

The Relationship between Distance to Water Source and Moderate-to-Severe Diarrhea in the Global Enterics Multi-Center Study in Kenya, 2008–2011

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Abstract. In the developing world, fetching water for drinking and other household uses is a substantial burden that affects water quantity and quality in the household. We used logistic regression to examine whether reported household water fetching times were a risk factor for moderate-to-severe diarrhea (MSD) using case–control data of 3,359 households from the Global Enterics Multi-Center Study in Kenya in 2009–2011. We collected additional global positioning system (GPS) data for a subset of 254 randomly selected households and compared GPS-based straight line and actual travel path distances to fetching times reported by respondents. GPS-based data were highly correlated with respondent-provided times (Spearman correlation coefficient = 0.81, $P < 0.0001$). The median estimated one-way distance to water source was 200 m for cases and 171 for controls (Wilcoxon rank sums/Mann–Whitney $P = 0.21$). A round-trip fetching time of > 30 minutes was reported by 25% of cases versus 15% of controls and was significantly associated with MSD where rain-water was not used in the last 2 weeks (odds ratio = 1.97, 95% confidence interval = 1.56–2.49). These data support the United Nations definition of access to an improved water source being within 30 minutes total round-trip travel time.

INTRODUCTION

Many households in the developing world, especially in rural areas in sub-Saharan Africa, lack piped water or access to nearby community water sources.^{1,2} Long distances must often be traversed to collect water, particularly from an “improved” water source for drinking and other household needs. The fetching of water can represent a substantial physical and economic burden that predominantly affects women and children.^{3–5} Households with travel times greater than 30 minutes have been shown to collect progressively less water.^{6,7} Limited water availability may also reduce the amount of water that is used for hygiene in the household. In a study by Sakisaka and others of a population in rural western Kenya, which largely depends on a single river for household water needs, after the installation of tube wells, respondents reported a decrease in water collection times from 30 to 15 minutes and increased water volume availability and household consumption.⁸ Population access to safe drinking water is an important metric for development and figures prominently in the Millennium Development Goals and post-2015 Sustainable Development Goals (SDG).⁹ The World Health Organization Joint Monitoring Program on water and sanitation states that “Access to drinking water means that the source is less than 1 kilometer away from its place of use and that it is possible to reliably obtain at least 20 liters per member of a household per day.”¹ For the post-2015 SDG’s, access to basic drinking water is proposed to be defined as “using an improved source with a total fetching time of 30 minutes or less for a round-trip including queuing.”¹⁰

We investigated the relationship between the distance to household water sources and occurrence of moderate-to-

severe diarrhea (MSD) in children using data from the Kenya site of the Global Enterics Multi-Center Study (GEMS), a multicenter 3-year case–control study conducted to estimate the burden, etiology, risk factors, and complications of MSD in children < 5 years of age in developing countries.^{11–13} Information on water, sanitation, and hygiene at the household level were collected from respondents for all participating case and control homes as part of the examination of potential risk factors for MSD. This sub-study carried out within the GEMS Kenya site focuses on water fetching. Few studies have examined distance to water source as a risk factor for diarrheal disease, and those that have are generally older, methodologically limited, and lack geographic information systems (GIS)–based distance measurements, which can provide improved precision and objectivity as they do not rely on respondent recall of distance or time. Most studies focused on the benefits of piped water versus other source types, or on comparison points < 30 minutes round-trip fetching time, which do not address the potential risks posed by longer trips, and very few compare different means of measuring distance to water source.^{14,15}

We examined the relationship between the distance from participating case and control households to their water sources and the occurrence of MSD in household residents under 5 years of age participating in GEMS (case or control status). To achieve this, we compared three methods of measuring the water fetching burden: 1) the actual distance as traveled from household to water source measured by study investigators who accompanied household members walking to the water source and recorded the path as GIS data, 2) straight line distances from the household to the water source measured using GIS, and 3) round-trip water fetching time as reported in GEMS by household members.

