ accessed July 2015

Figure 3 draws out the main characteristics of the water systems in the Ethiopian case study. Two districts were surveyed in the Amhara region: In Forega, river diversion is the predominant system of irrigation, mainly to produce onions and tomatoes; in Mecha, smallholders mainly produce both staple crops—typically wheat, barley and *teff*— and cash crops, such as peppers and potatoes. They benefit from the Koga irrigation project, south of Lake Tana: More than two thirds of the households reported practicing irrigation agriculture across the two districts. In both districts, most water sources do not provide sufficient water during the summer. Thus most households in these rural areas depend on multiple, unimproved water sources such as unprotected community wells/springs and rivers (51%), which are easily polluted by human and animal waste, or protected but shared wells or springs. The area is sparsely populated and the coverage of sanitation facilities, even simple pit latrines, is low (42%), with a majority of households preferring to defecate in the open. Thus a priori this case study should present more direct rural and environmental challenges to people's health than the Bangladeshi study with piped, deep groundwater resources and low open defecation. In both case studies, households keep several heads of livestock.

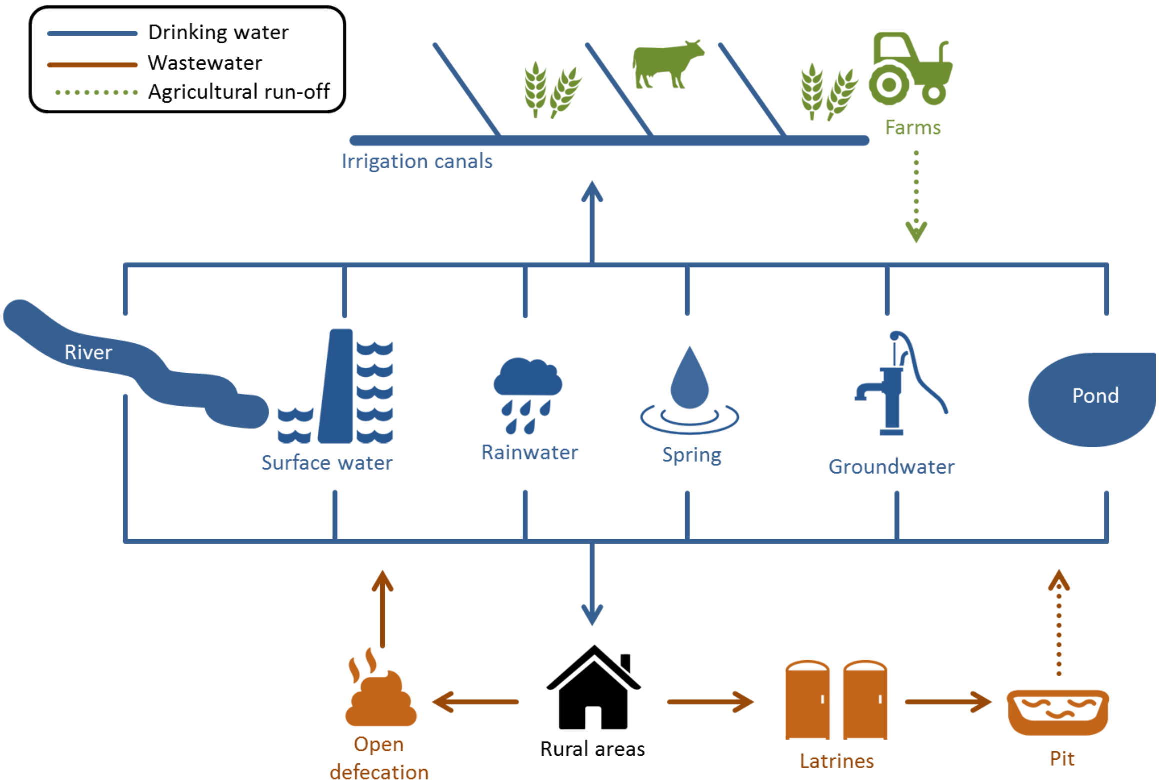

Figure 3: WATSAN system for the case study site in Ethiopia

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The case study in Ghana focusses on multiple uses of open water bodies and on the households' awareness about the quality of their drinking water. It surveyed 16 communities in the Greater Accra region of Ghana, a densely populated area. The WATSAN system is stylized in Figure 4. The communities situated along the coast of the Gulf of Guinea or along the Volta river and its catchment area use these water bodies for fishing, which is not represented in the figure. The Volta river is also used for irrigated agriculture through the

Kpong Irrigation Scheme (KIS), but less than a quarter of the households reported practicing irrigation agriculture. The extensive practice of fishing in the area (about 30% of the households), the low level of irrigation and the plurality of improved water sources (bottled and sachet water, truck delivery) are clear features of the Ghanaian case study compared to the other three.

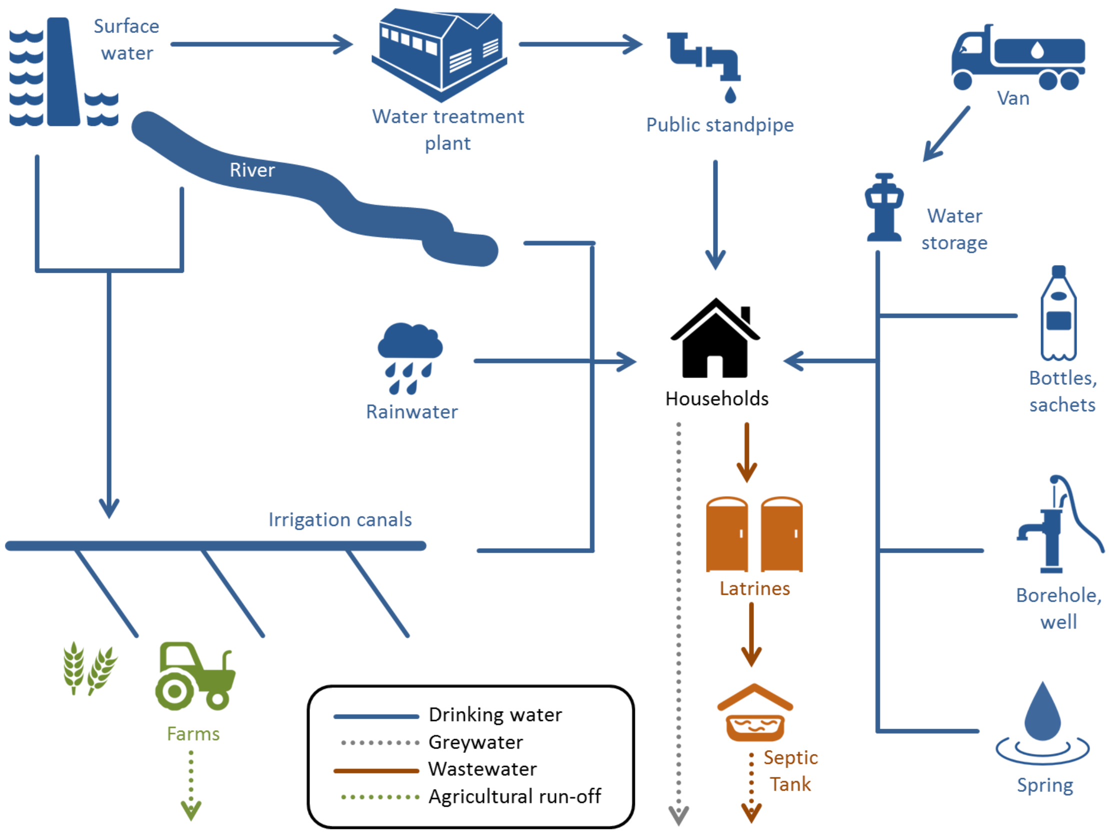

Figure 4: WATSAN system for the case study site in Ghana

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In India, the case study communities were selected to reflect peri-urban agriculture and the recycling of (urban) waste water into a valuable agricultural input. This general characteristic driving the study is reflected in Figure 5. In the peri-urban areas of Ahmedabad in the state of Gujarat, high urbanization rates coupled with insufficient sewage infrastructure lead to the release of much wastewater into the Sabarmati River and into other water bodies. The Sabarmati is the river with the highest level of fecal contamination in India. However, downstream from Ahmedabad, it is the main source of irrigation, together with canals and tube wells. The sewage water produced from the urban communities undergoes wastewater treatment in the sewage treatment plants and is then discharged into the river after primary or secondary treatment, but some community and industrial wastewater finds its way into the river directly without undergoing any treatment, especially during heavy rainfalls. As depicted in the figure, the fresh water is also treated before being used for drinking purposes in the urban and peri-urban households.

The study surveyed peri-urban households in the Ahmedabad and the Gandhinagar districts, selecting a number of villages based on their irrigation water systems: 6 villages relied on river wastewater and 10 villages relied mostly on freshwater (tube wells or rain water) for irrigation. As a result, 50% of the households reported relying on wastewater irrigation and 20-25% on clean water (tube well or rain) and canal water irrigation, respectively. The gray water generated from village households is drained into the village ponds, which farmers utilize at times for irrigation purposes. Beyond the irrigation system, the case study in India is also characterized by the high prevalence of open defecation but also by high access to improved water sources. None of the communities were open defecation-free, the lowest rate of open defecation at the community level being 25% (for about a third of the communities). The average across all communities was 47%, although 42% of the households have access to an improved toilet facility. This shows, as reported elsewhere, that infrastructure and use are two different issues. Almost universally (99%) the households in the study areas have access to an improved water source (mostly tap water) for their drinking water.

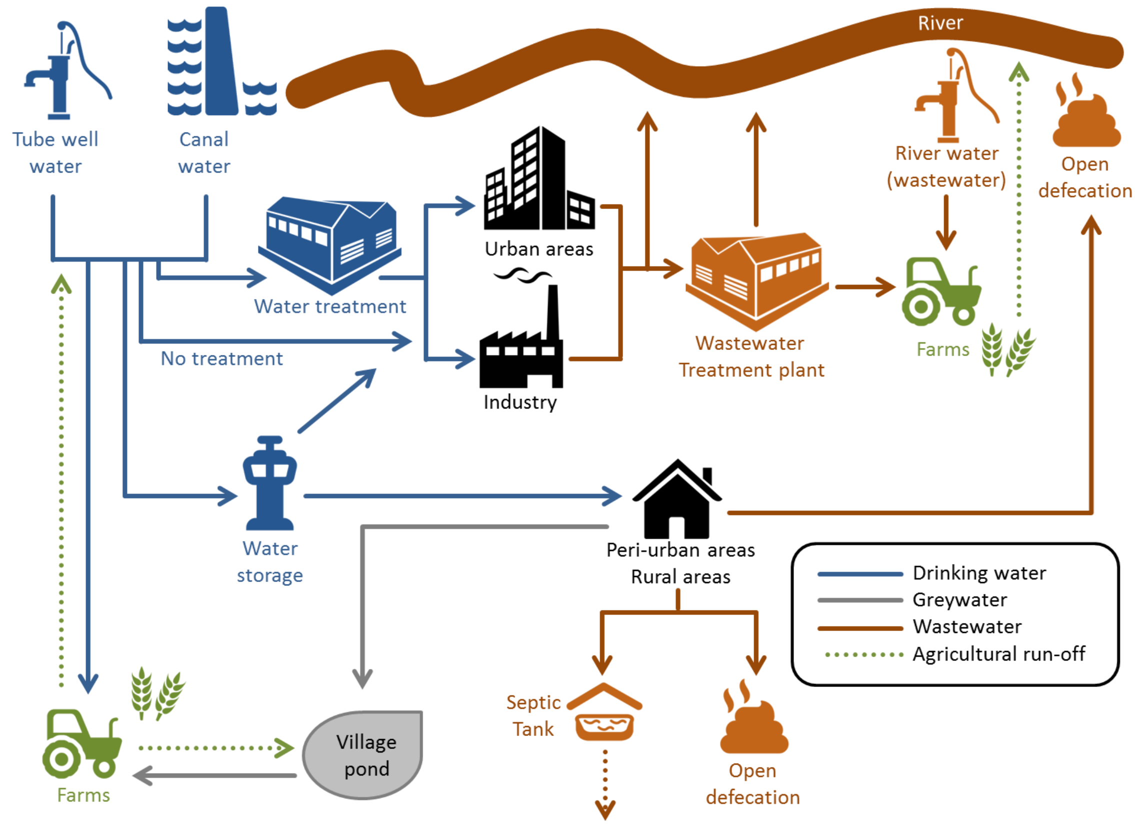

Figure 5: WATSAN system for the case study site in India

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As clearly illustrated in the above diagrams, a WATSAN system perspective is required to address the contamination of drinking water, which takes place at several points and from various contamination sources. In addition, household-level behavior impacts drinking water quality, which is not represented in the diagrams. Water storage and transport (e.g. in clean, covered containers), hygiene and sanitation behavior (e.g. washing hands with soap before handling water, cooking or feeding children, or after defecation; safe disposal of children's excreta; keeping latrines clean) play a key role in the water system. Solving "sectoral" water issues in isolation, without the whole system in mind, is unlikely to lead to the desired health and nutrition outcomes or the achievement of SDGs 2 and 6.

