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Impact of Intermittent Piped Water Supply on Health Outcomes among Children under five in Angola, Ethiopia, Tanzania, and Zimbabwe

By

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Master of Public Health

Global Epidemiology

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Committee Chair

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Illinois Wesleyan University
2014

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An abstract of
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Abstract

Impact of Intermittent Piped Water Supply on Health Outcomes among Children under five in Angola, Ethiopia, Tanzania, and Zimbabwe

By Colleen Leonard

Background: In many countries throughout the world, piped water is delivered intermittently. In Africa, it is estimated that over one-third of the urban piped water supplies deliver water intermittently. When the pipes deliver water intermittently, the water that is delivered is more likely to be contaminated because the positive pressure within the pipes cannot be maintained and as a result, pathogens may enter the distribution system. Drinking contaminated water can cause pathogens to enter the body and cause diarrhea. Children under five are especially vulnerable. Diarrhea is the second-leading cause of death among children under five years old and can lead to malnutrition, which can cause stunting and low weight.

Methods: This study used Demographic and Health Surveys (DHS) data to estimate the association between intermittent piped water supply and diarrhea, death, height-for-age (HAZ) and weight-for-age (WAZ) among children under five who live in urban areas. The DHS are nationally representative cross-sectional surveys, which collect health data from populations in low and middle-income countries. The country surveys included were: Angola (2015- 16), Ethiopia (2016), Tanzania (2015- 16), and Zimbabwe (2015). Multiple logistic regression models were fit to examine the relationship between intermittent piped water supply and diarrhea and death. Multiple linear regression models were fit to examine the relationship between intermittent piped water supply and HAZ and WAZ.

Results: Across all four countries (N= 6,288), 65% of children under five lived in households with an intermittent piped water supply. Overall, for all countries combined, there was a trend that intermittent piped water supply was associated with diarrhea among children under five (OR= 1.16, 95% CI: 0.87—1.54). Although, this result was not statistically significant. No associations were found between intermittent piped water supply and child death, HAZ, or WAZ.

Conclusion: Intermittent piped water supply may be associated with diarrhea among children under five. Further research on the association between intermittent piped water supply and diarrhea is warranted.

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INTRODUCTION

Background on Diarrheal disease

Diarrhea is one of the main causes of morbidity and mortality in the developing world (1). According to the World Health Organization (WHO), diarrhea is the second leading cause of death among children under five years old (2). In 2015, it was estimated that 499,000 children under five died from diarrhea worldwide (3). Diarrhea, especially in the developing world, is often caused by poor water quality or poor sanitation. Every day, almost 1,000 children die due to preventable water and sanitation-related diarrheal diseases (4). The burden of death due to diarrhea is largely concentrated in sub-Saharan Africa. As shown in Figure 1, the countries with the highest rate of mortality due to diarrhea among children under five are located in sub-Saharan Africa.

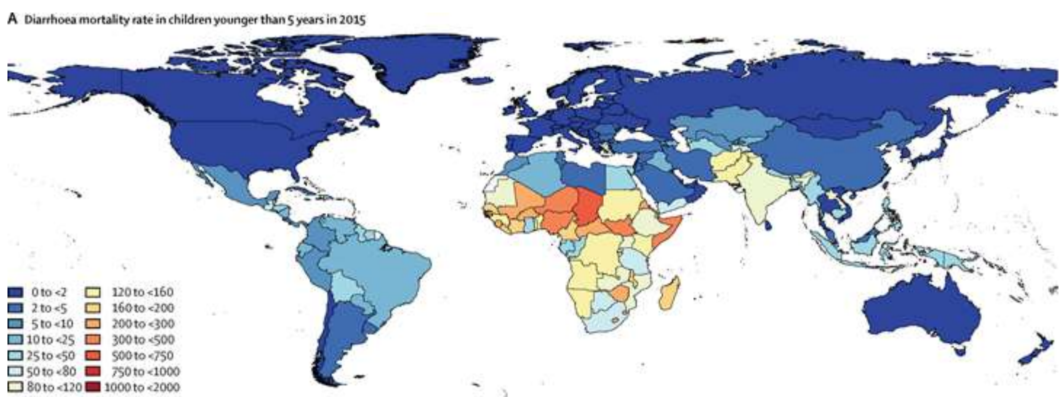

Figure 1. Global diarrhea mortality rate per 100,000 among children under five in 2015. Map Source: (3).

Etiology of diarrheal disease

Diarrhea is transmitted through the fecal-oral route via pathogens, such as bacteria, viruses or parasites (5). Drinking contaminated water or eating food with contaminated hands can cause pathogens to enter the body and cause diarrhea (6). About 58% of diarrheal deaths are due to unsafe water, inadequate sanitation and poor hygiene (7). Children who are malnourished or have compromised or underdeveloped immune systems are at highest risk for severe diarrhea. Therefore, children under five years of age are of particular interest for studying the incidence of diarrhea (2).

The Global Enteric Multicenter Study (GEMS) was one of the largest prospective, case-control studies to examine the causes and burden of diarrhea among children under five years of age in sub-Saharan Africa and south Asia. The study identified Rotavirus, *Cryptosporidium,* enterotoxigenic *E. coli*, and *Shigella* to be the main pathogens that cause moderate to severe diarrhea among children under five (8). *E. coli* is normally a harmless bacterium present in the intestinal flora of the human gut, but it has the potential to be pathogenic and cause infection in the gastrointestinal tract (9). The GEMS study found that S*higella* was the leading cause of diarrhea among children two to five years old. Rotavirus was the leading cause of diarrhea among children under two years old (8). Rotavirus is a major cause of life-threatening diarrhea in infants and children under five worldwide (10). Over 90% of children with fatal rotavirus infection live in low-income countries (11), which is likely due to lack of medical care and a greater prevalence of co-morbid conditions, such as malnutrition (10).

Malnutrition and Stunting

Diarrhea can last for many days and dehydrates the body, leaving the body without the water and salts that are necessary for survival. This can prevent children from absorbing important nutrients essential to their development. Therefore, diarrhea is a major cause of malnutrition in children (2). Moderate malnutrition is defined as a weight-for-age (WAZ) z-score between -3 and -2 standard deviations below the median of the WHO child growth standards (12). While there is conflicting information on whether malnutrition increases the incidence of diarrhea (13-16), there is a consensus that malnutrition lengthens the duration of diarrhea (13, 15, 17). Therefore, a cyclic pattern may develop where children who acquire diarrhea become malnourished, which then causes them to have diarrhea for longer or it may cause them to be more susceptible to diarrhea in the future. The MAL-ED study is a multinational study examining the interaction between repeat enteric infections and malnutrition among children. The study found that although diarrhea itself did not have a statistically significant effect on growth, it was estimated that children with high enteropathogen exposure are 1.21± 0.33cm ($p<0.001$) shorter at 24 months, on average, than children with low exposure (18).

Chronic malnutrition can lead to stunting in infants and children (19). Stunting is defined as below two standard deviations from the WHO median height-for-age (HAZ) z-score (12). A longitudinal study following children in northeastern Brazil found that diarrhea was associated with weight loss and a loss of appetite. Furthermore, the more episodes of diarrhea a child had, the more likely the child was to have lower gains in height, arm circumference, and weight for age. These findings were observed even after the researchers controlled for nutritional status of the child (20).

Stunting can lead to reduced cognitive function among children. One study assessed the cognitive function of nine-year-old children who had been followed for anthropometry, stool samples, and diarrheal status from birth to two years old. They found that the children with severe stunting in their second year of life scored 10 points lower (95% CI: 2.4, 17.5) on an intelligence test (Wechsler intelligence scale for children-revised) than those who did not experience severe stunting (19). In Ethiopia, researchers found that on average, stunted children scored significantly lower than non-stunted children on verbal reasoning and school-readiness tests (21). Other studies confirm that stunting is a significant predictor of decreased cognitive function (22).

Furthermore, according to the Cost of Hunger study in Ethiopia, stunted children achieve 1.1 fewer years of school compared to their non-stunted counterparts. Additionally, it is estimated that child stunting in Ethiopia costs about 16.2% of the country's Gross Domestic Product (23). Research shows that adults who were stunted as children are less productive than those who were not stunted and therefore are less able to contribute to the economy (24). This is certainly the case in Ethiopia where stunting has a detrimental impact on the country's economy.

Because of the detrimental health impacts of diarrhea, the global public health community has prioritized reducing the burden of diarrheal disease worldwide through improving access to clean water and sanitation. Goal 6 of the United Nation's Sustainable Development Goals (SDGs) is to "ensure access to water and sanitation for all" (4). The first target to achieve this goal is to "achieve universal and equitable safe and affordable drinking water for all" by 2030 (4).