MATERIALS AND METHODS

Study site. We used case–control data from the GEMS Kenya site from January 2008 to January 2011. The GEMS

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Kenya site was located in rural areas of Gem and Asembo, formerly in Nyanza Province (now in Siaya County), western Kenya, and included six participating sentinel health facilities and a Health and Demographic Surveillance System (HDSS).¹⁶ Cases were children < 5 years of age, who presented with MSD and were enrolled at sentinel health facilities in the HDSS. The methods for determining MSD eligibility and case enrollment procedures are described in detail elsewhere by Kotloff and others.¹¹ In brief, MSD was defined as having three or more loose stools in the previous 24 hours, with onset in the previous 7 days, and having one or more of the following criteria for MSD: loss of skin turgor, sunken eyes, required intravenous fluid rehydration, dysentery (blood in stool), or required hospitalization.¹¹ Control participants were children without a diarrhea illness for at least the previous week, selected randomly from the HDSS, who lived in the same village as case children, or a nearby village, and were the same age and gender; they were enrolled at home by project fieldworkers. GEMS field teams conducted follow-up interviews with the caretakers of enrolled case and control children at their household using a standardized questionnaire. The enrollment questionnaire covered household characteristics including water source types, reported hygiene and sanitation behavior, and observations of wealth indicators and other demographics, and information on the child's health status.¹¹

Sample selection and data types. We analyzed matched case-control data from the GEMS Kenya study, supplemented with additional, more detailed GIS data about water fetching collected from a random subset of households. The GEMS data include 1,476 case-control sets matched 1:1, 1:2, or 1:3 for a total of 3,359 households. From these, we randomly selected 199 cases and one of their corresponding controls (in 398 households) for more detailed GIS data collection by field teams (Figure 1). For logistical reasons, we did not include more than one control per case. For 127 of

these pairs, both the case and control participants were successfully located at their homes and available to participate in the GIS distance sub-study. For all 127 household pairs, global positioning system (GPS) coordinates were collected for the household and its main drinking water source. It is typical in this area for multiple family members to live in a common household compound and share resources such as water sources. If the water source was located at the family household or compound, GPS coordinates were captured there. This was the case in 90 (35%) of 254 household follow-up visits. If the household's water source was located beyond the immediate family compound's area, field teams asked a family member, if it was feasible, to guide the team to their water source, and the path traveled was recorded as vector data using handheld GPS devices. This was done for 113 (44%) household follow-up visits. If the family was present but unable to guide the team to the water source for some reason, such as being occupied with a household task, coordinate data for the water source were captured. Since the field staff included members of the community who were familiar with local water sources, participants who could not travel to the source were able to verbally indicate the source to the team. This was the case for 51 (20%) household follow-up visits. GPS data were recorded on Trimble® Geo-Explorer 3 and GeoXM devices (Sunnyvale, CA).

Analysis variables and statistical methods. We used the two GIS-based measurements described above for sources outside the compound to calculate an exposure variable for household distance to water source. The first of these measures was GIS-calculated distance of travel along the path to the water source. This value was measured as the distance in meters of the walked path as described above when available. All path data were overlaid on satellite imagery using Google Earth and manually reviewed for potential errors.

