Freshwater Availability and Water Fetching Distance Affect Child Health in Sub-Saharan Africa

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Introduction

Currently, more than two-thirds of the population in Africa must leave their home to fetch water for drinking and domestic use. The time burden of water fetching has been suggested to influence the volume of water collected by households as well as time spent on income generating activities and child care. However, little is known about the potential health benefits of reducing water fetching distances. Data from almost 200,000 Demographic and Health Surveys carried out in 26 countries were used to assess the relationship between household walk time to water source and child health outcomes. To estimate the causal effect of decreased water fetching time on health, geographic variation in freshwater availability was employed as an instrumental variable for one-way walk time to water source in a two-stage regression model. Time spent walking to a household’s main water source was found to be a significant determinant of under-five child health. A 15-min decrease in one-way walk time to water source is associated with a 41% average relative reduction in diarrhea prevalence, improved anthropometric indicators of child nutritional status, and a 11% relative reduction in under-five child mortality. These results suggest that reducing the time cost of fetching water should be a priority for water infrastructure investments in Africa.

ABSTRACT: Currently, more than two-thirds of the population in Africa must leave their home to fetch water for drinking and domestic use. The time burden of water fetching has been suggested to influence the volume of water collected by households as well as time spent on income generating activities and child care. However, little is known about the potential health benefits of reducing water fetching distances. Data from almost 200,000 Demographic and Health Surveys carried out in 26 countries were used to assess the relationship between household walk time to water source and child health outcomes. To estimate the causal effect of decreased water fetching time on health, geographic variation in freshwater availability was employed as an instrumental variable for one-way walk time to water source in a two-stage regression model. Time spent walking to a household’s main water source was found to be a significant determinant of under-five child health. A 15-min decrease in one-way walk time to water source is associated with a 41% average relative reduction in diarrhea prevalence, improved anthropometric indicators of child nutritional status, and a 11% relative reduction in under-five child mortality. These results suggest that reducing the time cost of fetching water should be a priority for water infrastructure investments in Africa.

INTRODUCTION

Currently, 44% of the world’s population must leave their homes to fetch the water they need for drinking and other domestic uses. Most of the households using such “non-networked” water supplies are located in sub-Saharan Africa and southern Asia. Women and children are known to be the main water carriers in low-income countries, often spending more than one hour per water collection trip and making multiple trips per day. Although the large global time burden of water fetching is well known, the majority of water-related health impact research has focused on water quality, leaving the relationship between time spent fetching and health understudied.

The time cost and physical burden associated with water fetching translates into reduced volumes of water accessed by households using non-networked sources. Previous research has found an inverse association between volume of water used and walk time to source; in particular, households whose water sources are located more than 30 min away often collect less water than is believed necessary for basic needs. The proximity of water available to a household has also been demonstrated to correlate with the frequency of hygiene behavior. For example, mothers in Burkina Faso with piped water supplies in their yards were three times more likely to perform regular hand washing as compared to mothers using wells or public standpipes outside their yards. Households in East Africa with access to piped water on their plot have been found to use twice the volume of water for personal hygiene as compared to those without on-plot access to piped water.

Previous research on water access and health has explored the impact of households gaining access to on-plot piped water connections, but little is known regarding the extent to which water fetching affects child health. One community-specific study in Ethiopia found that installation of village taps reduced time spent fetching water and child mortality, yet child malnutrition increased. A recent systematic review of studies investigating the relationship between distance from the home to water source and diarrheal disease identified only six studies, four of which did not adjust for possible confounding variables. The review authors were unable to calculate a quantitative relationship between distance and diarrheal risk and concluded that more research is needed on this topic.

To address this knowledge gap, this work investigates the association between access to water and under-five child morbidity and mortality. For the purpose of this analysis, water access is defined by reported one-way walk time to a household’s main drinking water source. Child health outcomes include prevalence of diarrhea, cough, and fever; anthropometrics (height and weight); as well as childhood mortality. Geographic variation in freshwater availability is employed as
an instrumental variable for walk time to water source. The instrumental variable approach is one strategy for estimating causal effects within nonexperimental settings; it is used here to estimate the effect of water access on child health outcomes. All data are drawn from sub-Saharan Africa, where 84% of the population lack access to piped water into the dwelling or yard.

