The challenge of global water access monitoring: evaluating straight-line distance *versus* self-reported travel time among rural households in Mozambique

Jeff C. Ho, Kory C. Russel and Jennifer Davis

ABSTRACT

Support is growing for the incorporation of fetching time and/or distance considerations in the definition of access to improved water supply used for global monitoring. Current efforts typically rely on self-reported distance and/or travel time data that have been shown to be unreliable. To date, however, there has been no head-to-head comparison of such indicators with other possible distance/time metrics. This study provides such a comparison. We examine the association between both straight-line distance and self-reported one-way travel time with measured route distances to water sources for 1,103 households in Nampula province, Mozambique. We find straight-line, or Euclidean, distance to be a good proxy for route distance ($R^2 = 0.98$), while self-reported travel time is a poor proxy ($R^2 = 0.12$). We also apply a variety of time- and distance-based indicators proposed in the literature to our sample data, finding that the share of households classified as having *versus* lacking access would differ by more than 70 percentage points depending on the particular indicator employed. This work highlights the importance of the ongoing debate regarding valid, reliable, and feasible strategies for monitoring progress in the provision of improved water supply services.

Key words | Africa, GIS, monitoring, Mozambique, water access, water fetching

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INTRODUCTION

As of 2012, almost half of the world's population must still leave their home to fetch water (WHO/UNICEF 2012). Roughly three-quarters of those fetching water outside the home are classified as having access to improved water supply as per the definition used by the United Nations–World Health Organization's Joint Monitoring Program (JMP) (WHO/UNICEF 2012). As many scholars and practitioners have noted, however, this definition considers only whether the household reports using an improved source (WHO/UNICEF 2012), and is not dependent on the distance between the household and the source, nor on the time costs of water fetching for household members (Hunter *et al*. 2010; Clasen 2012; WSMP Ghana 2012). Recent research indicates that the time spent walking to water is significantly associated with health outcomes (Wang & Hunter 2010; Pickering & Davis 2012). For example, Pickering and Davis find that a 15-minute decrease in one-way walk time to water source is associated with a 41% reduction in diarrhea prevalence, improved child nutritional status, and an 11% reduction in under-five child mortality. Other research has documented the effect of lengthy walks to water sources on the risk of gender-based violence (Shah 2002; Kirchner 2007; Ivens 2008; Sorenson *et al*. 2011; Thompson *et al*. 2011), as well as of injury from physical stress to joints and from accidents (Ivens 2008; Sorenson *et al*. 2011). Taken together, these findings suggest that incorporating time and/or distance considerations in the definition of access to improved water would better reflect the public health goals of the sector.

Whereas it has been acknowledged that incorporating distance or time to water source in the JMP's metric would be desirable (WHO/UNICEF 2000; UNDG 2003;

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Hunter *et al.* 2010), feasible field measurement capability of water fetching distances has been limited. The most accurate measures would require *in situ* field measurement, with an enumerator either measuring household-to-source distances manually (White *et al.* 1972) or accompanying each respondent on the walk to his/her water source (Pickering *et al.* 2011). These approaches are costly to apply on a large scale. Much more commonly, researchers ask household members to estimate the travel time (WHO & UNICEF 2006; ICF International 2011) or the distance (Demeke 2009) to their water source during an in-person survey. These strategies have documented biases and limitations (Nyong & Kanaroglou 1999; Buor 2004).

More specifically, self-reported measures of time often suffer from recall bias (Shiffman 1999). Biasing processes are prominent during self-reported recollections, as memory is distorted by interpretation processes influenced by the respondent's current state (Bradburn *et al.* 1987; Gorin & Stone 2001). Kahneman *et al.* (1982) argue that this bias is based on the availability of instances in memory when one is asked to recall specific events. A respondent who is asked to estimate water fetching travel time, for example, may more easily recall instances in which he/she explicitly took note of the travel time; these might be trips that took longer than normal, potentially biasing his/her responses. The key finding by Niemi (1993) that the accuracy of survey measurements depends critically on factors of memory supports this assertion. We are aware of only one other published study that assesses the accuracy of self-reported water fetching time. Using global positioning system (GPS) route data to measure fetching time, Davis *et al.* (2012) find that households in informal settlements in Kenya frequently overestimated their fetching time, despite spending less than 10 min total and traveling less than 400 meters on average. Together, this evidence suggests that using self-reported indicators of water fetching distance is not optimal.