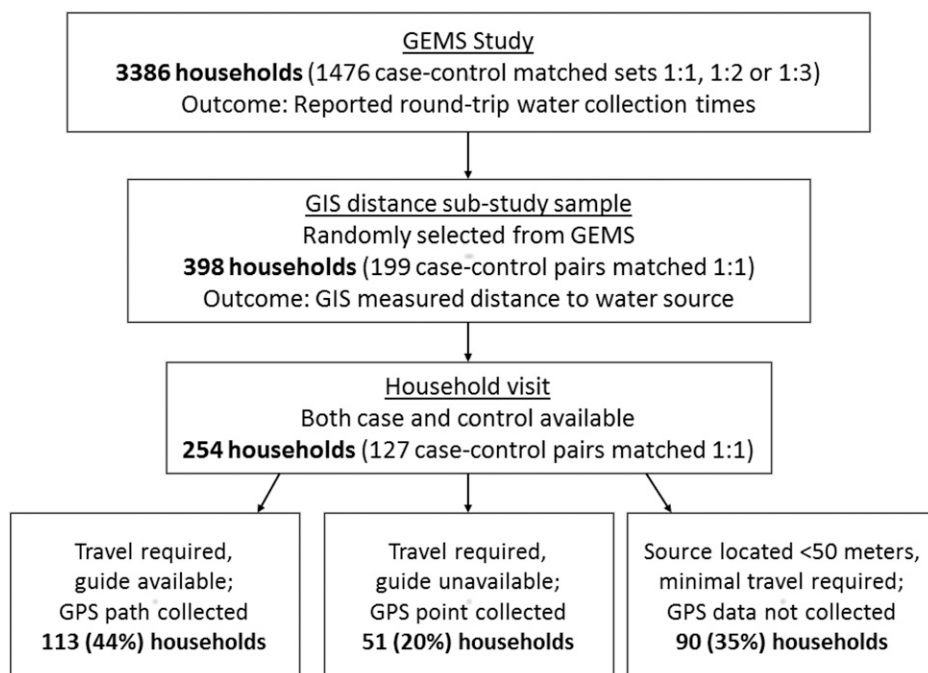


FIGURE 1. Sampling for geographic information systems (GIS) distance sub-study.

The second type of measurement was Euclidean distance and was used when the family was unavailable to guide the field team, and coordinate data were recorded for the water source. Where the household member was unable to travel, we calculated an estimated actual distance using the straight line distance from the house to the water source multiplied by the median of all of the values of each measured walked path's distance divided by its straight line distance. The median value of measured walked paths divided by their respective straight lines was equal to 1.17. For example, if a household did not have a path available and its direct length was 100 m, we estimated the actual travel distance to be 117 m ($100 \text{ m straight line} \times 1.17 = 117 \text{ m estimated distance}$). Thus, the two measurement types (walked paths and adjusted estimates based on Euclidean distance) were combined to form a single, best-estimate distance formula (Figure 2).

The third type of measure we used for distance to water source was total time needed to travel and fetch water reported by the respondent. This is a categorical variable of the round-trip water fetching time based on the question, "How long does it take to go there, get water and come back?" Response options included the source is located at house, < 15 minutes, 15–29 minutes, 30–59 minutes, 1–3 hours, and > 3 hours away. This question was asked of all 3,359 participating households. We also calculated elevation difference between the household and the water source using a digital elevation model at 30 m resolution, available from National Aeronautics and Space Administration Jet Propulsion Laboratory.¹⁷

To translate GIS-calculated distances into time ranges comparable with reported fetching times, we also created a categorical variable from the GIS-calculated distance to approximate the same categories reported by household respondents using 4 km/hour walking rate and a value of 5 minutes for the time needed to access the source and fill water containers.

Scarce data are available on travel rates of people fetching water in this setting; we used a value of 4 km/hour walking speed because 5 km/hour is a commonly cited average adult walking speed in developed countries, without the encumbrance of unpaved terrain and water containers or collection vehicles such as carts.¹⁸ We felt that because of such encumbering factors and because children frequently participate in water fetching, a lower figure was appropriate. GEMS field data collectors logged their times at the start and finish of path data collection for the GIS distance sub-study. Terrain varies from gentle hills with moderate underbrush in the Gem area to relatively flat in the Asembo area, which is closer to Lake Victoria, with seasonal rivers and subsistence agriculture common. The median rate of travel for GEMS field teams while walking the paths was 3.87 km/hour. One recent study of water fetching in Mozambique used a value of 3.75 km/hour.¹⁹ Clearly some households required more than 5 minutes at the water source for drawing water, so our estimate of the time at the source was intended to represent a plausible amount of time in the low end of the range expected to be needed for filling containers, pumping water, or otherwise accessing the source and to avoid possible overestimation of the burden of fetching times.