Water

As of 2015, 844 million people still lacked a basic source of drinking water (25). This means that they must either walk over 30 minutes roundtrip to collect an improved source of water or rely on unimproved water sources. Unimproved water sources include water from an unprotected dug well or unprotected spring (25). These unimproved sources are much more likely to be contaminated with fecal indicator bacteria (*E. coli* or thermotolerant coliforms) than improved sources and therefore, have the potential to cause diarrheal illness (26).

Piped water

Piped water, whether through a household connection or a public standpipe, is considered an improved drinking water source according to the Joint Monitoring Programme for Water Supply and Sanitation (25). Although piped water is an improved water source, it can still deliver water of poor quality to households. In fact, many piped water systems do not consistently supply microbiologically safe water. In Cambodia, 48% of water samples from household taps in two villages had high or very high health risk (greater than 10 *E. coli* colony forming units per 100 mL) (27). Some water suppliers simply provide untreated or inconsistently treated water through the piped systems (28). But more commonly, the piped water systems deliver water intermittently (27). Many cities in Asia supply water only a few hours per day or a few days per week (29). At least 300 million people worldwide receive an intermittent supply of piped water. Many developing countries, especially in sub-Saharan Africa, receive piped water intermittently (30). In Africa, it is estimated that over one-third of the urban piped water supplies deliver water intermittently (31).

Intermittent delivery of piped water can lead to contamination of the water supply. When the pipes deliver water intermittently, the water that is delivered is more likely to be contaminated because the positive pressure within the pipes cannot be maintained. When this happens, contaminants from outside the pipes can enter the pipes through backflow or intrusion and contaminate the piped water supply (30). Backflow occurs through cross-connections in the piped water supply when water from a nonpotable source mixes with the potable water. Intrusion occurs when contaminants enter the piped water distribution system through infrastructure deficiencies, such as cracks or breaks, that connect potable water with the outside environment. An adverse pressure gradient, a pathway between the environment and the distribution system, and a source of contamination are all needed for intrusion or backflow to occur (30).

An adverse pressure gradient occurs when the distribution system is at a lower water pressure than the contaminant source. This allows contaminants to enter the system if there is a pathway from the environment in which the contaminants can enter. There is a certain minimum pressure in the pipes required to prevent backflow, but this depends on the pressure of the contaminant source and guidelines for minimum distribution system water pressures vary by country (30). In some systems, the piped water supply is turned off at certain times during the day. Between supply cycles, the pipes may still contain water (at low or atmospheric pressure) or the pipes may drain completely. In these systems, the pipes can be at low or atmospheric pressure for hours or days at a time (32). Studies of continuous piped water systems have shown that intrusion can occur in large volumes during momentary periods of low pressure (33-36); therefore, days or hours of low pressure could allow for intrusion of large volumes of contaminated water as well. Intrusion of contaminants could lead to a public health outbreak resulting in diarrheal illness. For example, in New York, a *Giardia intestinalis* outbreak occurred in a trailer park after a power outage had caused a negative water pressure in the distribution system (37). Negative pressure occurs when the gauge pressure of the water in the distribution system is below zero (38).

Cities around the world with intermittent piped water systems have reported chronically low pressure in their systems (32, 39, 40). The persistent low pressure could be caused by trapped air, high demand, or changes in boundary pressures (30). When water rushes in to fill an empty pipe, it expels the air; however, air pockets can remain in the pipes after the pipes are filled if there is not enough pressure to expel the air. These air pockets can further reduce the pressure through reduced pipe capacity (30). Air pockets can block flow completely, or cause pipe bursts (41-43). Additionally, air pockets expose the pipes to oxygen, which could speed up corrosion of the pipes. Corrosion can provide sites for intrusion or biofilm growth. Over time, corrosion can reduce the quality of water through bacterial growth as well (44). Also, people who rely on piped water systems that operate only certain hours during the day or week often try to collect and store enough water when the system is on to meet their demands when the water distribution system is off. If the water supply time is short and everyone draws lots of water during this short period of time, this could cause the pressure to drop within the distribution system (30). A study among children in the United Kingdom found that there was a strong association between children who reported diarrhea and reported low-water pressure at their faucet (OR: 12.5, 95% CI: 3.5- 44.7) (45). This suggests that low water pressure could lead to lower water quality and cause diarrhea among children.

People who have intermittent water supplies use various strategies to cope with the unreliable supply, such as storing water in the home or collecting water from alternative sources. A systematic review of 28 studies from developing countries found that the choice of coping strategy is influenced by household income, education, land tenure, and the extent of unreliability of the water supply (46). Low income households most often collected water from alternative sources, while high income households resorted to drilling boreholes or installing water storage tanks to cope. Alternate sources of water include collecting rainwater or surface water, which are unimproved drinking water sources (46). Relying on unimproved drinking water sources when piped water is not being delivered could cause diarrhea in children.

Whether alternate sources of water are collected or not, households with intermittent water supply are often forced to store their water, which could lead to further contamination (27). Water often becomes contaminated during storage. A systematic meta-analysis on microbiological water contamination between the source and point-of-use in developing countries found that the bacteriologic quality of drinking water significantly decreases after collection in many settings. Further, there were no studies found where the proportion of contaminated samples was significantly lower at the point-of-use compared to the source (47). Further, one study in Cambodia found that *E. coli* counts were much higher in the stored piped water (1100 *E. coli* cfu/100 mL), than the piped water at the tap (520 *E. coli* cfu/100 mL), suggesting contamination during storage in household storage containers ($P < 0.0005$) (28). Also, if the piped water supply is limited, there is limited water available for hygiene (48). This could also lead to the spread of diarrhea through limited handwashing of the children's hands or their caretakers' hands.

Study Region

Four countries in sub-Saharan Africa were chosen for this analysis: Angola, Ethiopia, Tanzania and Zimbabwe. These four countries were chosen because they were all located in the same region and all had data collected on the frequency of piped water in their most recent Demographic and Health Survey (DHS). The DHS are nationally-representative household surveys that are completed in low and middle-income countries (LMICs) to monitor trends in population health. The surveys are conducted using multistage probability sampling. The household questionnaire provides information on the demographic, socioeconomic, and environmental conditions of the households. The women's questionnaire obtains information on women and children's health and direct anthropometric measurements.

All of these countries, except Ethiopia, were formally colonized by European countries. Following decolonization in the 1950s and 1960s, the countries were left to develop their own institutional and political systems, which often lead to corruption, ethnic conflict, and military rule. These countries currently have poor governance, with the exception of Tanzania which has average governance (49). Additionally, these countries share similar economic qualities. The four countries all score low on the Human Development Index (HDI) and have either low or lower-middle income economies (50, 51). Although some similarities can be made, there are many differences between (and within) the countries, including culture, language, religion, and climate (52). Over the past ten years, the child mortality rate has decreased in all four countries. Although child mortality has decreased, it still remains high (56- 83 deaths per 1,000 children under five) (53). Stunting rates among children under five are also high. For example, in Ethiopia, 38% of children under five are stunted (54).

Water supply in the sub-Sahara African countries

In Ethiopia, Tanzania, and Zimbabwe, piped water is often delivered less than 24 hours per day. For example, in Ethiopia, piped water is available for an average of 18 hours per day. In Tanzania, the average number of hours that piped water is available ranges from six to 23 hours per day depending on the city or town (55). Although the average number of hours with piped water per day was not found for Angola, there were an average of 83.5 days where the water supply failed for firms in Angola with piped water supply in 2006 (56).

There is a need to understand the health impacts of intermittent piped water supply on children under five. A literature search uncovered no studies that have assessed the difference between continuous and intermittent piped water supplies at a national or regional level. There have been two studies that compare diarrhea prevalence in children under five in households with continuous versus intermittent piped water supply- one in an urban city in India and one in the Addis-Ababa slums of Ethiopia (48, 57). The DHS provide a unique opportunity to assess this association on a population level.

METHODS

The purpose of this study was to explore health impacts of intermittent piped water supply on children under five years of age. More specifically, the goal of this research study was to evaluate the association of the frequency of piped water supply delivery and diarrhea, death, HAZ, and WAZ among children under five years of age in Angola, Ethiopia, Tanzania, and Zimbabwe.

Data

The data for this research study was obtained from the DHS conducted in four countries in sub-Saharan Africa from 2015- 2016. The country surveys included were: Angola (2015-16), Ethiopia (2016), Tanzania (2015-16), and Zimbabwe (2015). The four countries were chosen because they were located in sub-Saharan Africa and collected information on the frequency of piped water supply in the most recent DHS survey.

Participants and Settings

The DHS utilizes a stratified, two-stage sampling design. The first stage involves selecting clusters drawn from census data and the second stage involves selecting households within the previously selected clusters (58). The households were selected using systematic random sampling methods. The women's questionnaire is administered to all women ages 15- 49 years old who slept in the household the night before the survey. This questionnaire also collects information on their children born in the last five years who live in the same household.