In other fields, distance has been estimated *ex situ* with a geographic information system (GIS), rather than being measured *in situ* or estimated with household survey data. For example, GIS-measured estimates such as Euclidean distance and shortest-route distance have been used in identifying populations with poor access to health services (Love & Lindquist 1995; Bamford *et al.* 1999). Euclidean distance refers to the straight-line distance measured between two points. In this work, we investigate the applicability of straight-line distance between a household and its water source for measuring access to water supply (Figure 1).

Studies evaluating the efficacy of straight-line distance are not uncommon. Apparicio *et al.* (2008) find that straight-line distance is strongly correlated with distance as calculated based on a road network. Their findings are similar to those of Fortney *et al.* (2000), who find that Euclidean distance explains more than 90% of travel time to health providers in the United States. However, most studies evaluating straight-line distance have been conducted in the context of health care access rather than access to water supply; they have also been focused in urban areas with well-developed road networks. To our knowledge, there has been no study of the effectiveness of straight-line distance as a proxy for distance to water source in rural areas lacking road networks.

This is not to say that straight-line distance is not important for water supply planning; indeed, it is regularly used in siting water points. For example, it is common to draw a circle around a planned water point location and use

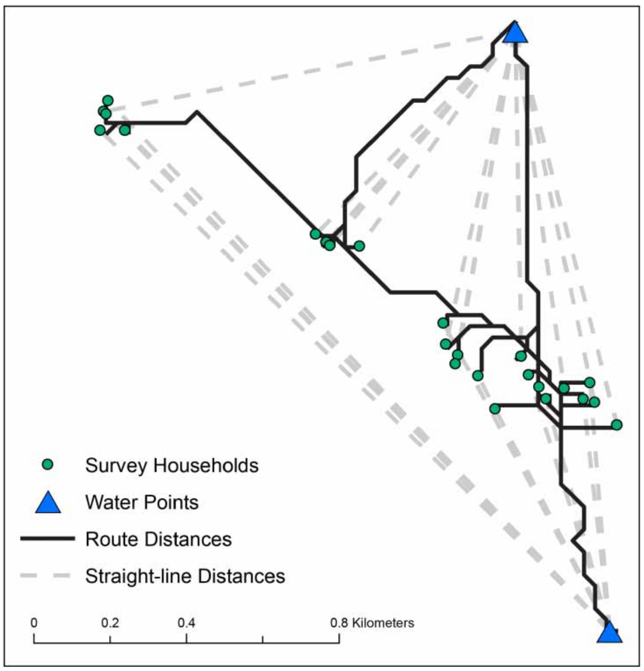

Figure 1 | Straight-line and route distances for households in one sample village.

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straight-line distance to ensure that intended beneficiary households lie within the distance as specified by sector policy (e.g., 500 meters or 1 kilometer). In addition, straight-line distance was once used to monitor access to improved water supply. Surveyors would simply count the number of households that lay within the specified distance of a water point and classify them as having access. Such practices were criticized for over-estimating access, however, because they assumed that all households located near the water point made use of it. Direct interview of household members about which water source(s) they use has become the preferred method of data collection for global monitoring of access.

This type of interview data is generally viewed as being valid and reliable with regard to household water source choice and water use. As discussed above, however, self-reported information about distance or travel time to a water source is likely to suffer from various types of bias. Recognizing that support is growing for the inclusion of such a distance or time measure in the definition of water access in the post-2015 period, this study explores the feasibility of using straight-line distance for global access monitoring.

METHODOLOGY

Data used in this study were collected from households in rural and peri-urban communities in the province of Nampula, Mozambique (Figure 2). Nampula's terrain is homogenous throughout the province, with 99% of the province classified as sandy topsoil (Food and Agricultural Organization 1974). This homogeneity in soil type is corroborated by household responses describing the terrain on their water fetching route: 76% of households indicate that their route's terrain is sandy. The slope along fetching routes also does not vary much, with a median slope in study areas of 2.9° as calculated from a digital elevation model (ASTER GDEM 2011). A study by Finley & Cody (1970) of urban pedestrians found that slopes up to 4° induce no change in walking pace. For this reason, and also partly due to difficulty in characterizing steepness of slope along water fetching routes, we do not consider slope in our analysis.