3.3 Pooled case studies data from Ethiopia, Ghana, India, Bangladesh

The case studies' survey data were collected from sites in Ethiopia, Ghana, Bangladesh and India. The selection of the four study sites was based on the identification of WATSAN and WASH hotspots. In each of the four sites, the purpose of the data has been to analyze the agriculture-WATSAN nexus in order to answer the critical research question: Why do poor nutrition and health outcomes persist in these hotspots, despite investments in and access to improved water and sanitation services? Clearly, child undernutrition has many cross-sectoral causes (e.g. poverty, food insecurity, inadequate child feeding practices or access to health care, etc.), all of which are relevant and need to be addressed. Yet the assumption behind our approach is that the reason for the lack of progress shown by water and sanitation programs lies beyond poor water quality at the source and beyond poor sanitation infrastructure, or even their related behavioral issues. The first two problems have been addressed to a large extent across the developing world, although behavior around the use of water and especially sanitation infrastructure remains a bottleneck in health and nutrition.[6] The latter has been targeted for instance in information and messaging campaigns, including in the research that generated the data presented here. Several studies have demonstrated a lack of impact on diarrhea prevalence and child growth when targeting behavioral change through integrated WASH and nutrition interventions (Humphrey et al. 2019; Luby et al. 2018; Null et al. 2018). Yet, as poor health and nutrition outcomes persist in our study sites, our hypothesis remains that controlling for WATSAN infrastructure and WASH behavior can highlight the many entry points for improved health and nutrition *only if water is addressed in a systemic perspective*. This means, in our settings, that the data must adequately cover the agriculture-WATSAN nexus. Such a comprehensive approach to health and nutrition is also advocated in Ngure et al. (2019) with respect to exposure to livestock feces.

Each study site was the focus of a doctoral research program that addressed a specific piece of this puzzle. In Ethiopia, the focus of the research program was on the interactions between irrigated agriculture and drinking water supply and sanitation in a rural context. The research determined the drivers of drinking water quality - approximated by E. coli contamination

[6] See for instance Ramani et al. (2017) on sanitation infrastructure use in India, and Waddington and Snilstveit (2009) on the stronger relative impüact of interventions on hygiene behavior over WATSAN infrastructure.

levels (Usman et al. 2018a) - and its interactions with sanitation infrastructure in affecting child health outcomes (Usman et al. 2018b). In Ghana, the interlinkages between water quality, water use, sanitation and hygiene were examined in the context of multipurpose water systems. A strong emphasis in that context was placed on the drivers of water use and sanitation behavior, which were analyzed by means of a randomized controlled trial approach with regard to their impact on health (Okyere et al. 2017). In Bangladesh, part of the research focused around a quasi-experimental setting and analyzed the agriculture-WATSAN linkages and their impacts on health in a post-intervention region of the country where households were given the choice of joining a public piped-water infrastructure scheme (Hasan & Gerber 2017). Finally, the India case study operated in a rural and peri-urban setting where waste water is valorized as an agricultural input. Various irrigation water types and qualities were captured in the survey, which provides an ideal setting for a deeper understanding of the irrigation-drinking water quality linkages (Vangani et al. 2016), and their impacts on child health (Vangani 2018). The design and sampling strategy of each study is therefore different and described in detail in these publications. For the purpose of this paper, we summarize the design of each case study in Table 15 in the Appendix.

Although the site-specific surveys naturally evolved to match the research questions at hand, reflecting the realities of the locations, a number of variables of interest to the cross-site and cross-country analyses could be compiled and harmonized. The intention, in line with the objective of the paper, is to illustrate the importance of a more comprehensive, systems approach to water management for health and nutrition, as opposed to "sectoral" approaches (i.e. irrigation water, drinking water, and sanitation "water" infrastructure). The list of harmonized variables and their definitions are provided in Table 16 in the Appendix. These variables were built using the same or similar definitions as in the national surveys presented earlier, with more variables used here to deepen our understanding of the agriculture-WATSAN linkages. Table 6 presents the summary statistics in the same way as Table 1 did for the national surveys, albeit with additional variables, in particular with respect to irrigation and the state of sanitation infrastructure.

Our data reveal that the agriculture-WATSAN linkages as described above do have a clear association with drinking water quality within the households (POU). Table 7 gives an overview of E. coli contamination in the drinking water stored in the households, by agricultural activities. Overall, contamination seems more likely among farming and irrigating households and among households keeping livestock in or around the house, although few of the differences are statistically significant. In India and Ghana, Table 7 also shows that the proportion of households that have E. coli in the drinking water is slightly higher if polluted water is used for irrigation, but the differences are not statistically significant. Interestingly, as shown in Table 17 in the Appendix, more than 60% of the richest households are consuming drinking water that is contaminated with E. coli (i.e. 62% in Ethiopia, 68% in Ghana, 72% in

Bangladesh and 74% in India) This might indicate that E. coli contamination of the drinking water is not a class or wealth issue.

Table 6: Summary statistics for the four case study data sets

VARIABLES	Pooled	Ghana	Ethiopia	Bangladesh	India
Farm - Yes=1	0.850	0.672	1	0.758	0.938
	(0.357)	(0.470)	(0)	(0.429)	(0.242)
Livestock in/at house - Yes=1	0.676	0.651	0.987	0.355	0.730
	(0.468)	(0.477)	(0.114)	(0.479)	(0.445)
Irrigation categories					
No irrigation	0.346	0.764	0.335	0.373	0.517
Clean water irrigation	0.406	0.145	0.335	0.627	0.459
Polluted water irrigation	0.248	0.091	0.330	0	0.489
Distance to water source (min. per round trip)	9.248	12.530	20.400	4.648	2.968
	(13.73)	(12.36)	(15.72)	(5.033)	(12.27)
Improved water source - Yes=1	0.790	0.678	0.496	0.959	0.938
	(0.407)	(0.468)	(0.501)	(0.199)	(0.242)
Water on premises - Yes=1	0.372	0.058	0.156	0.133	0.913
	(0.483)	(0.234)	(0.364)	(0.340)	(0.282)
E. coli in drinking water - Yes=1	0.738	0.833	0.581	0.781	0.783
	(0.440)	(0.374)	(0.494)	(0.414)	(0.413)
Sanitation categories					
Improved sanitation	0.341	0.197	0	0.678	0.409
Not improved & no OD	0.267	0.444	0	0.172	0.120
Not improved & OD	0.392	0.359	0.584	0.150	0.471
Clean sanitation - Yes=1	0.555	0.820	0.582	0.637	0.423
	(0.497)	(0.385)	(0.495)	(0.481)	(0.494)
HH size	5.840	6.127	5.978	4.723	6.421
	(2.298)	(2.609)	(1.772)	(1.692)	(2.504)
Education level HH head					
None	0.439	0.307	0.739	0.322	0.408
Primary	0.315	0.326	0.232	0.314	0.365
Secondary	0.213	0.321	0.029	0.339	0.172
Higher	0.033	0.047	0	0.023	0.054
Gender child - Female=1	0.492	0.454	0.533	0.469	0.491
	(0.500)	(0.499)	(0.499)	(0.500)	(0.501)
Age child, months	30.93	35.82	29.48	30.14	31.83
	(16.12)	(15.38)	(15.64)	(16.38)	(16.27)
Total number of children per household	2.031	2.497	3.324	1.158	1.508
	(1.513)	(1.788)	(1.330)	(0.381)	(1.244)
Share of children in HH	33.54	37.65	54.19	26.31	22.15
	(19.84)	(20.83)	(12.13)	(9.235)	(17.35)
Diarrhea - Yes=1	0.085	0.031	0.159	0.045	0.075
	(0.279)	(0.173)	(0.366)	(0.207)	(0.264)
Underweight - Yes=1	0.299	0.096	0.259	0.322	0.417
	(0.458)	(0.295)	(0.439)	(0.468)	(0.494)
Wasting - Yes=1	0.128	0.0398	0.076	0.127	0.235
	(0.334)	(0.196)	(0.266)	(0.333)	(0.424)
Stunting - Yes=1	0.395	0.230	0.391	0.363	0.533
	(0.489)	(0.422)	(0.489)	(0.481)	(0.500)
Weight-for-age Z-score	-1.484	-0.873	-1.338	-1.533	-1.801
	(1.077)	(1.216)	(0.954)	(1.011)	(1.150)
Weight-for-length/height Z-score	-0.773	-0.228	-0.610	-0.863	-1.013
	(1.141)	(1.424)	(0.961)	(1.043)	(1.281)
Length/height-for-age Z-score	-1.703	-1.417	-1.685	-1.632	-1.935
	(1.286)	(1.507)	(1.180)	(1.154)	(1.474)
Number of children (maximum)	1935	223	565	568	579
Number of households	2065	441	454	512	658

Notes: Standard deviations are in parentheses. A detailed description of the variables is presented in Table 16 in the appendix. Statistics and anthropometrics for children pertain to children under five years of age.

Table 7: E. coli contamination of drinking water by agricultural activities (% of households)

	Farming		Livestock in-house		Irrigation		Polluted irrigation water		All
	Yes	No	Yes	No	Yes	No	Yes	No	
Ghana	88. 9	72.0***	86.7	76.0**	96.6	79.0***	100.0	94.6	83.6
	[144]	[59]	[143]	[60]	[57]	[147]	[22]	[35]	[203]
Ethiopia	58.2		58.3	50.0	58.9	56.6	54.7	63.2	58.2
	[264]	-	[261]	[3]	[178]	[86]	[82]	[96]	[264]
India	79.1	67.5*	80.0	73.7	78.7	72.7	80.7	76.6	78.3
	[417]	[27]	[328]	[115]	[420]	[24]	[192]	[252]	[444]
Bangladesh	79.4	74.2	79.1	77.6	80.7	73.8*		78.1	78.1
	[308]	[92]	[144]	[256]	[259]	[141]	-	[400]	[400]

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01. The number of households is shown in square brackets. A dash denotes that there are no observations for this category.

Drinking water samples collected in the four study sites proved that having access to so-called improved water or sanitation does not necessarily go hand in hand with having access to water of an acceptable microbiological quality. For example, 43% of the Ethiopian households that had access to improved water as per JMP definition had E. coli in their drinking water (Table 8). For the same category of households (i.e. with access to improved water sources) in Bangladesh, India, and Ghana, the rates of E. coli contamination in households' drinking water were even higher (78%, 78%, and 84%, respectively), in the latter two cases these rate are even higher than among households without access to improved water sources.[7] According to the JMP definition, a protected drinking water source has to be protected from outside contamination – this does not guarantee, however, that the water that is supplied via a public standpipe or private tap is free from pathogens or chemical pollutants (e.g. arsenic contamination in Bangladesh).

Table 8: E. coli contamination of drinking water by drinking water source (% of households)

	Improved water		Water on premises		Sanitation		
	Yes	No	Yes	No	Improved	Unimproved, shared	Open defecation
Ghana	84.94	79.8	60.0**	84.9	76.9	81.7	90.0
	[141]	[63]	[6]	[196]	[40]	[89]	[72]
Ethiopia	43.1***	72.9	60.6	57.7	-	51.9	62.6**
	[97]	[167]	[43]	[221]		[98]	[166]
India	78.9	70.0	78.6	75.9	75.4	81.8	80.1
	[416]	[28]	[403]	[41]	[184]	[63]	[197]
Bangladesh	77.6	90.5	61.8***	80.6	76.1	80.7	84.4
	[381]	[19]	[42]	[358]	[364]	[71]	[65]

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01. The number of households is shown in square brackets. A dash denotes that there are no observations for this category.

[7] One possible reason for this result is that households using drinking water from unimproved sources are more likely to treat that water before consuming it. This is confirmed by the nationally representative (DHS) data.

Access to an improved water source (within the premises or not) does not account for water quantity. Even though a water source may be characterized as improved, delivery could only be intermittent or the water source could run dry during the dry season. Regression results show that there is a relationship between the storage quantity of drinking water and the distance to the water source with drinking water quality: The longer the distance to the water source, the more drinking water is stored at home, and the size of the water containers is positively related to the likelihood of having E. coli in the drinking water.[8]

The findings mentioned above suggest that E. coli contamination of drinking water is pervasive and cuts across economic strata, which means that it is, probably a systemic, cultural and behavioral issue. The systemic side obviously goes beyond the JMP water and sanitation infrastructure. We hypothesize that this is partly attributable to the agriculture-WATSAN linkages, with consequences for health and nutrition, see our sets of bivariate analyses below.

