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Population-based study of intra-household gender differences in water insecurity: reliability and validity of a survey instrument for use in rural Uganda

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ABSTRACT

Hundreds of millions of people worldwide lack adequate access to water. Water insecurity, which is defined as having limited or uncertain availability of safe water or the ability to acquire safe water in socially acceptable ways, is typically overlooked by development organizations focusing on water availability. To address the urgent need in the literature for validated measures of water insecurity, we conducted a population-based study in rural Uganda with 327 reproductive-age women and 204 linked men from the same households. We used a novel method of photo identification so that we could accurately elicit study participants' primary household water sources, thereby enabling us to identify water sources for objective water quality testing and distance/elevation measurement. Our psychometric analyses provided strong evidence of the internal structure, reliability, and validity of a new eight-item Household Water Insecurity Access Scale (HWIAS). Important intra-household gender differences in perceptions of water insecurity were observed, with men generally perceiving household water insecurity as being less severe compared to women. In summary, the HWIAS represents a reliable and valid measure of water insecurity, particularly among women, and may be useful for informing and evaluating interventions to improve water access in resource-limited settings.

Key words | gender, Uganda, water insecurity

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INTRODUCTION

Although the Millennium Development Goal 7c target of improving access to safe drinking water was announced as fulfilled in 2012, there still remain hundreds of millions of people with inadequate access worldwide, particularly in countries throughout sub-Saharan Africa (World Health Organization 2014). This gap represents an important public health problem because inadequate access to water compromises health and development in myriad ways, given the well-known impacts of poor water quality, extended distance to water source, and water collection time on health (Esrey *et al.* 1985; Fewtrell *et al.* 2005; Kremer *et al.* 2011; Pickering & Davis 2012) and other aspects of well-being (Crow & McPike 2009; Geere *et al.* 2010; Devoto *et al.* 2012). The most widely used measures of access to water typically assess the availability of water either by geographic proximity, e.g. presence of a water source within 1 kilometer (World Health Organization 2014), or by comparison to the potential user base, e.g. liters per capita per year (Falkenmark *et al.* 1989). However, other dimensions such as access to water and certainty of water supply are also important for health and well-being.

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A working definition of water insecurity can be adapted from the field of *food* insecurity studies, which arrived at consensus more than two decades ago (Anderson 1990; Maxwell & Smith 1992; Radimer *et al.* 1992). Borrowing from the work of the Expert Panel on Core Indicators of Nutritional State for Difficult-to-Sample Populations (Anderson 1990), we understand household water security to mean access by all people at all times to enough water for an active, healthy life. The construct of water security includes, at a minimum: (a) the ready availability of water of adequate quality and safety; and (b) the assured ability to consistently acquire water. Depending on the cultural context, the construct of water insecurity may also entail the ability to acquire water in culturally acceptable ways, e.g., without resorting to stealing or other unconventional coping strategies. More recently, Grey & Sadoff (2007) proposed a similar definition of water security that generalizes beyond the household to multiple levels of analysis: 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies' (pp. 547–548). Household water insecurity, conversely, exists whenever the availability of safe water or the ability to acquire safe water in culturally acceptable ways is limited or uncertain (Anderson 1990). As with problems of water availability, water insecurity is an important public health issue given its role in the production of anxiety, depression, and social stigma (Wutich & Ragsdale 2008; Stevenson *et al.* 2012; Wutich & Brewis 2014).

While well-validated measures of food insecurity are available (Radimer *et al.* 1990; Radimer *et al.* 1992; Wehler *et al.* 1992; Kendall *et al.* 1995; Frongillo *et al.* 1997; Carlson *et al.* 1999; Swindale & Bilinsky 2006), there is an urgent need for validated measures of water insecurity. Water insecurity is a daily reality for hundreds of millions of people around the world (World Health Organization 2014). Yet there have only been two studies that validate measures of household water insecurity: a study of 72 household heads (including 11 husband-wife pairs) from urban Bolivia (Wutich & Ragsdale 2008; Hadley & Wutich 2009; Wutich 2009) and a study of 324 women from rural Ethiopia (Stevenson *et al.* 2012). To address this gap in the literature, we conducted a population-based study of linked men and women in rural Uganda with the following aims: (a) to demonstrate the feasibility of a novel method of photo identification to accurately elicit study participants' primary household water sources so that we could objectively measure water source quality and distance/elevation; (b) to determine the reliability and validity of a new household water insecurity scale; and (c) to assess any potential intra-household gender differences in perceptions of household water insecurity.