This analysis includes data of all children born to an interviewed woman in the five years preceding the survey and who live in the household. Only households with piped water in urban areas were included in the analysis. Additionally, only households in which the women's questionnaire and household questionnaire were completed within 30 days of each other were included. The final analytic sample of children under five for all surveys was 6,288.

Measurements and Variables

There were three categories of piped water considered together in this analysis: piped into dwelling, piped into yard/plot, and piped to neighbor. Piped water frequency (intermittent versus continuous) was the dichotomous exposure variable. Intermittent piped water was defined as water unavailable for at least one full day within the past two weeks.

Children's health information was collected from their mothers. The outcome of diarrhea was a dichotomous yes/no variable indicating if the child had had diarrhea within the last two weeks. Anthropometric measurements were recorded by trained personnel in every country. Children's weight was measured using an electronic mother-infant scale (SECA flat). Height was measured using a measuring board (Shorr Board®). Children younger than 24 months were measured lying down on the board, while the older children were measured standing (54, 59, 60).

The HAZ and WAZ z-scores were calculated based on the WHO Child Growth Standards. These growth standards are based on the WHO multicentre growth reference study, which examined about 8,500 healthy, breastfed infants and young children from Brazil, Ghana, India, Norway, Oman, and the United States. The study utilized a longitudinal design from birth to 24 months and a cross-sectional design from 18-71 months of age (61). In this study, according to WHO guidelines, stunting is defined as below two standard deviations from the median height-for-age score. Children with a low

WAZ (below two standard deviations from the median WHO WAZ standard) are considered underweight (12).

Child age, sex, wealth, household water treatment, sanitation facility, household handwashing station, and season were considered as potential confounders for the association between piped water frequency and diarrhea. All of those covariates, except season, were also considered as potential confounders for the association between piped water frequency and child death, HAZ, and WAZ. Child age was categorized into less than two years old and two to five years old for the analysis of diarrhea and death outcomes. The DHS determined household wealth by collecting data on indicator variables related to household conditions (e.g. water source, type of flooring, sanitation facility, electricity), and ownership of consumer goods (e.g. a refrigerator, a television, a bicycle). Wealth was stratified into quintiles by the DHS (62). For this analysis, wealth was further categorized into richest quintile and less than richest quintile. Household water treatment was categorized into a yes/no variable according to efficacy. Therefore, straining water through a cloth and letting the water stand and settle were not considered as water treatment for modeling analysis (63, 64). Household sanitation facility was categorized into flush toilet versus other for modeling analysis because overall, the vast majority (78.4%) of children lived in a household with an improved sanitation facility, while about half (50.1%) of the children had a flush toilet in their home. Household handwashing station was categorized as follows: present with soap and water, present with water only, present with no water, and no handwashing station observed on the household premises. Season was categorized into dry season or not dry season. Dry seasons were determined for each region within each country using data from The World

Bank Group and European Union Climate Data (65, 66). A dry season month was defined as less than 60mm of rainfall in a month according to the Koppen climate classification (67).

Data Analysis

All analysis was conducted using SAS 9.4 software (SAS Institute Inc., Cary, NC, USA) and SAS-callable SUDAAN 11.0.1 (RTI International, Research Triangle Park, NC, USA).

Data Cleaning

Data from the DHS children's recode (KR) file was merged with a subset of data from the DHS household (HR) file for each country. Then, the merged files from the four countries were combined into one dataset for cleaning and analysis. For the pooled regional file, the individual country data files were de-normalized in order to provide population-level estimates and to analyze the pooled regional data. As recommended by the DHS, the provided sample weight was de-normalized by multiplying the provided weight by the total number of females aged 15- 49 in the country divided by the number of women aged 15- 49 interviewed in the survey using data from the United States Census Bureau International Programs Database (68, 69). Once the files were appended together, the cluster variable was modified so that each stratum could stand alone based on the country and countries could be analyzed individually.

A subset of the merged dataset was analyzed. This subpopulation included only children who lived in an urban area with piped water and who lived in the household with the respondent. Additionally, if the women's questionnaire and anthropometric measurements were completed more than 30 days from the household questionnaire, those children were removed from the analysis. Also, over half of the observations from Angola had missing data for HAZ and WAZ, 54.3% and 53.8% of the sample respectively. Therefore, Angola was excluded from the analysis of the association between piped water frequency and HAZ and WAZ. All of the “don’t know” responses were coded as missing.

Bivariate Analysis

To assess the similarities between countries, a bivariate analysis was conducted between all variables of interest and country. This was conducted using a Satterhwaite-adjusted chi-squared test or Wald F-test at alpha= 0.05. The difference in outcome prevalence (diarrhea and mortality outcomes) and mean (HAZ and WAZ outcomes) between the intermittent and continuous supplies was also examined for statistical significance using a two-sample t-test.

Multivariate Analysis

Several multivariate models were used to analyze the data. All analyses were conducted for all four countries combined and individually.

1. Logistic Regression- Piped water frequency vs. Diarrhea

Child age, sex, wealth, household water treatment, sanitation facility, household handwashing station, and season were considered as potential confounders from a review of the literature and directed acyclic graphs (Figure 2). Initially, univariate models between the predictor variables and the outcome (diarrhea) were created to assess the association between the outcome and each covariate individually. Then, an odds ratio adjusted for all potential confounders was obtained. This effect estimate was compared to the effect estimates produced by models controlling for all possible subsets of potential confounders. Only models producing effect estimates within 10% of the fully-adjusted model were considered. Collinearity was assessed by examining the condition indices (CIs) and variance decomposition proportions (VDPs). No collinearity was found, defined as if any CI was greater than 30 and two or more of the VDPs were greater than 0.5. Goodness of fit was assessed using the Hosmer-Lemeshow test (*alpha*= 0.05).

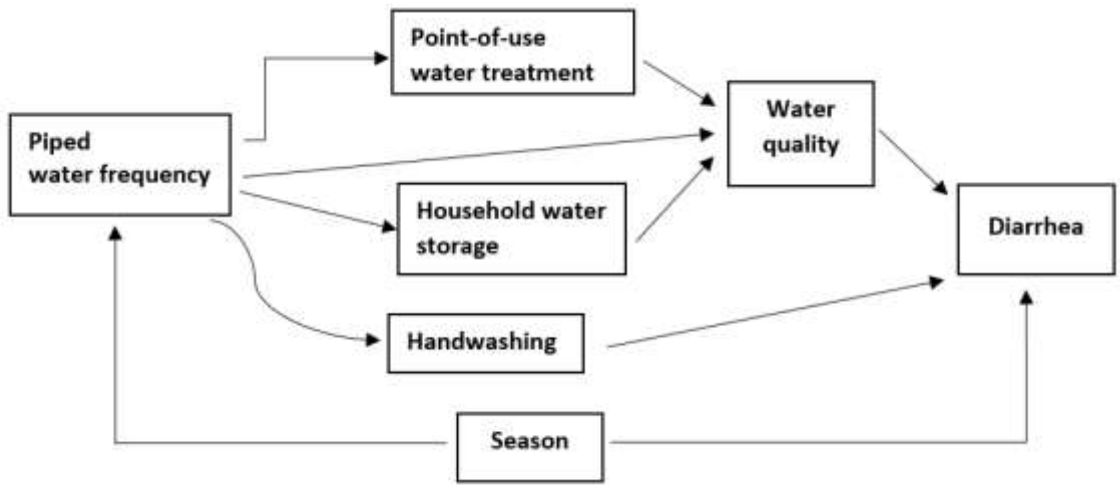

Figure 2: Directed acyclic graph of the association between piped water frequency and diarrhea.

2. <u>Logistic Regression- Piped water frequency vs. Mortality</u>

Child age, sex, wealth, household water treatment, sanitation facility, and household handwashing station were considered as potential confounders from a review of the literature and directed acyclic graphs. The same model selection process used for the diarrhea outcome was used in this model.

3. <u>Linear Regression- Piped water frequency vs. HAZ</u>

Child age, sex, wealth, household water treatment, sanitation facility, and household handwashing station were considered as potential confounders from a review of the literature and directed acyclic graphs. All predictor variables were examined for a linear relationship with the outcome variable (HAZ). Initially, an unadjusted model between the exposure (piped water frequency) and the outcome (HAZ) was created. The final model, adjusted for all confounders, was selected using the all possible subsets approach. Only models within 10% of the fully-adjusted model were considered. The regression coefficient (beta) obtained from this model represents the change in HAZ between intermittent and continuous (reference) piped water supplies, adjusting for the other covariates in the model. Collinearity was assessed by examining the variance inflation factor (VIF) for each predictor variable. No collinearity was found, defined as any VIF greater than 10. Regression diagnostics were assessed by examining the jackknife residuals, leverages, DFFITS, DFBETAS, and cook's distance values.