Diarrhea prevalence in children under five in relation to agricultural indicators (as described above) is given in Table 9. With regard to farming and using polluted irrigation water, our survey data suggest no clear trend on whether these factors have a systematically positive or negative association with childhood diarrhea. However, diarrhea prevalence among children is higher for households owning livestock across all sites; yet, the differences are not significant. All results must be interpreted with caution, as the number of children who had diarrhea in the last 14 days is relatively small in all sites. Thus the bivariate analysis is not conclusive in confirming our hypothesis about the aggravated exposure to pathogens through farming activities and especially keeping livestock close to or in the household leading to a higher prevalence of child diarrhea, despite the stronger evidence on E. coli contamination in Table 7. Irrigation *per se* is not associated with higher diarrhea prevalence; the India case study actually shows the opposite: Even households practicing polluted water irrigation have less diarrhea prevalence than those practicing no irrigation at all. These results must also be interpreted with caution: The polluted irrigation category is based entirely on a subjective classification and covers only those households using waste water for irrigation. Our water testing in India revealed that canal water, for instance, had a much higher level of E. coli contamination than waste water (Vangani et al. 2016).

[8] The results are not provided in this paper, but they can be presented upon request to the authors.

Table 9: Diarrhea prevalence in the past 14 days by agricultural activities (% under 5 children)

	Farming		Livestock		Irrigation		Polluted irrigation water		All
	Yes	No	Yes	No	Yes	No	Yes	No	
Ghana	4.6	2.9	5.3	1.3	4.6	3.9	3.5	5.4	4.6
	[8]	[2]	[9]	[1]	[3]	[7]	[1]	[2]	[3]
Ethiopia	15.7	-	15.9	0	15.4	16.2	13.7	17.0	15.7
	[88]		[88]	[0]	[58]	[30]	[25]	[33]	[88]
India	6.2	17.4***	7.6	5.1	6.3	16.3**	9.1	5.1*	7.0
	[33]	[8]	[34]	[6]	[34]	[7]	[26]	[15]	[41]
Bangladesh	4.7	4.4	4.9	4.4	5.1	3.7	-	4.6	4.6
	[20]	[6]	[10]	[16]	[18]	[8]		[26]	[26]

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01. The number of children in square brackets. A dash denotes that there are no observations for this category.

As expected, children under five living in households with access to improved water sources and in households with water on premises tend to be less prone to diarrhea (Table 10). Households practicing open defecation tend to have children with higher diarrhea prevalence than households with access to improved or shared sanitation facilities (yet, the differences across sanitation categories are mostly insignificant), except in Ethiopia. It is noteworthy to mention that the Ethiopian case study site had by far the lowest population density of all sites, which may explain this result. Further data analysis is needed in order to find out whether people with access to improved sanitation facilities are actually using the latter or whether any community effects (e.g. open defecation or unsafe waste disposal in the neighborhood) come into play. In India, it is surprising to see that more children are affected by diarrhea outbreaks in households with no E. coli in their drinking water (10.9% as opposed to 5.7% for households having contaminated water). Less surprising is the fact that E. coli contamination of drinking water and child diarrhea prevalence are not confined to poor households (Table 18 and Table 19, Appendix) but are rather an issue cutting across all wealth groups.

Chronic child malnutrition, captured by stunting, is associated with farming activities and practices in some study sites, see Table 11. Pathways for these associations are multiple and difficult to hypothesize a priori. According to our data, stunting among children is less prevalent in Bangladeshi farming households than in non-farming households. At the same time, irrigation shows a clear association with a lower prevalence of stunting in Ethiopia. However, higher stunting prevalence was observed among Indian households that used polluted irrigation water, compared to households that used clean water irrigation or no irrigation. This provides new insights as compared to the national data in Table 4: Farming per se may not be a source of risk, but irrigation from recycled waste water and other polluted water sources may have negative effects.

Table 10: Diarrhea prevalence in the past 14 days by WASH characteristics (% under 5 children)

	E. coli		Improved water		Water on premises		Sanitation		
	Yes	No	Yes	No	Yes	No	Improved	Unimproved, shared	Open defecation
Ghana	4.1	0.0	4.4	3.5	0.0	4.4	1.6	3.3	6.9
	[5]	[0]	[7]	[3]	[0]	[10]	[1]	[3]	[6]
Ethiopia	24.5	3.4***	12.8	18.3*	10.9	16.6	-	16.0	15.4
	[80]	[8]	[35]	[53]	[10]	[78]		[37]	[51]
India	5.7	10.9*	5.9	20.9***	6.0	15.9***	2.9	6.3	10.1 ***
	[22]	[10]	[32]	[9]	[31]	[10]	[6]	[5]	[30]
Bangladesh	5.4	1.6*	4.4	8.3	0.0	5.3**	4.3	2.2	8.6
	[24]	[2]	[24]	[2]	[0]	[26]	[17]	[2]	[7]

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01 (For the sanitation variable we use the F-test, thus reporting if any of the three categories is significantly different from any of the two others). The number of children is in square brackets. A dash denotes that there are no observations for this category.

Table 11: Prevalence of stunting by agricultural activities (% under 5 children)

	Farming		Livestock		Irrigation		Polluted irrigation water		All
	Yes	No	Yes	No	Yes	No	Yes	No	
Ghana	20.6	21.92	20.2	21.8	21.5	20.7	20.6	22.2	21.6
	[41]	[16]	[38]	[19]	[17]	[41]	[7]	[10]	[17]
Ethiopia	40.1	-	40.6	12.5	44.6	30.8***	40.5	40.7	40.1
	[192]		[191]	[1]	[144]	[48]	[78]	[66]	[144]
India	56.8	48.9	56.0	56.8	56.7	50.0	61.8	50.9**	56.1
	[276]	[22]	[235]	[63]	[277]	[21]	[157]	[141]	[298]
Bangladesh	34.2	42.8*	38.2	35.2	34.4	39.4	-	36.7	36.3
	[147]	[59]	[78]	[128]	[121]	[85]		[206]	[206]

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01. The number of stunted children is shown in square brackets. A dash denotes that there are no observations for this category.

Examining the WASH characteristics of the households (Table 12), our pooled case studies surveys suggest that E. coli contamination of the drinking water is associated with higher malnutrition rates (all 3 indicators, though statistical significance is rare), with India being the exception. The latter, counterintuitive, result needs further investigation in the multivariate analysis, although it is not statistically significant here. The association of access to improved water or water on the premises with malnutrition is somewhat less consistent and varies across countries and indicators, and the differences in prevalence rates that are significant are mostly counter-intuitive. As far as access to improved water is concerned, this is in line with the results from the nationally representative data in Table 5. Also consistent with those results is the fact that by and large, malnutrition prevalence is negatively associated with the existence and quality of sanitation infrastructure.

Table 12: Prevalence of undernutrition by WASH characteristics (% under 5 children)

	E. coli		Improved water		Water on premises		Sanitation		
	Yes	No	Yes	No	Yes	No	Improved	Unimproved or shared	Open defec.
Stunting									
Ghana	19.9	12.0	24.0	15.3*	20.0	21.6	17.7	20.5	22.6
	[28]	[3]	[43]	[15]	[3]	[55]	[12]	[23]	[21]
Ethiopia	40.8	38.9	36.8	43.3	52.5	37.6**	-	37.0	42.1
	[118]	[74]	[86]	[106]	[42]	[150]		[70]	[122]
India	53.9	58.6	56.8	48.8	57.2	47.5	48.7	55.7	61.6**
	[199]	[51]	[277]	[21]	[270]	[28]	[94]	[39]	[165]
Bangladesh	39.4	25.0***	36.2	37.5	32.9	36.8	35.2	34.8	43.2
	[175]	[31]	[197]	[9]	[25]	[181]	[139]	[32]	[35]
Underweight									
Ghana	7.9	4.0	10.2	4.1*	13.3	8.0	4.4	6.4	13.0*
	[11]	[1]	[18]	[4]	[2]	[20]	[3]	[7]	[12]
Ethiopia	28.7	22.6	27.3	25.0	30.4	25.3	-	25.7	26.5
	[92]	[51]	[73]	[70]	[28]	[115]		[57]	[86]
India	41.8	47.3	45.3	44.2	45.0	46.7	39.3	40.3	50.7**
	[157]	[43]	[231]	[19]	[222]	[28]	[79]	[29]	[142]
Bangladesh	34.9	22.6***	32.0	37.5	21.1	33.9**	29.4	35.9	42.0*
	[155]	[28]	[174]	[9]	[16]	[167]	[116]	[33]	[34]
Wasting									
Ghana	2.2	4.0	3.4	3.1	13.3	2.8**	2.9	3.7	3.3
	[3]	[1]	[6]	[3]	[2]	[7]	[2]	[4]	[3]
Ethiopia	10.0	5.3*	9.0	7.4	8.8	8.0	-	6.9	9.0
	[29]	[10]	[21]	[18]	[7]	[32]		[13]	[26]
India	23.3	24.1	23.8	30.2	23.7	28.8	23.8	18.6	26.1
	[86]	[21]	[116]	[13]	[112]	[17]	[46]	[13]	[70]
Bangladesh	13.7	8.9	12.1	25.0*	9.2	13.2	13.4	7.6	14.8
	[61]	[11]	[66]	[6]	[7]	[65]	[53]	[7]	[12]

Note: The mean difference between the two categories is statistically significant at * p<0.1, ** p<0.05, *** p<0.01 (For the sanitation variable we use the F-test, thus reporting if any of the three categories is significantly different from any of the two others). The number of children is shown in square brackets. A dash denotes that there are no observations for this category.

3.4 Comparing DHS and case studies data from Ethiopia, Ghana, India and Bangladesh

In summary of the bivariate analyses discussed above, and keeping in mind the differences observed between the descriptive statistics of the DHS sub-samples (which include only rural households) and those of our case studies household surveys (hereafter referred to as "case studies data"), a few topics emerge for further discussion in the regression analysis:

1. Using the nationally representative data, the bi-variate analysis exposes fundamental differences in the associations between agriculture and health/nutrition indicators, or between WATSAN and health/nutrition indicators; for instance,
    a. child diarrhea prevalence is lower in farming households in Bangladesh but higher in India;

b. households with access to better water infrastructure have lower child diarrhea prevalence in Bangladesh, but higher in India and Ghana;
c. farming households record lower prevalence of child stunting in Bangladesh and India, but higher in Ethiopia;
d. households with access to better water infrastructure have almost consistently lower prevalence of child malnutrition in Bangladesh and India, but these associations are less consistent for Ethiopia, and there are only insignificant associations for Ghana which are very ambiguous with regard to their direction.

2. The analysis of our case studies data picks up fewer statistically significant associations (which is to be expected considering the small sample sizes) and these are often in the opposite direction of those suggested in the DHS data
3. The lack of consistency in the direction of the associations across the DHS data sets on the one hand and comparing the DHS and our case studies data on the other hand confirms that there are complex dynamics at play in the agriculture-WATSAN nexus. This complexity should not be glossed over due to a high degree of aggregation in the data. Rather, system diversity may be the key influence behind those inconsistent associations and all efforts must be undertaken to describe and analyze this divert in order to concomitantly achieve improvements in the WATSAN and nutrition fields. This is the basic motivation for the analytical approach of the next section.
4. The bivariate analyses provide some support for our hypothesis that irrigation practices, rather than simply living in a farm household, may be associated with higher prevalence of child diarrhea and (especially) malnutrition, but the evidence is not consistent across the case studies.

4. Empirical analyses in the countries and study sites

In this section, we discuss our multi-variate analysis, focusing first on the results of the cross-country analysis of the nationally representative surveys, second on our agriculture-WATSAN case studies household surveys. The purpose remains the same: to test our hypothesis that persistent malnutrition among children cannot be tackled by improved water and sanitation infrastructure, even if coupled with WASH education and interventions. Rather, water and its handling need to be understood in a system perspective, as water-use is an issue cutting across the whole spectrum of household activities: from agricultural production and livestock-keeping, to cooking, washing and drinking.

4.1 Cross-country evaluation

Nationally representative data analysis

We have two types of anthropometric indicators on which to base our multivariate regression analyses: the standardized scores of under-5 children's height-for-age and weight-for-age measurements, and their associated binary categorical indicators of stunting and underweight, respectively. [9] We focus here on the presentation and discussion of the two continuous indicators of persistent child malnutrition, namely the height-for-age and weight-for-age. The regression results for the binary outcomes are broadly the same (Table 20 and Table 21 in the Appendix), but we feel that the interpretation of the results in our context and given our purpose is more intuitive when considering the standardized scores instead. We exclude the weight-for-height (wasting) indicator, as it might be overly sensitive to momentary circumstances.