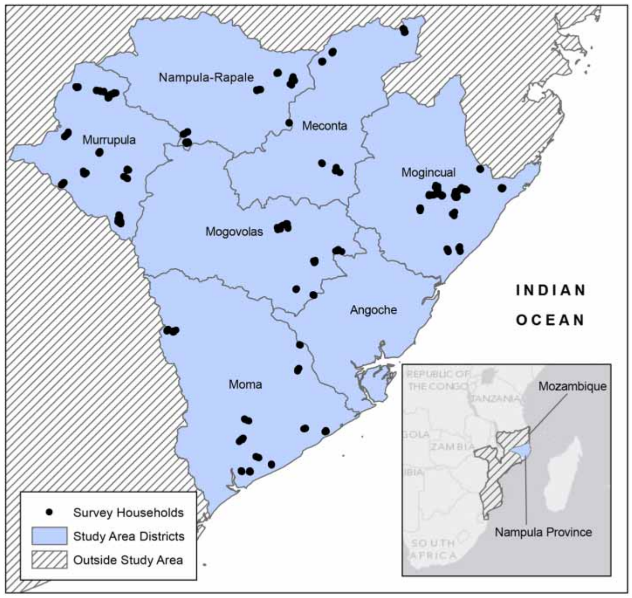

Figure 2 | Study area in Nampula province, Mozambique. Black dots represent communities. Inset map shows Nampula's location relative to Mozambique and Africa as a whole.

Data collection

This study uses data collected in June 2011 for a larger investigation into the impacts of rural and peri-urban water investments. A total of 54 clusters of households in six districts were selected at random; 1,606 households (approximately 27 to 30 households per cluster) were surveyed in all. Enumerators followed randomly determined transects within each of the 54 communities and selected every second or third household to be interviewed. Respondents were male (61%) or female (39%) heads of household. Informed consent was obtained from all participants, and the study protocol was approved by the Institutional Review Board of Stanford University, California, USA and the National Statistical Institute of Mozambique.

Each respondent was asked to identify the primary water source used by his/her household at the time of survey, and enumerators took GPS coordinates of each sampled household and all shared water points in each study community. Among sampled households, 503 (31%) reported using a primary water source other than a community water point, and/or a source for which GPS coordinates were not obtained. Given the objectives of this study, these households were removed from the dataset, leaving 1,103

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households. In addition, in order to identify the paths used to reach water sources in each community, enumerators collected GPS track data as they were escorted to each water point by local leaders. These GPS track data did not include all paths in each community; they therefore provide an incomplete picture of the true paths available for water fetching in these communities.

As a result of the incomplete GPS track data, we estimated water fetching distance using paths digitized from freely available, high-resolution satellite imagery. Satellite imagery has previously been used in estimating water fetching routes (Davis *et al*. 2012). As of March 2012, Google Earth provided 2.5 m resolution SPOT satellite imagery for all of the sites in our study area and sub-meter resolution DigitalGlobe or GeoEye imagery for 24 (44%) of our sites (Google Inc. 2012). The dirt paths and roads in these communities were visible via satellite imagery, so these paths were digitized and then used to determine and measure the shortest route from each household to its water source. For each satellite image used to digitize paths for a community, we recorded the landscape type (e.g., completely forested) and the image resolution (i.e., high (sub-meter) or low (2.5 m)). Twenty-eight percent of sites were completely forested, 17% partially forested, 40% with sparse shrubs and 15% were peri-urban. Once digitized, the paths were assessed for accuracy relative to the travel paths captured by enumerators with GPS track data. Over all study communities, the digitized paths overlapped with 82% of the total distance within the GPS track data. The majority of the uncaptured paths were not critical to the analysis: for example, they included the path between the community entrance and the local leader's house, which was often unrelated to paths between households and water points.