## METHODS

### Household Survey Data

Child health outcomes, water access, and other household-level data were obtained from the most recent Demographic and Health Survey (DHS) data set from all countries in sub-Saharan Africa that included a walk-time to water source variable, child anthropometrics, child diarrhea prevalence, and GPS coordinates of household clusters (Table 1). Surveys included in this analysis were conducted between the years of 1994 and 2009. The data set consists of all living children under the age of 5 years at the time of interview, as well as deceased children who would have been less than 5 years old if still alive at the time of interview. The DHS survey does not provide respondents with a specific definition for diarrhea. Height/length and weight were also measured for under-five children and then converted to height-for-age z-scores (HAZ), weight-for-age z-scores (WAZ), and weight-for-height z-scores (WHZ). Z-scores for each child were generated using World Health Organization (WHO) child growth standards as a reference, and indicate the number of standard deviations a child is above or below the normal value given his/her age.

Respondents in the DHS survey were asked how many minutes it takes to walk one way to their households’ main drinking water source. A value of 0 min was assigned for households with a water source located on their premises. Households reported the type of source from which they collected drinking water; these source water types were grouped into the following categories: piped, well, spring, surface, rainwater, vendor, and other.

### Freshwater Availability

The freshwater availability data set used in this analysis was generated by the University of New Hampshire (UNH)/Global Runoff Data Centre (GRDC) Composite runoff Fields (V1.0) climate driven water balance model. The model provides estimates of freshwater availability (i.e., runoff) at the 0.5° latitude by 0.5° longitude grid-based level. The area of each grid cell is approximately 55 km by 55 km (precise area varies with proximity to the equator). The water balance model takes into account precipitation, air temperature, soil type, and land cover to estimate a long-term average of total freshwater availability (mm/year); it is calibrated using river gauge discharge data. Figure 1 shows this gridded freshwater data set overlaid with GPS coordinates of household clusters included in the DHS data set.

### Estimating Strategy

This analysis employs an instrumental variable (IV) approach, a model estimation strategy designed to estimate causal effects with nonexperimental data. An important concern when analyzing such data is that the independent variable of interest (water access) shares a common cause with the outcome of interest (child health), and the observed association is a result of confounding. An example of a common cause that could confound the association between water access and child health is the wealth of the household. This issue can be addressed by identifying a source of exogenous variation in distance to water source that is not caused by endogenous variables such as household income. In sub-Saharan Africa, where water delivery infrastructure is limited, it seems reasonable to consider geographic differences in freshwater availability as a source of exogenous variation in household distance to water source. The IV modeling approach employs a first-stage equation to model walk time to water source as a function of freshwater runoff available to each household. The predicted values of walk times are then used in a second-stage equation modeling health outcomes as a function of water collection time at the household level.

### Model Specification

A two-stage model was estimated as follows:

\[
\text{TIME}_i = \beta_0 + \beta_1\text{Freshwater}_i + \sum_k \beta_k\text{Source}_{ik} + \beta_3\text{Age}_i + \beta_4\text{Gender}_i + \beta_5\text{Urban}_i + \epsilon_i
\]

\[
\text{Health}_i = \alpha_0 + \alpha_1\text{TIME}_i + \sum_k \alpha_k\text{Source}_{ik} + \alpha_3\text{Age}_i + \alpha_4\text{Gender}_i + \alpha_5\text{Urban}_i + \epsilon_i
\]

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where \( \text{TIME}_i \) is the one-way walk time to the main drinking water source reported by household \( i \) and \( \text{Freshwater}_i \) is the quantity of freshwater available in the immediate area of household \( i \) (Figure 1). \( \sum_k \text{Source}_{ik} \) is a series of dummy variables specifying the type of water source that household \( i \) accesses. The predicted values of walk time to source (\( \hat{\text{TIME}}_i \)) generated by the first stage were used in the second-stage health outcome model. Health outcomes modeled include 2-week prevalence of diarrhea, fever, and cough; WAZ, HAZ, and WHZ; and child mortality. Binary health outcomes (diarrhea, cough, fever, mortality) were estimated with probit models, whereas continuous outcomes (WAZ, HAZ, WHZ) were estimated using ordinary least-squares linear regression.

The parameter of interest in all health outcome models is \( \alpha_1 \), the estimated average effect of a one-minute change in walk time to water source for household \( i \).