METHODS

Study population and design

The study was conducted in Nyakabare Parish, Mbarara District, Uganda, located approximately 260 kilometers southwest of Kampala, the capital city. Nyakabare Parish consists of eight villages: Buhingo, Bukuna 1, Bukuna 2, Bushenyi, Nyakabare, Nyamikanja 1, Nyamikanja 2, and Rwembogo. The primary commercial hub for Mbarara District is Mbarara Town, listed in the 2014 census as having a population of 195,013 (Uganda Bureau of Statistics 2014). Most residents live in outlying rural areas like Nyakabare Parish, which is approximately 20 kilometers from Mbarara Town. The local economy is largely based on subsistence agriculture, and food insecurity is common (Tsai *et al.* 2011). We investigated potential study sites through an iterative process involving conversations with local officials and field investigations. Nyakabare Parish was selected because it was a tractable size both in terms of population and geographic area, the village leaders welcomed our participation, and non-governmental organizations had relatively little presence in the area.

Approximately three months prior to when we began the study, we conducted a population census within the parish and enumerated all 758 households. Of these, we identified all 358 households in which there was a child under the age of 5 years and a woman of reproductive age (18–49 years, or emancipated minors aged 16–18 years) who considered Nyakabare her primary place of residence, who was available to interview, and who was capable of providing consent. Among households in which there were multiple women of reproductive age, the oldest woman in that age range was identified. We excluded women younger than 18 years of age who were not emancipated minors; women who did not consider Nyakabare their primary place of residence; women who could not communicate with research staff, e.g., due to deafness, mutism, or aphasia; and women with psychosis, neurological damage, acute intoxication, or an intelligence quotient less than 70 (all of which were determined in the field by non-clinical research staff in consultation with a supervisor). These 358 women were designated our sampling frame of potentially eligible study participants.

Each potentially eligible study participant was approached in the field, typically at their home or (less frequently) place of work, by a research assistant who spoke the local language (Runyankore) and who requested their participation in the study. For each person who expressed potential interest, the study was described in detail and written informed consent to participate was obtained. If there were cultural literacy reasons why a written signature was not appropriate, study participants were permitted to indicate consent with a thumbprint. Once enrolled, each study participant was interviewed one-on-one in a private area, out of earshot from other people.

We solicited feedback on the study design from a community advisory board, comprised of eight community leaders (four men and four women), including the district community development officer. Ethical approval for all study procedures was obtained from the Partners Human Research Committee, Massachusetts General Hospital; and the Institutional Review Committee, Mbarara University of Science and Technology. Consistent with national guidelines, we received clearance for the study from the Uganda National Council for Science and Technology and from the Research Secretariat in the Office of the President.

Survey instrument

The survey was programmed into laptop computers for administration in the field, using the Computer Assisted Survey Information Collection (CASIC) Builder™ software program (West Portal Software Corporation, San Francisco, CA). Survey questions were first written in English, translated into Runyankore, and then back-translated into English to verify the fidelity of the translated text. The translation and back-translation was an iterative process involving in-depth consultation and pilot testing with 18 key informants.

The primary construct of interest was water insecurity, which we measured by adapting the Household Food Insecurity Access Scale (HFIAS) (Swindale & Bilinsky 2006). Rather than simply measuring food availability or nutrient intake, the HFIAS seeks to measure the experience of food insecurity by tapping into multiple dimensions of the construct, including perceptions of insufficient quantity or quality, feelings of uncertainty or anxiety over food access, and strategies for coping with insufficient food (Coates *et al.* 2006; Webb *et al.* 2006). The items of the new Household Water Insecurity Access Scale (HWIAS) closely parallel the items of the HFIAS except that they inquire about perceptions of insufficient quantity or quality of water, feelings of uncertainty or anxiety over water access, and strategies for coping with insufficient water for completing water-based tasks (Appendix A, available with the online version of this paper). Not all of the HFIAS items carried over to the HWIAS in a straightforward fashion. For example, the HFIAS item on dietary monotony ('Did you or any household member eat just a few kinds of food day after day due to a lack of resources?') did not have a close parallel with regard to water consumption. The HFIAS item about going an entire day without food ('Did you or any household member go a whole day without eating anything because there was not enough food?') was omitted given the infrequency with which it was observed in a similar study conducted in Ethiopia (Stevenson *et al.* 2012). The final HWIAS consisted of eight items, with each item scored on a four-point Likert-type scale of severity/frequency ranging from 0 to 3 ('never', 'rarely', 'sometimes', 'often') and a total score ranging from 0 to 24.

In addition to the HWIAS, the survey also included questions to elicit basic socio-demographic characteristics of the study participant. Household daily water usage was estimated by asking each participant to estimate the total number of small (5 liter), medium (10 liter), and large (20 liter) jerry cans used by household members for any purposes (e.g., whether for drinking, irrigation, or washing) in a typical day. Finally, because a secondary aim of this study was to investigate intra-household gender differences in perceptions of household water insecurity, we also administered the HWIAS to the oldest man aged 18–49 years in the same household (subject to the same exclusions, and following the same consent and survey procedures, as above). While the index female participants were the primary focus of this study, this design provided us with the opportunity to extend previous qualitative research (Wutich & Ragsdale 2008; Hadley & Wutich 2009; Wutich 2009) by comparing water insecurity experiences between linked men and women in the same households. Because this study focused on obtaining a population-based sample of women with young children, in the remainder of the manuscript we refer to the women as the 'index participants'.