4. Linear Regression- Piped water frequency vs. WAZ

The same confounders were considered for this model as for the HAZ outcome model. The model selection process used for this model was the same as in the HAZ model.

RESULTS

Descriptive Statistics

Among the households included in the study, the location of piped water that the household receives and its frequency of delivery are shown in Table 1 for each site. The majority of the households (66.15%) had piped water delivered directly to their compound (either into their dwelling or yard/plot), although this did vary substantially by country. Also, more households experienced intermittent water supply within the past two weeks of their survey date than continuous supply (61.05% vs. 38.95%).

Descriptive statistics of demographics and water, sanitation, and hygiene (WASH) characteristics are reported in Table 2. All of the demographic characteristics considered were statistically significantly different between countries, except for sex of the child. Additionally, almost all of the WASH characteristics were all statistically significantly different between countries. The exception was solar disinfection for water treatment, but this method was used for a very small percentage of the children or not at all in each country.

For the overall population, 45% of children were less than two years old. There were slightly more male than female children overall. The vast majority of children (88.4%) live in households that are considered rich (above the middle wealth quintile) according to the DHS wealth quintiles. Most children (60.1%) lived in households that did not treat their water at all. This varied greatly by country, from 39.4% with no water treatment in Tanzania to 85.3% in Ethiopia. The majority of children lived in a household with an improved sanitation facility (78.3%), ranging from a low of 56.4% in Ethiopia to 97.3% in Zimbabwe. Most children (76.3%) lived in a household with a household handwashing station; however, only 42.1% of children lived in a household with a handwashing station with soap and water present at observation by DHS surveyors.

The outcome variables and potential confounders were compared between piped water frequency groups for each country combined and individually (Table 3). The children in the intermittent supply households had a higher prevalence of diarrhea than the children living in households with continuous water supply overall (15.39% vs. 13.56%), and within each country. This difference was only significant in Angola. There were no significant differences in HAZ or WAZ found between the continuous and intermittent supply groups. The variables child age, sex, and household water treatment had similar proportions between the continuous and intermittent supply groups. The other potential confounders (household wealth, season, flush toilet and handwashing station) differed by more than 7% between piped water frequency group. There was a higher prevalence of children who live in wealthy households in the intermittent supply group compared to the continuous supply group. On the other hand, as expected, there was a higher proportion of children with flush toilets in the household in the continuous supply group compared to the intermittent supply group (57.2% vs. 46.1%). Not surprisingly, there was a higher percentage of children with a handwashing station without water present in the intermittent compared to the continuous supply group overall and for each country individually.

Diarrhea among children under five

There was a higher prevalence of diarrhea among children under five in the intermittent supply compared to the continuous supply group overall; however, this difference was not statistically significant (p-value: 0.31) (Table 4). Each country also had a higher prevalence of diarrhea in the intermittent supply compared to the continuous supply group when examined individually. The highest difference in diarrhea prevalence was seen in Angola (5.31%) and this difference was statistically significant (p-value: 0.04). Ethiopia and Zimbabwe only had slightly higher levels of diarrhea in the intermittent supply group. Also, it is interesting to note that there was a larger difference in diarrhea prevalence between the intermittent and continuous supply groups among the children in lower wealth households compared to the wealthiest households (3.00 vs. 1.42).

Multivariate results

The model selection process found that there was no evidence of confounding from the potential confounders (age, sex, wealth, sanitation facility, water treatment, handwashing station, or season) using the all-possible subsets model selection approach. Table 5 shows the unadjusted and fully-adjusted odds ratios (OR) for the effect of intermittent piped water supply on child diarrhea from the logistic regression model. There was also no evidence of confounding when examining each country independently (Table 6). Overall, for all countries combined, intermittent piped water supply was associated with a 16% increase in the odds of diarrhea among children under five (OR= 1.16, 95% CI: 0.87—1.54), but this difference was not statistically significant. This measure of effect was driven by Angola and Tanzania, while Ethiopia and Zimbabwe had odds ratios very close to the null (Figure 3). Almost every covariate had a very similar odds ratio between the univariate and fully-adjusted models. The one exception to this was season, which had a larger effect in the fully-adjusted model compared to the unadjusted model, with season as the sole predictor variable.

Mortality among children under five

There was essentially no difference found in mortality between the continuous and intermittent water supply groups (5.34% vs. 5.04%) (Table 4). The largest difference was seen in Tanzania, where there were 3.06% (95% CI: -0.5—6.63) more deaths among children under five in the intermittent compared to the continuous water supply group. For all other countries, there was actually a higher prevalence of child mortality in the continuous versus intermittent supply groups, although the percentages were not statistically significantly different.

Multivariate Results

No evidence of confounding was found using all-possible subsets model selection approach for the effect of intermittent piped water supply on child death from a logistic regression model. The potential confounders assessed were: age, sex, wealth, sanitation facility, water treatment, and household handwashing station. Table 7 shows the unadjusted and fully-adjusted odds ratios for the effect of intermittent piped water supply on child death from the logistic regression model. There was also no evidence of confounding found when examining each country independently (Table 8). There was no association found between intermittent piped water supply and child death (OR= 1.06, 95% CI: 0.68—1.67).

Height-for-age z-score

The mean HAZ estimate for all children under five with piped water in Ethiopia, Tanzania, and Zimbabwe was -0.94 [95% CI: (-1.04, -0.84)], so on average, children are below the WHO reference median for HAZ by almost one standard deviation. There was no difference found for HAZ between the intermittent and continuous water supply groups. Taking the simple difference in mean z-score revealed a non-significant difference of 0.05 (95% CI: -0.14—0.25) with the intermittent supply group with the slightly higher z-score (Table 9). There were no statistically significant differences in HAZ between the intermittent and continuous piped water supplies in any of the three countries analyzed.

Multivariate Results

For the overall model with all countries, there was no evidence of confounding found for the association between intermittent piped water supply and HAZ using the all-possible subsets model selection approach. Confounders that were considered were: age, sex, wealth, sanitation facility, water treatment, and household handwashing station. However, the country-specific models did reveal confounding for different covariates and all covariates were found to be confounders in at least one of the country-specific models. Taking this into account and the suggested confounders from the literature, the fully-adjusted models were reported for each country. Unadjusted and adjusted models are shown in Table 10. There was no association found between intermittent supply and HAZ (beta= 0.06, st. error =0.09). Beta coefficients ranged from 0.09 (SE 0.11) in Tanzania to -0.2 (SE 0.11) in Zimbabwe. None of the beta coefficients were statistically significant.

Weight-for-age z-score

The mean WAZ estimate for all children under five with piped water in Ethiopia, Tanzania, and Zimbabwe was -0.55 [95% CI: (-0.64, -0.46)], so on average, children are below the WHO reference median for WAZ. There was essentially no difference found for WAZ between the intermittent and continuous water supply groups (Table 9). Taking the simple difference in mean z-score between intermittent and continuous groups revealed a non-significant difference of -0.07 (95% CI: -0.22—0.08). Overall, children with intermittent supply are of slightly lower weight than their counterparts with continuous supply. This trend was really driven by Tanzania, which showed a WAZ difference of -0.14 (95% CI: -0.34—0.06) between the intermittent and continuous supply groups. There were no statistically significant differences in WAZ between the intermittent and continuous piped water supply groups in any of the three countries analyzed.

Multivariate Results

Confounding assessed for the overall and country-specific models using the all-possible subsets model selection approach. Confounding was found for age, flush toilet, and handwashing station for the overall model. For the Ethiopia model, confounding was found for all covariates considered (age, sex, wealth, sanitation facility, water treatment, and handwashing station). The models for Tanzania and Zimbabwe found fewer variables to be considered as confounders. Taking this into account and the suggested confounders from the literature, the fully-adjusted models were reported for each country. Unadjusted and adjusted models are shown in Table 10. There was no association found between intermittent supply and WAZ (beta= -0.04, st. error =0.07). Beta coefficients ranged from -0.10 (SE 0.10) in Tanzania to 0.12 (SE 0.09) in Zimbabwe. None of the beta coefficients were statistically significant.