The two-stage estimation strategy was employed because \( \text{TIME}_i \) is likely to be correlated with \( \varepsilon_i \). The control variables \( \sum_k \text{Source}_{ik} \) were included to address the possibility that freshwater availability may affect the type of water source accessed by households, which in turn may affect the quality (and safety) of water. For example, areas with abundant water resources may have a high prevalence of shallow wells or surface water sources. Such sources generally deliver water with higher microbial contamination that can cause diarrheal illness as compared to piped water or deep groundwater.\(^{16} \) To address this issue, all models control for household water source type as a proxy for water quality; surface water is the reference category in all models.

One subgroup analysis was performed to compare the estimated effect of water access on child health among households with and without access to sanitation. The sample was stratified into two groups: (1) households reporting use of any type of sanitation facility (improved or unimproved); and (2) households practicing open defecation.

To increase precision, all models include the gender and age of each child (in months), and whether the household is located in an urban or rural area. DHS-generated population weights were used to obtain representative results. Standard errors were adjusted to account for within-cluster correlation at the geo-referenced cluster level. STATA 11 (StataCorp LP, College Station, TX) was used for all data analysis.

**RESULTS**

**Household Characteristics.** Respondents include mothers with a mean age of 29 (SD 7) and a mean 3.4 years of education (SD 4). Approximately one-quarter of the total child-level observations were collected from urban households, and...
the rest from households classified as rural. Almost one-fifth (19%) of included households had access to electricity; 31% owned a bicycle, 7% owned a fridge, and 60% had an earth floor in their home. Access to sanitation facilities was varied: 7% used flush toilets, 12% used ventilated improved pit (VIP) latrines, 43% used non-VIP latrines, 36% had no facility, and 1% used other types of facilities (e.g., bucket latrine).

One quarter (25%) of households identified a piped source (private or public tap) as their principal water source. Another 48% reported using protected or unprotected wells, whereas 10% used springs and 16% used surface water. Fewer than 1% of surveyed households reported using rainwater (0.6%), vendors (0.7%), bottled water (0.2%), or an “other” (0.6%) type of principal water source. The mean one-way walk time to a household’s main water source was 23 min (SD 37, median 10 min); 18% (N = 34,948) of households reported a water source located on the premises.

**Child Health.** A total of 17% of children were reported to have experienced diarrhea in the two weeks prior to interview. Respondents reported fever for 27% of children and cough for 25% in the previous two weeks. The mean WAZ was −1.04 (N = 110,455, SD = 1.32), with 22% of children classified as underweight by World Health Organization (WHO) standards (WAZ < −2.0). The mean HAZ for children was −1.56 (N = 115,316, SD = 1.8), with 41% classified as stunted (HAZ < −2.0). A total of 11% of children measured were identified as Wasted (WHZ < −2.0), with a mean WHZ of −0.21 (N = 110,455, SD = 1.49). Under-five child mortality was 9.9%.

**First-Stage Model.** Average freshwater runoff was 344 mm/yr (median 178, SD = 470, N = 191,333) and mean monthly precipitation was 113 mm (median 95, SD = 103, N = 196,711). The results of the first-stage regression of one-way walk time as a function of freshwater runoff and other control variables are presented in Table S1 of the Supporting Information (SI). As necessary for employing the instrumental variable estimation approach, freshwater runoff is strongly correlated to water fetching time in the expected direction (t-statistic = −5.32, p < 0.001): as runoff increases, walk time to source decreases. Diagnostic tests indicate that walk time is sufficiently identified by freshwater availability (see SI for details).17–20

**Second-Stage Model.** The average marginal effects (ME) of walk time to water source on child health outcomes are presented in Table 2. A 15-min decrease in one-way walk time to water source is associated with a 7.1 percentage point reduction in diarrhea (2-week prevalence), equivalent to a 42% relative reduction from the mean prevalence in the study population. The same 15-min decrease in one-way walk time is also associated with a 4.5 percentage point reduction (15% relative reduction) in fever, and with a 3.9 percentage point reduction (15% relative reduction) in cough (all symptoms refer to 2-week prevalence). The same decrease in one-way walk time is associated with an increase of 0.6 in WAZ (improved weight-for-age), an increase of 0.3 in HAZ (reduced stunting) and a 0.5 increase in WHZ (reduced wasting). Under-five child mortality is lower by 1.1 percentage points (11% relative reduction) with a 15-min decrease in walk time (Figure 2). The estimated effect of walk time to source on child health was much greater among households with access to sanitation facilities as compared to those households practicing open defecation (Table S2 of the SI).

