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Water borrowing is consistently practiced globally and is associated with water-related system failures across diverse environments

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ABSTRACT

Water problems due to scarcity, inaccessibility, or poor quality are a major barrier to household functioning, livelihood, and health globally. Household-to-household water borrowing has been posited as a strategy to alleviate unmet water needs. However, the prevalence and predictors of this practice have not been systematically examined. Therefore, we tested whether water borrowing occurs across diverse global contexts with varying water problems. Second, we tested if household water borrowing is associated with unmet water needs, perceived socio-economic status (SES), and/or water-related system failures, and if water access moderated (or changed) these relationships. Using survey data from the Household Water Insecurity Experiences (HWISE) study from 21 sites in 19 low- and middle-income countries (n = 5495 households), we found that household-to-household water borrowing was practiced in all 21 sites, with 44.7% (11.4–85.4%) of households borrowing water at least once the previous month. Multilevel mixed-effect logistic regression models demonstrate that high unmet water needs (odds ratio [OR] = 2.86], 95% confidence interval [CI] = 2.09–3.91), low perceived SES (OR = 1.09; 95% CI = 1.05–1.13), and water-related system failures (23–258%) were all significantly associated with higher odds of water borrowing. Significant interactions (all $p < 0.01$) between water access, unmet water needs, and water-related system failures on water borrowing indicate that water access moderates these relationships. These data are the first to demonstrate that borrowing water is commonly used by households around the world to cope with water insecurity. Due to how prevalent water borrowing is, its implications for social dynamics, resource allocation, and health and well-being are likely vast but severely under-recognized.

1. Introduction

In 2017, 2.1 billion people, or 29% of the global population, lacked access to safely managed water while 11% lacked access to improved water services within 30 min round-trip from the household (WHO and UNICEF, 2017). Many more live in places with poor water quality, inadequate sanitation, and excess water due to flooding, all which likely exacerbate household water insecurity (Mekonnen and Hoekstra, 2016; WHO and UNICEF, 2017; Young et al., 2019a). Hydroclimatic perturbations related to climate change will likely increase risk of water problems around the world and undermine clean water availability by affecting precipitation and evaporation patterns (Konapala et al., 2020). In fact, projections indicate that up to 5 billion people around the world will deal with water contamination problems and water shortages by 2050, and that populations living in sub-Saharan Africa and South Asia will most acutely experience these negative effects (Chaplin-Kramer et al., 2019).

The myriad costs of living with water insecurity shape many aspects of life. Water insecurity has numerous implications for health and human biology (Rosinger and Young, 2020), such as: heightened exposures to water-borne infectious pathogens and mosquito-borne diseases (Akanda and Johnson, 2018), elevated exposures to

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environmental toxins (Stoler et al., 2019), higher risk of dehydration in children (Rosinger, 2018), traumatic injuries and risk of sexual assault (Geere et al., 2018; Sorenson et al., 2011), heightened food insecurity (Brewis et al., 2020; Workman and Ureksoy, 2017), and elevated levels of depression and other mental illnesses (Boateng et al., 2020; Cooper et al., 2019; Cooper-Vince et al., 2018). In addition, water insecurity can lead to loss of productive time (Pruss-Ustun and Organization, 2008) and increased financial strains (Javidi and Pierce, 2018). Overall, water problems and related contamination are estimated to be the cause of 1.8 million premature deaths per year (Landrigan et al., 2017).

Over the last century, public water systems, particularly in high-income countries, have increasingly enabled access to safe, abundant, and affordable water, thereby radically improving human health and life expectancy (Bartram and Cairncross, 2010; Cutler and Miller, 2005; Staddon, 2016). Recognizing that access to clean water underlies many aspects of human health and well-being, universal and equitable access to improved and affordable drinking water has been adopted as UN Sustainable Development Goal 6.1 (Bartram and Cairncross, 2010). Yet, projections indicate that gains in water access may halt or even reverse in coming decades (Chaplin-Kramer et al., 2019; Konapala et al., 2020; McDonald et al., 2011; Mekonnen and Hoekstra, 2016; Mullin, 2020). This is due to a combination of factors, including: (1) growing socio-economic inequalities, (2) water quality failures, such as inadequate water monitoring, maintenance, and remediation by public health and water agencies, (3) water availability failures related to insufficient coverage and infrastructural aging, and growing water use which affect (4) water access, (5) market supply failures related to ownership, allocation, and availability, and (6) higher frequency and intensity of dangerous climatic events (Adane et al., 2017; Cinner et al., 2018; Elliott et al., 2017; McDonald et al., 2011, 2014). This suggests that water-stressed households will need to find additional means to cope with water challenges, often outside of governmental or other institutional support, to meet their day-to-day water needs (Adane et al., 2017; Cinner et al., 2018; Elliott et al., 2017; Nelson et al., 2020). Previous research has identified some coping strategies, like using multiple water sources when dealing with water stress (Elliott et al., 2017; Majuru et al., 2016), or reducing barriers to water storage for times of need (Cinner et al., 2018), but there is far less work examining direct water transfers between households.

Household-to-household water transfers are one possible under-examined coping response that have important implications for (re) shaping the distribution of water within communities. A limited historical and ethnographic record suggests that “water sharing” – transfers of water as either gifts or loans – is one way that humans have historically dealt with extreme water insecurity (Wutich and Brewis, 2014; Wutich et al., 2018). For example, among the Ju/'hoansi in the African Kalahari, people formed sharing relationships called *xaro* that enabled them to access water and other resources in times of need (Wiessner, 2002). Such sharing (called *jie shui*) was also common in parts of western China through the 1990 s (Clarke-Sather, 2017). Other examples of water sharing have been documented among Muslims in the context of prayer and the White Mountain Apache gifts of sacred water (Wutich et al., 2018). However, water sharing can have many negative ramifications as reciprocity can be both socially and financially costly (Dirks et al., 1980; Sahlins, 2017). These observations sit within a wider set of studies that show how humans in small-scale societies often devise self-organized systems for sharing critical and limited resources, such as food, which have played a large role in our evolution, cognitive and emotional function, and adaptation to new environments (Ember et al., 2018; Wiessner, 2002; Wutich and Brewis, 2014).

Few studies have documented household-to-household water-sharing practices within communities dealing with water scarcity (Pearson et al., 2015; Wutich et al., 2018). Water borrowing is defined as asking for water from another household or neighbor and receiving it with or without an expectation of anything in return (Wutich et al., 2018). A pilot study of water sharing practices in eight community sites in Sub-Saharan Africa suggested that water borrowing was common in that limited context, that most transfers were effected as gifts between neighbors, and that direct or explicit reciprocity was not expected (Brewis et al., 2019). There are currently no studies, to our knowledge, that empirically examine water sharing beyond a single region (Cole, 2017; Stoler et al., 2019; Wutich, 2011). It is therefore still unknown whether these practices are common globally, and how structural and environmental factors shape them.

Classic reciprocity research indicates that giving and receiving in reciprocal exchange systems tends to bind people together in mutual solidarity, esteem, and prestige (Cashdan, 1985; Mauss, 2002; Wiessner, 1982). However, more recent research on reciprocity broadly (González de la Rocha, 2001; Moser et al., 1997), and water sharing specifically (Wutich et al., 2018), suggests that it may be more burdensome in contemporary economic contexts. For example, people who borrowed water in Cochabamba, Bolivia were more likely to report fear, worry, bother, and anger over water than individuals who did not borrow water (Wutich and Ragsdale, 2008). Shame and embarrassment were common when people requested water loans repeatedly or were denied requests (Wutich, 2011; Wutich et al., 2016). As such, the hidden costs of water sharing have not yet been established cross-culturally, but could potentially include status loss, social indebtedness, time costs, and health risks (Stoler et al., 2019; Wutich and Brewis, 2014; Wutich et al., 2018).