Using the subset of GEMS data for the GIS distance sub-study in 127 case-control pairs (254 households), we performed a descriptive analysis including three measures: a calculated combined best estimate of the distance from household to water source in meters based on GIS-measured paths or adjusted straight line distances (whichever could be measured, as described above), this calculated distance from household to water source categorized by the estimated distances needed to match the reported fetching time categories and the actual reported fetching times provided by respondents. We used a Wilcoxon rank sums test to evaluate the difference of medians of the GIS-based distance estimates

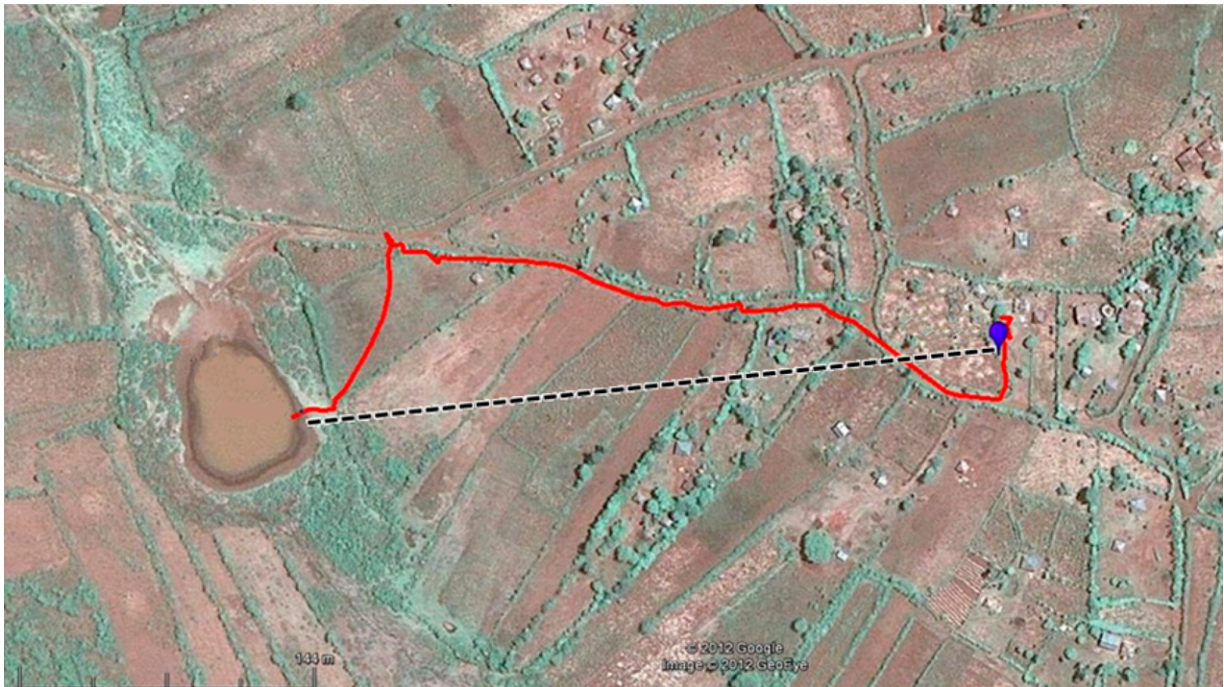


FIGURE 2. Example of path and vector data of distance from household to water source.

between case and control households. We calculated the Spearman correlation of reported fetching times and GIS-measured distances.