DISCUSSION

This study assessed the potential public health impacts of intermittent piped water supply on children under five in developing countries. Although theoretical evidence suggests that intermittent water supply may cause public health consequences, such as diarrhea (70-72), few studies have assessed the public health impacts of intermittent compared to continuous piped water supply. The main finding from this study is that there is a trend that intermittent piped water supply is associated with an increased odds of diarrhea among children under five, although this trend was not statistically significant. This association was statistically significant only for Angola. This could be due to multiple reasons. First, Angola had the largest sample size and had a fairly even distribution of children between the continuous and intermittent supply groups. It is possible that an association was seen in Angola because of its large sample size, but was not seen elsewhere due to their smaller sample sizes. This association is likely because households with a continuous water supply do not have to rely on coping strategies that may contaminate the water, such as storing water in the home or collecting water from alternative, unimproved sources (46). Also, the lack of statistically significant results in the other countries could be due to misclassification. In the capital of Zimbabwe, the piped water is usually only supplied sporadically (73). Therefore, perhaps many in the continuous supply group still had interrupted supply, just not for one full day in the past two weeks. This could explain the null findings for Zimbabwe. On the other hand, Tanzania has frequent water shortages (74) and a higher percentage of people were included in the intermittent supply group compared to Zimbabwe. Therefore, it may be that those who were included in the continuous group were more likely to actually have a continuous water supply.

The dry season had a statistically significant effect on elevating diarrhea rates (OR= 1.37, 95% CI: 1.03—1.84). Dry conditions have been shown to lead to the accumulation of fecal contamination in water sources (75), which could lead to humans ingesting pathogens and becoming ill with diarrhea. Also, dry conditions or drought may lead to or exacerbate intermittent piped water supply. Since information on piped water supply frequency and diarrhea were both assessed over the past two weeks and diarrheal illness from ingesting a pathogen has a relatively short latency period (from a matter of hours to 7-14 days, depending on the pathogen) (76), diarrhea due to intermittent water likely would be captured, whereas the other outcomes might not have been.

There was no evidence found that intermittent piped water supply affects HAZ, WAZ, or child mortality. HAZ, WAZ, and mortality would likely be long-term effects from having an intermittent piped water supply. Repeated diarrheal illness may lead to stunting (height-for-age z-score of less than -2) or malnutrition as measured by WAZ over time. Because the DHS only collected information on the frequency of piped water supply within the past two weeks, it is unknown for how long the children have experienced intermittent piped water supply. Therefore, some children in the intermittent supply group may not typically experience intermittent piped water supply. It would be interesting to examine the average number of hours per day with piped water to look at the effects of varying degrees of piped water frequency on health outcomes. Furthermore, there are many factors that affect stunting and malnutrition that unfortunately were not able to be controlled for, such as the intake of nutritious foods and adequate calories.

Death is a very severe consequence of diarrhea, it may be that intermittent piped water supply causes mild to moderate diarrhea but does not usually cause severe diarrhea. A cohort study that assessed the association between piped water supply frequency and diarrhea, growth, and mortality among children in developing countries did not find any statistically significant associations (48). However, there have been mixed results regarding the association between intermittent piped water supply and diarrhea. A matched case-control study among children in the slums of Addis Ababa, Ethiopia found a strong association between intermittent piped water supply and diarrhea (OR= 4.8, 95% CI: 1.3—17.8) (57). Also, one systematic review found a statistically significant association between chronic water outages in an intermittent supply system and gastrointestinal illness (OR= 1.61, 95% CI: 1.26—2.07) (70). The current epidemiological evidence suggests that intermittent water supply has been associated with epidemics of water-borne diseases, such as cholera and typhoid, but overall statistically meaningful associations between intermittent water supply and endemic gastrointestinal illness have been difficult to establish (77).

Limitations

There are several limitations to this study. First, this study used cross-sectional data and therefore, a direct measure of the risk of piped water supply could not be calculated. The sample size may have been insufficient to see statistically significant associations for Ethiopia, Tanzania, and Zimbabwe. Additionally, in Ethiopia and Tanzania, there were 2- 3 times more children in the intermittent compared to the continuous supply group, which could have led to a biased result. Furthermore, the assessment of intermittent piped water supply was based on the water supply frequency within the past two weeks. Therefore, there might have been some misclassification where some households may have been included in the intermittent supply group that do not usually experience piped water or the opposite may be true. Also, it was unknown whether the piped water was chlorinated or not at the distribution level; only household-level water treatment information was obtained. If a household did not treat their water, it might not have been microbiologically safe; although, this may not have necessarily been the case if the distribution system was providing chlorinated water and the water was not contaminated from the source to the point of use. Water quality likely depends on if the water was stored or not (28). Unfortunately, no information on water storage practice was obtained by the DHS. Also, there was a potential for measurement and/ or recall bias for the outcome of diarrhea because child diarrhea was reported by the mother. Mothers may not always be able to recall or discern episodes of diarrhea for her children within the past two weeks. Many studies utilize a 7-day recall period for diarrhea(78); however, this study utilized a two-week recall period, which may have led to missing some cases of diarrhea. Numerous studies have shown that symptom recall past seven days is unreliable (79-83), so this presents a limitation for the results regarding the diarrhea outcome.

Future Directions and Conclusion

This study is the first of its kind to explore the population-level effects of intermittent piped water supply on health outcomes among children under five in sub-Saharan Africa. It serves as a starting point and identifies areas that should be pursued for further research. In particular, this study shows that there may be an association between intermittent piped water supply and diarrhea; therefore, studying the association between diarrhea and intermittent piped water supply should be prioritized. Particularly natural experiments or cohort studies would be useful to assess changes in diarrhea when intermittent supplies are upgraded to a continuous supply. It would also be interesting to further explore the effects of dry season or drought on piped water supply and diarrhea. As drought may cause or exacerbate intermittent piped water supply, it may also affect diarrhea through this pathway. Water scarcity is becoming an ever-increasing problem throughout the world due to climate change (84). Consequently, intermittent water supply will likely affect more people in the future; therefore, there is a need to better understand the health impacts of intermittent water supply.

Tables and Figures

Table 1: Piped water among households in urban areas with children under five in all countries, combined and individually. Percentages for each group are shown. Reported p-values test the null hypothesis that there is no difference between countries.

	Total	Angola, 2015-16	Ethiopia, 2016	Tanzania, 2015	Zimbabwe, 2015	p-value[a]
Piped water Location, %						**<0.0001***
Piped into dwelling	21.04	14.14	6.69	13.77	56.79	
Piped into yard/plot	45.11	42.12	74.65	35.15	39.81	
Piped to Neighbor	33.85	43.74	18.66	51.07	3.39	
Piped water supply frequency, %						**<0.0001***
Intermittent[b]	61.05	58.96	75.23	66.16	48.72	
Continuous	38.95	41.04	24.77	33.84	51.28	

*P-value is significant at the alpha= 0.05 level
[a]P-values calculated using Satterwaite-adjusted chi-squared test.
[b]Intermittent supply is defined as water unavailable for at least one full day in the past two weeks.

Table 2: Descriptive statistics of children under five from all countries. Mean values or percentages for each category are shown. The reported p-value tests the null hypothesis that there is no difference between countries.

	Total	Angola, 2015-16	Ethiopia, 2016	Tanzania, 2015	Zimbabwe, 2015	
	Mean/%	**Mean/%**	**Mean/%**	**Mean/%**	**Mean/%**	**p-value[a]**
Demographics						
Age, %						**0.033***
< 2 years	45.02	43.06	47.93	45.62	39.60	
2- 5 years	54.98	56.94	52.07	54.38	60.40	
Male, %	51.39	50.24	50.46	54.17	49.90	**0.264**
Mean number of persons per household	5.67	6.45	4.95	5.82	5.01	**< 0.0001***
Mean number of children under 5 who live in the household	1.60	1.93	1.37	1.54	1.46	**< 0.0001***
Household wealth[b], %						**< 0.0001***
Rich	88.42	69.09	98.96	94.70	100	
Middle	9.66	27.30	0.46	3.18	0	
Poor	1.92	3.61	0.59	2.12	0	
Education of mother, %						**< 0.0001***
None	11.84	10.66	20.14	7.41	0.23	
Primary	37.43	33.81	30.82	58.19	7.21	
Secondary	38.88	49.36	23.54	32.05	79.00	
More than secondary	11.85	6.17	25.49	2.36	13.56	