Building on anthropological theory related to water insecurity and reciprocity (Wutich and Brewis, 2014), here we provide a global analysis of water borrowing as a cross-cultural phenomenon in communities dealing with water problems in low- and middle-income countries (LMICs). Our first objective was to examine how widespread the practice of water borrowing was among households in the prior month in 21 diverse, low-resource communities, spanning sub-Saharan Africa, the Middle East, Central/South America, and Asia (Fig. 1; Table 1). Our second objective was to test if borrowing water was predicted by unmet water needs (operationalized as not having enough water/having water problems affecting bathing, washing hands, drinking water, changing foods cooked, going to sleep thirsty, and no water whatsoever in the household). We also examined how perceived socioeconomic status (SES), water quality failure (proxied by perceived water safety), water availability failure (i.e., interruptions to daily life due to water), market supply failure (i.e., inability to buy water because there is nowhere to buy it from), water access failure (i.e., roundtrip time to fetch water including wait time), and seasonal differences were associated with borrowing water.

We hypothesized that greater unmet water needs, lower SES, each of the water system failures, and the dry season would be associated with higher probability of households borrowing water due to higher vulnerability, fewer resources to pay for water or water infrastructure, greater water stress, and less water availability in the environment, respectively. Second, we hypothesized that access to water, as measured by round-trip water fetching time, moderates the relationship between unmet water needs and the other failures and borrowing water due to higher time demands needed to acquire water regardless of other underlying water issues. Finally, we conducted a sensitivity analysis to test how household water insecurity experiences relate to water borrowing as an alternative way to capture unmet water needs and water system failures. We conclude with reflections on the implications of widespread water borrowing for future research on water security and insecurity, especially at the individual and household scales.

2. Materials and methods

We used data from the Household Water InSecurity Experiences (HWISE) study to estimate prevalence of water borrowing practices. Briefly, in 2017–2018, the HWISE study systematically collected comparative evidence on water borrowing in diverse, low-resource

communities known to have water issues by the researchers working in the sites, spanning sub-Saharan Africa, the Middle East, Central/South America, and Asia (Young et al., 2019a, 2019b). Households were randomly-sampled from within geographically defined districts or neighborhoods (Young et al., 2019b). All respondents provided informed consent and the main study was approved by IRB board at Northwestern University with additional approvals obtained for each study site. A detailed description of sampling, study design, and details related to water problems, including all IRBs of record across sites, is provided elsewhere (Young et al., 2019a, 2019b). Adults who self-identified as being knowledgeable about the water situation in their household were eligible for inclusion. Interviews were conducted in their native language. They reported the frequency of inter-household borrowing in the previous month and other water-related household factors. For this study, we restricted our analysis to 21 sites in 19 countries that had more than 40 households with complete covariate information (n = 5870 households total in the 21 sites; n = 5495 households with information on water borrowing; full description of analytic sample below) (Fig. 1). See Table 1 for site-specific data related to sampling design, sample size, water source, and other details.

2.1. Dependent variable

To assess water borrowing, the respondent for each household was asked: "In the last 4 weeks/30 days, how frequently have you or anyone in your household asked to borrow water from other people?" Responses were "never" (0 times), "rarely" (1–2 times), "sometimes" (3–10 times), "often" (11–20 times), or "always" (20 + times). We examined the distribution of responses to this question across sites and dichotomized responses into households that borrowed water at least once in the previous month and those that had not.

2.2. Independent variables

Unmet water needs was constructed through responses to six questions asked in the same format that represented a range of water issues (See Supplemental Table 1 for variable operationalization). These were: "In the last 4 weeks/30 days, how frequently has there/have you or anyone in your household __ because of problems with water" 1) Changed what was eaten, 2) had to go without washing hands after dirty activities, 3) gone without washing their body, 4) not been as much water to drink as you would like, 5) gone to sleep thirsty because there wasn't any water to drink, 6) been no water whatsoever in the household. The response categories were "never" (0 times) = 0, "rarely" (1–2 times) = 1, "sometimes" (3–10 times) = 2, "often" (11–20 times) = 3, and "always" (20 + times) = 4. A single component was extracted through principal components analysis, which explained 58.5% of the variation. We then created tertiles within sites from this variable so that unmet need would be comparable across sites. Uneven tertiles reflect clumping of results in some sites where the score ties were lumped at the lower score (SI Appendix, Fig. 2a).

Perceived socioeconomic status: To consider how inequalities related to socioeconomic status within sites may relate to borrowing water, respondents were shown a ladder [modified from the MacArthur ladder of Subjective Social Status (Adler et al., 2000; Giatti et al., 2012)] and asked to point to a rung on it to indicate their household's relative socio-economic standing compared to others in their community. The scores ranged from 1 (highest standing) to 10 (lowest standing) (SI Appendix, Fig. 2b).

Water quality failure: As an indicator of potential institutional or public health failure in ensuring access to clean water, participants were asked about the number of times they consumed water they perceived to be unsafe. "In the last 4 weeks/30 days, have you drank water that you thought was unsafe?" We analyzed responses as never, 1–2 times, or 3 or more times (which included the responses of sometimes, often [11–20 times], and always [20 + times]) to provide an equal distribution in the categories since the often and always responses were not reported frequently across sites (SI Appendix, Fig. 2c).

Water availability failure: To examine failure in water availability, we asked respondents about the number of times their days were interrupted due to water: "In the last 4 weeks/30 days, how many times has your day been interrupted/changed plans due to problems with the water situation." We analyzed responses as never, 1–2 times, or 3 or more times (SI Appendix, Fig. 2d).

Market supply failure: To examine a proxy for market supply failure, we asked participants about their household's inability to purchase

Fig. 1. Location of the 21 HWISE sites in 19 countries used for this analysis.

Table 1
Descriptive characteristics of 21 sites with water borrowing information from the HWISE study.