Using the full GEMS Kenya data set of 3,359 households, we generated conditional logistic regression models of MSD with water fetching time. Water fetching time was defined as the reported time for round-trip water fetching classified using a 30 minute cutoff as a risk factor for MSD using conditional logistic regression. We assessed several demographic, socioeconomic indicators, water, sanitation, and hygiene variables collected in GEMS as potential effect modifiers of water fetching. In addition, we specifically assessed potential age group (0–11, 12–23, and 24–59 months) interactions and report stratified results if needed.¹² We included any interaction terms significant at $P < 0.05$ in the multivariable model and evaluated additional covariates as potential confounders by assessing effect size changes of 10% or greater. Covariates considered included reported main water source type and water sources used within 2 weeks, water fetching frequency, whether water was stored, household water treatment or disinfection methods, feces disposal and handwashing practices, access to latrine facilities, presence of both parents in the home, educational level of the child's primary caretaker, presence of animals (rodents, cows, sheep, fowl, dogs, and cats) in the compound, and age and socioeconomic variables. We used three wealth index classifications based on the principal component analysis: electrical assets, transportation assets, and improved household features. Matched odds ratios (mOR) and 95% confidence intervals (CI) for multivariable modeling of self-reported time to water source are presented in Table 1. Analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC) and ArcGIS 10.2 (ESRI, Redlands, CA). The GEMS study protocol was reviewed and approved by the Scientific and Ethical Review Committees of the Kenya Medical Research Institute (KEMRI protocol no. 1155) and the Institutional Review Board (IRB) of the University of Maryland, Baltimore, MD (UMD protocol no. H-28327). The IRB for the Centers for Disease Control and Prevention (CDC), Atlanta, GA, deferred its review to the UMD IRB (CDC protocol no. 5038). Informed consent was obtained from the parent or guardian of each child before performing study procedures.

RESULTS

GIS-calculated distance measurements and estimated travel times. We collected and analyzed detailed GIS data for 127 from a random sample of 199 GEMS case-control pairs. For 72 case-control pairs, at least one of the household pairs had relocated or was otherwise unavailable to participate (there were no refusals). The median GIS-estimated distance to water source was 194 m overall, 200 m among cases (max-

imum = 1,768 m) and 171 m among controls (maximum = 1,440 m), with a Wilcoxon rank sums $P = 0.21$ (Figure 3). To compare with the reported water fetching times categories, we also included the GIS-calculated distances categorized as expected times required for travel (Table 2). The majority households of both cases ($N = 76/127$, 60%) and controls ($N = 89/127$, 70%) had GIS-calculated distances to water source in the lowest two categories of estimated travel time; either the source was located adjacent to the house or within 15 minutes estimated travel time. In the farthest categories of our GIS-calculation-based estimate of time required to fetch water, the majority were cases, with 12/127 (9%) cases versus 5/127 (4%) controls beyond the distance we estimated for a 30-minute round-trip (conditional logistic regression OR = 2.75, 95% CI = 0.88–8.64; $P = 0.08$). Continuous GIS-calculated distance was significantly correlated with the reported round-trip water fetching time provided by respondents in the full GEMS data set, with a Spearman correlation coefficient of 0.81 and $P < 0.0001$. The median elevation difference for both cases and controls was 15 m (maximum = 67 m).

Reported fetching times by respondents. The GEMS study collected enrollment data for 1,475 matched case-control sets in 3,358 households by interview (one respondent among the 3,359 enrollments did not provide a response for the question about the water source use). The majority of respondents for cases ($N = 916/1,475$, 62%) and controls ($N = 1,274/1,883$, 68%) reported that their household was located adjacent to or within 15 minutes travel time of their water source (Table 2). More respondents in case households reported travel times over 30 minutes ($N = 371/1,475$, 25%) than controls ($N = 290/1,883$, 15%). Reported time was significantly associated with MSD in a single categorical exposure model at $P < 0.0001$. A binary 30-minute cutoff time to water source was significantly associated with MSD as a bivariable risk factor at $P < 0.0001$, with an OR of 1.84 (1.54–2.21).

