

Research Paper

Irrigation, drinking water quality, and child nutritional status in northern Ethiopia

Muhammed A. Usman and Nicolas Gerber

ABSTRACT

In this paper, we investigate the relationship between household drinking water quality and irrigation and child nutrition using primary household survey data and microbiological water sample testings in two rural districts of Ethiopia. Anthropometric measures such as height-for-age z-scores (HAZ), weight-for-age z-scores (WAZ), and weight-for-height z-scores (WHZ) were used to measure stunting, underweight, and wasting, respectively. Our survey results show that 41% of the children are stunted, 26% underweight, and 8% wasted. More than 58% of household's stored drinking water samples were also contaminated with *Escherichia coli* bacteria. The multivariate regression results suggest that irrigation farming and on-premises water sources are significantly associated with lower HAZ, while uncontaminated household stored drinking water quality is correlated with higher WAZ. The results also reveal that dietary diversity score and the number of antenatal care visits by the primary caretaker are statistically significant predictors of child nutritional status. These findings, however, cast doubt on the hypothesis that irrigated agriculture exclusively has a positive effect on child nutrition outcomes.

Key words | child nutrition, irrigated agriculture, rural Ethiopia, water quality

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HIGHLIGHTS

- Using a primary household survey data, we discuss interlinkages between WATSAN and irrigation agriculture and their association with child nutrition in two rural districts of Ethiopia where multiple-use of water is common.
- Drinking water quality is determined by testing the microbiological quality of stored household water samples.
- Irrigation farming and on-premises drinking water sources are associated with higher odds of child stunting by 1.7 and 2.9, respectively. On the other hand, uncontaminated household's stored water quality is associated with lower odds of child underweight.
- 58% of the household's stored drinking water samples were contaminated with *E. coli*.
- Among irrigating households, more than half of them reported that they withdraw water from irrigation water sources for domestic purposes, such as drinking, cooking, and washing.

INTRODUCTION

According to the 2017 Global Food Policy Report, 155 million under-five children are stunted (a low height-for-age), 52 million children are wasted (a low weight-for-height), and

815 million people are chronically undernourished. Poor nutrition contributes to approximately 45% of all deaths of under-five children globally (IFPRI 2017). More than 50% of child

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undernutrition is due to both repeated diarrhea and intestinal infections because of a lack of improved water supply and sanitation (WATSAN) and insufficient hygiene practices (Prüss-Üstün *et al.* 2008). In Ethiopia, the problem of child malnutrition is among the highest in the world, for example 38% of under-five children are stunted (an indicator of chronic malnutrition), and 18% are severely stunted in 2016 (CSA & ICF International 2017), most of these children are living in rural areas (a child is considered as severely stunted if his/her height-for-age z-score is below -3 standard deviations below the mean on the WHO Child Growth Standards).

Child nutritional outcomes (hereafter child nutrition) are good indicators of a child's health. The first two years of children's life are essential for their optimal growth and development. Child nutrition is governed mainly by access to WATSAN, healthcare access and utilization, adequate diet, and care (UNICEF 1990; CSA & ICF International 2012; Ali 2019), all of which are inadequate in rural Ethiopia. Undernutrition can impair long-term cognitive development, school performance, and labor productivity (Humphrey 2009). Malnourished children also have lower resistance to diseases and are more susceptible to suffer from subsequent diarrheal and other infections (UNICEF 2013). For instance, a severely undernourished child (low weight-for-age) is almost ten times more likely to die from diarrhea compared to the average (Black *et al.* 2008).

Access to improved WATSAN is vital for improved child health and growth. Infections and repeated diarrheal diseases are one of the major causes of undernutrition (Prüss-Üstün *et al.* 2008; Dewey & Mayers 2011). Recent studies also suggest that environmental enteropathy, a disorder of the small intestine, significantly contributes to child undernutrition (Lin *et al.* 2013; Mara 2017). Environmental enteropathy is caused by a lack of adequate sanitation and proper hygiene practices and damages the wall of the small intestine; consequently, the capacity to absorb energy and nutrients is reduced, and they are diverted from growth to the immune system to fight the infection (Humphrey 2009; Mara 2017). So, preventing diarrheal and other infectious diseases through improving WATSAN can break the cycle and result in improved child nutrition.