World Region	Site	Sample size	Female%	Mean age (SD)	Mean HH size (SD)	Season	Language	Sampling strategy	Urbanicity	Primary source of drinking water, %
Africa	Kahemba, DRC	392	65.6	38.5 (14.7)	6.7 (2.7)	Dry	Kikongo, Lingala	Cluster random	Rural	Surface water, 99.7
	Bahir Dar, Ethiopia	259	100	36.0 (13.0)	5.0 (2.2)	Rainy	Amharic	stratified random	Rural	Unprotected dug well, 25.1
	Accra, Ghana	229	78.2	37.3 (12.9)	6.2 (5.2)	Rainy	English	stratified random	Urban	Bagged/sachet water, 86.0
	Kisumu, Kenya	247	81.3	39.9 (15.5)	5.5 (2.8)	Neither rainy nor dry	Luo, Swahili, English	Simple random	Rural	Surface water, 17.4
	Lilongwe, Malawi	302	86.8	32.3 (12.0)	5.2 (2.3)	Neither rainy nor dry	Chichewa, English	Cluster random	Peri-urban	Standpipe, 45.4
	Lagos, Nigeria	239	73.5	39.2 (10.8)	4.8 (3.1)	Rainy	English, Yoruba, Pidgin	Multi-stage random	Urban	Bagged/sachet water, 48.9
	Morogoro, Tanzania	300	78.3	40.1 (14.9)	6.2 (3.5)	Dry	Swahili	Cluster random	Urban and *peri*-urban	Standpipe, 70.7
	Arua, Uganda	250	85.6	36.5 (14.8)	6.1 (2.9)	Rainy	Lugbara, English	Cluster random	Rural	Protected dug well, 64.8
Europe & Central Asia	Dushanbe, Tajikistan	225	73.3	41.0 (14.4)	5.5 (2.7)	Dry	Tajik, Russian	Cluster random	Urban	Piped water, 58.2
Latin America and the Caribbean	San Borja, Bolivia	247	58.6	40.0 (14.6)	5.8 (3.0)	Dry	Spanish	Simple random	Peri-urban and rural	Standpipe, 41.6
	Cartagena, Colombia	266	69.2	40.8 (15.1)	5.3 (2.8)	Dry	Spanish	Simple random	Urban	Piped water, 46.2
	Honda, Colombia	196	63.6	52.2 (15.2)	3.4 (1.9)	Rainy	Spanish	Cluster random	Peri-urban	Piped water, 74.5
	Chiquimula, Guatemala	314	86.6	38.8 (15.0)	6.1 (2.5)	Dry	Spanish	Systematic random	Rural	Bottled water, 70.2
	Mérida, Mexico	250	63.2	45.3 (15.5)	4.7 (2.7)	Dry	Spanish	Cluster random	Urban	Bagged/sachet water, 50.0
	Torreón, Mexico	249	73.1	46.3 (16.6)	3.7 (2.3)	Dry	Spanish	Stratified cluster random	Urban	Bottled water, 70.2%
Middle East and North Africa	Beirut, Lebanon	574	63.8	42.9 (14.9)	4.2 (1.9)	Rainy	Arabic	Cluster random	Urban	Small water vendor, 54.5
	Sistan & Balochistan, Iran	306	99.0	33.3 (10.9)	5.4 (2.3)	Dry	Farsi	stratified random	Urban, *peri*-urban, & rural	Small water vendor, 48.0
South Asia/Pacific	Rajasthan, India	248	27.0	41.9 (13.1)	6.3 (3.6)	Dry	Hindi	stratified random	Urban	Tanker truck, 55.2
	Labuan Bajo, Indonesia	279	44.8	38.2 (11.3)	4.6 (1.9)	Dry	Indonesian	Simple random	Urban	Bagged/sachet water, 36.9
	Kathmandu, Nepal	263	71.5	41.4 (13.3)	4.8 (2.2)	Rainy	Nepali	Cluster random	Urban	Bottled water, 49.8
	Punjab, Pakistan	235	57.5	35.9 (10.1)	8.1 (2.8)	Dry	Seraikee, Urdu	Cluster random	Rural and *peri*-urban	Standpipe, 26.6

water when they wanted to: "In the last 4 weeks/30 days, how many times have you tried to buy water but there was nowhere to buy it from." Again, responses were analyzed as never, 1–2 times, or 3 or more times (SI Appendix, Fig. 2e).

Water access failure: To determine access and the time cost or relative distance to the primary water source, we asked participants how many minutes a round-trip took to fetch water at their primary drinking water source, including wait time. We categorized responses as 0 min (which indicated that they had a tap on their premises), 1–29 min, 30–59 min, and 60 or more minutes (WHO and UNICEF, 2017) (SI Appendix, Fig. 2f).

Season of data collection: As rain and flooding influence the relative supply of water households have access to, it may also affect likelihood of borrowing water. Since water supplies may be lower in the dry season due to less rain, we examined the season of data collection. Site investigators reported the season of data collection, which were categorized as dry, rainy, or neither dry or rainy.

Water insecurity score: We constructed our household water insecurity scores using items from the HWISE Scale (Young et al., 2019a). Following Stoler (Stoler et al., 2020), we used an adapted 11-item version of the cross-culturally validated 12-item HWISE Scale because one question was not asked in some sites. The 11-item score accounted for 99.3% of the variation in the 12-item HWISE Scale scores (Stoler et al., 2020). Some of these items were the same questions used for the unmet water needs and failure variables, but as a single index related to water availability, quantity, hygiene, and psychosocial dimensions [full description available in (Young et al., 2019a)]. Responses to each question were scored from 0 to 3 as: 0 = "never", 1 = "rarely" (1–2 times in the previous four weeks), 2 = "sometimes" (3–10 times), 3 = "often" (11–20 times) or "always" (20 + times). We summed the score for each household for the 11 items, and treated this as a continuous variable ranging from 0 to 33, where higher scores indicate greater water insecurity.

2.3. Demographic controls

The demographic variables that were included in the analysis as control variables were: 1) whether the household was rural or urban/*peri*-urban (as identified by site leads), 2) the sex of the household head, 3) age and age-squared as this relationship may change over the life-course due to changing needs and abilities, 4) whether the primary drinking water source was improved (WHO and UNICEF, 2017) (piped, stand pipe, tubewell, protected borehole, protected dug well, protected spring, rainwater, small water vendor, tanker truck, or bottled water) or not (unprotected dug well, unprotected spring, surface water, other person, or other), and 5) whether the household had 5 L of drinking water per person stored in the household or not (Gleick, 1996). These covariates were selected *a priori* based on documented factors that affect water availability and needs within households, which may affect borrowing water (Gleick, 1996; WHO and UNICEF, 2017).

2.4. Statistical analysis

Analyses were estimated using Stata Version 15.1 (College Station, TX). Spearman's rank correlations were used to examine the relationship between the main water-related system failure proxy variables and water borrowing (SI Appendix, Table S2). Two-level, mixed-effect logistic regression models of 5495 households nested within 21 sites with random intercepts for each site and robust standard errors clustered within the sites were used to estimate the relationship between our dichotomous outcome of borrowing water and predictors since households are nested within sites. These models, when estimates are exponentiated, provide odds ratios (Searle et al., 2009). First, we examined how household unmet water need tertiles were associated with borrowing water adjusted for covariates. Models 2–6 (Table 2) then examined how relative perceived SES and each additional failure proxy (water quality failure, water availability failure, market supply failure, and water access failure) were associated with borrowing water to examine how their inclusion affected the strength of the relationship of unmet water needs, controlling for socio-demographics and seasonality.

We next used post-estimation marginal standardization from the multilevel mixed-effect logistic regressions using the fully-adjusted model (Table 2, Model 6) to generate predicted probabilities of water borrowing by the specified predictors (SI Appendix, Table S3–S7), controlling for the distribution of the covariates to illustrate the absolute effects within sites since the underlying prevalence of water sharing varied widely across sites (Muller and MacLehose, 2014). Finally, we tested an interaction between water access or time to fetch water including wait time with unmet water needs and the other three failure variables to examine whether water access moderates (or affects) these relationships. For this model, we included the fully adjusted model and added separate interaction terms (SI Appendix, Table S8, Models 1–4). We then generated the predicted probabilities as described above.

As a sensitivity analysis, we re-estimated the fully adjusted two-level, mixed-effect logistic regression model with household water insecurity as the primary predictor of borrowing water in place of unmet water needs and the other water system failure variables (SI Appendix, Table S9, Model 1). We then re-tested the interaction between water access with water insecurity (SI Appendix, Table S9, Model 1.

2.5. Data availability

Dataset and associated code will be deposited at ICPSR. Protocol of the HWISE study is available open access (Young et al., 2019b).