Identification of household water sources

From the index female participants, we elicited each household's primary source of water so that we could assess its quality and measure its distance from the household. In the identification of household water sources, there exist multiple sources of potential error. Many water sources have different names, or different community members may know them by different names. For example, some community members may refer to a water source by the name of the village ('Bukuna 1 well'), by an informal name adopted by community members ('Kinuka'), or by the name of the community member on whose land it is located ('Banturaki's well').

To facilitate accurate identification of household water sources, we used photo identification, a technique that has been employed in social network studies to accurately identify social network ties in settings where ambiguity in naming conventions provides for multiple sources of potential error (Apicella *et al.* 2012). First, we constructed a water source registry consisting of all public water sources, and as many private water sources as we could identify, in Nyakabare Parish. For each of these 89 water sources, the registry contained its latitude and longitude coordinates, its elevation, a photograph of the water source and its surroundings, and all known formal or informal names in use by members of the community. To elicit the household's primary source of water, we asked each index female participant, 'In which cell is your household's main source of water for drinking in the current season? If you obtain drinking water from more than one source, please think of the main source.' The research assistant could query the database by geographic location and type of water source (Figure 1). Each query returned a number of results displayed on the screen, thereby enabling the research assistant to confirm that the water source selected was indeed the water source she intended to name (Figure 2). Latitude, longitude, and elevation coordinates, based on the World Geodetic System 84 standard (National Imagery and Mapping Agency 2000), were obtained for each participant's

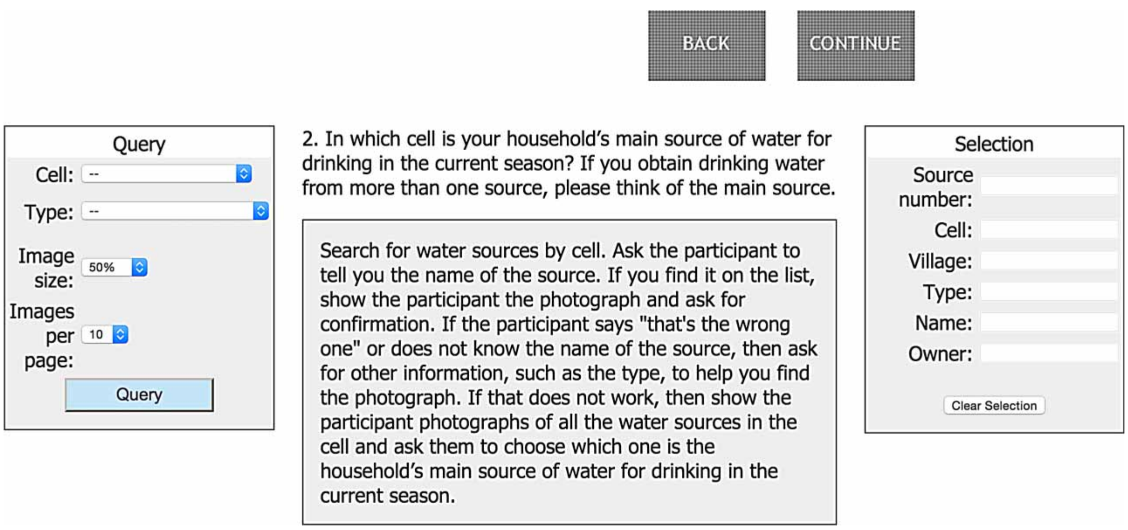

Figure 1 | Database query screen (English language version) for photo-assisted identification of household water source using Computer Assisted Survey Information Collection (CASIC) Builder™ software.

Figure 2 | Sample query results (English language version) for photo-assisted identification of household water source using Computer Assisted Survey Information Collection (CASIC) Builder™ software.

household and each identified water source. We used the great circle distance formula, assuming a sphere of radius 6,371 kilometers, to compute the Euclidean distances between each household and identified water source pair.

While our team was enumerating all households for the population census, we also conducted water quality tests of the water sources in Nyakabare Parish, selecting a purposive sample of only 50 of the water sources listed in our registry due to budgetary limitations: we sought to test a variety of water sources that were not redundantly connected to each other (e.g., in the same gravity flow scheme) and that were geographically dispersed throughout the parish. At each selected water source site, field staff trained in aseptic sampling techniques collected 1 liter of water according to a standardized protocol. For unimproved water sources, samples were taken from the middle of the water source. For improved water sources, the water outflow pipe (e.g., borehole spout or tap) was first disinfected and sterilized before sampling containers were filled. Approximately one inch of space was left at the top of the sampling containers, and the caps were replaced aseptically. Water samples were then packed in coolers with ice and transported to an International Organization for Standardization (ISO)/International Electrotechnical Commission 17025 accredited laboratory for storage in a refrigerated container operating at 4–6 °Celsius. The ISO 9308-1 standard was used to enumerate *Escherichia coli* and coliform bacteria counts per 100 mL. Quality control procedures were used to ensure the validity of the water quality testing, including duplicate samples, control standards, and re-analysis of control samples after every 10 runs.