The first lesson from Table 13 is that the two indicators of farm activities do not have a clear association with malnutrition: The results show that the weight-for-age of children living in farming households is on average 0.06 standard deviations higher than for children from non-farming households (Column 2, Table 13).[10] The regressions indicate no statistical associations between children living in farming households and their height-for-age score, or between children living in a household that keeps livestock and either of the two anthropometric scores. As it is impossible to hypothesize *ex ante* the sign of such association for the two variables (holding livestock and being a farm household), we are not surprised. Indeed, intrinsically, life in a farming household and/or around livestock might both mean increased exposure to pathogens such as E.coli (a negative association is then expected), but could also mean access to a better diet, both in terms of quantity and quality (e.g., a diet including animal

[9] Standardized scores and binary indicators are compiled following the WHO guidelines and methodology. See WHO (2010) for details. The software applied by the WHO to compile anthropometric measures is available at https://www.who.int/childgrowth/software/en/ .

[10] We mean here standard deviations a measured by the z-score. This is true for all regressions results in the remainder of the paper.

protein and micronutrient-rich foods) in particular (and thus a positive association would be expected). As income effects are controlled for by including the wealth variable (serving here as an approximation for income), they are mostly taken out of the variables for farming and keeping livestock. Whether another variable reflecting the farm water system could capture critical, intrinsic dynamics in pathogenic exposure and their malnutrition impacts will be addressed in the analysis of our own case studies data.

The second lesson from Table 13 may come as a surprise: the regression results suggest that access to improved drinking water is significantly and negatively associated with child nutrition (Columns 1 and 2, Table 13). For instance, the height-for-age of children living in households with access to improved water sources on average is 0.14 standard deviations lower than for children living without access to improved water sources, the weight-for-age 0.11 standard deviations lower. We will cross-check this finding in our case studies data analysis, but this already points at the potential inaptitude of improved water infrastructure to deal with malnutrition: improved drinking water at *source* may not mean much for quality of drinking water at *point of use*.

On the other hand, access to improved sanitation is significantly and positively associated with child nutrition. Children living without any access to sanitation facilities (open defecation) are 0.21 and 0.15 standard deviations lower respectively in height-for-age and weight-for-age than children living with access to improved sanitation facilities (Columns 1-2, Table 13). Such a negative association also exists when comparing access to unimproved latrine, which is a risk factor for poor nutrition outcomes, with access to improved sanitation (0.14 and 0.10 standard deviations for height-for-age and weight-for-age, respectively). Again, we will deepen this analysis of the role of sanitation for nutrition in our case studies data analysis, but the critical nature of open defecation practices is highlighted here, above and beyond the role of appropriate infrastructure. Hence in short, the WATSAN infrastructure investments might pay off in the case of sanitation, but the results are much less clear for improved drinking water infrastructure. The critical issue of behavior around latrine use or the handling of drinking water is re-emphasized here and will be investigated further in the coming sections.

The results further suggest that household wealth and education of the household head, which are used here as approximations for the financial and knowledge resources that the household can summon as it attempts to meet the nutrition needs of its members, are indeed strongly and significantly associated with children's nutritional status. For instance, as compared to being in the lowest wealth quintile, being in higher quintiles is systematically associated with higher height-for-age and weight-for-age scores. Moreover, we can see that the size of the coefficient monotonically increases, from 0.13 standard deviations for the 2nd lowest quintile to 0.60 standard deviations for the highest quintile in the case of height-for-age, and similarly for weight-for-age. The same monotonic increase in coefficients predicting child nutrition outcomes is observed when going from the lowest to the highest level of education: the height-for age score increases from 0.08 standard deviations when comparing household heads with primary education to household heads with no education, to 0.32 standard deviations when comparing household heads with higher education to household heads with no education (0.09 to 0.15 standard deviations increases in the case of weight-for-age).

These results have policy implications of relevance in our context. Increasing the financial resources at the disposal of the households, as they seek to ensure good nutrition for their members, may not be directly achievable (although social safety nets can contribute to improving food and nutrition security). On the other hand, and in so far as knowledge actually translates into behavioral adaptations, it seems that interventions addressing knowledge and behavior around WATSAN in a water system perspective could potentially produce significant nutritional pay-offs. This is part of the motivation for this paper and is discussed further in the next sections.

Finally, we do not comment on the set of child controls (gender, age and the number of children under five in the household) as they are necessary but their interpretation is not central to our purpose. The country dummies on the other hand tell us something about how child nutrition in Bangladesh compares with Ethiopia, Ghana and India. We can see that controlling for the independent variables in the regression, Bangladesh quite systematically displays the lowest z-scores; height-for-age scores in India are the exception to this rule because they roughly equal the very low scores in Bangladesh. It is tempting but not advised to compare the other three countries to each other. The value of these coefficients will become apparent in the next section, as we attempt to repeat the analysis of this section with our purposive primary surveys.

Table 13: Nationally representative multivariate regression results for the standardized z-scores (rural areas)

	(1) Height-for-Age	(2) Weight-for-Age
Farming: Yes=1	0.000	0.062**
	(0.031)	(0.026)
Livestock: Yes=1	0.004	-0.005
	(0.037)	(0.025)
Improved water source: Yes=1	-0.138**	-0.109***
	(0.056)	(0.038)
Sanitation categories (Base: Improved Toilet)	ref.	ref.
Not improved	-0.143***	-0.095***
	(0.038)	(0.032)
Open Defecation	-0.213***	-0.148***
	(0.042)	(0.035)
Wealth Quintiles (Base: Lowest Quintile)	ref.	ref.
2nd quintile	0.131***	0.120***
	(0.045)	(0.035)
3rd quintile	0.348***	0.274***
	(0.053)	(0.038)
4th quintile	0.417***	0.412***
	(0.052)	(0.045)
5th quintile	0.601***	0.588***
	(0.068)	(0.057)
Education level of HH head(Base: None)	ref.	ref.
Primary	0.084*	0.087***
	(0.047)	(0.032)
Secondary	0.115***	0.114***
	(0.038)	(0.028)
Higher	0.321***	0.154***
	(0.058)	(0.058)
Number of children under 5 in the HH	0.003	-0.011
	(0.031)	(0.016)
Gender: Female=1	0.070***	0.044**
	(0.026)	(0.021)
Child age in months	-0.088***	-0.038***
	(0.004)	(0.003)
Child age squared	0.001***	0.000***
	(0.000)	(0.000)
Survey Dummies (Base: Bangladesh)	ref.	ref.
Ethiopia	0.140**	0.347***
	(0.055)	(0.043)
Ghana	0.576***	0.798***
	(0.057)	(0.049)
India	0.118***	-0.009
	(0.034)	(0.032)
Constant	-0.470***	-1.088***
	(0.093)	(0.080)
Observations	174761	174907
Pseudo R^2	0.126	0.126
Model F-stat	74.22	87.59
Model p-value	0.000	0.000

Notes: Linearized standard errors are in parentheses; statistical significance denoted at * p<0.1, ** p<0.05, *** p<0.01

Pooled case studies data analysis

With our pooled case studies survey data, we conduct two sets of regressions for the continuous height-for-age and weight-for-age scores (Table 14): The first one applies the expenditure quintiles as key household characteristic approximating the households' access to financial resources that can be used to provide for children's nutritional needs (Columns 1-2); the second one applies the education level of the household head (Columns 3-4), as key household characteristic approximating the households' access to knowledge resources that can be used to take care of children's nutritional needs. The two variables are strongly correlated in our dataset and we thus do not use them simultaneously (as was done with the nationally representative datasets) in order to avoid this strong source of multicollinearity. This is a problem that arises partly due to the smaller sample sizes covered in our case studies surveys, as opposed to the much larger sample sizes covered in the nationally representative surveys, and potentially also to the fact that our sampled households are representative of smaller areas (districts) within which there is not a large degree of variation in income or behavior (with knowledge then playing less of a role).

Reminiscent of the results showed in the bivariate analysis (Table 11), we do not find here a clear association of the farming activities with the child malnutrition outcomes. The keeping of livestock in or around the house has no association with height-for-age, but a strong, significant positive association with weight-for-age (+0.22 standard deviations, Table 14 Columns (2) and (4)). This could suggest that the negative hygiene impacts of proximity to livestock are more than compensated for by the positive dietary impacts of access to animal products. On the other hand, belonging to a farming household shows no statistically significant association with the height-for-age score (Table 14 Columns (1) and (3)), although the size of the coefficient is much higher than in the national data analysis (Column (1), Table 13). Another contrast with those latter results is that farming is here quite strongly and negatively associated with weight-for-age, although the statistical significance is low (Column (4)). This difference may be driven by the fact that an important feature of farming is now captured separately in our case studies data: whether the households irrigating their fields or not, and which type of irrigation water they mostly rely on.

The categorical variable for irrigation shows that living in a household irrigating with polluted water, as opposed to households not practicing irrigation, is associated with at least 0.30 standard deviations lower height-for-age scores for the children under 5 years of age (Table 14 columns (1) and (3)). Whilst there is no statistically significant association with weight-for-age z-scores, the lack of association of clean water irrigation and children's anthropometric scores suggests that the type of irrigation water needs to be carefully considered in planning for agricultural and water infrastructure for health and nutrition.

Indeed, as in the analysis of the nationally representative surveys in the previous section, access to improved drinking water sources is negatively and strongly associated with children's height-for-age. This suggests that behavior and use, rather than infrastructure, could determine the impacts of water on health and nutrition, even once irrigation practices are controlled for.

Our regressions also draw attention to the importance of sanitation infrastructure and use. Our categorical variable this time points at the strong and negative association between households practicing open defecation and their children's nutrition outcomes (0.31 to 0.41 standard deviations lower adjusted scores). This association is stronger than for the national data, regardless of the model specification or the nutrition indicator. Although there are no strongly significant associations with the use of non-improved sanitation (such as pit latrines), we believe this further hints at a strong role of behavior over infrastructure.

In our samples, which are representative of the districts in which they were drawn, we can assume that the income distribution is narrower than in the national data. This is probably even truer for expenditures, as the rural and peri-urban areas we cover surely present fewer opportunities for diverse consumption than the national economy does. This may be the reason why instead of the monotonically increasing association between wealth quintiles and the two anthropometric indicators in Table 13, we find here (Table 14, (1) and (2)) that the expenditure quintiles are only significantly and strongly associated with higher z-scores when comparing the "richest" and "poorest" quintiles (+0.21 and +0.37 standard deviations for the height-for-age and weight-for-age z-scores, respectively). As additional information, we provide in Figure 6 a graph of the right-skewed distributions of household expenditures.

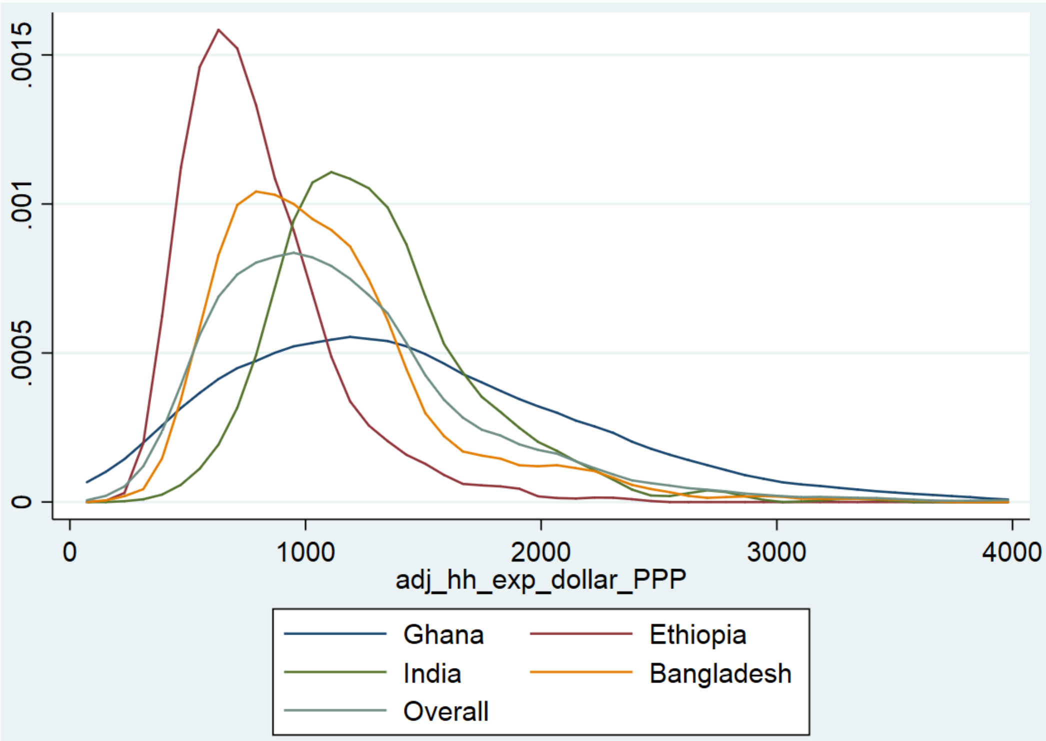


Figure 6: Distribution of the adjusted (PPP) household expenditures per case study country

Source: compiled by the authors

On the other hand, education of the household head, as indicator of the households' access to knowledge, does not show any significant association with the anthropometric outcomes (Table 14, (3) and (4)). This is despite the fact that education of the household head is showing considerable variation in Table 6, where we see that only the Ethiopian sample almost exclusively consists of households with no or primary education; the three other samples exhibit greater variation in education, all the way to tertiary. We can conclude from this that households are either not educated about WATSAN and its linkages with health and nutrition, especially in the context of agricultural practices, or that they do not perceive WATSAN problems as relevant for their situation. These issues are intimately related with behavior around water use and are investigated further in the next section.