2.6. Analytic sample

We requested data in 2018 from all 24 HWISE sites that implemented a random sampling design; 3 of those sites (Acatenango, Guatemala [21% of households borrowed water], Gressier & Léogâne, Haiti [32%], Ceará, Brazil [15.1%]) had missing information on one or more key covariates which did not allow for the modeling we proposed to do. Therefore, our analyses were conducted on 21 sites, which included a total of 5495 households with information on water borrowing. Missing observations from covariates were dropped if the respondent indicated that the question did not apply to them, they did not know, or they declined to respond. In model 1, examining household water need and controls, 4980 households had information on all variables (Table 2, Model 1). In the fully-adjusted model, 4417 households had information on all independent variables and control variables for water borrowing (Table 2, Model 6). To estimate whether participants with missing covariate information differed from those with complete data, we analyzed participant differences in age, sex of head of household, household size, and percent borrowing water between those with and without missing covariate information. We found no statistical differences in age (39.8 [14.7 SD] vs 39.9 [14.6 SD] years) or household size (5.3 [2.9 SD] vs 5.3 [2.8 SD]), while sex of head of household (60.0% vs 69.0% male) and percent reporting borrowing water at least once in the previous 4 weeks (39.1% vs 43.6%) between those with and those without missing covariate data differed slightly, indicating that the missingness of covariate data likely occurred non-systematically.

3. Results

3.1. Prevalence of water borrowing

To test our first hypothesis, we examined the overall prevalence of borrowing across sites. Household water borrowing occurred at all 21 study sites, with 44.7% of sampled households reporting having borrowed water at least once in the past month (Fig. 2a). However, there

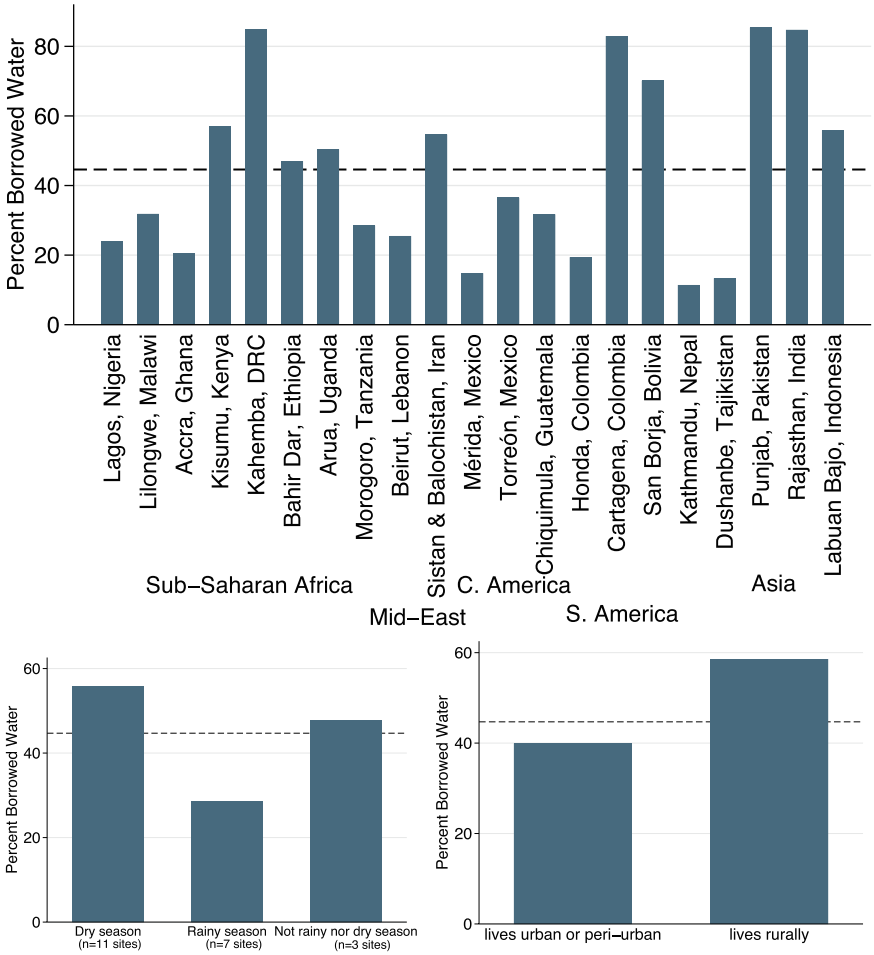

Fig. 2. Mean percent of households in each site that reported borrowing water at least once in the previous 4 weeks by (a) site/region, (b) by season, and (c) urbanicity. *Note*: Reference line is overall sample mean 44.7%. ANOVA F = 183; P < 0.0001 for differences across seasons; t = 12.2; P < 0.0001 for differences by rurality.

was considerable inter-site variation in prevalence, from 11.4% of households that borrowed water in urban Kathmandu, Nepal during the rainy season where there was high reliance on privately purchased water, to 85.4% in rural Punjab, Pakistan in the dry season where water was primarily drawn from community standpipes and tubewells (Table 1; Fig. 2a). Borrowing water was also prevalent in all seasons sampled, though water borrowing was twice as common in sites sampled in the dry season than the rainy season (55.7% vs 28.5%, Anova F = 183; P < 0.0001). It was common among households in both urban/*peri*-urban and rural environments, though more common among rural households (58.6% vs 39.9%; t = 12.2; P < 0.0001) (Fig. 2b, c). Additionally, a proportion of households at all perceived SES levels reported borrowing water, though there was a strong inverse association between water borrowing and greater SES (SI Appendix, Fig. S1).

Some sites, like Cartagena, Colombia, had both high prevalence of ever having borrowed water (83%) and a high proportion of households that borrowed frequently (11.4% of households reported borrowing water 20 or more times in the prior month). Other sites had lower household prevalence of any borrowing but higher frequencies of borrowing among those who did. For example, in Accra, Ghana where only 20.5% of households borrowed water, 2% of the households reported 20 or more water-borrowing instances in the prior month (Fig. 3).

3.2. Expectation of return

Of those that borrowed water, we asked what was expected to be given in return. This was a free-form text answer to which 2829 households responded. Of these, 70.5% of the respondents who borrowed said they were not expected to give anything explicit in return as it was a gift/free, while 1.0% said that they gave thanks, gratitude, or acknowledgement. Of the 28.5% of the sample (805 households) that stated that something was expected in return, 71.8% stated they gave water back at a later date, 18.0% stated they gave money, 3.6% reported they gave food items like vegetables, fruit, or ingredients like salt or sugar, 3.0% stated they performed labor, favors, or chores like cleaning or fetching water, 3.1% reported a non-specified item as exchange, and 0.5% said they gave back electricity or charged items.

3.3. Regression analysis

To test our second hypothesis about factors that drive water borrowing, we fitted two-level, mixed-effects logistic regression models (Searle et al., 2009). The distribution of unmet water needs, perceived SES, and water-related system failures varied across sites (SI Appendix, Fig. S2a–f) and were strongly correlated with borrowing water (SI Appendix, Table S2). We first examined this hypothesis by examining if