We used a least-cost path method in ArcGIS 10 to estimate the route from each household to its reported primary water point (ESRI Inc., Redlands, CA, USA). We created a 30-meter resolution cost raster in which path cells were assigned a low cost and other cells were assigned an arbitrarily high cost. This approach ensured that the identified least-cost route would extend from the household to the closest digitized path, and then along that path to the water point. Tanser *et al*. (2006) employ a similar method to model travel time to health clinics in rural South Africa. Straight-line and route distances for one of the sample communities are shown in Figure 1.

Analytical methods

We compare the water route estimations from satellite path data to straight-line distances using ordinary least squares (OLS) regression. We then use the residual value between the two distance measures as the dependent variable in a second OLS model designed to identify the factors associated with comparatively good (or poor) predictive accuracy. Using the same methods (OLS regression plus modeling of residuals), we compare self-reported one-way travel time with route time estimates calculated from route distance. We estimate route time from route distance using a typical walking pace as reported for the region in published literature. A conversion factor of 62.5 m/min was used as the typical walking pace for the region, calculated from the average of 41.5 m/min (2.5 km/h) (Tanser *et al*. 2006) and 83.3 m/min (5 km/h) (Calvo 1994). As before, we model the residuals (i.e., absolute value of the difference between self-reported time and estimated travel time) using multiple OLS regression to evaluate the factors associated with better (or worse) prediction.

For both models, we expect the accuracy of the indicator to depend on the robustness of the route estimation method vis-à-vis variations in satellite image landscape and resolution. We therefore include both parameters in each model to distinguish between the performance of the indicators and systematic errors in the route estimation method. The distance model also includes straight-line distance as an independent variable to test whether the prediction accuracy varies with indicator magnitude.

The time model includes household and respondent characteristics that we hypothesize may influence the accuracy of self-reported travel time, including respondent education, age, and gender, household wealth, and cell phone ownership. We also include three indicators related to water fetching practice: the share of total fetching time spent queuing (as opposed to walking), whether fetching is typically undertaken alone or with a companion, and the number of person-trips for water fetching taken each week by the respondent. Route slope and terrain may also contribute to self-reported travel time accuracy, but as noted above, the study communities are

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characterized by limited variation in slope and terrain. We have thus omitted these indicators from all models.

We include respondent education, age, and gender, as well as household wealth, to test whether socioeconomic factors influence the prediction ability of respondent time estimates. An array of literature suggests that such factors are associated with the accuracy of recall (Ferber 1965; Butler *et al.* 1987; Mathiowetz & Duncan 1988; Niemi 1993; Beckett *et al.* 2001). We included a simple educational attainment dummy variable that takes the value of 1 if the respondent completed any formal schooling and 0 otherwise. We measured wealth similarly with a dummy variable that takes the value of 1 if the respondent's household owns both a bicycle and a radio, and 0 otherwise. We include cell phone ownership in the model to test the hypothesis that the clocks on mobile phones may make respondents more aware of the time spent on daily activities. We also hypothesize that increased share of fetching time spent queuing (as opposed to walking) decreases the respondent's prediction ability, owing to respondents potentially conflating long queue time with long walk time when recalling fetching experiences. Finally, we include in our time model the presence of a companion while fetching, expecting that respondents who fetch alone may be better able to estimate their one-way travel time. A study by Niemi (1993) reported that activities that are clearly distinct from others (i.e., with no overlap in purpose) produce more accurate results in time surveys. Thus, if water fetching is combined with socializing, we might expect survey responses regarding the time spent on water fetching to be less accurate.

RESULTS

Among the 1,103 households included in our final sample, the mean number of people in the household was 4.1 (median of 4.0). Twenty-five percent of households reported owning both a bike and a radio while only 6% of households reported owning a cell phone. The average respondent age was 40, and 58% of respondents reported having completed at least some formal schooling. Sample households use an average of 23.2 liters of water per capita per day (median of 19.9). The 577 respondents who fetched water for their households took an average of 13 trips per week; almost half (45%) of the total time spent water fetching was spent queuing, as opposed to walking to and from the source. Of the respondents, 332 (58%) reported fetching water alone *versus* with others. Forty-one percent of sample households reported using more than one domestic water source at the time of interview, an average of 1.4 sources per household overall. For 64% of households, the primary source (from which the greatest share of water was obtained) was a shallow hand-dug well (*poço traditional*); 22% used a deep (mechanically drilled) borewell (*furo*), and 14% fetched water from a river or lake.