Statistical analysis

All statistical analyses were conducted using the Stata/MP software package (version 13.1, StataCorp LP, College

Station, TX). We performed factor analysis on the scale items, using principal-factors extraction and orthogonal varimax rotation. We used three criteria to investigate candidate factors for retention. First, we examined the factor eigenvalues for those factors with eigenvalues greater than 1.0 (Guttman 1954; Kaiser 1960). Second, we graphed the eigenvalues in decreasing order to identify the scree, i.e., the portion of the graph where the slope of decreasing eigenvalues approaches zero (Cattell 1966). Third, we examined the loadings of the individual items on the different factors. An item was assigned to a factor if its factor loading was greater than or equal to 0.40 (Floyd & Widaman 1995). We calculated Cronbach's alpha to assess the internal consistency of the identified factor, using 2,000 bootstrap replications to compute the standard error. We examined item-test correlations, and then re-calculated the Cronbach's alpha after sequentially deleting each of the items in turn.

As with prior work, we did not have access to a gold standard criterion of water insecurity to assess criterion-related validity (Hadley & Wutich 2009). Instead we relied upon several different assessments of construct validity. First, we estimated the correlation between water insecurity and other constructs that were hypothesized, on the basis of prior work, to be related to water insecurity: distance and elevation difference in kilometers and meters, respectively (White *et al.* 1972); quality of water source (Crow & McPike 2009); and seasonality (Hadley & Wutich 2009). The elevation difference was calculated with the household's elevation as the index value, such that positive elevation differences indicated the number of meters a person would need to potentially climb after filling canisters from the household's primary water source. For distance and elevation differences, we calculated the Pearson product-moment correlation coefficient. We used three dichotomous indicators of water quality: (a) whether the water source was classified as 'improved' (piped water, public tap, borehole, protected well or spring, rainwater harvesting tank) or 'unimproved' (unprotected well or spring, surface water), following standard definitions promulgated by the World Health Organization/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (World Health Organization 2014); (b) total coliform bacteria count, dichotomized at the median value across the 50 water sources tested ($\geq$305 per 100 mL vs. <305 per 100 mL); and (c) total *E. coli* bacteria count, also dichotomized at the median ($\geq$18 per 100 mL vs. <18 per 100 mL). We used one dichotomous indicator of seasonality, whether or not the interview was conducted during one of Uganda's rainy seasons (either March through May, or September through November). For these dichotomous variables, we used the test statistics derived from two-sample *t*-tests to calculate point-biserial correlation coefficients. Second, based on the findings by Hadley & Wutich (2009) and Stevenson *et al.* (2012) that water insecurity was unrelated to household water use, we estimated the correlation between water insecurity score and household water use (with the *a priori* expectation that we would also find a lack of a statistically significant association between the two variables). To summarize, our analyses of construct validity were motivated by the hypothesis that water insecurity would be correlated with these related constructs: we expected that water insecurity would be greater among households located farther away from their primary water sources, among households accessing lower-quality water sources, and among households interviewed during the dry season.

To assess the extent to which there was an observed threshold of distance to water source above which no further increases in water insecurity scores could be observed, we plotted water insecurity scores against distances, using locally weighted scatterplot smoothing (Cleveland 1979). After observing a potential breakpoint at 0.25 kilometers, we then fitted a multiple linear regression model to predict water insecurity score, specifying distance to water source as a linear spline with a single knot at the observed breakpoint. The estimated association was adjusted for elevation difference, quality of water source, and seasonality, as well as for a set of socio-demographic characteristics (age, educational attainment, marital status, and number in the household).

We investigated intra-household gender differences in water insecurity using data on the linked men and women. Inter-rater agreement was calculated using Cohen's kappa, with confidence intervals calculated using the goodness-of-fit approach (Donner & Eliasziw 1992). For each item, we compared men and women using paired *t*-tests and assessed the extent to which men systematically reported severity/frequency ratings that were higher or lower than the linked women.

RESULTS

Characteristics of the sample

Of the 358 potentially eligible women initially identified in the census, from June 2014 to February 2015 we interviewed 327 index female participants, for a response rate of 91%. Among the remaining 31 women, 26 were confirmed to be ineligible because they did not consider Nyakabare Parish to be their primary residence or because there were no longer any children under age 5 years living in the household, four could not be located again for the interview, and one had died shortly after the initial census was conducted. The median age of the women in our sample was 31 years (interquartile range [IQR], 27–38), 165 (50%) had completed primary school, and 272 (83%) were either married or cohabiting with a partner. The median number of children per household was 3 (IQR, 2–4). Less than one-tenth of the interviews were conducted during one of Uganda's rainy seasons (30 [9%]). The median daily household water usage was 60 liters (IQR, 40–80).