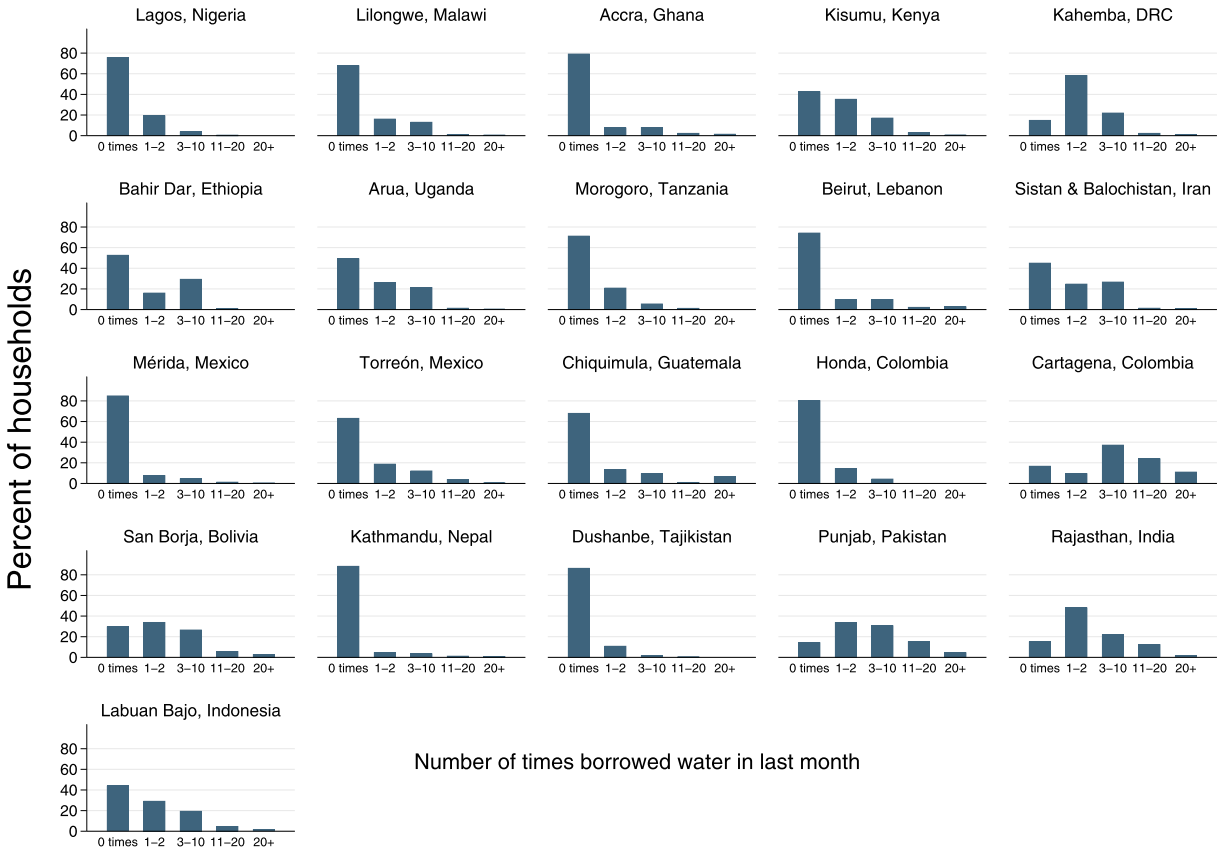

Fig. 3. Percent of households in each site that reported borrowing water in previous 4 weeks, by frequency. Note: (n = 5495); sites ordered by region.

unmet water needs was associated with water borrowing after adjusting for household-level and site-level covariates (Table 2, Model 1).

Borrowing water at least once was positively associated with unmet water needs across all models, regardless of additional water system failures (Table 2; Models 1–6). In the fully adjusted model, households in the medium unmet water need tertile had more than two times higher odds of borrowing water (odds ratio [OR] = 2.18, 95% confidence interval [CI]: 1.49–3.19, $P < 0.001$) compared to the low water need tertile, while households in the high water need tertile had almost three times the odds of borrowing water (OR = 2.86, 95% CI: 2.09–3.91, $P < 0.001$) (Table 2; Model 6; Fig. 4).

Next, we tested whether perceived SES, proxies of water-related system failures, and seasonality were associated with higher odds of water borrowing (Table 2, Models 2–6; Fig. 4). As hypothesized, lower perceived SES was positively associated with the odds of borrowing water. Every unit reduction in perceived SES standing within the community on the 10-rung McArthur-style ladder was associated with 9% greater odds of borrowing water (OR = 1.09; 95% CI: 1.05–1.13, $P < 0.001$).

In the third model, we found that households that reported *water quality failures* (i.e., drinking unsafe water) 3 or more times in the prior month had 57% higher odds (OR = 1.57; 95% CI: 1.12–2.19, $P = 0.008$) of borrowing water in the prior month. Households that reported *water availability failures* (i.e., interruptions to their day due to water problems) 1–2 times (OR = 1.81; 95% CI: 1.33–2.47, $P < 0.001$) and 3 or more times in the preceding month (OR = 2.53; 95% CI: 1.68–3.81, $P < 0.001$) had higher odds of borrowing water compared to households that did not experience daily interruptions. Similarly, households that reported experiencing *market supply failures* (i.e., being unable to purchase water when they wanted to) 1–2 times (OR = 1.51, 95% CI: 1.13–2.03, $P = 0.006$) or 3 or more times (OR = 1.52, 95% CI: 1.10–2.11, $P = 0.011$) in the previous month had higher odds of borrowing water than households that did not report an inability to buy water. Households with *water access failures* (i.e., longer fetching times) had higher odds of borrowing water than households with taps on their premises. Having a round-trip time of 60 or more minutes was associated with 2.58 times the odds of borrowing water in the prior month (95% CI: 1.77–3.76, $P < 0.001$).

Finally, seasonality was significantly associated with reported water borrowing practices. Being surveyed in the dry season was associated with more than double the odds of borrowing water (OR = 2.15; 95% CI: 1.10–4.20, $P = 0.026$) compared to sites surveyed in the rainy season (Table 2, Models 1–6; Fig. 4).

We next used marginal standardization of the fully adjusted multilevel mixed-effect logistic regression model to examine how the predicted probability of borrowing water changed within sites by unmet water need and the proxy measures of water-related systems failures (Fig. 5; SI Appendix, Tables S3–S7). The predicted probability of borrowing water increased as unmet water need increased (Fig. 5a). However, the underlying prevalence of water borrowing did affect the relative increase reflected in the probability. For example, in a setting with high prevalence of water borrowing, such as Punjab, Pakistan, households in the low unmet water need tertile had 63% (95% CI: 48.9 – 77.0) predicted probability of borrowing water, which increased among households in the high unmet water need tertile to 81% (95% CI: 72.4 – 89.3) (SI Appendix, Table S3). Whereas in a setting with low prevalence of water borrowing, such as Merida, Mexico, households in the low unmet water need tertile had a 22% (95% CI: 13 – 32) predicted probability of borrowing water, which increased to 42% (95% CI: 30 – 54) in the high need tertile – thereby almost doubling.

As households experienced higher levels of the proxy measures for water quality, water availability, market supply, and water access failures, they had a higher probability of borrowing water within and across sites, though the shape of the association varied by failure. First, drinking water perceived as unsafe three or more times in the prior month was associated with higher probability of borrowing water

Table 2
Mixed-effect nested logistic regression examining the relationship of water need and institutional failures on odds of borrowing water.