Finally, the survey dummies highlight some key differences between our survey samples and those of the nationally representative surveys. Table 13 shows that according to the national surveys, Bangladesh has the lowest weight-for-age score among children, and its height-for-age scores are about as low as those India when controlling for the independent variables in the regression. This is not the case in Table 14, where India shows significantly lower weight-for-age and height-for-age than Bangladesh. This could reflect the marginal living conditions of the households interviewed in the Indian survey, as they are located located in a peri-urban area with high usage of waste water for irrigation.

Table 14: Pooled case studies data multivariate regression results for the standardized z-scores

	(1) Height-for-Age	(2) Weight-for-Age	(3) Height-for-Age	(4) Weight-for-Age
Farm - Yes=1	0.135	-0.203	0.133	-0.229*
	(0.173)	(0.124)	(0.175)	(0.128)
Livestock in/at House - Yes=1	0.054	0.222**	0.041	0.220**
	(0.107)	(0.086)	(0.109)	(0.088)
Irrigation categories (Base= No Irrigation)	ref.	ref.	ref.	ref.
Clean water irrigation	-0.036	0.025	-0.004	0.060
	(0.114)	(0.089)	(0.112)	(0.092)
Polluted water irrigation	-0.349**	-0.173	-0.316**	-0.143
	(0.154)	(0.115)	(0.144)	(0.114)
Improved water source - Yes=1	-0.219*	-0.118	-0.206*	-0.136
	(0.116)	(0.086)	(0.114)	(0.089)
Sanitation categories (Base=Improved Sanitation)	ref.	ref.	ref.	ref.
Not improved	-0.198	-0.099	-0.234*	-0.104
	(0.123)	(0.093)	(0.121)	(0.096)
Open defecation	-0.362***	-0.310***	-0.408***	-0.322***
	(0.116)	(0.086)	(0.117)	(0.088)
Expenditure Quintiles (Base=Lowest Quintile)	ref.	ref.		
2nd quintile	-0.096	-0.032		
	(0.129)	(0.095)		
3rd quintile	-0.051	0.081		
	(0.135)	(0.098)		
4th quintile	0.113	0.105		
	(0.131)	(0.093)		
5th quintile	0.213*	0.370***		
	(0.126)	(0.103)		
Education Level HH head (Base=None)			ref.	ref.
Primary			-0.046	0.059
			(0.096)	(0.074)
Secondary			-0.050	0.099
			(0.114)	(0.093)
Higher			-0.155	0.131
			(0.231)	(0.127)
Gender child - Female=1	0.116*	0.131**	0.138**	0.139**
	(0.070)	(0.056)	(0.068)	(0.056)
Age child	-0.069***	-0.046***	-0.066***	-0.045***
	(0.010)	(0.009)	(0.010)	(0.009)
Age child Squared	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Total number of children	0.041	0.013	0.044	0.001
	(0.046)	(0.028)	(0.045)	(0.029)
Survey Dummies (Base= Bangladesh)	ref.	ref.	ref.	ref.
Ethiopia	0.025	0.221*	0.033	0.291**
	(0.163)	(0.119)	(0.175)	(0.124)
Ghana	0.333**	0.672***	0.357**	0.691***
	(0.167)	(0.124)	(0.171)	(0.134)
India	-0.246**	-0.208**	-0.278**	-0.228**
	(0.118)	(0.093)	(0.121)	(0.093)
Observations	1709	1709	1699	1699
Peusdo R-squared	0.111	0.169	0.108	0.157
Ymean	-1.670	-1.415	-1.674	-1.423

Notes: Robust standard errors clustered at the household level are in parentheses; statistical significance denoted at * p<0.1, ** p<0.05, *** p<0.01. The constant term is omitted.

4.2 What the cross-country analysis shows – and hides

The results presented in the previous section for the nationally representative surveys and our own purposive micro-household surveys strongly re-inforce each other and the associations suggest similar impacts, indeed even to similar magnitudes of impacts, of the WATSAN variables on child nutrition outcomes as measured by height-for-age and weight-for-age scores (or the corresponding categorical indicators of stunting and underweight, respectively). These can be summarized in the following points:

- The coefficients of access to *improved water sources* are consistently negative, which means that this variable is associated with lower height-for-age and weight-for-age scores (that is, worse child nutrition outcomes) – a finding potentially mitigating by the limitation sof our cross-sectional data. As discussed briefly earlier, our hypothesis on improved water infrastructure is that it cannot compensate for harmful behavior in water handling and storage. Indeed, as seen in Table 8, the vast majority of households have E. coli contaminated drinking water, irrespective of their drinking water source. The cases in Bangladesh and India are particularly telling: literally all households have access to improved water sources, yet about 78% of them have E. coli in their stored drinking water. The tests were conducted on stored drinking water found in the households, hence at the last stage before consumption, and provide a very direct indication of exposure to health and nutrition risks.
- *Open defecation* is robustly associated with worse child nutrition outcomes in both the case study data and the DHS data. As shown in the literature, the existence of sanitation infrastructure does not guarantee its use and the eradication of open defecation (Ramani et al. 2017), and open defecation has worse effects on child health in more densely populated areas (Hathi et al. 2017). This again points to behavioral issues, this time in the realm of sanitation, which also has potential linkages to the issue of water handling and storage (through contamination by unclean hands).
- The addition of a categorical variable for *irrigation* that reflects the type of irrigation water used by the farming households and is specific to our purposive cross-section, does not change the effect of the other variables, but points at a potential role for this variable as hypothesized at the onset of the paper. There are several reasons why this hypothesized impact does not come out strongly in our regression analyses. As mentioned earlier, the survey instruments deployed at each site are different, serving site-specific research objectives. The set of variables reported in Table 14 and Table 21 thus includes variables constructed from survey data that were not necessarily collected using the same questions. One example includes the irrigation water categories:

  - The India case study records irrigation water according to the following categories: waste water, canal water, and tube well/rain water, no irrigation/no farm involvement.
  - In Ethiopia, the type of irrigation water was assessed by means of a subjective statement on the part of the farmers who answered the following question: "Do you think your irrigation water is polluted?"
  - Considering these differences, it seems plausible that our common categorization across study sites does not reflect the actual quality of the irrigation water, which is the determining factor that influences the transmission of pathogens (E. coli in particular) in the realm of the household water system, and thus the child nutrition outcomes.
  - Indeed, in the case of India, households that irrigate with canal water are similar to waste water irrigators when it comes to the quality of stored drinking water (in those two groups, 84% and 86% of households, respectively, have E. coli-contaminated drinking water stored in the house, compared to around 70% of households that do not irrigate or irrigate with clean water). This warrants further investigation, which can only be carried out with locality-specific indicators at the case study level.
- Farming and livestock ownership do not have a significant association with height-for-age scores or stunting, and only an inconsistent association with weight-for-age scores and underweight. As mentioned earlier, this reflects the lack of a priori knowledge on the direction of the effects of these variables.

These points lead us to a discussion of the two main issues: the importance of behavior around the handling of drinking water, and (more generally) hygiene practices, and the need for a context-specific analysis of the impact of different irrigation water types on water quality and child malnutrition.

Behavioral issues around WASH

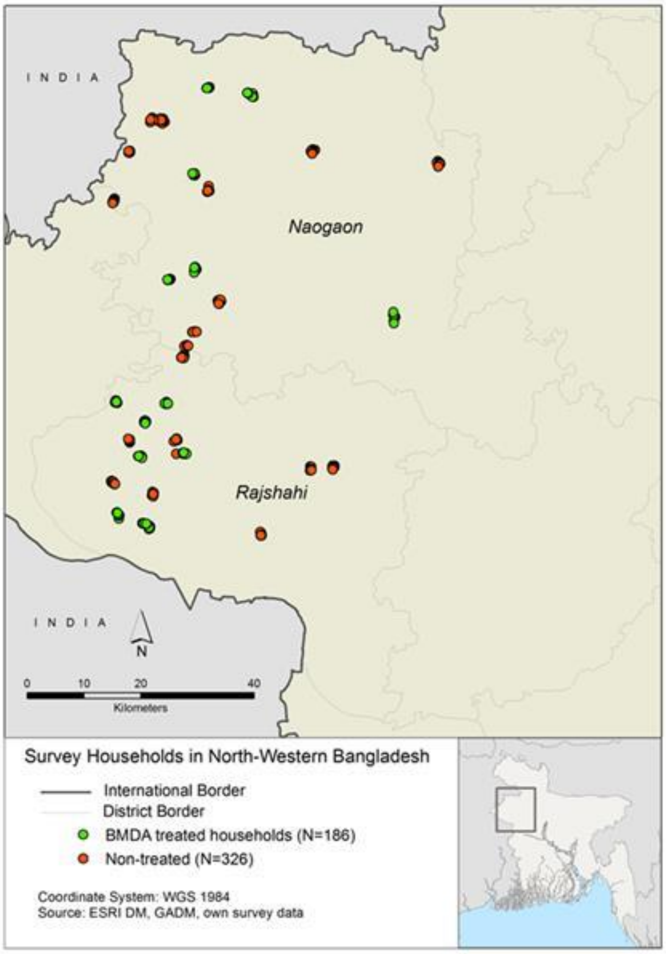
The literature review has already pointed out the importance of behavioral issues in the WASH sector. Different categorizations of interventions to tackle poor WASH environments are suggested in the literature. One is to differentiate between "hardware interventions" and "software interventions" (Varley et al. 1998; Waddington et al. 2009), the former relating mostly to infrastructure and its maintenance and the latter to interventions seeking to inform and educate households about safe water handling, storage and use, for example.

Since contaminated water, either at point of source (POS) or POU, is one of the main causes of diarrhea (Nath et al. 2006; Prüss et al. 2002; Prüss-Üstün et al. 2008; Zwane & Kremer 2007), and since interventions to improve water quality are generally effective in averting the occurrences of diarrhea among all ages, including children under five years of age (Clasen et al. 2007), much attention should be paid to protecting water quality at POS and at POU as well. Although this is clearly a simplification, one could generally say that the former is addressed with hardware interventions, the latter with software interventions.

Yet, providing access to improved water sources (i.e. addressing water quality at POS) does not necessarily translate into positive health impacts (Devoto et al. 2012; Hasan & Gerber 2016; Klasen et al. 2012), or does so only to a limited extent (Waddington et al. 2009; Wright et al. 2004; Zwane & Kremer 2007). Indeed, it is widely reported that water is frequently contaminated during water collection, transportation or storage in the household because of improper handling (Clasen & Bastable 2003; Crampton & Aid 2005; McGarvey et al. 2008; Baker et al. 2013; Gunther & Schipper 2013; Hasan & Gerber 2017; Rufener et al. 2010; Shields et al. 2015; Vangani et al. 2016; Wolf et al. 2014; Wright et al. 2004), thus affecting water quality at POU and health outcomes such as diarrheal diseases. Jalan & Ravallion (2003) also show that access to piped water interacts with many other determinants of child health such as hygienic water storage, water treatment, sanitation infrastructure, medical treatment and nutrition. It is even suggested that access to piped water improves neither water quality nor health, but rather helps save time and reduces intra-household conflict (Devoto et al. 2012), or that it might even worsen health outcomes if water is rationed (Klasen et al. 2012), potentially through the impact of the discontinuous water supply on increased water storage and bacterial growth (Brown et al. 2013b). Our work in Bangladesh (Box 1) points at the same underlying issue of discontinuous supply and poor quality of stored drinking water, and its consequences for child health and nutrition outcomes. This highlights the complex interactions between water quantity, water quality and human health.