Nearly all women (319 [98%]) identified a primary water source that was contained in our registry of parish water sources. Of the eight unusable responses, two women enumerated a water source in a neighboring parish (that was therefore outside the scope of our data collection), and six were missing because the participant could not provide a response. Nearly all women (304 [95%]) reported relying primarily on a public, rather than a private, water source. Most women (218 [67%]) reported a primary household water source that could be classified as 'improved'. Study participants lived a median distance of 269 meters (IQR, 166–421) from their household's primary water source, with 10 women reporting a primary water source that was located more than 1 kilometer away from the residence. The median household was located 23 meters (IQR, 5–47) above the primary water source.

Water insecurity among women

The distribution of women's responses to the eight items of the HWIAS is shown in Figure 3. The frequency of 'never'

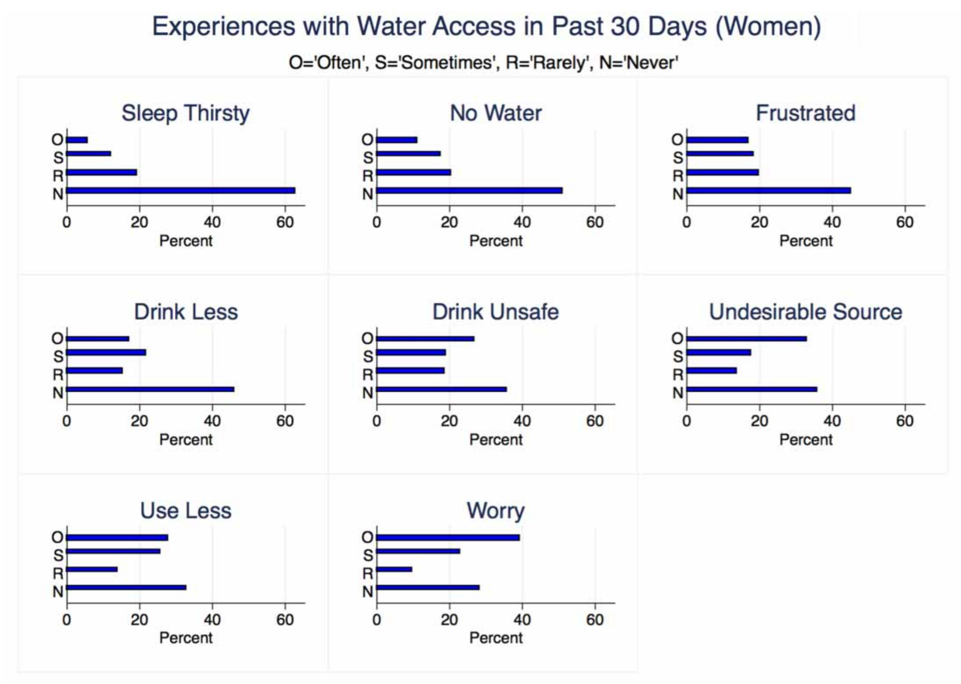

Figure 3 | Distribution of responses to items in the Household Water Insecurity Access Scale ($N = 327$).

responses ranged from 28 to 63%. The three items with the highest frequency of 'often' responses were the items about worry, having to drink water from an undesirable source, and having to drink less water than needed.

Exploratory factor analysis revealed one factor with an eigenvalue of 3.84 explaining 96% of the variance. All eight items loaded positively on this factor, with factor loadings ranging from 0.65 to 0.77. None of the squared multiple correlations were so small as to warrant exclusion of any item. There was scant evidence for a second factor: the two-factor solution had a smaller Akaike Information Criterion value than the one-factor solution, but the second factor only had an eigenvalue of 0.45, no items had factor loadings exceeding 0.4 on this factor (two items had factor loadings of 0.37 and 0.39), and the scree plot suggested only a single factor. We therefore proceeded with a single factor model. The resulting eight-item HWIAS was internally consistent, as suggested by its Cronbach's alpha of 0.88 (95% confidence interval [CI], 0.86–0.90). The entire range of potential values of the total HWIAS score was represented. The median HWIAS score was 9 (IQR, 4–15), and the mean was 9.8 (standard deviation, 6.8). Item-test correlations were approximately equal for all items and ranged from 0.68 to 0.80 (Table 1). Deletion of any single item did not appreciably increase the average inter-item covariances or the Cronbach's alpha; however, several items could potentially be deleted with limited impact on internal consistency.