Using satellite imagery and the distance estimation methods described in the section 'Data collection', the average one-way water fetching route distance for sample households was 925 m (standard deviation, SD = 988 m) and the average straight-line distance was 726 m (SD = 759 m) (Table 1). The average self-reported one-way travel time from the survey was 48.5 min (SD = 53.2 min). In contrast, the average one-way route time as calculated from

Table 1 | Summary statistics for distance and time metrics and model-dependent variables

		Mean	Standard deviation	Median	Range
A	Route distance from satellite path data (m)	925	988	656	1.5–7,200
B	Straight-line distance (m)	726	759	506	1.5–5,500
C	One-way route time from route distance using literature conversion (62.5 m/min) (min)	14.8	15.8	10.4	0–116
D	Self-reported one-way travel time (min)	48.5	53.2	30	1–540
E	Self-reported queue time (min)	81.4	120	30	0–1,440
Model-dependent variables					
Distance model: A minus B (m)		202	275	115	6.3–2,600
Time model: Absolute value of D minus C (min)		25.8	40.1	14.8	0–450

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route distance (using the conversion factor based on typical walking rates in the literature) was 14.8 min (SD = 15.8 min).

Straight-line *versus* self-reported measures

As shown in Figure 3(a), straight-line distance performed very well as a predictor of route distance overall ($R^2 = 0.98$). However, the slope of the regression line implies that straight-line distance under-predicts route distance by an average of 23%, which translates to a distance of 202 m (SD = 275 m). By contrast, self-reported one-way travel time is a poor predictor of route distance among sample households (Figure 3(b), $R^2 = 0.12$). No systematic over- or under-estimation is observed in these data.

Models of indicator accuracy

Table 2 presents the results of a multiple linear regression model of the difference between the two distance measures. Both variables used to test the robustness of the route estimation method are significant in the model. Using a high resolution satellite image (sub-meter *versus* 2.5 meter) when digitizing paths for route estimation is associated with a 77 m improvement in prediction on average ($p < 0.01$). Having a landscape covered in sparse shrubbery (as compared to a peri-urban landscape) is similarly associated with a 59 m improvement ($p < 0.01$), while a completely forested landscape is associated with a 51 m worsening in average prediction ($p < 0.01$). Straight-line distance itself is also significant; each 100 m increase is associated with a 29 m worsening in prediction on average.

The results of the time model are shown in Table 3. None of the socioeconomic indicators (respondent education, gender, age, or household wealth) was found to have a statistically significant effect. Share of fetching time spent queuing (queue time share) is significant ($p < 0.01$); however, contrary to expectations a 10% increase in queue time share is associated with a 5 min improvement in prediction by respondents on average. In other words, if two respondents each spend a total of 60 min fetching water, but one respondent spends 30 min queuing and the other spends 36 min queuing, the respondent who spends more time queuing is 5 min better in his/her walk time prediction, all else held constant. Three-quarters of sample households spend between 4 and 85% of their total fetching time queuing, so this effect size represents a fairly significant improvement in prediction among households in our dataset. The direction of effect was the opposite of what we expected, however.

The number of person-trips made by the respondent to his/her water source each week is also significant in the time model ($p < 0.01$), with each additional trip associated with a 45 s improvement in prediction on average. Three-quarters of household respondents report between 6 and 21 person-trips per week, so this effect size represents a fairly small improvement in prediction over the range of observed values. We also find no evidence that owning a cell phone allows water fetchers to produce better