WATSAN is closely linked with agriculture since domestic and irrigation water sources are often interchangeable in rural communities (Usman & Gerber 2019), with

potential health risks. Irrigation can affect health and nutrition through a variety of pathways (see Figure 1). For example, poor irrigation practices could bring adverse impacts on the environment and human health through increasing water-related diseases and domestic water contamination (Usman & Gerber 2019). On the other hand, irrigation water may reduce the burden of water collection time (Usman & Gerber 2019). Further, irrigation allows households to grow more and diversified crops. A study of child nutrition in Kenya found evidence of higher energy intakes and lower chronic malnutrition in children where communities have access to irrigation as compared to communities without access (Kirogo *et al.* 2007). Despite its potential for improved food and nutrition security in sub-Saharan Africa, the overall effect of irrigation on health and nutrition is difficult to know a priori (see the review by Domenech & Ringler 2013).

Although previous studies show that poor WATSAN services are a cause for poor child health, empirical studies and knowledge of the nexus between WATSAN, irrigation, and child nutrition are lacking (Gerber *et al.* 2019). This study, therefore, investigates the relationship between household drinking water quality, irrigation, and child nutrition in

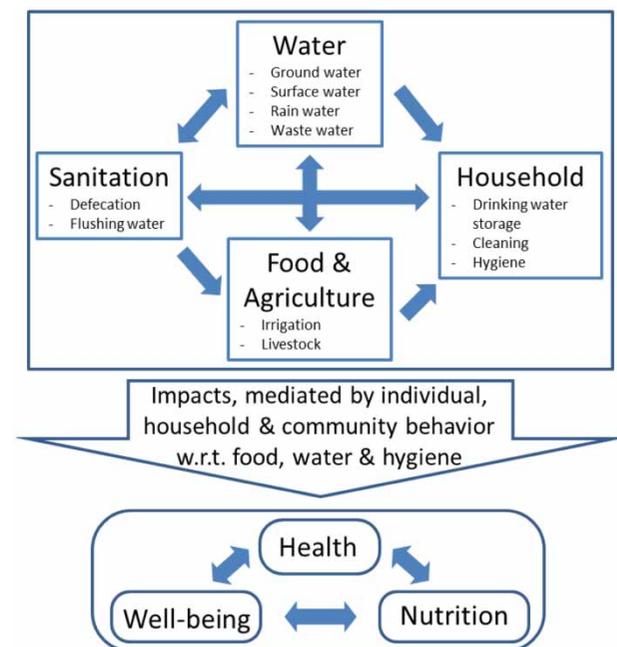


Figure 1 | The agriculture-WATSAN system: an integrated framework with health and nutrition links (Source: Gerber *et al.* 2019).

rural areas of Ethiopia. The paper makes two contributions. First, since multiple-use of water is common in the study areas, we take irrigation practice into account in the multivariate regression analysis. Second, drinking water quality is determined by testing the microbiological quality of stored household water. Identifying the principal risk factors that influence child nutrition will help policymakers and practitioners to design the right intervention to improve child health and well-being. The main findings of the paper are that contrary to our expectations, having the drinking water source on-premises and engaging in irrigated agriculture are significantly associated with inferior child nutrition in the study areas.

MATERIALS AND METHODS

Household sample selection

For this analysis, a household survey was conducted in Fogera and Mecha districts of Ethiopia between February and March 2014. The survey covers 454 households with

562 under-five children. The sample households were selected using a stratified two-stage cluster sample design. In the first stage, 61 villages (the primary sampling units) were selected randomly from 20 identified *kebeles* (the lowest geographic administrative division in the country). In the second stage, 454 households were selected based on a systematic random sampling method. The selected districts are shaded, and the black dots represent the sampled households (see Figure 2).

Microbiological water quality tests

One of the most commonly used indicators for microbial water quality is the level of *Escherichia coli* (*E. coli*) bacteria, which only comes from human and animal feces and is associated with health risks, such as childhood diarrhea (Usman *et al.* 2019). In this study, *E. coli* concentrations are reported as colony-forming units per 100 mL (CFU/100 mL) of the water sample. The general WHO drinking water quality guideline suggests that the number of *E. coli* CFU/100 mL water sample should be zero for the water supply to be potable. Water samples were collected from