Table 1 | Reliability of the Household Water Insecurity Access Scale among women ($N = 327$)

	No. (%) responding 'often'	Factor loading	Item-test correlation	Cronbach's alpha if deleted
Worry about enough water	128 (39)	0.63	0.70	0.87
Drink water from undesirable source	107 (33)	0.74	0.77	0.86
Drink unsafe water	87 (27)	0.67	0.72	0.86
Drink less water than needed	56 (17)	0.72	0.76	0.86
Use less water than needed	91 (28)	0.77	0.80	0.85
No water at all	36 (11)	0.66	0.70	0.86
Go to sleep thirsty	19 (6)	0.65	0.68	0.87
Feel angry or frustrated	55 (17)	0.69	0.73	0.86

Evidence in support of the scale's construct validity was provided in analyses showing statistically significant correlations between the total HWIAS score and distance to water source ($r = 0.16$; 95% CI, 0.05–0.27) and elevation difference ($r = 0.20$; 95% CI, 0.10–0.31). The mean HWIAS score was lower among women whose households relied on an 'improved' water source (8.7 vs. 11.8; $t = 3.84$, $P < 0.001$, corresponding to a point-biserial correlation of 0.21). Conversely, the mean HWIAS score was higher among women whose households relied on a water source characterized by high levels of coliform (10.3 vs. 8.3; $t = 2.4$, $P = 0.02$, corresponding to a point-biserial correlation of 0.14) and *E. coli* bacteria (10.3 vs. 7.5; $t = 3.31$, $P < 0.001$, corresponding to a point-biserial correlation of 0.20). The mean HWIAS score was also lower among women who were interviewed during the rainy season (8.7 vs. 9.9; $t = 0.90$, $P = 0.37$), but the difference was not statistically significant. Finally, consistent with the findings of Hadley & Wutich (2009) and Stevenson *et al.* (2012), we found no statistically significant correlation between total HWIAS score and daily household water usage ($r = 0.03$; 95% CI, −0.08 to 0.14).

Locally weighted scatterplot smoothing suggested that the total HWIAS score increased with distances up to 250 meters, after which subsequent increases in the total HWIAS score were minimal (Figure 4). In the piecewise

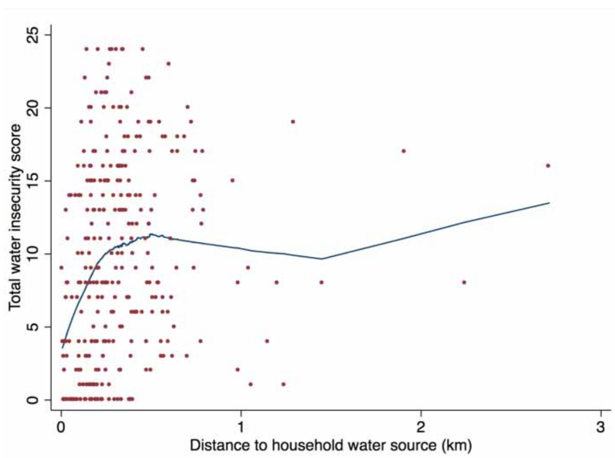

Figure 4 | Plot of water insecurity among women vs. distance to source, using locally weighted scatterplot smoothing ($N = 319$).

multiple linear regression model, the total HWIAS score had a statistically significant association with distance to water source up to the 250-meter threshold (b = 18.2; 95% CI, 2.8–33.6) but not with distances after the 250-meter threshold (b = −1.4; 95% CI, −4.4 to 1.6). A *t*-test rejected the null hypothesis that the slopes were equal ($t = 2.46$, $P = 0.01$).

Intra-household differences in water insecurity by gender

In 267 of the 327 households of the index female participants, there was a potentially eligible adult man available for interview. Of these, there were 204 households in which there was a man in the same age range of 18–49 years. The median age of these men was 35 years (IQR, 31–42), 136 (67%) had completed primary school, and 188 (92%) were either married or cohabiting with a partner (who may have been, but was not necessarily, the index female participant). We repeated all of the above analyses to investigate the reliability and validity of the HWIAS among men (Appendix B, available with the online version of this paper). Exploratory factor analysis suggested a single factor. We observed weaker evidence of construct validity, as the magnitudes and statistical significance of the estimated correlations were lower among men compared to women.

Within each linked pair of men and women, across the eight items the kappa statistics ranged from −0.03 to 0.20 (Table 2). In general, men reported experiences of different dimensions of water insecurity as being less severe/frequent than women. Across the eight items, within each linked pair 27–43% of the men gave a severity/frequency rating that was less than the rating reported by the woman in the same household. These differences were also reflected in the global differences across households: the mean HWIAS score was lower among men compared to women (8.9 vs. 10.3; $t = 2.23$, $P = 0.03$). Compared to the standard deviation among women, this represented $1.4/6.8 = 0.21$ standard deviation units.