### Table 2. Average Marginal Effect (ME) on Child Health Outcomes of Reduced One-Way Walk Time to Water Source

<table>
<thead>
<tr>
<th>Health outcome</th>
<th>ME (1-min decrease)</th>
<th>SE</th>
<th>N</th>
<th>Δ associated with 15-min decrease (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>diarrhea</td>
<td>−0.0047</td>
<td>0.0003</td>
<td>160,734</td>
<td>−7.1 (6.1−8.0) pp</td>
</tr>
<tr>
<td>fever</td>
<td>−0.0030</td>
<td>0.0004</td>
<td>160,539</td>
<td>−4.5 (3.2−5.8) pp</td>
</tr>
<tr>
<td>cough</td>
<td>−0.0026</td>
<td>0.0004</td>
<td>160,799</td>
<td>−3.9 (2.6−5.2) pp</td>
</tr>
<tr>
<td>WAZ</td>
<td>0.0371</td>
<td>0.0032</td>
<td>102,013</td>
<td>+0.6 (0.5−0.7)</td>
</tr>
<tr>
<td>HAZ</td>
<td>0.0176</td>
<td>0.0025</td>
<td>106,573</td>
<td>+0.3 (0.2−0.3)</td>
</tr>
<tr>
<td>WHZ</td>
<td>0.0337</td>
<td>0.0031</td>
<td>102,013</td>
<td>+0.5 (0.4−0.6)</td>
</tr>
<tr>
<td>mortality</td>
<td>−0.0008</td>
<td>0.0002</td>
<td>183,267</td>
<td>−1.1 (0.5−1.7) pp</td>
</tr>
</tbody>
</table>

*pWalk time to water source is instrumented by freshwater availability (runoff); all models include water source type, urban or rural region, child gender, and child age in months. SE is standard error of the marginal effect; pp stands for percentage points; WAZ is weight-for-age; HAZ is height-for-age; WHZ is weight-for-height. Probit model. p < 0.001.

**DISCUSSION**

This analysis of nationally representative data from 26 countries in sub-Saharan Africa identifies walk time to water source as an important determinant of child health. Even a 5-min decrease in walk time to source is associated with an average 14% relative reduction in 2-week diarrhea and an average increase of 0.2 in the WAZ score for an under-5 child (Figure 2). A 15-min decrease in one-way walk time to water source is associated with an average relative reduction in risk of diarrhea by 41%, which is comparable to the range of diarrhea risk reduction found in meta-analyses of water quality, handwashing, and sanitation interventions.21 These findings suggest that investments that reduce the time costs of water fetching may provide health benefits on par with those achieved by water disinfection and hygiene promotion programs. Further research should evaluate the health impact of technologies and strategies that reduce water fetching time for households, such as carts, bicycles, flexible hoses, and self-supply options such as rainwater collection systems and hand-dug wells.22,23

Walk time to source was found to have a greater impact on child health among households with access to sanitation (Table S2 of the SI). This result is consistent with research by Esrey et al. (1996) in sub-Saharan Africa, in which health benefits associated with gaining access to water supply at the household were only observed when improved sanitation was also present.24 One possible explanation for this finding is that close proximity to a water source may allow for more hygienic use of a sanitation facility (e.g., pour flushing, cleaning, postdefecation handwashing), which results in significant health benefits. Evidence for such complementary health effect of latrine access and increased water usage has been documented previously in Lesotho.25

Several causal mechanisms underlying the observed relationship between time to water source and child health are plausible (Figure S1 of the SI). Further walk times could restrict the volume of water collected by households, thus impeding the use of water for sanitation services and hygiene behaviors, such as handwashing, that are known to reduce diarrheal and respiratory illness.26,27 Longer storage time of drinking water may offer increased opportunities for microbial contamination though repeated extraction with dirty utensils and hands.28 Mothers that must spend significant time fetching water may have less time to care for their children in ways that affect health, such as seeking health care services when a child is ill.29
A distant water source may also preclude households from using water for on-plot gardening, which can improve family nutrition, or from using water for additional productive activities (e.g., brick-making) that can augment income. Finally, time spent collecting water reduces the time available to engage in other income generating activities that can contribute to household consumption. Additional research is needed to assess the relative contribution of each of these causal pathways to child health.