	Total	Angola, 2015-16	Ethiopia, 2016	Tanzania, 2015	Zimbabwe, 2015	
	Mean/%	Mean/%	Mean/%	Mean/%	Mean/%	
Water, Sanitation and Hygiene						
Piped water location, %						**< 0.0001***
Piped into dwelling	15.25	13.21	6.68	14.40	56.73	
Piped into yard/plot	50.14	42.92	73.49	35.15	40.04	
Piped to neighbor	34.61	43.87	19.83	50.45	3.23	
Piped water supply frequency, %						**0.0001***
Intermittent[c]	65.04	58.40	74.99	66.55	47.95	
Continuous	34.96	41.60	25.01	33.45	52.05	
Point of use treatment[d], %						
Treated by boil	21.37	15.32	4.09	51.31	9.21	**< 0.0001***
Treated by bleach/ chlorine	17.66	40.75	7.38	5.99	9.01	**< 0.0001***
Strain through a cloth	5.37	No data	0.57	12.42	0	**< 0.0001***
Water filter	1.14	0.50	2.50	0.67	0.09	**0.002***
Solar disinfection	0.14	0.25	0.01	0.22	0	**0.355**
Stand and settle	2.79	0.92	0.01	8.77	0.30	**0.0002***
None	60.13	47.28	85.28	39.43	82.38	**< 0.0001***
Type of toilet, %						
Improved sanitation facility[e]	78.26	89.99	56.44	83.74	97.30	**<0.0001***
Flush toilet	49.97	73.95	14.36	49.42	94.45	
Latrine	45.47	18.67	79.81	49.54	4.51	
Other	1.21	1.99	1.75	0	0.37	
No facility	3.34	5.40	4.08	1.04	0.68	
Household Handwashing station, %						**< 0.0001***
Present with soap and water	42.10	33.58	25.75	67.93	48.78	
Present with water only	15.20	3.80	16.08	20.90	35.04	
Present with no water	19.00	12.85	41.00	2.23	15.59	
No handwashing station observed	23.70	49.77	17.17	8.94	0.59	

[a]P-values calculated using Satterwaite-adjusted chi-squared test or Wald F-test.
[b]Categorized by combining DHS wealth quintiles. Rich= richer and richest quintiles, middle= middle quintile, and poor= poorer and poorest quintiles.
[c]Intermittent supply is defined as water unavailable for at least one full day in the past two weeks.
[d]Participants could indicate more than one method used by the household.
[e]Includes: flush toilet to piped sewer system, septic tank, or pit latrine; ventilated improved pit latrine, composting toilet, or pit latrine with slab.
*P-value is significant at the alpha= 0.05 level

Table 3: Description of outcome and potential confounder variables of children under five with continuous and intermittent piped water supplies, stratified by site. Mean values or percentages for each group are shown.

	Total		Angola, 2015-16		Ethiopia, 2016		Tanzania, 2015		Zimbabwe, 2015	
	Continuous	**Intermittent[a]**	**Continuous**	**Intermittent**	**Continuous**	**Intermittent**	**Continuous**	**Intermittent**	**Continuous**	**Intermittent**
	Mean/ %	**Mean/%**	**Mean/%**	**Mean/%**	**Mean/%**	**Mean/%**	**Mean/%**	**Mean/%**	**Mean/%**	**Mean/%**
Outcome variables										
Diarrhea within the last two weeks, %	13.56	15.39	13.75	19.07	11.22	11.46	13.55	16.15	17.01	17.74
Deaths of children under five, %	5.04	5.34	4.12	2.96	6.81	5.39	4.74	7.81	5.21	4.45
Mean height-for-age z-score	-0.97	-0.92	-	-	-0.86	-0.83	-1.07	-1.02	-0.98	-1.03
Mean weight-for-age z-score	-0.50	-0.57	-	-	-0.66	-0.62	-0.44	-0.59	-0.33	-0.22
Potential confounders										
Child Age, % < 2 years old	42.91	46.16	40.83	44.65	44.62	49.04	46.55	45.16	38.39	40.92
Sex of child, % male	51.79	51.17	49.23	50.97	52.77	49.69	55.82	53.34	49.09	50.79
Wealth, richest quintile, %	60.21	67.30	31.87	34.83	93.96	96.90	74.35	65.60	53.96	50.19
Dry season, %	31.13	22.83	*n/a*	*n/a*	*n/a*	*n/a*	73.47	60.56	87.87	84.14
Household water treatment, %	38.05	36.63	43.90	55.34	19.51	11.74	57.03	53.21	13.80	21.01
Flush toilet, %	57.23	46.07	74.34	73.67	17.71	13.24	48.60	49.83	94.75	94.12
Household handwashing station										
Present with soap and water, %	45.59	40.22	31.21	35.26	29.45	24.52	74.87	64.44	54.55	42.52
Present with water only, %	13.37	16.19	3.57	3.97	18.86	15.15	13.50	24.62	32.00	38.34
Present with no water, %	14.39	21.47	12.43	13.16	34.91	43.04	0.72	2.99	12.69	18.75
No handwashing station observed, %	26.65	22.12	52.79	47.61	16.77	17.30	10.91	7.96	0.77	0.40

N/a= not applicable. There were no interviews conducted during the dry season in Angola or Ethiopia.

[a]Intermittent supply is defined as water unavailable for at least one full day in the past two weeks.

Table 4: Diarrhea and mortality among children under five, stratified by frequency of water supply. The reported p-values test the null hypothesis that there is no difference between intermittent and continuous supply groups.

	Intermittent Supply[a]		Continuous Supply			
	N	Prevalence % (95% CI)	N	Prevalence % (95% CI)	Difference (95% CI)	p-value[b]
Diarrhea						
Total population	3,486	15.39 (13.10, 18.00)	2,508	13.56 (11.14, 16.41)	1.83 (-1.68, 5.34)	0.306
By Country						
Angola	1,342	19.07 (15.53, 23.18)	1,017	13.75 (10.45, 17.89)	5.31 (0.23, 10.40)	0.041*
Ethiopia	946	11.46 (7.64, 16.84)	317	11.22 (5.01, 23.27)	0.24 (-9.38, 9.86)	0.961
Tanzania	602	16.15 (12.20, 21.08)	372	13.55 (10.05, 18.02)	2.60 (-3.03, 8.24)	0.366
Zimbabwe	596	17.74 (13.82, 22.48)	802	17.01 (14.02, 20.48)	0.73 (-4.02, 5.49)	0.763
By Wealth						
Richest quintile	1,990	14.35 (11.38, 17.94)	1,303	12.92 (10.25, 16.17)	1.42 (-2.84, 5.69)	0.513
Lower wealth	1,496	17.52 (14.82, 20.60)	1,205	14.52 (11.17, 18.68)	3.00 (-1.71, 7.71)	0.212
Child mortality, < 5 years of age						
All observations	3,659	5.34 (3.95, 7.18)	2,629	5.04 (3.75, 6.73)	0.30 (-1.91, 2.52)	0.788
By Country						
Angola	1,393	2.96 (1.91, 4.57)	1,063	4.12 (2.64, 6.37)	-1.16 (-3.38, 1.07)	0.308
Ethiopia	989	5.39 (2.72, 10.41)	327	6.81 (3.30, 13.53)	-1.42 (-7.58, 4.58)	0.652
Tanzania	650	7.81 (5.51, 10.94)	395	4.74 (2.94, 7.55)	3.06 (-0.50, 6.63)	0.092
Zimbabwe	627	4.45 (2.93, 6.71)	844	5.21 (3.60, 7.49)	-0.76 (-3.50, 1.98)	0.586
By Wealth						
Richest quintile	2,079	5.53 (3.67, 8.23)	1,364	4.67 (3.04, 7.09)	0.86 (-2.14, 3.86)	0.573
Lower wealth	1,580	4.95 (3.61, 6.76)	1,265	5.59 (3.58, 8.64)	-0.64 (-3.60, 2.32)	0.670

[a]Intermittent supply is defined as water unavailable for at least one full day in the past two weeks.
[b]P-value from two-sample t-test.
*P-value is significant at the alpha= 0.05 level

Table 5: Unadjusted and adjusted effect of intermittent piped water supply on diarrhea among children under five in Angola, Ethiopia, Tanzania, and Zimbabwe (N= 5,993). The reported odds ratios and 95% confidence intervals come from a logistic regression model with diarrhea as the outcome.

	Unadjusted OR (95% CI)	**Adjusted**[a] OR (95% CI)
Covariates		
Piped water frequency		
Intermittent	1.16 (0.87, 1.54)	1.20 (0.89, 1.62)
Continuous	ref	ref
Age of child		
< 2 years	2.11 (1.68, 2.65)*	2.13 (1.70, 2.67)*
2-5 years old	ref	ref
Sex of child		
Male	1.00 (0.79, 1.25)	1.00 (0.79, 1.27)
Female	ref	ref
Sanitation facility		
Flush toilet	1.23 (0.92, 1.65)	1.23 (0.94, 1.63)
Latrine, other or no facility	ref	ref
Wealth		
Richest quintile	0.83 (0.64, 1.06)	0.89 (0.68, 1.15)
Lower wealth	ref	ref
Household water treatment[b]		
Yes	1.16 (0.89, 1.53)	1.13 (0.88, 1.45)
No	ref	ref
Handwashing station		
Present with soap and water	0.66 (0.49, 0.90)*	0.56 (0.40, 0.79)*
Present with water only	0.86 (0.59, 1.24)	0.72 (0.48, 1.07)
Present with no water	0.82 (0.51, 1.32)	0.85 (0.51, 1.39)
Not present	ref	ref
Season		
Dry season	1.37 (1.03, 1.84)*	1.62 (1.21, 2.18)*
Not dry season	ref	ref

[a]Adjusted for all covariates listed in the table, with piped water frequency as the exposure.
[b]Household water was considered treated if at least one of the following methods was used: boiling, bleach/chlorine, water filter or solar disinfection.
*Statistically significant at alpha= 0.05

Table 6: Unadjusted and adjusted effect of intermittent piped water supply on diarrhea among children under five in Angola, Ethiopia, Tanzania, and Zimbabwe. The reported odds ratios and 95% confidence intervals come from a logistic regression model with diarrhea as the outcome.