Multivariable regression analysis of reported fetching times. We reviewed 88 covariates captured in the GEMS case and control enrollment questionnaire for interaction and confounding with water fetching. Any reported use of rainwater in the 2 weeks before the caretaker interview was identified as an effect modifier. Reported round-trip water fetching times greater than 30 minutes were significantly associated with MSD (mOR = 1.97, 95% CI = 1.56–2.49) where rainwater was not used as one of the household water sources in the last 2 weeks (Table 1). The association between water fetching times and MSD was not significant where rainwater was used. No confounders were identified by assessing effect size changes of 10% or greater. Multicollinearity was not observed in the model. Therefore, the model included the rainwater interaction, and stratified results are reported. Although wealth and educational level of the caretaker were not identified as confounders, these were

TABLE 1
Multivariable modeling results for reported 30 minute or greater round-trip fetching times*

Exposure	N	OR (95% CI)
Water fetching	3,358	1.84 (1.54–2.21)
Stratified results		
Water fetching, no reported use of rainwater in last 2 weeks	1,436	1.97 (1.56–2.49)
Water fetching, reported use of rainwater in last 2 weeks	1,922	0.98 (0.70–1.37)

CI = confidence interval; OR = odds ratio.

*Self-reported, 30 minute or greater round-trip water fetching time exposure modeled for outcome of moderate-to-severe diarrhea.

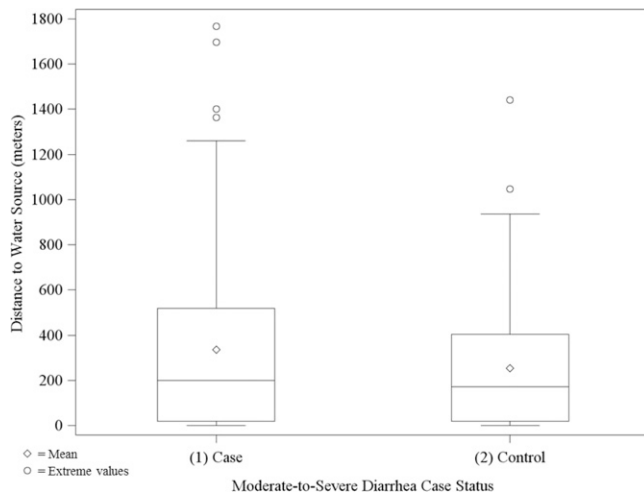


FIGURE 3. Distribution of geographic information systems-calculated distances from household to water source by case and control status ($N = 254$; 127 case-control pairs).

included in a model for comparison purposes; the change in mOR was negligible.

DISCUSSION

Summary. Using GEMS data, we sought to describe the burden of water fetching in rural western Kenya, compare different means of measuring distance from households to their water sources, and assess the association between distance to water source and MSD. On the basis of both objective GIS-based measures and travel times provided by respondents, most households were able to use a water source with a round-trip collection time of less than 15 minutes. About three times as many case households compared with controls reported round-trip collection times greater than 30 minutes, and over twice as many had GIS-measured distances farther than about 833 m (the distance we estimated to take at least 30 minutes round-trip). We found that a reported water fetching time greater than 30 minutes round-trip was significantly associated with MSD in households that did not include rainwater collection (typically done at the

household) in their water sources (mOR = 1.97, CI = 1.56–2.49). This association was true when evaluating covariates that, if included in the model, would result in > 10% change in the OR of the main effect (though none were identified). Hereby, we describe the effects for users of rainwater, which were not significant. Households using rainwater collection could represent a distinctly different water fetching pattern, potentially leading to different transmission routes or protective circumstances. Rainwater collection is typically done at the residence using catchments from roofs. During rainy periods, water is often abundant in the household, which may affect storage practices and increase availability for hygiene purposes. This may also reduce or eliminate the need for fetching water from surface water sources, which could be subject to environmental contamination from human excreta and runoff from agricultural activities. Rainwater is also subject to contamination, but since raised containers are often used, the pattern of contamination is likely different; potential concerns with rainwater collection systems include contamination from animals present on rooftops (e.g., birds or rodents), decomposition of organic material (e.g., thatch), and algal growth.²⁰ Analyses of the containers have shown distributions of pathogenic microbes in rainwater collection systems, though the risk to human health is less than clear.^{21,22} A systematic review found that, in a pooled analysis, rainwater was associated with a reduced risk of illness compared with unimproved sources.²³

Comparing distance measurement methods. By using a random subsample within GEMS for the GIS water fetching sub-study, we sought to better understand different measurement methods of water fetching burden. This information could be useful in interpreting respondent-provided data and planning data collection efforts. Our data suggested that both GIS- and interview-based measures are useful, though characteristics of the study setting should be carefully considered in comparing these types of data.