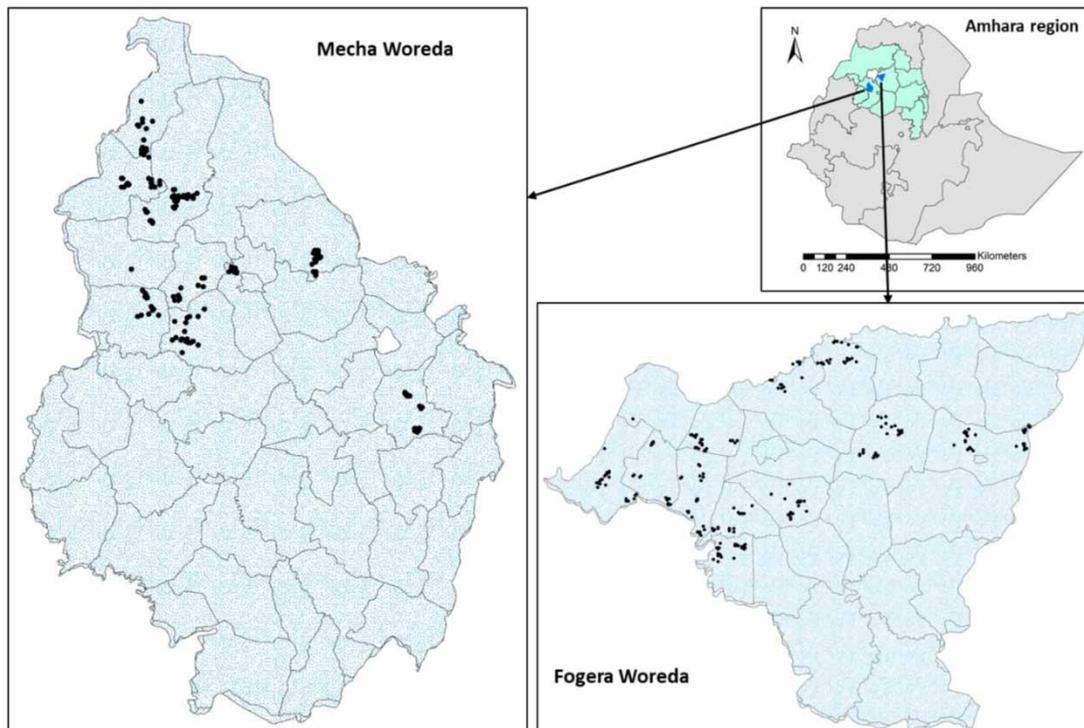


Figure 2 | Map of the study districts (Source: Usman & Gerber 2019).

the households' stored drinking water, and the samples were immediately placed into the portable test kit (a product of Wagtech WTD, UK) on-site and incubated for a maximum of 24 hours at 44 °C to detect the level of *E. coli* concentration.

ANTHROPOMETRIC MEASURES

Information on the height and weight of all under-five children were collected to evaluate their nutritional status. Our measurements were carried out by the local health extension workers: following the DHS standards, children younger than 24 months were measured lying down on a board, and older children were measured while standing. The weight of young children was obtained by subtracting his/her mother's weight from their combined weight. A total of 562 under-five children were eligible to be weighed and measured; however, data are presented for 547 of these children for weight-for-age, and 479 children for height-for-age, and weight-for-height measurement indices. The sample for height-for-age is small because the height measurements for most children under six months old were not obtained. These children were afraid of lying down on the measuring board. However, we estimated the models for children aged 6–59 months only, but the results are the same.

The study protocol was approved by the Medical Ethics Commission of the Federal Republic of Germany (*Arbeitskreis Medizinischer Ethikkommissionen in der Bundesrepublik Deutschland*). In compliance with ethical considerations, selected households consented about their willingness to participate in the study, and a signed consent form was collected.

Nutritional outcomes

Anthropometric data on height and weight can be used as indicators of under-five child nutrition. Weight and height/length measurements were converted to weight-for-age z-scores (WAZ), height-for-age z-scores (HAZ), and weight-for-height z-scores (WHZ) for each child to form the standardized measures. The anthropometric indicators of children were calculated based on the new child growth standards released in 2006 by the WHO (2006). The

z-scores are generated using the *zscore06* Stata package (Leroy 2011). The z-scores indicate the number of standard deviations (SD) a child is below or above the median child. Child nutrition indicators such as height-for-age (stunting), weight-for-age (underweight), and weight-for-height (wasting) z-scores were computed. To be identified as stunted, underweight, or wasted, the child is at least –2 SD below the WHO child growth standards.

RESULTS AND DISCUSSION

Table 1 presents the descriptive statistics of the main variables for this study. The variable antenatal care (ANC) indicates the number of visits from a health professional during the pregnancy period, and the dietary diversity score measures the number of food groups (out of six food groups) consumed in the last 24 hours preceding the survey (the food groups include milk & milk byproducts, grains, vegetables, fruits, meat, and egg). According to Table 1, about 26% of children are underweight, 41% stunted, and 8% wasted. The anthropometric indicators against the WHO child growth standards are also shown in Figure A1 in the Supplementary material.