Box 1: Impacts of piped water in North-Western Bangladesh

Our findings in North-Western Bangladesh tend to confirm the importance of behavioral issues around water storage. In a quasi-experimental setting, Hasan (2018) shows that participation in a public piped water scheme (the Barindra Multipurpose Development Authority or BMDA drinking piped water scheme) is related to a 8.6 liter higher water storage capacity within the household. This might first seem counterintuitive, yet focus group discussions shed light on the finding: the scheme delivers piped water on the household's premises through a network of deep tube wells and water towers, but is unable to provide a continuous flow of water and hence to increased need for storage. This result potentially explains also the lack of statistically significant impact of the piped water scheme on the quality of water at POU, hygiene behavior such as hand washing, or indeed on the incidence of child diarrhea or on the age adjusted height and weight of the households' children below the age of five. These results are robust to estimation technique (propensity score matching or regression analysis).

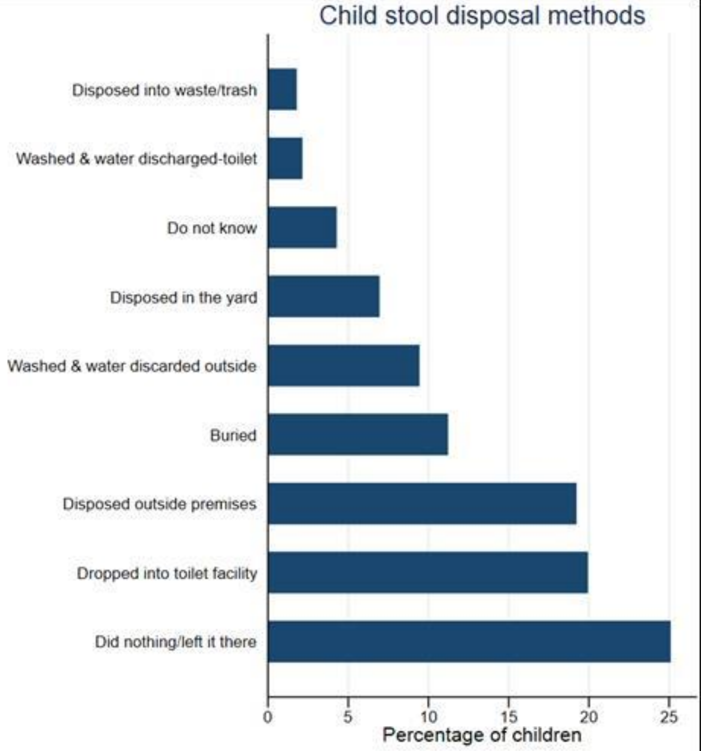


Behavior with regard to water usage is also related to hygiene and sanitation behavior and infrastructure, and has close interactions with health outcomes. A systematic review of impact evaluations by Waddington et al. (2009) shows that water, sanitation and hygiene interventions can all reduce the prevalence of diarrhea among children in developing countries, though differentiating the effectiveness of POS versus POU water quality interventions can be challenging and hinges on methodological issues. They generally conclude, however, that the sustainable and sustained use of "hardware interventions" is necessarily determined by behavioral factors. In another systematic review of the literature, Cairncross et al. (2010) conclude that "hand washing with soap, improved water quality and excreta disposal" interventions were all associated with a reduction of diarrhea risk, by about 48, 17 and 36 percent respectively. Crucially, Waddington et al. (2009) highlight the lack of impact studies capturing the combined effects of multiple (types of) interventions: Some studies have shown that using various combinations of interventions is more effective than using one alone (Alam et al. 1989; Esrey et al. 1991; van der Hoek et al. 2001), although a comprehensive meta-analysis found that multiple (i.e. combined) interventions were not more effective than single interventions (Fewtrell et al. 2005).

WHO/UNICEF (2009) confirm that improving sanitation facilities is an important step in reducing diarrhea incidence: Diarrheal morbidity can be reduced by 33 percent by improving sanitation, with further potential benefits arising from spillover effects from sanitized to non-sanitized villages (Guiteras et al. 2015; Kaiser 2015). Proper sewage infrastructure is also related to sanitation (and excreta disposal in particular) and health, and was shown to reduce diarrhea incidence by about 30 percent (Norman et al. 2010). Yet the existence of improved infrastructure can only have a positive impact on health and nutrition if it is used sustainably, maintained and accompanied by appropriate hygiene practices. However, it is clear from the literature that conventional hygiene education messages are unrealistic, irrelevant and incomplete in the local context of most poor people, and related recommendations are therefore not followed by individuals (van Wikj & Murre 2003). Besides the enabling factors (i.e. skill, time and means), individuals make decisions over what guidelines to follow based on community practices, own beliefs, and values, existing own and community resources, attitude and external influences (Hubley 1993; Ramani et al. 2017). We find similar community practices and beliefs at play in Ethiopia with respect to the disposal of child stools (Box 2).

Box 2: Sanitation culture and community practices in rural Ethiopia

The interactions between sanitation infrastructure, beliefs and practices are highlighted in Usman (2017). Access to and use of improved sanitation facilities are low in the rural communities surveyed in the Amhara region, Ethiopia. About 42% of the households reported that they have simple pit latrines while 58% of the households defecated in the open. Moreover, most adult women preferred defecating in a bush. The survey also reveals that more than 74% of the primary caretakers practiced open defecation for the last stool before the survey. As many of the latrines were constructed in response to a push by the local government, open defecation is still the norm and practiced by a majority of the population in the study areas. Further, again due to limited awareness, the diagram shows that only 38% of children's last stools preceding the survey were adequately disposed of.



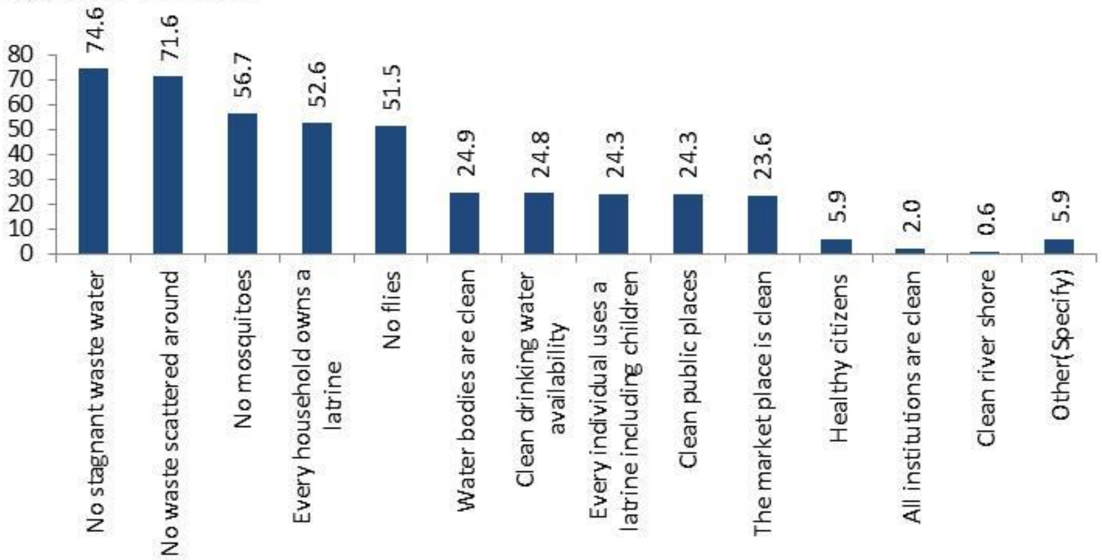
Leaving child stool stools in the immediate vicinity or the yard increases the risk of young children coming into direct contact with stools, which causes diarrheal diseases.

Results in Usman et al. (2018b) suggest that safe child stool disposal decreased child diarrhea by more than 20 percentage points, whereas latrine density increased it by more than 14 percentage points. These results are robust to all model specifications and the choice of estimation technique, and to the age group of the children (below three or below five years). The finding that neighborhood latrine density increased the risk of diarrhea in young children casts serious doubt on the assumed health and social benefits of moving from open to fixed-location defecation, and about the beneficial impact of sanitation infrastructure without sustainable use and maintenance.

Interventions at the community level are particularly crucial as they may create more space for the individuals to react and improve their behavior, leading to greater spill-over effects inside the community. It has been reported that greater effectiveness of communal behavior with regard to hygiene is generated when the community members themselves jointly address a problem and undertake actions to permanently improve the conditions (van Wikj & Murre 2003). Community interventions can gather community members to target either hardware or software issues, and both types of intervention can then enable appropriate WASH behavior at the household or individual level. In the Indian case study, we record similar dynamics at the community level. Our investigations reveal that community infrastructure and services are most often perceived as the determinants of the village's cleanliness, not household or individual behavior (Box 3).

Box 3: Community infrastructure and behavior in peri-urban Ahmadabad, India

Vangani (2018) inquires about the importance of community-level infrastructure and behavior by directly asking the members of the community about their opinion. Asked about the attributes of a clean and healthy village, over 70 percent of the 660 households mention the role of drainage and of garbage/waste collection.



When looking at bivariate associations, households in open drainage *(kutcha)* villages have a significantly higher (+48%) incidence risk ratio (IRR) of longitudinal diarrhea prevalence among children below the age of five and a 10 percentage-point higher parasitic prevalence (19 versus 29%), compared to households in villages with closed drainage. The safe disposal of waste, practiced at the household level, is also shown to have a significant and strong association with decreased IRR of child diarrhea prevalence (28%), but this is not the case for actual community-level garbage collection schemes, which show no association. These strong associations are not confirmed in multi-variate (regression) analyses, which however present methodological challenges due to endogeneity and multicollinearity issues.

Changes in people's behavior are difficult to achieve and sometimes the lack of appropriate and applicable information is the problem. For example, several studies have examined the role of information for the choice and use of safe water sources (Madajewicz et al. 2007; Hamoudi et al. 2012; Brown et al. 2014; Jalan & Somanathan 2008). Households in resource-poor environments seem to consume water from contaminated sources due to the lack of adequate information on the quality of the water or even of the source.

The information bottleneck extends also to what constitutes appropriate or safe behavior. This is confirmed by Vangani (2018) in the context of safe sanitation behavior: Among the 660 households interviewed, their overwhelming perception about open defecation is that it is not "convenient" because it requires to walk long distances (85%), is impractical during the rainy season (78%), and requires waking up early in the morning (68%). Very few of these households associate open defecation with common diseases (7%), environmental pollution (4%) or water contamination (2%).

A better understanding of the role of information for safe water behaviors including the use of improved water sources, water treatment, safe storage and transport was provided by several recent studies. Luoto et al. (2014) show that in Kenya and Bangladesh, consistent exposure of households to health risk messages on the relevance of safe drinking water increases the usage of water treatment products and other safe water behaviors. Likewise, dissemination of information on arsenic water contamination in Bangladesh, or on POU fecal contamination of drinking water in India, induced households to collect water from safe wells (Madajewicz et al. 2007) or to apply water treatment before drinking the water (Jalan & Somanathan 2008), respectively. However, the impacts of household water quality testing and information on health outcomes, on sanitation and on hygiene-related risk-mitigating behaviors remain understudied. Especially rigorous impact evaluation studies are rare (Lucas et al. 2011). Two of our case studies can contribute to closing this gap: Whilst both the Bangladesh and the Ghana studies were not able to capture significant effects of their information interventions on health outcomes due to the short time period between waves, their randomized controlled trial approach clearly identifies effects on behavior in the WASH domain and their impact on the fecal contamination of drinking water (Box 4). Testing the persistence of such impacts over time is another area where more research is needed: The work in Bangladesh identifies declining effect sizes even within the short time frame of the study.

Box 4: Information for WASH behavioral change – experimental evidence from Bangladesh and Ghana

Two of our case studies, in Bangladesh and Ghana, have tested the impact of information messages on the fecal contamination of drinking water and kitchen utensils, in randomized controlled trial settings. In Ghana, the experiment took place in communities of the Greater Accra region; in Bangladesh, the communities surveyed are from the North-West (same households as in Box 1).

Ghana: successful behavioral changes around water handling

The study allowed participants to undertake water quality self-testing and encouraged households to get involved in water quality testing and to use the information in managing household water. Water quality improvement messages in the form of handouts were also distributed to participants. After seven months of household participation in the information intervention, the study finds evidence of changes in safe water behaviors; for example, households were less likely to use surface water sources (-3 to -10%) and they were more likely to adopt safe water storage behaviors such as the covering of stored drinking water (+3 to +5%). Although treated households undertake many safe water behaviors, treated households are less likely to treat drinking water (-3 to -9%). Impact ranges are reported, noting that households where children were "treated" (i.e. trained to water testing) are better off with regard to most of the safe water behavior indicators than their counterparts in the adult household members' intervention group. The study also finds limited evidence that households with male participants are worse off than households with female participants. On the other hand, the intervention shows little impact on health and nutrition outcomes, or even on sanitation and hygiene-related risk-mitigating behaviors. A key issue here is that the duration of the intervention between baseline and follow-up surveys may simply have been too short to identify an impact on health outcomes. The lack of behavioral impact may reflect a perceived focus of the intervention on water quality and handling (the visual tests) rather than sanitation, hygiene and health.