	1	2	3	4	5	6
VARIABLES	Borrowed water Odds ratio (95% CI)	Borrowed water Odds ratio (95% CI)	Borrowed water Odds ratio (95% CI)	Borrowed water Odds ratio (95% CI)	Borrowed water Odds ratio (95% CI)	Borrowed water Odds ratio (95% CI)
Unmet water need: Low tertile (REF)	1	1	1	1	1	1
Middle water need tertile	3.29***	3.12***	2.85***	2.41***	2.29***	2.18***
	(2.22–4.87)	(2.11–4.63)	(1.94–4.17)	(1.67–3.47)	(1.57–3.33)	(1.49–3.19)
High water need tertile	6.18***	5.44***	4.53***	3.25***	3.09***	2.86***
	(4.32–8.84)	(3.84–7.70)	(3.26–6.29)	(2.33–4.52)	(2.24–4.25)	(2.09–3.91)
Relative SES (perceived standing)		1.11***	1.10***	1.09***	1.10***	1.09***
		(1.05–1.18)	(1.05–1.16)	(1.04–1.14)	(1.06–1.14)	(1.05–1.13)
Water safety: None (REF)			1	1	1	1
Rarely (1–2 times)			1.34**	1.27**	1.19	1.23**
			(1.07–1.67)	(1.03–1.56)	(0.96–1.48)	(1.00–1.51)
Some or more (3 + times)			1.86***	1.66***	1.51**	1.57***
			(1.41–2.45)	(1.23–2.24)	(1.10–2.08)	(1.12–2.19)
Day interrupted: None (REF)				1	1	1
Rarely (1–2 times)				1.96***	1.88***	1.81***
				(1.49–2.57)	(1.40–2.52)	(1.33–2.47)
Some or more (3 + times)				2.57***	2.61***	2.53***
				(1.73–3.80)	(1.72–3.94)	(1.68–3.81)
Unable to buy water: None (REF)					1	1
Rarely (1–2 times)					1.60***	1.51***
					(1.18–2.17)	(1.13–2.03)
Some or more (3 + times)					1.58***	1.52**
					(1.13–2.21)	(1.10–2.11)
Water fetching time: 0 min (in home: REF)						1
1–29 min						1.51***
						(1.15–1.98)
30–59 min						1.63***
						(1.14–2.33)
60 + minutes						2.58***
						(1.77–3.76)
Improved drinking water source (yes)	1.10	1.07	1.09	1.09	1.06	1.13
	(0.84–1.44)	(0.83–1.38)	(0.83–1.42)	(0.85–1.40)	(0.84–1.32)	(0.89–1.42)
Rainy season (REF)	1	1	1	1	1	1
Dry season	3.16**	3.09**	2.73**	2.44**	2.23**	2.15**
	(1.18–8.46)	(1.19–8.03)	(1.13–6.58)	(1.14–5.24)	(1.02–4.87)	(1.10–4.20)
Not rainy nor dry season	2.22**	1.98*	1.90**	1.55	1.45	1.45
	(1.06–4.66)	(0.98–4.00)	(1.03–3.49)	(0.88–2.74)	(0.79–2.66)	(0.77–2.74)
Rural (yes)	1.20	1.17	1.14	1.19	1.22	1.13
	(0.79–1.81)	(0.81–1.70)	(0.77–1.68)	(0.82–1.71)	(0.83–1.79)	(0.78–1.64)
Drinking water storage greater than 5 L per person	0.89	0.90	0.89	0.90	0.89	0.89
	(0.64–1.24)	(0.65–1.24)	(0.64–1.23)	(0.65–1.26)	(0.64–1.24)	(0.63–1.26)
Age	0.99	1.00	0.99	0.99	1.00	1.00
	(0.96–1.02)	(0.97–1.02)	(0.96–1.02)	(0.96–1.02)	(0.97–1.03)	(0.97–1.03)
Age-squared	1.00	1.00	1.00	1.00	1.00	1.00
	(1.00–1.00)	(1.00–1.00)	(1.00–1.00)	(1.00–1.00)	(1.00–1.00)	(1.00–1.00)
Head of household sex (male)	0.98	1.00	0.99	0.96	0.97	0.98
	(0.81–1.18)	(0.83–1.20)	(0.82–1.19)	(0.79–1.17)	(0.78–1.20)	(0.79–1.21)
Observations	4,980	4,883	4,852	4,823	4,444	4,417
Number of sites	21	21	21	21	21	21

Robust 95% confidence intervals (CI) in parentheses.
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.
Site-level clusters and constant included in model, but not shown. HH: Household; REF: Reference category; SES: Socio-economic status.

across sites (Fig. 5b; SI Appendix, Table S4). In contrast, there was more of a linear increase in probability of borrowing water as interruptions to daily activities due to water problems increased (Fig. 5c; SI Appendix, Table S5). The unavailability of water for purchase even 1–2 times in the prior month resulted in a statistically significant increased predicted probability of borrowing water and that elevated probability stayed constant when experiencing this 3 or more times (Fig. 5d; SI Appendix, Table S6). Finally, as water access became more challenging, represented by a longer round-trip and queue time to fetch water, reported water borrowing increased, with the highest probabilities for households with a 60 min or longer average round-trip to fetch water (Fig. 5e; SI Appendix, Table S7).

3.4. Interaction analysis

Next, we tested how water access (round-trip time to source) moderated unmet water needs and the other failures proxies. We found significant interactions (SI Appendix Table S8, Models 1–4; Fig. 6a–d) between round-trip time categories and at least one other category for each of the other four predictors (all $p < 0.01$), indicating that water fetching time moderates the relationship between unmet water needs, the water-related system failure variables, and water borrowing.

For example, those households with 60 min or more water fetching time per trip who have low unmet water needs had significantly higher probability of borrowing water (52.9%, 95% CI: 39.6 – 66.2) than those with water on premises (0 min) (21.6%, 95% CI: 14.3 – 28.8) with low unmet water needs (Fig. 6a). But for households at medium and high unmet water needs, there was not a significant difference by water

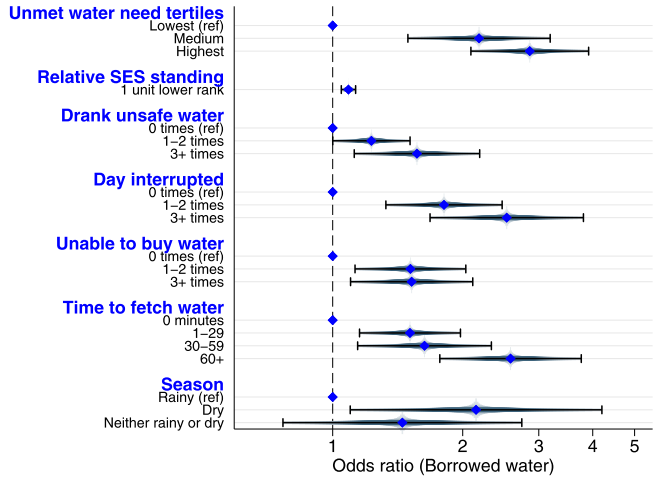

Fig. 4. Multilevel mixed-effect logistic regression examining the relationship between water need, perceived SES, water-related failures in water quality, availability, market supply, and access, and seasonality in predicting water borrowing. Notes: Model adjusted for all covariates listed and urbanicity of site, sex of household head, whether the primary drinking water source was improved or not, whether household had 5 L or more per person in drinking water stored, age, and age-squared. Robust standard errors nested within sites. n = 4417 in 21 sites. Ref: reference category. Full model in Table 2, Model 6.

fetching times in borrowing water.

3.5. Sensitivity analysis: Water insecurity as a predictor of borrowing water

We re-estimated the fully adjusted mixed effect logistic regression model to test how household water insecurity score (in place of the unmet water needs and water failure variables) was associated with borrowing water. We found results consistent with the primary analyses, as each point higher on the water insecurity scale was associated with 10% (OR = 1.10; 95% CI: 1.08, 1.13; $P < 0.001$) higher odds of borrowing water (SI Appendix, Table S9, Model 1). Distance to water source was again strongly associated with borrowing water and all other covariates had similar relationships as prior models. We found a significant interaction ($P < 0.001$) between water insecurity and distance to water source (SI Appendix, Table S9, Model 2). While the households with water on their premises had the lowest probability to borrow water at low water insecurity scores, the shape of the relationship changed form and accelerated as water insecurity scores increased, unlike those with long round-trip times to fetch water which had more of a linear increase (Fig. 7).