	Angola		Ethiopia		Tanzania		Zimbabwe	
	N= 2,359		N= 1,263		N= 973		N= 1,398	
	Unadjusted OR (95% CI)	Adjusted[a] OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Covariates								
Frequency								
Intermittent	1.48 (1.01, 2.16)*	1.44 (0.96, 2.17)	1.02 (0.39, 2.68)	0.93 (0.36, 2.43)	1.23 (0.79, 1.92)	1.28 (0.79, 2.06)	1.05 (0.76, 1.46)	1.05 (0.75, 1.48)
Continuous	ref	ref	ref	ref	ref	ref	ref	ref
Age of child								
< 2 years	2.20 (1.59, 3.04)*	2.16 (1.57, 2.98)*	2.17 (1.21, 3.91)*	2.15 (1.15, 4.03)*	2.15 (1.42, 3.27)*	2.21 (1.45, 3.39)*	2.00 (1.41, 2.83)*	1.98 (1.39, 2.82)*
2-5 years old	ref	ref	ref	ref	ref	ref	ref	ref
Sex of child								
Male	1.13 (0.85, 1.49)	1.11 (0.84, 1.48)	1.03 (0.51, 2.08)	1.05 (0.48, 2.29)	0.77 (0.54, 1.10)	0.76 (0.52, 1.12)	1.22 (0.88, 1.68)	1.20 (0.86, 1.68)
Female	ref	ref	ref	ref	ref	ref	ref	ref
Sanitation facility								
Flush toilet	0.84 (0.60, 1.17)	0.87 (0.57, 1.34)	0.40 (0.18, 0.90)	0.48 (0.20, 1.15)	1.67 (1.05, 2.66)*	1.63 (1.06, 2.50)*	0.96 (0.38, 2.41)	0.99 (0.38, 2.56)
Latrine, other or no facility	ref	ref	ref	ref	ref	ref	ref	ref
Wealth								
Richest quintile	0.99 (0.72, 1.37)	1.10 (0.75, 1.62)	0.52 (0.19, 1.41)	0.60 (0.18, 1.99)	1.30 (0.79, 2.14)	1.09 (0.62, 1.89)	0.73 (0.52, 1.04)	0.79 (0.56, 1.12)
Lower wealth	ref	ref	ref	ref	ref	ref	ref	ref
Household Water treatment[b]								
Yes	1.10 (0.83, 1.47)	1.06 (0.77, 1.45)	0.90 (0.34, 2.37)	1.05 (0.42, 2.62)	1.13 (0.71, 1.81)	1.07 (0.66, 1.73)	0.78 (0.41, 1.48)	0.77 (0.39, 1.53)
No	ref	ref	ref	ref	ref	ref	ref	ref
Handwash								
Present with soap and water	0.69 (0.47, 1.01)	0.67 (0.44, 1.02)	0.51 (0.17, 1.53)	0.60 (0.20, 1.82)	0.64 (0.38, 1.10)	0.54 (0.30, 0.98)*	0.10 (0.03, 0.38)*	0.11 (0.03, 0.43)*
Present with water only	1.02 (0.47, 2.24)	0.96 (0.41, 2.25)	0.70 (0.29, 1.70)	0.69 (0.27, 1.79)	0.91 (0.45, 1.84)	0.75 (0.36, 1.57)	0.12 (0.03, 0.49)*	0.14 (0.03, 0.53)*
Present with no water	1.01 (0.53, 1.91)	0.96 (0.48, 1.91)	0.88 (0.31, 2.45)	0.87 (0.29, 2.58)	1.93 (0.69, 5.35)	1.40 (0.45, 4.30)	0.12 (0.03, 0.49)*	0.14 (0.04, 0.54)*
Not present	ref	ref	ref	ref	ref	ref	ref	ref
Season								
Dry season	n/a	n/a	n/a	n/a	1.89 (1.13, 3.15)*	1.94 (1.17, 3.20)*	1.27 (0.71, 2.26)	1.16 (0.63, 2.12)
Not dry season	n/a	n/a	n/a	n/a	ref	ref	ref	ref

[a]Adjusted for all covariates listed in the table, with piped water frequency as the exposure.

[b]Household water was considered treated if at least one of the following methods was used: boiling, bleach/chlorine, water filter or solar disinfection.

*Statistically significant at alpha= 0.05

Figure 3: Odds ratios (95% confidence interval) plotted on the log scale for the association between intermittent piped water supply and diarrhea among children under five.

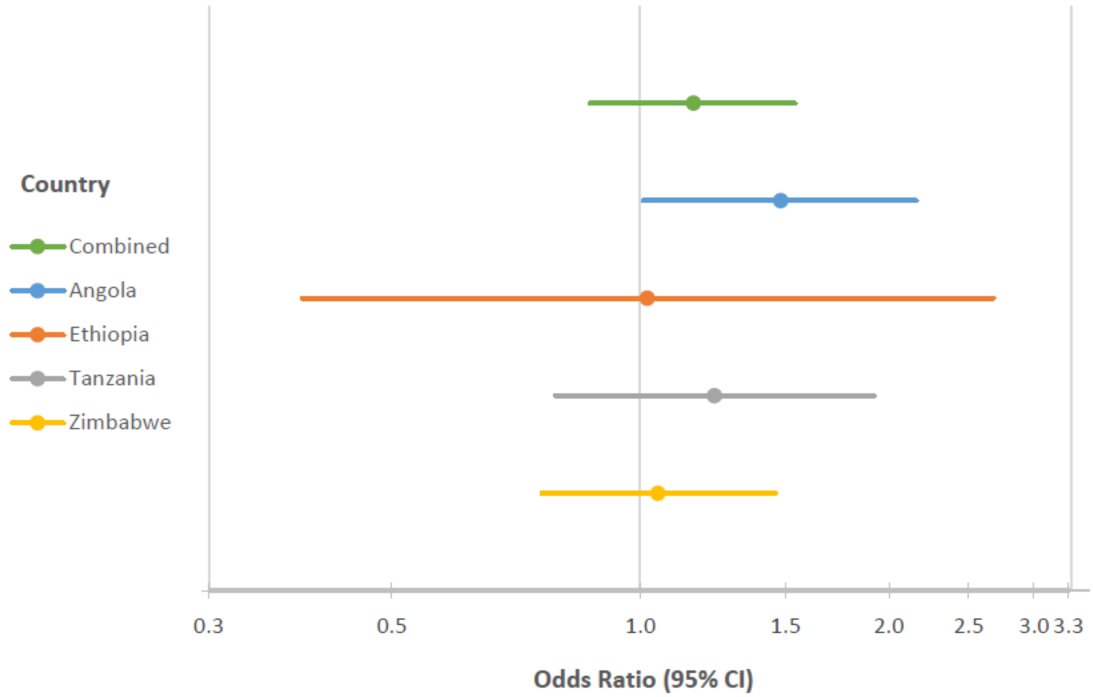

Table 7: Unadjusted and adjusted effect of intermittent piped water supply on death among children under five in Angola, Ethiopia, Tanzania, and Zimbabwe (N= 6,287). The reported odds ratios and 95% confidence intervals come from a logistic regression model with death as the outcome.

	Unadjusted OR (95% CI)	**Adjusted**[a] OR (95% CI)
Covariates		
Frequency		
Intermittent	1.06 (0.68, 1.67)	1.07 (0.70, 1.63)
Continuous	ref	ref
Age of child		
< 2 years	0.81 (0.56, 1.16)	0.81 (0.57, 1.17)
2-5 years old	ref	ref
Sex of child		
Male	1.27 (0.84, 1.94)	1.27 (0.83, 1.93)
Female	ref	ref
Sanitation facility		
Flush toilet	0.71 (0.47, 1.07)	0.69 (0.47, 1.02)
Latrine, other or no facility	ref	ref
Wealth		
Richest quintile	1.01 (0.65, 1.56)	1.05 (0.66, 1.66)
Lower wealth	ref	ref
Household water treatment[b]		
Yes	0.72 (0.47, 1.10)	0.69 (0.46, 1.03)
No	ref	ref
Handwash		
Present with soap and water	0.91 (0.53, 1.55)	0.96 (0.55, 1.68)
Present with water only	0.55 (0.27, 1.12)	0.51 (0.25, 1.06)
Present with no water	0.72 (0.41, 1.29)	0.62 (0.35, 1.11)
Not present	ref	ref

[a]Adjusted for all covariates listed in the table, with piped water frequency as the exposure.
[b]Household water was considered treated if at least one of the following methods was used: boiling, bleach/chlorine, water filter or solar disinfection.
*Statistically significant at alpha= 0.05

Table 8: Unadjusted and adjusted effect of intermittent piped water supply on child death among children under five in Angola, Ethiopia, Tanzania, and Zimbabwe. The reported odds ratios and 95% confidence intervals come from a logistic regression model with death as the outcome.