Descriptive analysis

Reported in Table 2 is the prevalence of child malnutrition by WATSAN and child characteristics. It is interesting that the variation in child malnutrition based on access to improved water sources, on types of drinking water sources, and access to pit latrine is not significant. There is, however, a difference in the prevalence of child malnutrition by the household's drinking water quality. Children from households whose stored water is contaminated with *E. coli* are more likely to be wasted than their counterparts. Finally, children of irrigating households are more likely to be stunted or underweight than children of non-irrigating households.

Multivariate regression results

Reported in Table 3 are estimates of the odds of a child being stunted, underweight, and wasted, while the ordinary

Table 1 | Summary statistics

Variables	Description	N	Mean	S.D.
Outcome variables				
Stunted	1 = yes; 0 otherwise	479	0.40	
Height-for-age z-scores		479	-1.71	1.20
Underweight	1 = yes; 0 otherwise	547	0.26	
Weight-for-age z-scores		547	-1.32	1.00
Wasted	1 = yes; 0 otherwise	479	0.08	
Weight-for-height z-scores		479	-0.62	0.99
Water, sanitation, and hygiene				
Water quality (1 = no <i>E. coli</i>)	1 = uncontaminated stored water quality; 0 otherwise	454	0.42	
Drinking water source	1 = protected; 0 otherwise	454	0.50	
Water source location	1 = own yard; 0 otherwise	454	0.16	
Pit latrine	1 = yes; 0 otherwise	454	0.42	
Under-5 children characteristics				
Child age	Age in months	562	29.02	16.30
Child sex	1 = male; 0 = female	565	0.46	
Under-five years children	Number of children under-five	454	1.24	0.45
Dietary diversity score	The mean food groups consumed	505	1.84	1.04
Antenatal care (ANC)	Number of antenatal-care visits	558	1.93	1.51
Delivery with a health professional	1 = yes; 0 otherwise	561	0.16	
Household characteristics				
Irrigation practice	1 = yes; 0 otherwise	454	0.67	
Livestock holdings	Livestock holding in Tropical Livestock Units	454	3.97	1.87
Asset values	Total assets value in 1,000 Birr ^a	454	5.88	6.20
Primary caretaker age	Age of primary caretaker in years	453	30.29	6.73
Primary caretaker literacy	1 = yes; 0 otherwise	453	0.09	
Household head education	Household head completed years of education	454	1.02	1.96
Household size	Number of household members	454	5.98	1.77

Source: Authors' computation based on own survey data.

^aThe exchange rate during the time of the survey was 1 Euro = 26.02 Ethiopian Birr. Livestock is excluded in computing the household's assets values.

least squares (OLS) results based on the z-scores are summarized in [Table 4](#). Robust standard errors adjusted for clustering at the village level are reported for each model. We include constant terms and district effects in all regressions. The explanatory power of the model ranges from 0.09 to 0.30 for nutritional outcomes.

The regression results reported in [Tables 3](#) and [4](#) indicate that household drinking water quality is positively correlated with child nutrition. For example, the weight of children living in households with uncontaminated stored drinking water quality is, on average, 0.18 SD higher

compared to their counterparts (column 2, [Table 4](#)). Water source location is positively and significantly associated with child stunting (HAZ): children living in households with their own drinking water sources are 2.9 times more likely to be stunted than children living without their own water source (column 1, [Table 3](#)).

According to [Table 3](#), in contrast to our expectation, children from irrigating households are 1.7, 3.0, and 2.4 times more likely to be stunted, underweight, and wasted, respectively, than children from non-irrigating households. Similarly, the height (weight) of children from irrigating

Table 2 | Prevalence of malnutrition by WATSAN and child characteristics

Variables	Obs.	Stunting (%)	P-values	Wasting (%)	P-values	Obs.	Underweight (%)	P-values
<i>Age of child in months</i>								
6–11	47	19.15	0.002	8.51	0.018	55	23.64	0.829
12–23	98	34.69		16.33		100	31.00	
24–35	123	49.59		4.88		130	26.15	
36–47	120	42.50		5.83		122	30.33	
48–59	91	43.96		6.59		92	29.35	
<i>Gender of a child</i>								
Male	223	43.05	0.331	8.97	0.556	252	29.37	0.165
Girl	257	38.50		7.39		295	23.73	
<i>Water source type based on WHO</i>								
Improved	235	37.45	0.147	8.94	0.516	267	27.34	0.535
Unimproved	245	43.67		7.35		280	25.36	
<i>Drinking water source</i>								
Private-protected dug well	26	46.15	0.213	7.69	0.854	30	33.33	0.365
Shared-protected well/spring	209	36.45		9.09		237	26.58	
Unprotected well/spring	191	41.88		7.85		218	27.06	
Surface water	54	50.00		5.56		62	19.35	
<i>Stored water quality</i>								
Contaminated	289	41.52	0.681	10.03	0.062	321	28.97	0.111
Uncontaminated	191	39.27		5.24		226	22.57	
<i>Pit latrine</i>								
Yes	188	37.23	0.237	6.91	0.415	222	25.68	0.838
No	292	42.81		8.90		325	26.77	
<i>Irrigated agriculture</i>								
Yes	323	45.20	0.004	9.29	0.188	368	30.42	0.002
No	157	31.21		5.73		179	17.88	