4. Discussion

In this first global study of water borrowing, our primary objective was to examine how widely this was practiced across diverse sites with varying water problems. We found that water borrowing was reported in all 21 study sites, that 44.7% of households reported at least one borrowing event in the prior month, and that large variation existed across sites as this behavior ranged from 11.4% to 85.4% of sampled households. For those who borrowed, 71.5% stated nothing explicitly was expected in return, whereas those with an expectation of return primarily gave back water, money, food, or labor. Water borrowing occurred across seasons, but was more common during the dry season when water was scarcer, and degrees of rurality, suggesting that it emerges organically as an informal response to escalating water problems regardless of other background conditions. When adjusting for water system failures, rurality did not significantly predict likelihood of borrowing water, signifying that other factors are more important in predicting water borrowing. Whereas prior studies have highlighted the hidden costs of household responsibilities for water acquisition (e.g. attempting to find water from multiple sources, time costs, etc.) (Geere et al., 2018; Majuru et al., 2016; Pattanayak et al., 2005), the present study greatly expands this thinking. We present evidence that water acquisition through non-market exchanges is much more widespread as a coping response than previously documented (Pearson et al., 2015; Schnegg and Linke, 2015; Wutich, 2011; Zug and Graefe, 2014), and may even represent a universal cross-cultural coping strategy in households living in communities with water problems, though the extent to which it is relied upon depends on site and household level conditions.

Second, we tested the hypothesis that greater unmet water need, water-related system failures, and lower SES would be associated with greater water borrowing. We found that households that experienced the highest levels of unmet water need and water quality, water

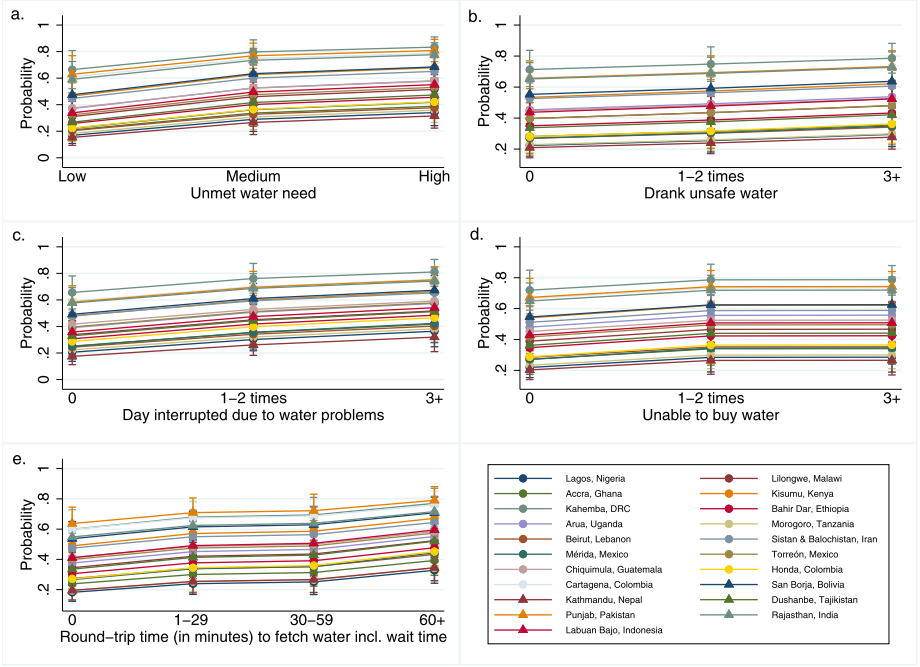

Fig. 5. Predicted probability and 95% confidence intervals of borrowing water by a) unmet water need tertiles; b) drank unsafe water; c) interruptions of the day's activities; d) inability to purchase water; e) time to fetch water; all calculated within sites. Notes: Figures generated using marginal standardization adjusted for unmet water need, water safety, daily water interruptions, inability to purchase water, round-trip time to fetch water, and perceived SES, season, urbanicity, sex of household head, whether household had 5 L or more per person in drinking water stored, whether household used an improved water source, age, and age-squared. N = 4,417 in 21 sites. Values for all 5 figures shown in SI Appendix, Tables S3-S7.

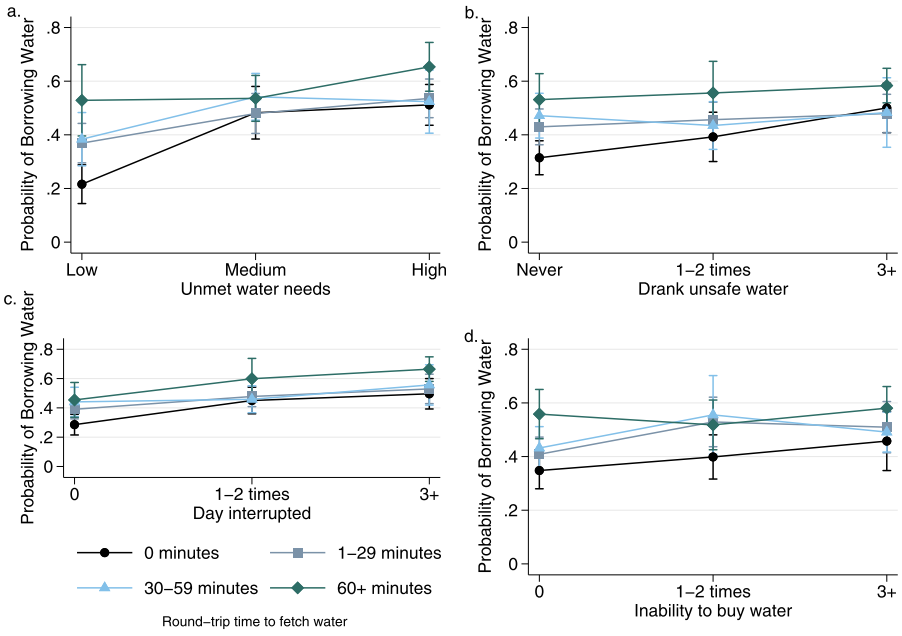

Fig. 6. Predicted probability and 95% confidence intervals of borrowing water as reflected by interactions between time to water source and a) unmet water need tertiles; b) times drank unsafe water; c) interruptions of the day's activities; d) inability to purchase water. Notes: Figures generated from models 1–4 in Table S8 using marginal standardization adjusted for unmet water need, water safety, daily water interruptions, inability to purchase water, round-trip time to fetch water and interactions between round-trip time to fetch water and the 4 key predictors, and perceived SES, season, urbanicity, sex of household head, whether household had 5 L or more per person in drinking water stored, whether household used an improved water source, age, and age-squared. N = 4417 in 21 sites.

availability, market supply, and water access failures were more likely to borrow water. This indicates that water borrowing is not just a practice linked to a specific cultural setting. While there are documented cases of non-need based water sharing [e.g., the White Mountain Apache gifts of sacred water (Goodwin, 1969; Wutich et al., 2018)], we provide better and more systematic evidence that unmet water needs and water-related system failures are strongly associated with water borrowing. Moreover, we found that household water insecurity is strongly associated with borrowing water. Each point higher on the water insecurity scale was associated with 10% higher odds of borrowing water. Additionally, as predicted, we found that water borrowing increased as perceived community SES decreased. This finding further indicates that vulnerable households cope with water problems by relying on outside channels to meet water needs. Households whose round-trip time for fetching water was just 1–29 min still had 51% higher odds of borrowing water than households that had water available on premises, while many households were spending considerably more time fetching water. While we did not ask households specifically what conditions precipitated their borrowing water, that households borrowed water even when their water source was on their premises indicates that improved infrastructure does not ensure water security. Indeed, intermittent water supply and unexpected interruptions can lead these households to borrow water.