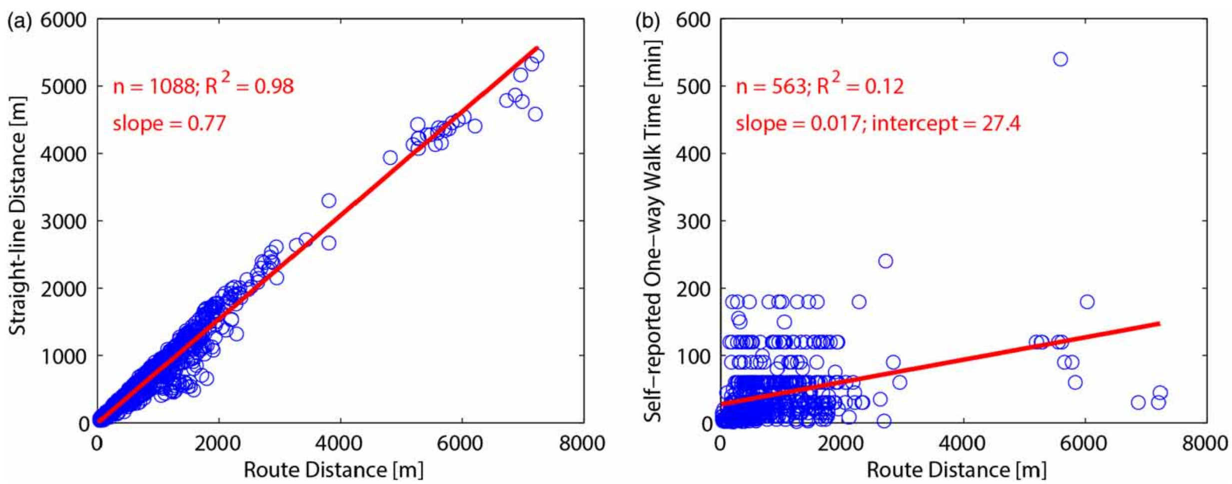

Figure 3 | Ordinary least squares regressions of route distance on straight-line distance (a) and self-reported one-way walk time (b).

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Table 2 | Ordinary least squares regression of difference (in meters) between straight-line and route distance

	ß	Std. error	p-value
Intercept	37.8	15.8	0.02
Straight-line distance (100 m)	28.6	0.71	<0.01
Satellite image characteristics			
High resolution (dummy)[a]	−76.6	11.4	<0.01
Completely forested landscape[b]	50.6	18.0	<0.01
Partially forested landscape[b]	−20.3	17.8	0.26
Sparse shrubbery landscape[b]	−59.5	17.3	<0.01
Adjusted $R^2 = 0.65$; Number of observations = 1,088			

[a]Represents the effect of high resolution satellite images (e.g., GeoEye, DigitalGlobe) used during path digitization *versus* using low resolution satellite images (e.g., SPOT).
[b]All landscape parameters relative to images with peri-urban landscape.

Table 3 | Ordinary least squares regression of difference (in minutes) between self-reported one-way travel time and travel time estimated from route distance using literature-based conversion factor ($n = 520$)

	ß	Std. error	p-value
Intercept	60.8	11.2	<0.01
Route distance (100 m)	0.24	0.18	0.19
Share of fetching time spent queuing (%)	−0.51	0.05	<0.01
Respondent dry season trips per week	−0.73	0.25	<0.01
Fetched water alone (dummy)	−4.60	3.33	0.17
Household and respondent characteristics			
Some formal education (dummy)	−0.81	3.40	0.81
Gender (dummy; 1 = male)	−2.60	3.54	0.46
Bike and radio ownership (dummy)	−0.63	3.77	0.87
Age (years)	−0.05	0.12	0.69
Cell phone ownership (dummy)	0.86	7.28	0.91
Satellite image characteristics			
High resolution[a]	−5.05	3.57	0.16
Completely forested landscape[b]	3.90	5.77	0.50
Partially forested landscape[b]	1.83	5.90	0.76
Sparse shrubs landscape[b]	1.76	5.61	0.76
Adjusted $R^2 = 0.22$; Number of observations = 520			

[a]Represents the effect of high resolution satellite images (e.g., GeoEye, DigitalGlobe) used during path digitization *versus* using low resolution satellite images (e.g., SPOT).
[b]All landscape parameters relative to images with peri-urban landscape.

self-reported estimates of travel time. This result should be interpreted with caution, however, given the small share of sample households with phones (6%) and the fact that we do not know which respondents actually carry a phone while fetching. Finally, we find no evidence that solitary water fetchers provide better estimates as compared to those who regularly fetch with one or more companions. We re-estimated this time model using an average walking pace for survey respondents (7.7 m/min *versus* 62.5 m/min from the literature) and observed no substantive change in our results.