Source: Authors' estimates using own survey data. The *p-values* generated from the two-side t-test in mean difference.

households, on average, is 0.28 SD lower compared to children living in non-irrigating households (columns 1 and 2 of Table 4). On the other hand, livestock ownership is marginally associated with a lower risk of childhood underweight and wasting (columns 2 and 3 of Table 3). Livestock improves child nutrition by supplying richer animal proteins, such as cow's milk, which may be the only essential source of animal protein and micronutrients for children in rural communities (Hoddinott *et al.* 2015). Livestock holding, however, can reduce household water quality in rural areas (Usman *et al.* 2018), which could partly offset its positive impact on child nutrition. As expected, the dietary

diversity score is significantly associated with improved child nutrition in both model specifications.

The associations between child nutrition and access to health facility indicator variables (the number of ANC visits and delivery with health professionals) are also statistically significant and positively associated with child nutrition (Tables 3 and 4). The effects of ANC visits appear large and robust, and this could mean that it captures the influence of other variables such as health knowledge of the primary caretaker or access to health services. Even though access to or utilization of health facilities is inadequate in the country, a study by Headey (2014) reported

Table 3 | Multivariate regression results for stunting, underweight, and wasting

Explanatory variables	(1) Stunting: Yes = 1	(2) Underweight: Yes = 1	(3) Wasting: Yes = 1
Water quality (No <i>E. coli</i> , Yes = 1)	0.884 [0.23]	0.558** [0.16]	0.403* [0.19]
Water source on-premises, Yes = 1	2.883** [1.21]	1.121 [0.37]	0.955 [0.55]
Pit latrine, Yes = 1	1.024 [0.28]	1.816** [0.51]	1.509 [0.68]
Irrigating household, Yes = 1	1.807** [0.46]	2.933*** [0.86]	2.583** [1.14]
Livestock holding in TLUs	1.129 [0.13]	0.801** [0.08]	0.753* [0.11]
Dietary diversity scores	0.214*** [0.04]	0.384*** [0.07]	0.410*** [0.12]
Delivery with a health professional, Yes = 1	0.371*** [0.13]	0.260*** [0.10]	0.096** [0.11]
Number of ANC visits	0.710*** [0.06]	0.685*** [0.05]	0.894 [0.12]
Log (assets value)	0.879 [0.13]	0.660*** [0.09]	0.607 [0.19]
Child age in months	1.124*** [0.04]	1.157*** [0.04]	0.944 [0.05]
Child age square (/100)	0.859*** [0.05]	0.811*** [0.04]	1.037 [0.09]
Child is male	1.312 [0.29]	1.576** [0.36]	1.572 [0.67]
Primary caretaker age	0.953* [0.03]	0.975 [0.02]	1.011 [0.04]
Household head education	0.899 [0.06]	1.219*** [0.07]	1.284** [0.13]
Household size	1.183 [0.12]	1.052 [0.11]	1.107 [0.18]
Observations	472	540	472
Pseudo R-squared	0.30	0.24	0.21
Model Chi ²	126.70	151.0	48.99
Model <i>p</i> -value	0.000	0.000	0.000

Notes: Robust standard errors adjusted for clustering at the village level are in square brackets.

Statistical significance denoted at * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Reported coefficients are odds ratios. We checked the robustness of these results to the exclusion of children below 6 months old due to length measurement issues, but the results did not change (Table A3 in the Supplementary material).

similar results that four or more ANC visits are significantly associated with improved HAZ. Children delivered with the help of health professionals are also 63, 74, and 90% less likely to be stunted, underweight, and wasted, respectively (Table 3). Of note, only 16% of children were delivered with the help of health professionals, which may drive the results.