Comparisons of different GIS data types should account for local terrain and geography. The difference between the length of a path from a household to its water source over a travel network (e.g., a road or trail) and the length of a straight line distance between the same end points provides a measure of the impediments posed by geographic features. Terrain in this study area varies from moderately hilly to flat,

TABLE 2
Reported round-trip fetching times and GIS-measured distances to water source

Reported time		Cases ($N = 1,475$) n (%)	Controls ($N = 1,883$) n (%)	Total ($N = 3,358$) n (%)	OR (95% CI)
No travel		542 (37)	769 (41)	1,311 (39)	Referent
< 15 minutes		374 (25)	505 (27)	879 (26)	1.05 (0.86–1.28)
15–29 minutes		188 (13)	319 (17)	507 (15)	0.88 (0.70–1.10)
30–59 minutes		248 (17)	233 (12)	481 (14)	1.53 (1.21–1.93)
1–3 hours		119 (8)	57 (3)	176 (5)	2.96 (2.05–4.25)
≥ 3 hours		4 (< 1)	0	4 (< 1)	–
Estimated travel time for distance (minutes)	GIS distance (meters)	Cases ($N = 127$) n (%)	Controls ($N = 127$) n (%)	Total ($N = 254$) n (%)	OR (95% CI)
Minimal	< 50	42 (33)	48 (38)	90 (35)	Referent
< 15	50–333	34 (27)	41 (32)	75 (30)	0.87 (0.44–1.72)
15–29	334–833	39 (31)	33 (26)	72 (28)	1.45 (0.72–2.92)
30–59	834–1,833	12 (9)	5 (4)	17 (7)	3.19 (0.96–10.53)
≥ 60	≥ 1,834	0	0	0	–

CI = confidence interval; GIS = geographic information system; OR = odds ratio.
*Round-trip at 4 km/hour with 5 minutes spent at water source.

but is typically passable on foot with few major natural obstructions such as dense foliage or large geological features. Evaluation of individual path vectors over satellite imagery suggests required deviations from a straight path to the source were minor, such as around a fenced agricultural establishment (Figure 2). In our GIS data, paths were not substantially longer than straight line distances, with a median 17% difference. Collecting path data was resource intensive, since it required travel over specified routes, involvement of household members, and additional GIS capability beyond simply capturing point coordinates. In circumstances with similar terrain and limited expected difference between straight line and path distance values, point data collection could likely be a reliable, objective approach. We also calculated a median elevation change of only 15 m difference between households and sources, but this figure only represents a net difference rather than total elevation change over travel along the route, which would be a more revealing measure about the required effort and energy expenditure.

Fetching times provided by respondents are more efficient to collect but are subject to bias. This study was conducted in a rural, predominantly agricultural area in one region of Kenya. It may not be common to use a clock to track time spent on various activities. Furthermore, it has been shown that time perception can vary for some activities, such as waiting in line, across a range of settings and is subject to overestimation of recalled travel times associated with increasing distance.^{24–26} Thus, it was of interest to compare reported water fetching times with an objective measure provided by GIS. In our analysis, reported water fetching times correlated strongly with our subset of objective GIS-based measures. We felt this supported the validity of using reported water fetching times in multivariable analysis, as these data are available for a much larger proportion of GEMS households. This is in contrast to another study that found poor correlation of recall-based versus objective measures of distance or time to water source in Mozambique.¹⁹