	Angola		**Ethiopia**		**Tanzania**		**Zimbabwe**	
	N= 2,456		**N= 1,316**		**N= 1,044**		**N= 1,471**	
	Unadjusted OR (95% CI)	**Adjusted**[a] OR (95% CI)	**Unadjusted** OR (95% CI)	**Adjusted** OR (95% CI)	**Unadjusted** OR (95% CI)	**Adjusted** OR (95% CI)	**Unadjusted** OR (95% CI)	**Adjusted** OR (95% CI)
Covariates								
Frequency								
Intermittent	0.71 (0.37, 1.35)	0.77 (0.40, 1.50)	0.78 (0.27, 2.26)	0.73 (0.28, 1.94)	1.70 (0.90, 3.20)	1.87 (0.98, 3.57)	0.85 (0.47, 1.54)	0.87 (0.48, 1.58)
Continuous	ref	ref	ref	ref	ref	ref	ref	ref
Age of child								
< 2 years	0.71 (0.39, 1.30)	0.73 (0.40, 1.33)	1.07 (0.55, 2.10)	1.03 (0.55, 1.94)	0.66 (0.36, 1.23)	0.68 (0.37, 1.24)	0.61 (0.28, 1.34)	0.58 (0.27, 1.24)
2-5 years old	ref	ref	ref	ref	ref	ref	ref	ref
Sex of child								
Male	1.44 (0.86, 2.41)	1.46 (0.87, 2.45)	0.83 (0.33, 2.07)	0.76 (0.31, 1.86)	1.78 (0.97, 3.27)	1.75 (0.94, 3.26)	1.23 (0.64, 2.39)	1.25 (0.64, 2.44)
Female	ref	ref	ref	ref	ref	ref	ref	ref
Sanitation facility								
Flush toilet	0.53 (0.27, 1.04)	0.69 (0.33, 1.46)	0.35 (0.10, 1.26)	0.38 (0.10, 1.50)	1.22 (0.68, 2.20)	1.08 (0.57, 2.06)	1.07 (0.44, 2.62)	1.34 (0.53, 3.35)
Latrine, other or no facility	ref	ref	ref	ref	ref	ref	ref	ref
Wealth								
Richest quintile	0.31 (0.15, 0.63)*	0.42 (0.19, 0.94)*	0.45 (0.10, 2.09)	0.69 (0.14, 3.36)	1.29 (0.66, 2.54)	1.24 (0.55, 2.81)	0.61 (0.35, 1.05)	0.54 (0.29, 1.02)
Lower wealth	ref	ref	ref	ref	ref	ref	ref	ref
Household water treatment[b]								
Yes	0.44 (0.21, 0.94)*	0.54 (0.25, 1.16)	0.49 (0.15, 1.56)	0.48 (0.14, 1.66)	0.97 (0.57, 1.67)	0.84 (0.46, 1.55)	0.94 (0.31, 2.84)	1.01 (0.33, 3.09)
No	ref	ref	ref	ref	ref	ref	ref	ref
Handwash								
Present with soap and water	0.57 (0.24, 1.38)	0.83 (0.34, 2.01)	0.43 (0.11, 1.67)	0.49 (0.13, 1.90)	0.86 (0.39, 1.89)	0.81 (0.34, 1.89)	1.31 (0.18, 9.48)	1.31 (0.17, 10.16)
Present with water only	0.91 (0.19, 4.43)	1.17 (0.21, 6.39)	0.36 (0.09, 1.38)	0.33 (0.08, 1.41)	0.25 (0.07, 0.89)*	0.23 (0.07, 0.81)	0.99 (0.13, 7.39)	0.88 (0.11, 7.25)
Present with no water	1.06 (0.44, 2.55)	1.04 (0.43, 2.51)	0.36 (0.15, 0.86)*	0.36 (0.16, 0.83)*	1.28 (0.28, 5.86)	1.05 (0.25, 4.49)	1.00 (0.13, 7.61)	0.93 (0.11, 7.79)
Not present	ref	ref	ref	ref	ref	ref	ref	ref

[a]Adjusted for all covariates listed in the table, with piped water frequency as the exposure.

[b]Household water was considered treated if at least one of the following methods was used: boiling, bleach/chlorine, water filter or solar disinfection.

*Statistically significant at alpha= 0.05

Table 9: Height-for-age and Weight-for-age Z-scores of children under five in all Ethiopia, Tanzania, and Zimbabwe stratified by frequency of water supply. The reported p-values test the null hypothesis that there is no difference between intermittent and continuous supply groups.

	Intermittent Supply[a]		Continuous Supply			
	N	Mean Z-score (SE)	N	Mean Z-score (SE)	Difference in Z-score (95% CI)	p-value[b]
Height-for-age Z-score						
Total population	1,925	-0.92 (0.07)	1,377	-0.97 (0.06)	0.05 (-0.14, 0.25)	0.592
By Country						
Ethiopia	817	-0.83 (0.13)	285	-0.86 (0.12)	0.03 (-0.34, 0.41)	0.874
Tanzania	574	-1.02 (0.08)	363	-1.07 (0.08)	0.05 (-0.17, 0.27)	0.648
Zimbabwe	534	-1.03 (0.10)	729	-0.98 (0.07)	-0.05 (-0.28, 0.18)	0.670
By Wealth						
Richest quintile	1,431	-0.86 (0.09)	947	-0.90 (0.07)	0.04 (-0.18, 0.26)	0.712
Lower wealth	494	-1.16 (0.10)	430	-1.22 (0.09)	0.06 (-0.22, 0.34)	0.662
Weight-for-age Z-score						
All observations	1,949	-0.57 (0.06)	1,390	-0.50 (0.06)	-0.07 (-0.22, 0.08)	0.331
By Country						
Ethiopia	830	-0.62 (0.10)	293	-0.66 (0.12)	0.04 (-0.23, 0.30)	0.794
Tanzania	579	-0.59 (0.08)	366	-0.44 (0.07)	-0.14 (-0.34, 0.06)	0.158
Zimbabwe	540	-0.22 (0.07)	731	-0.33 (0.06)	0.11 (-0.07, 0.28)	0.245
By Wealth						
Richest quintile	1,451	-0.57 (0.07)	959	-0.45 (0.07)	-0.12 (-0.29, 0.06)	0.193
Lower wealth	498	-0.61 (0.08)	431	-0.68 (0.08)	0.07 (-0.14, 0.29)	0.502

[a]Intermittent supply is defined as water unavailable for at least one full day in the past two weeks.
[b]P-value from two-sample t-test.
*P-value is significant at the alpha= 0.05 level

Table 10: Unadjusted and adjusted effect of intermittent piped water supply on Height-for-age and Weight-for-age among children under five in Ethiopia, Tanzania, and Zimbabwe. The reported betas and standard errors come from linear regression models with HAZ or WAZ as the outcome.

	All sites[a]		Ethiopia		Tanzania		Zimbabwe	
	Unadjusted β (SE)	Adjusted[b] β (SE)	Unadjusted β (SE)	Adjusted[b] β (SE)	Unadjusted β (SE)	Adjusted[b] β (SE)	Unadjusted β (SE)	Adjusted[b] β (SE)
Height-for-age Z-score								
Intermittent	0.05 (0.10)	0.06 (0.09)	0.03 (0.19)	0.06 (0.16)	0.05 (0.11)	0.09 (0.11)	-0.05 (0.12)	-0.02 (0.11)
Continuous	ref	ref	ref	ref	ref	ref	ref	ref
Weight-for-age Z-score								
Intermittent	-0.07 (0.08)	-0.04 (0.07)	0.04 (0.14)	0.09 (0.13)	-0.14 (0.10)	-0.10 (0.10)	0.11 (0.09)	0.12 (0.09)
Continuous	ref	ref	ref	ref	ref	ref	ref	ref

[a]All sites, except Angola, were included in this analysis.
[b]Adjusted for age, sex, wealth, flush toilet, water treatment and handwashing infrastructure.

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