Regarding the other control variables, household assets have a positive association with better nutrition outcomes. Male children are slightly more likely to be underweight than female children. For instance, the weight of male children, on average, is expected to be 0.23 SD lower than female children (Table 4). This finding is consistent with previous studies showing that girls have relatively better nutritional status than boys (Kabubo-Mariara *et al.* 2009; CSA & ICF International 2012). It is worth pointing that child nutrition is a result

of the complex interaction of different variables, and WATSAN is one of the many ingredients for improved child growth outcomes.

Our results suggest that while uncontaminated drinking water quality is significantly associated with higher weight-for-age z-scores, having a drinking water source on-premises is consistently and significantly associated with stunting (HAZ). The latter is in contrast with an earlier finding that water collection time is negatively associated with improved child nutrition (Pickering & Davis 2012). It is assumed that the time saving from a water collection trip is used for other activities (e.g. homemaking, childcaring) that could improve child nutrition (e.g. Sorenson *et al.* 2011; van Houweling *et al.* 2012). The paradox may be partially attributable to the poor water quality of the source, for example households with a pit latrine and having water sources close to their dwelling have poor stored water

Table 4 | Multivariate regression results for the standardized z-scores

	(1) Height-for-Age z-scores	(2) Weight-for-Age z-scores	(3) Weight-for-Height z-scores
Water quality (No <i>E. coli</i> , Yes = 1)	0.062 [0.11]	0.180** [0.09]	0.194* [0.10]
Water source on-premises, Yes = 1)	-0.486*** [0.14]	-0.173 [0.12]	0.125 [0.16]
Pit latrine, Yes = 1	0.013 [0.12]	0.019 [0.10]	-0.004 [0.13]
Irrigating household, Yes = 1	-0.283** [0.13]	-0.293*** [0.10]	-0.147 [0.11]
Livestock holding in TLUs	-0.038 [0.05]	-0.009 [0.04]	0.052 [0.04]
Dietary diversity score	0.418*** [0.06]	0.266*** [0.05]	0.159** [0.06]
Delivery with a health professional, Yes = 1	0.307** [0.14]	0.104 [0.11]	0.053 [0.14]
Number of ANC visits	0.146*** [0.04]	0.113*** [0.03]	0.040 [0.03]
Log (assets value)	-0.017 [0.07]	0.127** [0.05]	0.187*** [0.07]
Child age in months	-0.049*** [0.02]	-0.060*** [0.01]	0.012 [0.01]
Child age square (/100)	0.071*** [0.02]	0.078*** [0.02]	-0.019 [0.02]
Child is male	-0.230** [0.10]	-0.148* [0.08]	-0.038 [0.08]
Primary caretaker age	0.017 [0.01]	0.008 [0.01]	0.002 [0.01]
Household head education	0.037 [0.03]	-0.004 [0.03]	-0.006 [0.03]
Household size	-0.031 [0.04]	-0.004 [0.03]	-0.026 [0.03]
Observations	472	540	472
R-squared	0.25	0.23	0.09
Model F-stat	13.00	8.35	3.09
Model p-value	0.000	0.000	0.001

Notes: Robust standard errors adjusted for clustering at the village level are in square brackets. Statistical significance denoted at * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

quality. About 16% of the sampled households have a water source on-premises, of which 67% of the water sources are open wells. In this case, the result may not be surprising except that the effect size is large.

The impact of irrigated agriculture on child nutrition is counter-intuitive. Irrigated agriculture is likely to improve household food availability and nutrition since irrigation helps farmers to grow micronutrients and fresh vegetables (Kirogo *et al.* 2007). Irrigation also allows farmers to produce and sell high-value crops throughout the year and increases their income, which can enhance household nutrition (von Braun *et al.* 1989). Indeed, our survey shows that irrigating households (mainly involved in the production of rice, onions and tomatoes) reported higher income from agriculture than non-irrigating households, but the dietary diversity score was almost equal in both groups. In line with our findings, a recent study in Ethiopia shows that although irrigation increases production diversity, it does

not translate into the consumption of higher dietary diversity (Passarelli *et al.* 2018). However, poor child nutrition among irrigating households could be partly explained by less time for childcare due to the high labor demand for irrigated agriculture (Usman & Gerber 2019). Typically, irrigated agriculture is more labor-intensive and demands more family labor than rain-fed agriculture. Alternatively, irrigation may create new sources of drinking water contamination that leads to poor child health (Gerber *et al.* 2019). Indeed, about 51% of the irrigating households use irrigation water for domestic purposes, such as drinking, cooking, and washing. So, the effects of irrigation on child nutrition seem inconclusive, highly complex, and context-specific.