DISCUSSION

Our results indicate that, for this sample of households, straight-line distance serves as a reasonable proxy for route distance. Whereas there is some discrepancy between straight-line and route distance, the significant effect of satellite image resolution in the distance model indicates that systematic error during route estimation, rather than poor predictive ability, may be the principal explanation. The interpretation of landscape type significance in the distance accuracy model is less clear. For example, completely forested landscape could create more winding water fetching routes and therefore worse alignment between straight-line and route distance, but it could also contribute to increased error in path digitization and less accurate route estimation. Nonetheless, the high correlation of straight-line distance with route distance ($R^2 = 0.98$) implies that overall straight-line distance could be a useful proxy for water fetching distance. This result is consistent with findings from several other studies comparing straight-line and route distance to health care facilities (Phibbs & Luft 1995; Fortney *et al.* 2000; Apparicio *et al.* 2008).

That said, we find that straight-line distance underestimates the actual distance that sample households travel to fetch water by 23% on average. In addition, straight-line distance does not account for variations in land cover (Noor *et al.* 2006); nor does it capture the physical challenges associated with water fetching in mountainous regions (Perry & Gesler 2000) or areas with uneven or steep hillsides (Sorenson *et al.* 2011). Among sample households with the greatest discrepancy between straight-line and route distance, many traverse winding paths through heavily forested landscape. In the most extreme case, these factors add up to a two-kilometer discrepancy between straight-line and route distance. Finally, use of satellite images to

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determine straight-line distance requires that each household's water source(s) are known and visible in the imagery.

By comparison, self-reported travel time is poorly correlated with route distance ($R^2 = 0.12$, Figure 3(b)), bringing into question the validity of this widely used indicator. It is important to note that this conclusion is dependent on the homogeneity of terrain found in the study area (and the resulting assignment of a single walking pace to all households). In other settings, variations in terrain could lead to differences in the time required for water fetching for households located at equivalent distances from their source. At the same time, our results are consistent with those of Davis *et al.* (2012), who found a similar discrepancy between self-reported water collection times and GPS-measured trip times in Kenyan informal settlements.

We tested two potential explanations for why self-reports may be poor in this work. The first relates to selective memory bias as described above (Kahneman *et al.* 1982). If this explanation were correct, we would expect socioeconomic factors such as age, education, and wealth to be significantly associated with the accuracy of self-reported travel time in our multivariate model, as suggested by a large literature (Ferber 1965; Butler *et al.* 1987; Mathiowetz & Duncan 1988; Niemi 1993; Beckett *et al.* 2001). We find, however, that self-reported travel time is a poor predictor of route time for sample households regardless of socioeconomic and demographic characteristics, although limited variation in these attributes could be the cause of this result. The second possible explanation we explored was the presence of time-keeping devices in the household; however, we observe no association between household cell phone ownership (the most commonly used time-keeping device in the study area) and improved time prediction. In sum, respondent and household characteristics provided little insight regarding the reasons that self-reported travel time so poorly predicts route time among sample households.

Features of the water fetching activity itself were more helpful in explaining variation in respondents' ability to estimate their travel time. For example, we found that the accuracy of a respondent's estimate improves as the share of total fetching time spent queuing increases. This result was counter to our expectations, as we hypothesized that respondents with a high share of queue time would be more likely to conflate queue time with travel time. One possible explanation could be that a long queue creates a 'break' in the fetching trip that allows a respondent to better distinguish walk time from wait time. This result would imply that self-reported travel times may be more accurate for water points with substantial queue times, all else held constant.