Limitations. The outcome variable in our analysis of reported water fetching times was categorical. Thus, it was not possible to evaluate thresholds smaller than 15 minutes. It is possible that using finer categories would reveal additional, more detailed information about an association with MSD. However, recalling smaller, more precise categories may present a challenge for some respondents. GPS data, while objective and precise, is labor intensive and logistically challenging to collect compared with interview-based measures; this constrained the size of our random sample. In this study, we collected GPS measurements for a subset of 254/3,359 (7.6%) study households. A separate household visit was required to collect GPS data; in some instances, this occurred several months after the original visit. Some randomly selected households that were unavailable for GIS data collection may have differed from those that were able to participate, which could introduce bias (e.g., by missing some households that were potentially affected by socioeconomic conditions potentially requiring the household to migrate elsewhere). Our GPS data are continuous, but with the exception that source inside and adjacent within 50 m of the compound are categorized in a single group. This limited our ability to compare associations for sources within compounds with those just outside the compound. Although our observed correlation between reported times and observed distances supports the

validity of the self-reported measure, the accuracy of recall of fetching times is not fully addressed by evaluating distance; it does not account for total time spent fetching water, which could vary substantially due to differences in travel rates during an actual water fetching trip, slower travel during the return portion compared with an unburdened trip, time spent at queues at the water source, collection means (e.g., use of a cart compared with hand-carried containers), and differing speed of the person fetching. Though a direct comparison is not possible with these two data types, respondents generally reported longer fetching times than distance-based time estimations. The most accurate and comprehensive measurement methods would probably be structured observation during water fetching or the use of sensors in containers used for water fetching. Such assessments would likely contribute valuable information about comparisons of measures of water fetching burden, but have limited feasibility in large studies as they are very resource-intensive, even compared with GIS methods such as those used in our study. The generalizability of our findings is also limited since the data are from one region in Kenya.

CONCLUSIONS

Our GIS analysis suggests that, in terrain similar to these areas in western Kenya, coordinate data for straight line analyses may be sufficient for analyzing distance to water source. It is encouraging that respondent-provided times appeared trustworthy in these data and may be useful for certain analyses of distance-based risk compared with more labor-intensive GPS methods, since this measure is straightforward to collect and notably is included in Demographic Health Surveys (DHS).²⁷ Analyses of DHS data have suggested increased distance to water source is associated with negative childhood health outcomes including diarrhea.²⁸ Utilizing measures of both distance and time for a round-trip would provide the most complete assessment of water fetching burden.

Our findings support the perception that reported water fetching times greater than 30 minutes increases risk of diarrheal disease and highlight the importance of considering distance from household to water source in classifying access to improved water sources. Further comparisons of methods of measuring distance to water source and time spent fetching water could improve the full range of understanding of this burden for many households in the developing world. Successful development efforts to reduce the burden of household water fetching would likely provide a range of economic and health benefits, of which the potential for reduced diarrheal illness in children is just one.

Received May 26, 2015. Accepted for publication January 21, 2016.

Published online February 29, 2016.

Acknowledgments: This study includes data generated by the Kenya Medical Research Institute/Centers for Disease Control and Prevention (KEMRI/CDC) Health and Demographic Surveillance System (HDSS), which is a member of the International Network for the Demographic Evaluation of Populations and their Health (INDEPTH). We acknowledge the contributions of and thank the KEMRI/CDC HDSS team; the Global Enteric Multicenter Study (GEMS) Kenya staff for supporting the data collection and processing; the GEMS Data Coordinating Center, Perry Point Veterans Administration Medical Center, Perry Point, MD; and Jeff Switchenko and Katharine Schilling for analytical support. We are grateful to the caretakers in the Asembo and Gem Community who participated in this work. This manuscript is published with the approval of the director of KEMRI.

Financial support: The GEMS study was funded by the Bill & Melinda Gates Foundation through the University of Maryland School of Medicine and Center for Vaccine Development, Baltimore, MD. Additional support for technical assistance with this sub-study was provided by the U.S. Agency for International Development through an Inter-Agency Agreement with the U.S. Centers for Disease Control and Prevention.

Disclaimer: The findings and conclusions in this report are the findings and conclusions of the authors and do not necessarily represent the official position of the U.S. Centers for Disease Control and Prevention.

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