A fundamental limitation of this nonexperimental analysis is the inability to directly assess whether freshwater runoff affects child health only through its influence on domestic water supply access. To explore this issue, several robustness checks were carried out. For example, freshwater runoff in regions with high precipitation levels may affect health through wealth earned by differential income generating opportunities, such as agriculture. In order to assess household wealth as a potential confounding variable, all models were re-estimated after including a household wealth index variable. Controlling for this wealth index did not reduce the magnitude or significance of any estimate. Similarly, estimates were not significantly changed after controlling for educational attainment of the respondent, nor of household participation in agriculture (Table S3 of the SI).

For the subset of households from which dietary data were collected (N = 76,038), a dietary diversity index (DDI) was created as a proxy for nutritional intake of children and included in re-estimated models of illness and anthropometrics (see SI for details). With the exception of fever, all associations between water access and health were preserved in models that included the DDI, although the magnitudes of the effect estimates on the anthropometric outcomes were reduced (Table S3, column D of the SI). This reduction in effect size would be expected if convenient access to water allows households to irrigate, grow, and consume nutrient-rich foods. Notably, access to irrigation increases the diversity of crops that can be grown and has been shown to improve nutritional intake among households in sub-Saharan Africa.

There is evidence that precipitation and other climatic factors can affect transmission of diarrheal pathogens. To control for potential seasonality effects on health that might be related to runoff, IV models were re-estimated after including the mean monthly precipitation (mm/month) during the month in which a survey was conducted. Including monthly precipitation did not change the association between water access and diarrhea, WAZ, HAZ, or WHZ; however, walk time associations with fever and cough were no longer significant (Table S3 of the SI).

A review conducted in 1987 of studies on water use volumes decrease further when collection time exceeds 30 min. Water source and volume of water collected may well be nonlinear; however, there are limited recent data on this association. A review conducted in 1987 of studies on water use and time costs of collection found the following: (1) water volumes used by households decrease sharply when the travel time to source exceeds 5 min; (2) volumes remain fairly constant during a collection time range of 5–30 min; and (3) volumes decrease further when collection time exceeds 30 min. This pattern implies that there could be differentially large health benefits for households with access to a water source in the home or yard. In this analysis, when households with their own water source are excluded, the magnitude of the effect of walk time to source on health outcomes decreases only slightly
(Table S3, column A of the SI). This result, however, may be affected by a shift in the first-stage regression, as households with their own source tend to live in regions with relatively lower runoff than those walking short distances to their water source (see SI for additional discussion).

One implication of these findings is that water infrastructure improvements that do not deliver water close to the home may be unlikely to have major impacts on infectious disease among children under five. This is particularly concerning for sub-Saharan Africa, where gains in access to improved water supply over the past two decades have almost exclusively taken the form of non-networked (off-plot) services. During the period 1990–2008, access to piped water into the dwelling, lot or yard decreased in urban areas in sub-Saharan Africa (from 43% to 35%) and remained near constant (at 4–5%) in rural areas.1 The WHO/UNICEF Joint Monitoring Program (JMP) does not consider proximity to water source when monitoring global progress toward Target 10 of the Millennium Development Goals, “to reduce by half the proportion of people without access to safe drinking water and sanitation by 2015.”36 Although it is unofficially recognized that a water source should be located within 1 km of the home, only water source type is actually used by JMP to assess access to safe water (e.g., piped water, borehole, or pump).36,37 This work suggests that walk time to water source should be given more emphasis as an essential indicator for monitoring global access to safe water.

Finally, when considered alongside predicted decreases in freshwater availability for sub-Saharan Africa,38 these findings suggest that the morbidity and mortality burden of water fetching on African children will likely increase over the next several decades. Recent research indicates that, by the year 2050, more than 1 billion people will live in areas with serious water shortage, defined as having access to less than 100 L per person per day.39 Wealthy countries can mitigate this water security threat by building water delivery infrastructure and treatment systems, but low-income countries struggle to make these types of investments.40

# ASSOCIATED CONTENT

## Supporting Information
See Supporting Information for additional details on methods, further discussion of results, Tables S1–S3, and Figure S1. This information is available free of charge via the Internet at http://pubs.acs.org/

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# REFERENCES