DISCUSSION

In this population-based study, we have shown that water insecurity is relatively common in rural Uganda among both men and women. Our analyses provide strong evidence for the internal structure and construct validity of a new experience-based measure of household water insecurity, calculated from eight items administered by questionnaire. We used a novel method of photo identification so that we could accurately elicit study participants' primary household water sources, thereby enabling us to identify water sources for objective water quality testing and distance/elevation measurement. Finally, we demonstrated significant intra-household gender differences in perceptions of household water insecurity. Our findings have important programmatic implications and suggest the HWIAS may be used to measure the construct of water insecurity in rural East African settings, particularly among women.

Table 2 | Within-household differences for individual water insecurity scale items among linked men and women ($N = 204$)

	Cohen's kappa (95% CI)	Mean,[a] men vs. women (*P*-value)	No. (%) linked pairs in which men reported same or lower frequency or severity than women
Worry about enough water	0.16 (0.01–0.30)	1.63 vs. 1.87 (0.04)	74 (36)
Drink water from undesirable source	−0.01 (−0.14 to 0.14)	1.40 vs. 1.51 (0.35)	79 (39)
Drink unsafe water	−0.03 (−0.18 to 0.10)	1.21 vs. 1.41 (0.09)	83 (41)
Drink less water than needed	0.09 (−0.05 to 0.22)	1.06 vs. 1.14 (0.48)	66 (32)
Use less water than needed	0.08 (−0.06 to 0.21)	1.28 vs. 1.61 (0.004)	88 (43)
No water at all	0.20 (0.06–0.32)	0.79 vs. 0.98 (0.05)	68 (33)
Go to sleep thirsty	0.18 (0.04–0.31)	0.63 vs. 0.70 (0.44)	56 (27)
Feel angry or frustrated	0.08 (−0.08 to 0.19)	0.82 vs. 1.13 (0.003)	80 (39)

[a]Each item on the Household Water Insecurity Access Scale was scored on a four-point Likert-type scale of severity/frequency ranging from 0 to 3 ('never', 'rarely', 'sometimes', 'often').

Previously published qualitative and quantitative work has generated findings similar to our own. In qualitative studies conducted in urban Bolivia (Wutich & Ragsdale 2008; Hadley & Wutich 2009; Wutich 2009) and rural Ethiopia (Stevenson *et al.* 2012), several dimensions of water insecurity experiences were characterized, including anxiety, bother, water insufficiency, water quality, and coping strategies. Drawing on these findings, Hadley & Wutich (2009) developed a 33-item water insecurity scale and Stevenson *et al.* (2012) developed a 24-item water insecurity scale. These measures were correlated with seasonality and type of water source (thereby providing evidence of construct validity) but not with household daily water usage. Our eight-item scale contains fewer items principally because we used an abbreviated set of items for assessing different dimensions of water insecurity (e.g., instead of using 11 different items to characterize strategies for coping with insufficient water, we used a single item for the entire range of household needs) so that the scale would be more suitable for administration in a brief, population-based survey. Importantly, our study extends their findings of construct validity by correlating water insecurity scores with objective measures of distance, elevation, and water quality.

Our analyses further suggest that the construct of water insecurity may enrich current policy and programmatic discussions about clean water access, which have (for example) focused on the extent to which households have access to an ‘improved’ water source that is located within 1 kilometer (World Health Organization 2014). In our data, while water insecurity scores were generally higher among women who did not have access to an ‘improved’ water source, a large proportion of women had access to an ‘improved’ water source yet remained water insecure. These findings are consistent with the observations by Bain *et al.* (2012) and Parker *et al.* (2010) that water sources classified as ‘improved’ are frequently not characterized by a suitable degree of microbial safety. Likewise, echoing the classic finding by White *et al.* (1972) of a ‘plateau effect’ in demand, we observed a plateau in water insecurity at a much lower threshold, and there was substantial variation in water insecurity scores below the 1-kilometer distance threshold conventionally considered to be accessible enough for consistent use. And finally, elevation differences represent an added dimension of bother and quality of life that is not accounted for by distance measurements.

The intra-household gender differences in water insecurity assessments were notable. The men’s responses indicated that, on average, they perceived each aspect of water insecurity as being less severe or frequent compared to women. These estimates are consistent with the findings of a small study from urban Bolivia (Wutich & Ragsdale 2008; Hadley & Wutich 2009; Wutich 2009). Extending their results, we found that the estimated Cohen’s kappa coefficients for inter-rater agreement (i.e., between the man and woman of each pair) on each item and on the summary categorization were relatively low, suggesting ‘slight’ (Landis & Koch 1977) or ‘poor’ (Fleiss 1981) agreement according to commonly accepted rules of thumb. Correspondingly, within the same households (in which they were presumably subject to the same conditions of water insufficiency or restrictions on drinking/usage) a large proportion of men gave a severity/frequency rating that was less than the rating reported by the index female participant. Whether our findings are suggestive of an actual gender bias within the household (Behrman 1988; Jayachandran & Pande 2015) cannot be determined from these data. It is possible that these gender differences are explained by the fact that, in Uganda, women represent the majority of the labor force in agriculture (Ellis *et al.* 2006). Women in general, and in Uganda specifically, are also generally responsible for housework, water collection, and food preparation (Ellis *et al.* 2006; Ray 2007; Crow & McPike 2009; Sorenson *et al.* 2011). Given that many of these activities are largely contingent upon an adequate, consistent, and safe supply of water, it would not be unexpected to observe gendered patterning in water insecurity scores.