Bangladesh: successful short-term behavioral changes due to food and hygiene education

Hasan (2018) devised an information treatment consisting of: (1) microbiological test results of *E. coli* bacterial contamination in drinking water and on kitchen utensils, (2) training to maintain food hygiene at the household level, and (3) a poster with hygiene messages to be hung in the dining area. The treatment was administered sequentially to the 512 households: Communities were randomly selected for treatment in round 1 or round 2 and were stratified to avoid spill-over effects in adjacent communities. The results of testing for the contamination of the water and utensils were communicated to the caregivers in each household during the intervention, which was administered to group 1 directly after the baseline and to group 2 one month later, with the final survey taking place yet one month later. The results reveal several behavioral changes or their effects: 21% of treated households no longer have contaminated drinking water (POU) after one month (75% of them had contaminated water at the baseline), and there seem to be benefits in being treated two months ago versus 1 month ago. No impact was detected on the contamination of food utensils. Yet, after one month 27% of households increased their handwashing with soap after defecation and 15% of the households increased the frequency of cleaning water jars with soap. Treated households also managed to decrease the number of child diarrhea episodes by 26% after one month, and by 19% after 2 months. The figures are 14 and 17%, respectively, for diarrheal episodes across all age groups of the family. No significant impacts on child malnutrition were recorded, probably due to the short period between treatment and survey rounds.

Impacts of irrigation water quality on malnutrition

By and large, the literature on the impact of irrigation on nutrition and health focuses on the food availability and access pathways. Irrigation has the potential to boost yields and thus income, thereby delivering significant pay-offs in terms of health and nutrition. This is discussed for instance in Domenech and Ringler (2013), who also point out the necessity for more studies of a different nature: They must explicitly account for health, nutrition and women's empowerment to guide irrigation programs and investments so that they can transcend goals of increased food production and contribute toward broad poverty reduction and improved nutrition as defined under SDGs 1 and 2.

We have reviewed existing literature on the interactions between irrigation water and drinking water quality and their health and nutrition outcomes in Section 2. These interactions are complex and offer multiple pathways to health and nutrition outcomes. What we postulate in our water system perspective is that investments in water and sanitation infrastructure alone, as defined in SDG targets 6.1 and 6.2, for instance (access to safe drinking water and adequate sanitation and hygiene for all) cannot suffice to improve health and eradicate malnutrition. There is no easy solution to address these problems and the mix of solutions must reflect the complexity of the interactions between the water, sanitation and food production spheres.

We were able to demonstrate in our cross-country analysis that polluted water irrigation can have a negative net association with nutrition indicators (Table 14). In the case of Ethiopia, we find that irrigation water is clearly detrimental to health and nutrition if used as drinking water or for domestic purposes (Box 5). These can be considered as net associations, as the analysis controls for income (expenditures) and other factors that irrigation could influence and which are known to have an impact on health and nutrition.

Box 5: The impacts of irrigation on health and child malnutrition outcomes in rural Amhara, Ethiopia

In Ethiopia, where the case study focuses on farming households, Usman (2018) reports on several aspects of water consumption and use and their associations with health and nutrition. Among the 329 responses stating the main source of irrigation water, only 20% can be considered non-contaminated water sources (ground/well water)., Twenty-five percent of the households reported drinking irrigation water when working in the fields. This seems to be associated with health problems:

Drinking water source while in the fields	Incidence of health issues			
	Diarrhea	Water-related diseases	Morbidity	Observations
Irrigation water	14.12	17.06	43.24	340
Unprotected well	10.24	13.78	36.61	254
Protected well	10.71	11.43	33.57	140
Carried from home	7.35	10.82	28.85	721

Note: The Pearson chi-squared test statistics are above the critical points ($p<0.01$) - implying that the null hypothesis of independence can be rejected.

Although Usman (2018) reports beneficial time-saving effects of the domestic use of irrigation water for the primary caregiver in the household, the multivariate analysis confirms what the bivariate associations above show for water-related diseases other than diarrhea and for overall morbidity: Both are significantly increased (+12 and +13 percentage points, respectively, IRR +47 and +26%, respectively) when irrigation water is used for domestic purposes, and the results are robust to model specifications and the choice of estimation technique. The translation of these household level effects into child malnutrition outcomes (among children under five years) is partially confirmed: Usman (2018) finds that being part of an irrigating household significantly decreases the weight-for-age score of a child and increases her/his likelihood of being underweight by 12 percentage points. Also, children in irrigating households have a 9 percentage points higher likelihood to be stunted.

It is particularly important to investigate the association between irrigation on the one hand and health and nutrition on the other hand, as water becomes an increasingly rare resource, especially water of good quality. This is highlighted to some extent in the case of multiple water uses in Ethiopia, and even more so in the case study of peri-urban Ahmadabad. In the latter case, the use of recycled waste water as a valuable input into agriculture is encouraged in several of the surveyed communities. The associations between different irrigation water types and the health and nutrition outcomes are presented below (Box 6).

Box 6: Irrigation water types and health and malnutrition outcomes in peri-urban Ahmadabad, India

Waste water irrigation, if not practiced with care, can be a source of bacterial contamination for the people and households practicing it or living close to irrigation infrastructure. As was shown in a case study in peri-urban Ahmadabad, India, one of the assumed pathways from contaminated irrigation water to health outcomes is through the contamination of drinking water stored in the house. This can occur because of the use of irrigation water as drinking water, or because of poor handling of drinking water by people who are in touch with contaminated irrigation water. Vangani (2018) reports that 86% and 84% of households irrigating with canal and waste water, respectively, had contaminated drinking water at home at the time of the tests. For the households irrigating with tube well water and the non-irrigating households, the respective figures drop to 68% and 72%. The table below reports the bivariate associations between irrigation categories of the households and longitudinal diarrhea prevalence and incidence risk ratio (IRR). Clearly, wastewater-irrigating households are more likely and tube well irrigators less likely to have experienced diarrhea in the considered period than canal water irrigators. The agricultural production mode thus affects health outcomes. Wastewater-irrigating households are also reported to exhibit the highest IRR for parasitic prevalence (Vangani, 2018).

Variable	Category	N	Mean LPD (*PPY*)	Unadjusted IRR	Standard Error
Irrigation Water	Surface-Canal (25%)	167	1.2	*Reference*	
	Tube well/Rain (16%)	112	1	0.820*	(0.097)
	Wastewater (50%)	337	2	1.649***	(0.133)
	No Farming (6%)	45	1.4	1.193	(0.171)

Robust standard errors in parentheses Significance level *** p<0.01, ** p<0.05, * p<0.1

Mean LPD *(PPY) is* Mean Longitudinal Diarrhoea Prevalence per Person Years

The results are partly corroborated by the multivariate analysis. Vangani (2018) reports that the IRR for diarrhea among children under 5 years old is statistically much higher for wastewater-irrigating households. No statistically significant associations between irrigation water types and malnutrition or parasitic prevalence can be detected in the regression models.

5. Conclusions and implications for research

With respect to the achievement of the Sustainable Development Goals 2 (zero hunger) and 6 (clean water and sanitation), the research presented in this paper highlights potential trade-offs among their associated targets and the complexity and challenges of improving health and nutrition among the rural poor. This complexity necessitates understanding WASH and nutrition within a system perspective. The water and the agriculture and food system interact. Agriculture plays a special role in this perspective, as water uses for agricultural production interact with other, domestic water uses.

The dual analysis of existing nationally representative data and of our pooled case studies data from Ethiopia, Ghana, Bangladesh and India, illustrates the richness and diversity of the agriculture-WATSAN systems, across as well as within systems. This diversity should not be glossed over but embraced in the pursuit of SDGs 2 and 6 and of improved health: There is not one template to achieve those goals, other than the necessity to approach them jointly and with due consideration to national and local contexts.

Our case studies data was collected with the intent to reflect on the diversity of the local agriculture-WATSAN systems. We surveyed rural and peri-urban households with the aim to disentangle the net effects of behavior around water, sanitation and hygiene on nutrition, including irrigation practices in our coverage of water use. The analysis of the pooled survey data and of the individual case studies sheds light on data deficiencies and on issues not captured in the analysis of the nationally representative data that are often used to monitor progress toward the SDGs (for instance the high levels of E. coli contamination of drinking water discussed below).

Referring to our guiding research questions, we recall and interpret here the main findings of our analyses. First, our examination underlines the necessity for behavioral change at household and community level for improved water infrastructure to pay dividends in terms of better drinking water quality. Although improved water sources deliver water of better average quality (as per E. coli contamination indicators), the overwhelming majority of households in our pooled case study data stored drinking water in the household that is E. coli-contaminated, irrespective of the expenditure quintile they belong to. In the India and Bangladesh case studies, 78% of the households had contaminated drinking water in the household, although more than 90% of them had access to improved water sources. This contamination takes place between POS and POU, due to water handling or storage practices (we find for instance a strong association between size of the drinking water containers and the probability of the water to be contaminated), or to the hygiene practices of those handling or transporting water (e.g. washing hands with soap after defecation). Our work in Bangladesh and Ghana reveals that interactive information campaigns on water quality and handling, especially if information is co-produced for instance through water testing by household members, can be an effective way to change behavior. Positive changes were observed in personal hygiene (e.g. hand-washing with soap), in the maintenance of water containers, in the mode of water storage and in the choice of water source.

These changes potentially contributed to the observed decrease in E. coli contamination and in diarrhea episodes in the treated households, which brings us to the second guiding question: Is access to improved water and sanitation infrastructure associated with better health and nutrition? A positive answer to that question would be the most direct justification for investments in WATSAN infrastructure in the context of the SDGs. In the analysis of the nationally representative data, improved sanitation is associated with higher height-for-age and weight-for-age for children under the age of five, the worst anthropometric outcomes were observed for children from households defecating in the open. On the other hand, access to improved water infrastructure is associated with poorer child anthropometric outcomes, suggesting a negative association between improved water infrastructure and nutrition and health status.[11] These results are confirmed in the analysis of our pooled case study data, with some nuances. We interpret these results as proof of the crucial role of WATSAN behavior: open defecation is still preferred in many of the study settings for cultural and other reasons, washing hands with soap is not consistently practiced, water from an improved sourced is believed to be safe without consideration for its handling and storage, and therefore improved water sources do not translate into safer drinking water in the households and even with worse child anthropometrics. In results not reported here, we find no statistical evidence in our pooled cross-sectional case study data of an association between access to improved water source and the prevalence of child diarrhea in the households – potentially for the same reasons as explained above. Lack of access to improved sanitation or practicing open defecation, on the other hand, have a significant association with high child diarrhea prevalence. We must emphasize that our pooled case study data analysis controls for the type of irrigation water used by the households.

This leads to our examination of the last research question: How do the complex linkages between water uses in agriculture and in the household interact with improved drinking water and sanitation and what are the linkages to nutrition and health? The pooled case study data analysis confirms that irrigation, probably by bringing new water sources and their potential bacterial contaminants into the realm of domestic water, can have negative effects on human health and nutrition, even when looking across sites and countries). The case study evidence helps us qualifying this association by adding more specific evidence on possible pathways. Notably, it draws attention to the complex interactions between water and sanitation behavior on the one hand and highlights a potentially negative effect of wastewater irrigation on child health on the other hand. In both cases, much of the negative associations are

[11] Keeping in mind the restrictions due to our cross-sectional data, this counter-intuitive result (and contrary to Fink et al. (2011) panel data analysis) is confirmed in country specific regressions for the case of India. The association remains negative, but insignificant, for the other three countries.

activated through the contamination of drinking water, which can be improved through appropriate behavior change interventions, community level sanitation infrastructure and its use and the general cleanliness of the communities' environment, for instance by improving garbage collection. The negative impacts of wastewater irrigation could be partially addressed by similar interventions, but the economic trade-offs around multiple water uses (e.g. aspects of time allocation, productivity impacts of irrigation agriculture), especially for water of different qualities (waste, open canal or clean irrigation water), need to be addressed for a more comprehensive impact on multi-dimensional poverty reduction across age and gender groups.

We summarize these main observations in the table below, in a manner of comparison between evidence from the nationally representative data often used in tracking progress on SDGs 2 and 6 and from our own pooled cross-sectional data in the same four countries (Bangladesh, Ethiopia, Ghana and India).