So far, irrigation was measured as a dummy variable (whether a household practices irrigation farming) that did not capture the extent to which a household is engaged in irrigated agriculture. We then measured the variable as the

proportion of irrigated land (Table A1). Again, irrigation is significantly and positively associated with stunting and underweight, but no longer with the z-scores. If irrigation affects child nutrition through water quality, we should find a higher proportion of undernourished children living in irrigating households who report using irrigation water for domestic purposes. To test this, we estimated the models for irrigating households of the sample (Table A2); however, the domestic use of irrigation water has only a limited effect on stunting. This suggests that the impact of irrigation infrastructures that influence child nutrition may not be captured fully at the household level.

Finally, this analysis would have benefited if the mother's nutrition and child's birth-weight information was available. For instance, children who are small at birth are also more likely to be malnourished than children who are average/larger at birth (CSA & ICF International 2012). Birth weights, however, were not known for many babies as most of them were delivered at home and not weighted at birth.

CONCLUSIONS

Although Ethiopia has made remarkable progress in reducing child malnutrition, a substantial portion of the population is still undernourished. The country also lags the rest of the world in terms of access to improved WATSAN services. Using primary household survey data, we explore the degree of association between WATSAN services, irrigation, and child nutrition in two rural districts of Ethiopia. Our findings reveal that preschool children in rural Ethiopia have a lag in HAZ and WAZ relative to the WHO child growth standards. The results explain a small portion of the variations in child nutrition, which is influenced by a range of interconnected variables. The study highlights the need to promote water treatment at the point-of-use and the protection of drinking water sources from external contamination. Moreover, providing diverse food groups that supply all the vital micronutrients to meet the requirements for optimal child growth is crucial for young children. Generally, solving the problem of child malnutrition requires a mix of instruments and working across various sectors (e.g. WATSAN, health, agriculture). For instance, providing improved drinking water without

proper water treatment and fundamental behavioral changes will not work. Likewise, providing adequate nutrition without a safe WATSAN environment, then the latter will undo much of the gains from improved diets.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories (https://data.zef.de/geonetwork_zef/apps/search/?east_collapsed=true&s_search=&s_E_any=usman&s_timeType=true&s_scaleOn=false&s_E_hitsperpage=20).

REFERENCES

- Ali, M. 2019 *Multisectoral approach to nutrition in Pakistan*. *J. Water Sanit. Hyg. Dev.* **9** (1), 152–163. doi:10.2166/washdev.2018.122.
- Black, R. E., Allen, L. H., Bhutta, Z. A., Caulfield, L. E., de Onis, M., Ezzati, M. & Child Undernutrition Study, G. 2008 *Maternal and child undernutrition: global and regional exposures and health consequences*. *Lancet* **371** (9608), 243–260. doi:10.1016/S0140-6736(07)61690-0.
- CSA & ICF International 2012 *Ethiopia Demographic and Health Survey 2011*. Central Statistical Agency (CSA) & ICF International, Addis Ababa, Ethiopia and Calverton, Maryland, USA. Retrieved from: www.measuredhs.com/pubs/pdf/FR255/FR255.pdf.
- CSA & ICF International 2017 *Ethiopia Demographic and Health Survey 2016*. Central Statistical Agency (CSA) & ICF International, Addis Ababa, Ethiopia, and Rockville, Maryland, USA. Retrieved from: <https://dhsprogram.com/pubs/pdf/FR328/FR328.pdf>.
- Dewey, K. G. & Mayers, D. R. 2011 *Early child growth: how do nutrition and infection interact?* *Matern. Child Nutr.* **7**, 129–142. doi:10.1111/j.1740-8709.2011.00357.x.
- Domenech, L. & Ringler, C. 2013 *The Impact of Irrigation on Nutrition, Health, and Gender: A Review Paper with Insights for Africa South of the Sahara (IFPRI Discussion Paper No. 01259)*. Retrieved from: <http://ssrn.Com/abstract=2249812>
- Gerber, N., von Braun, J., Usman, M. A., Hasen, M. M., Okyere, C. Y., Vangani, R. & Wiesmann, D. 2019 *Water, Sanitation and Agriculture Linkages with Health and Nutrition Improvement. (ZEF-Discussion Papers on Development Policy No. 282)*. Retrieved from: <http://dx.doi.org/10.2139/ssrn.3455952>.
- Headey, D. 2014 *An Analysis of Trends and Determinants of Child Undernutrition in Ethiopia, 2000–2011*. International Food Policy Research Institute (IFPRI), Washington, DC (Working paper 70). Retrieved from: <https://pdfs.semanticscholar.org/7865/1f4222cb92d8d251014ac12ef6bbdb9eadce.pdf>.