Our study has a number of important strengths and limitations. First, current work on water insecurity is still in its infancy, anchored by the previously discussed studies from urban Bolivia (Wutich & Ragsdale 2008; Hadley & Wutich 2009; Wutich 2009) and rural Ethiopia (Stevenson *et al.* 2012). Unlike those studies, we did not employ qualitative methods to generate potential scale items. We adapted our scale items from their work, and previously published studies of the related but distinct construct of food insecurity (Swindale & Bilinsky 2006). A qualitative component would have permitted us to potentially develop culturally-specific items as well as explore our findings in greater depth. For example, in an ongoing qualitative study that was initiated after this population-based study was completed, participants have revealed that coping with water insecurity sometimes may involve stealing – a method of acquisition that is considered socially unacceptable in this context. Prevailing definitions of the construct of food insecurity typically incorporate notions of socially acceptable methods of food acquisition (i.e., without stealing, begging, or eating stigmatized foods) (Coates *et al.* 2006), so it may be useful for future studies of water insecurity to examine this issue in greater detail. As shown by Coates *et al.* (2006), observed commonalities in the experience of food insecurity across cultures, and the identification of common domains across multiple country-specific measures of food insecurity, suggest that efforts to measure water insecurity can build on common domains that have already been identified in other contexts.

A second limitation is that each household's primary source of water was elicited from only the index female participant. It is therefore possible that the intra-household gender differences in perceptions of water insecurity could have resulted from divergent understandings of the household's primary water source (i.e., the linked men and women did not have the same water source in mind when responding to the HWIAS items) rather than from divergent perceptions of water insecurity. We believe this possibility to be unlikely, given that men and their linked counterparts were actually more concordant on item #2 (about collecting water from an undesirable source) compared to the other scale items measuring other aspects of water insecurity.

Third, our data were collected from only a single region in south-western Uganda, so it is unclear whether our findings would generalize to other regions. However, we obtained a greater than 90% response rate from a sampling frame consisting of *all* households in which reproductive-age women resided with a young child. Given the centrality of women in water collection worldwide, and given that health outcomes among children have always been a major focus of intervention research in the field (Esrey *et al.* 1985; Fewtrell *et al.* 2005; Kremer *et al.* 2011), we believe our results apply broadly. The inclusion of a large sample of men in our study – a notable addition to the literature – further underscores its generalizability. Fourth, we did not survey women about the time they spent traveling to the water source or collecting water, both of which are well known determinants of quality of life and overall burden associated with fetching water (Ray 2007; Crow & McPike 2009; Zuin *et al.* 2011). Measures of distance may not necessarily be better measures of bother, but time spent collecting water is frequently estimated poorly in surveys (Crow *et al.* 2013; Ho *et al.* 2014) and straight-line distance is known to be a good proxy for route distance in rural settings (Siedner *et al.* 2013; Ho *et al.* 2014). Finally, our study acknowledged the importance of water for both non-drinking (e.g., laundry, bathing, small enterprises, irrigation, etc.) and drinking purposes, but there was an implicit focus on the use of water for drinking purposes. When eliciting primary water sources, we asked households to identify the household's primary source of water for drinking. And of the eight items in the HWIAS, four items focused specifically on drinking water. Thus our study implicitly focused to a greater extent on issues related to quality rather than quantity. The lack of correlation between water insecurity and household daily water usage could potentially be explained by this implicit focus, given that households were asked to estimate daily water usage for all purposes. Future work may explore the construct of water insecurity in greater depth by characterizing household use of water for non-drinking purposes.

CONCLUSIONS

The HWIAS represents a reliable and valid measure of water insecurity, particularly among women. Our use of objective measures of distance, elevation, and water quality represents a new contribution to the literature on validating measures of water insecurity. As with the HFIAS, which is frequently used either as an exposure (Tsai *et al.* 2012; Dewing *et al.* 2013) or as an outcome (Weiser *et al.* 2015), we believe the HWIAS can be productively used in epidemiological and intervention research. To our knowledge, no intervention studies to date have examined water insecurity as an outcome of interest, likely reflecting the field's predominant focus on water availability and water quality. With increasingly robust validation studies of water insecurity measures in diverse cultural and ecological contexts, we hope the field will increasingly consider the reduction of water insecurity to be an urgent imperative.

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