The number of water fetching trips that a respondent makes per week was also found to be significant in the time model, albeit with small effect size, consistent with our hypothesis that increased familiarity with the route might increase the accuracy of self-reported fetching time. Although not tested with our data, it may be that this effect is greater in communities whose water source is in a central location that individuals may pass by even when not fetching water. Finally, whether or not the respondent usually fetches water alone was not statistically significant in the time model, although the direction of effect indicates that respondents who collect water alone have predictions that are an average of 4.6 min more accurate as compared with those who collect water with others.

This finding raises another limitation of self-reported fetching time, namely that water fetchers may derive some benefit (such as opportunities to socialize) from the activity that also increases the total time spent fetching (Short & Thompson 2003; Devoto *et al.* 2012). Disaggregating the time burden of water fetching into these components for the purpose of global monitoring of access would seem quite challenging. Within our sample, 58% of respondents reported that they typically fetch water with one or more companions. These individuals reported an average one-way walk time to their water source that is 5 min longer as compared to those who fetch alone, holding straight-line distance to source constant. Whether this 5-minute increment should be considered part of the total time burden of fetching is a question that, to our knowledge, has not been explicitly considered within the global monitoring framework to date.

One major limitation of this work is that it assumes water carriers travel the most direct path to their source, which may not always be true. Water fetchers face many hazards that may lead them to take indirect routes to collect water, including danger from road traffic (Sorenson *et al.* 2011), abuse from wealthy landowners (Shah 2002), or the risk of assault or animal attack (Ivens 2008; Sorenson *et al.* 2011). We are unsure to what extent this limits the

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Table 4 | Percentage of sample households classified as having access to water supply using alternative indicators

Indicator	Access criterion		
	Household within 1 km of water source	**Water fetching travel time <30 min**	
Straight-line distance	79, ($n = 1{,}103$)		
Route distance	68, ($n = 1{,}103$)		
Self-reported time		*Including queue time*[a]	*Without queue time*
Per trip		7, ($n = 1{,}386$)	31, ($n = 1{,}525$)
Per day		4, ($n = 988$)	20, ($n = 836$)
Estimated time using literature walking pace		*Including queue time*[a]	*Without queue time*
Per trip		17, ($n = 1{,}011$)	65, ($n = 1{,}103$)
Per day		10, ($n = 535$)	42, ($n = 577$)

Number of households included in each indicator calculation shown in parentheses.
[a]All queue times are self-reported.

effectiveness of straight-line distance as an indicator for water access, and note it as a topic for future study. In addition, we limited our analysis to each household's primary water source at the time of interview, whereas households may use multiple water sources and/or change their water source at different times of the year.

This work was motivated by the desire of many in the sector to incorporate a time and/or distance indicator into the global monitoring of access to improved water supply. Among our sample households, assuming that all other criteria were satisfied, the choice of a particular time/distance criterion would have substantial impact on the percentage classified as having *versus* lacking access (Table 4). For example, using a distance threshold of 1 km (WHO/UNICEF 2000) and a straight-line distance measure for each household, 79% of the sample would be deemed to have access. This percentage falls to 68% if route distance is used. By comparison, using a threshold of 30 min round-trip travel time (WHO/UNICEF 2008; Pond & Pedley 2011), between 31 and 65% of households would be classified as having access (depending on whether self-reported or estimated travel time were used). Applying the 30-minute threshold to total fetching time, i.e., walk time and queue time, would reduce these values to 7 and 17%, respectively. Finally, using a per-day (rather than per-trip) time threshold of 30 min, between 20 and 42% of sample households would be classified as having access if only walk time were considered, compared with 4 to 10% if total fetching time (including queuing) were considered.

In sum, despite general consensus that any notion of 'access' to water supply should incorporate some measure of associated time cost and/or physical burden, many questions remain regarding what specifically should be the focus of measurement, as well as the best indicators to employ for regular monitoring. Among our sample of rural Mozambican households, a higher percentage would be classified as having access with a straight-line distance-based indicator, and a lower percentage with a self-reported time indicator, both as compared to an indicator based on route distance from the household to its water point. Given that even these relative findings are unlikely to hold across different geographies and contexts, it seems important for future work to evaluate the conditions under which different indicators perform comparatively better or worse. More generally, this work highlights the importance of the ongoing debate about valid, reliable, and feasible strategies for monitoring progress in the provision of improved water supply services.

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