Table 15: Summary of differences between associations recorded in the case study and DHS data analyses

	Case study data vs DHS data	
Key variables	Height-for-age	Weight-for-age
Improved water source	[- ; --]	[0 ; ---]
Improved sanitation (base)		
Not improved	[0 ; ---]	[0 ; ---]
Open defecation	[--- ; ---]	[--- ; ---]
Farming	[0 ; 0]	[0 ; ++]
Irrigation (base = no irrigation)		
Clean water	[0 ; NA]	[0 ; NA]
Polluted water	[-- ; NA]	[0 ; NA]
Livestock	[0 ; 0]	[++ ; 0]

Note: 0=no significant effect; the +/- sign denotes the direction of the association (positive/negative), and the number of +/- signs the significance level of the coefficient; NA= not applicable (since data on irrigation are not available from the DHS)

It must be noted that our identification strategy cannot claim to determine causal effects of the set of specific variables on nutritional outcomes. The main issue arises because of the cross-sectional nature of the data and the inability to comprehensively address the endogeneity problem with such data. For instance, when looking at irrigation–nutrition linkages, irrigation is itself endogenous to other control variables (e.g. income, wealth, education, etc.), which also impact nutrition outcomes. The same argument holds for the sanitation–nutrition linkages. Only an instrumental variable approach would help to partly alleviate the endogeneity problem in this setting, but this is not possible here due to data limitations in the pooled case study data analysis. We have kept a similar cross-sectional format for the nationally representative data in order to better compare our results.

Yet, our approach is valid given the purpose of this paper: to identify various (groups of) determinants of the nutrition outcomes in an agriculture-WATSAN context that includes irrigation practices of the households. A water and food systems perspective is shown to be necessary to comprehensively address the nutrition–water–sanitation–hygiene nexus and the SDG 2 related targets: end by 2030 all forms of malnutrition and achieve by 2025 the agreed targets on stunting (less than 100 million children affected) and wasting (less than 5% prevalence) for children up to five years of age.

In particular, our purpose is to highlight that undernutrition in young rural and peri-urban children is not an issue of poor farming households, or bad water or sanitation infrastructure, but rather an issue of "water practices around farming" issue necessitating a water and food systems perspective to address it comprehensively.

Future research aiming to consolidate these findings, and to provide a clear discussion on the economic trade-offs of irrigation in terms of increased income versus water contamination and their nutrition and health impacts, needs to focus on the size of the causal effects. This would require a substantial investment in panel data collection with a rural water system perspective and covering (often local-specific) behavioral issues around this system.

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Appendix

Table 16: Summary of site-specific study designs

Ethiopia	A quasi-experimental study was conducted in rural areas of Fogera and Mecha districts of the Amhara National Regional State. Access to improved drinking water is inadequate and improved sanitation services are virtually non-existent. The sampled households were selected using a stratified cluster sample design. Drinking water sample testing was conducted for each selected household. The sample included 454 households with 565 under-five children.
Ghana	The study was based on a randomized-controlled trial design, where the randomization was done at the school level. The intervention focused on group-based training on the use of water testing kits and self-water quality testing by participants using their own water sources. Moreover, handouts with messages on water quality improvement were distributed to households. The study targeted both schoolchildren and adult household members. The study was carried out in the Ga South Municipal Assembly (GSMA) (urban district) and the Shai-Osudoku District of the Greater Accra Region (rural district). The sample size was 505 households with 404 under-five children.
Bangladesh	This is also a randomized-controlled trial study, and the intervention was the distribution of poster with hygiene messages and water testing results to households. The study was conducted in two peri-urban and rural districts, and the sample size was 512 households with 568 under-five children.
India	The study is an observational study, and it was conducted in peri-urban areas of Ahmedabad in Gujarat where rivers, canals, and wastewater are used for irrigation activities. The sampled households were selected based on multi-stage sampling procedures. The sample size was 658 households with 646 under-five children.

Table 17: Description of the main variables

Variable	Description
Farm	Owning a farm and/or primary occupation is working on a farm
Livestock in/at House	1=Yes, Accounts for Livestock living with/very close to the household members
Irrigation categories	0= No Irrigation, 1= Clean water irrigation (self-reported), 2=Polluted water irrigation (self-reported) *Note:* Only irrigation carried out by the farmer is considered (no community level or neighboring scheme considered). This categorical variable is created by interacting household level irrigation status & types of irrigation water.
Distance to Water	Time to a primary water source in minutes (round trip)
Improved Water Source	Yes=1, Classification according to the WHO guidelines
Water on Premise	Yes=1 if the distance to water=0 minutes
E. coli	1=Yes. Presence of a critical amount of E. coli bacteria in the drinking water, according to WHO guidelines. *Note*: Each study relied on a different test technology, with a similar aim: is the water potable or not (i.e. does it contain E. coli bacteria or not?)
Drinking Water Quintiles	Self-reported amount of per capita drinking water available/stored in the household yesterday or today *Note:* Quintiles are identical across countries/study sites, that is, represent the same quantity of stored water.
Water Quintile*Distance	Interaction term, Distance to water*Drinking Water Quintile
Sanitation categories	1=Improved sanitation, 2=Not improved sanitation, 3= open defecation. Classification of improved sanitation according to WHO guidelines, but excluding improved shared facilities (classified here as "Not improved")
Clean Sanitation	1=Clean. Interviewer statement on the cleanliness of the sanitation facility.
HH size	Total number of household's members
Education Level HH head	0=None, 1=Primary, 2=Secondary, 3=Higher
Expenditure Quintiles	Site-specific expenditure quintiles per country (i.e. no aggregation across country/study sites). For the DHS data we use countryspecific wealth indexes.
Total number of children	Number of children below 15/16 years of age living in the HH
Gender child	1=Female, gender of the child below the age of 5
Age child	Age of the child in months
Diarrhea	1=Yes. If the child had experienced diarrhea in the last 14 days.
Weight-for-age Z score	Weight for age standard deviation (WHO 2006 reference population)
Height-for-age Z score	Height for age standard deviation (WHO 2006 reference population)
Weight-for-height Z score	Weight for height standard deviation (WHO 2006 reference population)
Underweight	Yes=1 if the "Weight-for-Age" Z-score is two standard deviations lower than the norm.
Wasting	Yes=1 if the "Weight-for-Height" Z-score is two standard deviations lower than the norm.
Stunting	Yes=1 if the "Height-for-Age" Z-score is two standard deviations lower than the norm.

Table 18: E. coli contamination of drinking water by expenditure quintiles and agricultural activities (% of households) – Case study data

	Expenditure quintiles					Total
Countries	**Poorest**	**2nd**	**Middle**	**4th**	**Richest**	
Ghana	90.2	93 5	86.0	77.8	68.2	83.3
	[46]	[43]	[43]	[42]	[30]	[204]
Ethiopia	56.4	52.8	60.4	59.3	62.2	58.2
	[51]	[48]	[55]	[54]	[56]	[264]
India	81.3	79.0	82.5	75.2	74.0	78.3
	[91]	[83]	[94]	[85]	[91]	[444]
Bangladesh	86.4	81.4	72.8	78.4	71.6	78.1
	[89]	[83]	[75]	[80]	[80]	[400]

Note: The number of households is shown in square brackets

Table 19: Diarrhea prevalence in the past 14 days by expenditure quintiles (% under 5 children) - Case study data

	Expenditure quintiles					Total
	Poorest	**2nd**	**Middle**	**4th**	**Richest**	
Ghana	0.0	4.92	7.0	2.5	6.5	4.1
	[0]	[3]	[4]	[1]	[2]	[10]
Ethiopia	15.1	21.5	17.5	11.8	12.5	15.7
	[18]	[23]	[20]	[13]	[14]	[88]
India	5.5	4.6	9.6	10.2	5.4	7.0
	[9]	[6]	[12]	[11]	[3]	[41]
Bangladesh	3.5	9.1	2.7	3.4	4.5	4.6
	[4]	[10]	[3]	[4]	[5]	[26]

Note: The number of children is shown in square brackets

Table 20: Multivariate regression results predicting the probability of child undernutrition – DHS data

	(1) Stunting - Yes=1	(2) Underweight - Yes=1
Farming: Yes=1	0.981	0.905**
	(0.046)	(0.046)
Livestock: Yes=1	1.061	1.041
	(0.058)	(0.050)
Improved water source: Yes=1	1.147**	1.157**
	(0.075)	(0.079)
Sanitation categories (Base: Improved Toilet)	ref.	ref.
Not improved	1.221***	1.131*
	(0.090)	(0.072)
Open defecation	1.250***	1.241***
	(0.087)	(0.077)
Wealth Quintiles (Base: Lowest Quintile)	ref.	ref.
2nd quintile	0.870**	0.834***
	(0.055)	(0.046)
3rd quintile	0.654***	0.634***
	(0.047)	(0.045)
4th quintile	0.550***	0.493***
	(0.042)	(0.037)
5th quintile	0.415***	0.389***
	(0.046)	(0.046)
Education level (Base: None)	ref.	ref.
Primary	0.845***	0.897*
	(0.050)	(0.051)
Secondary	0.786***	0.812***
	(0.044)	(0.043)
Higher	0.606***	0.802
	(0.071)	(0.111)
Number of under-5 children	1.035	1.045
	(0.033)	(0.030)
Gender: Female=1	0.860***	0.939
	(0.034)	(0.037)
Child age in months	1.111***	1.049***
	(0.006)	(0.005)
Child age squared	0.999***	0.999***
	(0.000)	(0.000)
Survey Dummies (Base: Bangladesh)	ref.	ref.
Ethiopia	1.039	0.595***
	(0.080)	(0.049)
Ghana	0.394***	0.235***
	(0.039)	(0.028)
India	1.071	1.045
	(0.062)	(0.064)
Constant	1.039	0.595***
	(0.080)	(0.049)
Observations	174761	174907
Model F-Stat	47.89	43.53
Model p-value	0.000	0.000

Notes: Linearized standard errors are in parentheses; statistical significance denoted at * p<0.1, ** p<0.05, *** p<0.01. The estimated coefficients are odds ratio.

Table 21: Multivariate regression results predicting the probability of child undernutrition – case study data

	(1) Stunting - Yes=1	(2) Underweight - Yes=1	(3) Stunting - Yes=1	(4) Underweight - Yes=1
Farm - Yes=1	0.849	0.920	0.843	0.930
	(0.223)	(0.286)	(0.226)	(0.285)
Livestock in/at House - Yes=1	0.944	0.762	0.974	0.751
	(0.164)	(0.151)	(0.172)	(0.149)
Irrigation categories (Base= No Irrigation)	ref.	ref.	ref.	ref.
Clean water irrigation	1.034	1.100	0.987	1.053
	(0.197)	(0.248)	(0.186)	(0.233)
Polluted water irrigation	1.502*	1.444	1.463*	1.359
	(0.335)	(0.350)	(0.315)	(0.326)
Improved water source - Yes=1	1.197	1.277	1.232	1.292
	(0.213)	(0.222)	(0.219)	(0.224)
Sanitation categories (Base=Improved Sanitation)	ref.	ref.	ref.	ref.
Not improved	1.057	1.216	1.089	1.184
	(0.196)	(0.217)	(0.202)	(0.212)
Open defecation	1.388**	1.834***	1.486**	1.790***
	(0.232)	(0.304)	(0.257)	(0.291)
Expenditure Quintiles (Base=Lowest Quintile)	ref.	ref.		
2nd quintile	1.105	0.928		
	(0.210)	(0.180)		
3rd quintile	1.121	0.941		
	(0.210)	(0.178)		
4th quintile	0.867	0.808		
	(0.162)	(0.155)		
5th quintile	0.566***	0.652**		
	(0.112)	(0.138)		
Education Level HH head (Base=None)			ref.	ref.
Primary			1.007	1.097
			(0.145)	(0.161)
Secondary			1.056	0.869
			(0.200)	(0.154)
Higher			1.106	0.339***
			(0.449)	(0.135)
Gender child - Female=1	0.930	0.698***	0.919	0.709***
	(0.106)	(0.079)	(0.104)	(0.080)
Age child	1.109***	1.051***	1.101***	1.051***
	(0.018)	(0.017)	(0.017)	(0.017)
Age child Squared	0.998***	0.999***	0.998***	0.999***
	(0.000)	(0.000)	(0.000)	(0.000)
Total number of children	0.991	1.032	1.003	1.050
	(0.053)	(0.051)	(0.052)	(0.052)
Survey Dummies (Base= Bangladesh)	ref.	ref.	ref.	ref.
Ethiopia	0.961	0.662	0.910	0.626*
	(0.240)	(0.168)	(0.229)	(0.163)
Ghana	0.724	0.267***	0.715	0.293***
	(0.200)	(0.086)	(0.201)	(0.093)
India	1.623***	1.270	1.660***	1.331
	(0.294)	(0.237)	(0.302)	(0.250)
Observations	1709	1709	1699	1699
Pseudo R^2	0.061	0.079	0.053	0.077
Ymean	0.408	0.297	0.410	0.301

Notes: Robust standard errors clustered at the household level are in parentheses; statistical significance denoted at * p<0.1, ** p<0.05, *** p<0.01. Estimated coefficients are odds ratio. The constant term is omitted.