- Hoddinott, J., Headey, D. & Dereje, M. 2015 Cows, missing milk markets, and nutrition in rural Ethiopia. *J. Dev. Stud.* **51** (8), 958–975.
- Humphrey, J. H. 2009 Child undernutrition, tropical enteropathy, toilets, and handwashing. *Lancet* **374** (9694), 1032–1035. [https://doi.org/10.1016/S0140-6736\(09\)60950-8](https://doi.org/10.1016/S0140-6736(09)60950-8).
- IFPRI 2017 2017 *Global Food Policy Report*. International Food Policy Research Institute, Washington, DC. <https://doi.org/10.2499/9780896292529>.
- Kabubo-Mariara, J., Ndenge, G. K. & Mwabu, D. K. 2009 Determinants of children's nutritional status in Kenya: evidence from demographic and health surveys. *J. Afr. Econ.* **18** (3), 363–387.
- Kirogo, V., Wambui, K. & Muroki, N. 2007 The role of irrigation on improvement of nutritional status of young children in central Kenya. *Afr. J. Food Agric. Nutr. Dev.* **7** (2), 1–16.
- Leroy, J. L. 2011 *zscore06: Stata Command for the Calculation of Anthropometric Z-Scores Using the 2006 WHO Child Growth Standards*. Retrieved from: www.ifpri.org/staffprofile/jef-leroy.
- Lin, A., Arnold, B. F., Afreen, S., Goto, R., Huda, T. M. N., Haque, R. & Luby, S. 2013 Household environmental conditions are associated with enteropathy and impaired growth in rural Bangladesh. *Am. J. Trop. Med. Hyg.* **89** (1), 130–137. doi:10.4269/ajtmh.12-0629.
- Mara, D. 2017 The elimination of open defecation and its adverse health effects: a moral imperative for governments and development professionals. *J. Water Sanit. Hyg. Dev.* **7** (1), 1–12. doi:10.2166/washdev.2017.027.
- Passarelli, S., Mekonnen, D., Bryan, E. & Ringler, C. 2018 Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania. *Food Secur.* **10** (4), 981–997.
- Pickering, A. J. & Davis, J. 2012 Freshwater availability and water fetching distance affect child health in sub-Saharan Africa. *Environ. Sci. Technol.* **46** (4), 2391–2397. doi:10.1021/es203177v.
- Prüss-Üstün, A., Bos, R., Gore, F. & Bartram, J. 2008 *Safer Water, Better Health: Costs, Benefits and Sustainability of Interventions to Protect and Promote Health*. World Health Organization, Geneva.
- Sorenson, S. B., Morssink, C. & Campos, P. A. 2011 Safe access to safe water in low income countries: water fetching in current times. *Soc. Sci. Med.* **72** (9), 1522–1526. <http://dx.doi.org/10.1016/j.socscimed.2011.03.010>.
- UNICEF 1990 *Strategy for Improved Nutrition of Children and Women in Developing Countries*. A UNICEF Policy Review. E/ICEF/1990/L.6, New York, NY.
- UNICEF 2013 *Improving Child Nutrition: The Achievable Imperatives for Global Progress*. United Nations Children's Fund (UNICEF), New York. Retrieved from: www.childinfo.org/files/NutritionReport_April2013_Final.pdf.
- Usman, M. A. & Gerber, N. 2019 Assessing the effect of irrigation on household water quality and health: a case study in rural Ethiopia. *Int. J. Environ. Health Res.* doi:10.1080/09603123.2019.1668544.
- Usman, M. A., Gerber, N. & Pangaribowo, E. H. 2018 Drivers of microbiological quality of household drinking water—a case study in rural Ethiopia. *J. Water Health* **16** (2), 275–288.
- Usman, M. A., Gerber, N. & von Braun, J. 2019 The impact of drinking water quality and sanitation on child health: evidence from rural Ethiopia. *J. Dev. Stud.* **55** (10), 2193–2211. doi:10.1080/00220388.2018.1493193.
- van Houweling, E., Hall, R. P., Diop, A. S., Davis, J. & Seiss, M. 2012 The role of productive water use in women's livelihoods: evidence from rural Senegal. *Water Alternat.* **5** (3), 658–677.
- von Braun, J., Puetz, D. & Webb, P. 1989 *Irrigation Technology and Commercialization of Rice in the Gambia: Effects on Income and Nutrition (Research Report 75)*. Retrieved from: <http://ageconsearch.umn.edu/record/42167/files/rr75.pdf>.
- WHO 2006 *WHO Child Growth Standards: Length/Height-for-age, Weight-for-age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-age: Methods and Development*. World Health Organization, Geneva.

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