Finally, to test our hypothesis that limited water access may moderate these unmet water needs and water-related failures on borrowing water, we examined multiple interactions. Our results indicate that having an hour or more round-trip to fetch water is associated with greater water borrowing, even if households do not experience other water-related system failures. It is clear that water fetching time shapes borrowing behaviors even if the other risk factors, like unmet water needs, are low. In fact, 56.7% of households in which fetching took more than an hour borrowed water at least once in the prior month despite not experiencing the other factors. That households with medium and high unmet water needs did not have statistically different probabilities of borrowing water by round-trip fetch time may indicate that these households are already more vulnerable. This was further supported by the results illustrating a significant interaction between household water insecurity score and water access. Again, distance was the predominant factor shaping borrowing water probability at low levels of water insecurity, but as water insecurity increased, those who had water on their premises had a sharper acceleration in probability of borrowing water, likely due to interruptions in supply.

These findings highlight the reality that even those households reporting access to "safe and affordable drinking water" (as specified in SDG 6.1) may cope with water challenges in socially complex ways that can create or reinforce future obligations to others (Cole, 2017; Mehta and Movik, 2014; Satterthwaite, 2016). Such obligations can be extremely stressful, especially for households already facing multiple material challenges (Wutich and Ragsdale, 2008). This is supported qualitatively: In Labuan Bajo, one of the HWISE sites included here, relations with neighbors were affected by "needing to ask" and "feeling ashamed of asking", giving some neighbors power over others and creating indebtedness leading to further emotional strain. Moreover, research on reciprocal exchange systems indicates that asymmetrical

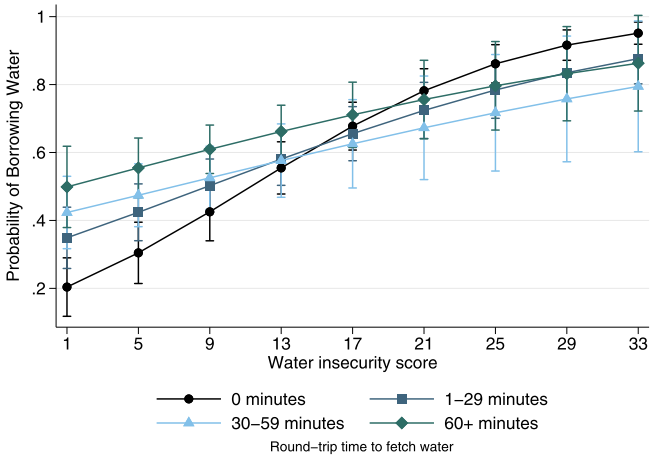

Fig. 7. Predicted probability and 95% confidence intervals of borrowing water as reflected by interaction between time to water source and household water insecurity score. Notes: Figure generated from model 2 in Table S9 using marginal standardization adjusted for water insecurity, round-trip time to fetch water, and interactions between round-trip time to fetch water and water insecurity, and perceived SES, season, urbanicity, sex of household head, whether household had 5 L or more per person in drinking water stored, whether household used an improved water source, age, and age-squared. N = 4984 in 21 sites.

resource sharing relationships between peers (e.g., from repeated borrowing or gift-receiving) can lower the receiver's social status (Wiessner, 2002), though these dynamics are not well understood in the context of water sharing. In the classic anthropological formulation of Mauss, gifting (of anything, including water or food) was both a material and a spiritual transaction, the giver and the receiver acting out a social bond witnessed by the broader community (Mauss, 2002). This bond could become a source of personal stress and strain in the absence of any prospect of reciprocity, not least because ability to lend and propensity to borrow seem to become part of a mutually reinforcing cycle. While often there may not be an explicit obligation to return water immediately, an implicit expectation of future return occurs in some sites (Brewis et al., 2019).

As public water systems are predicted to be increasingly stressed by local and global forces, such as global climate change (Adane et al., 2017; Cinner et al., 2018; Elliott et al., 2017; Mapulanga and Naito, 2019; McDonald et al., 2011, 2014), our work portends a possible need to understand the dynamics of water sharing and other non-market water systems at the household level. Borrowing water may help solve immediate crises but may also aggravate health and other risks by increasing exposures and stress for those who must increasingly cope by borrowing water (Stoler et al., 2019). This is further complicated by our finding that households that have lower perceived SES, worse water access, and higher water insecurity—that is, those who are already amongst the most vulnerable—were more likely to borrow water. This finding underlines the reality that while water borrowing is a proximate means to cope, widespread use of water sharing under conditions of need might inadvertently trap participating households in a vicious cycle of poverty, low self- and community esteem, and social indebtedness. Nevertheless, water borrowing clearly has important social, economic, and health tradeoffs beyond just receiving water for both the receiving and lending households. Engaging in this practice may enhance (or erode) bonds between households, which may become advantageous later when the other party is in need (Wutich et al., 2018). Social norms and cultural practices are clearly important to managing critical water sources at multiple scales, including the household level (Castilla-Rho et al., 2017; Koehler et al., 2018).

4.1. Limitations

Direct observations of water borrowing might produce higher estimates of this practice as households may forget one or more water borrowing instances over the course of a month through recall bias. Second, social desirability bias of household surveys may have affected some responses to questions where the topic may have been sensitive, like not having enough water to wash hands after dirty activities, though all interviews were conducted in the participant's primary language by trained local intermediaries to minimize invasiveness and improve rapport, and cognitive interviews were conducted to ensure that questions could be answered (Krumpal, 2013). Third, this study was cross-sectional and thus our results should be interpreted as associations. While the one-month survey recall period for water borrowing and the various predictors align, we cannot confirm the directionality of these relationships. Nevertheless, previous longitudinal ethnographic work supports our core findings that water borrowing is associated with water need and water-related system failures (Pearson et al., 2015; Schnegg and Linke, 2015; Wutich, 2011; Zug and Graefe, 2014). Additionally, our data only identified whether households borrowed water and how frequently. We did not collect information on how much water was shared, the quality of the water shared, the source of the water, or the impact on the neighbor's stored water supply. Finally, while random sampling was conducted within each site, sites were not themselves selected to represent the larger geographic area within which they were located. They nevertheless span distinct cultures and settings from different world regions and thus serve as a reasonable global test of this practice among communities dealing with diverse water problems.

5. Conclusions

This first global systematic study of water borrowing practices across an array of low- and middle-income country sites yields four key observations. First, household water borrowing is a cross-cultural practice that occurs globally across sites. Borrowing water may be a larger, and growing, component of daily life across the world than previously thought. Second, greater unmet household water needs are associated with more frequent water borrowing. Third, water borrowing across and within sites may act as a response to broader failures related to water quality, water availability, market supply, and water access systems (both formal and informal) that constrain household access to safe, reliable, and affordable water. Finally, water borrowing is more common among water-insecure households that are likely the most vulnerable (i.e., those who report the lowest perceived SES and have the longest water fetching times) within these already water-stressed communities. This suggests that water sharing is a coping response borne of material deprivation and water insecurity, rather than social preference; it is possible, however, that people who lack water perceive themselves to have lower SES.

Further attention to water sharing networks in water-insecure settings is critical for uncovering when, how, and why this virtually invisible, informal coping strategy works, as well as clarifying development needs and potential interventions since many socioeconomic and health-related tradeoffs are involved in this practice (Stoler et al., 2019). Failure to acknowledge the prevalence of water sharing could lead to misleading reporting of Sustainable Development Goal targets. For instance, at an aggregate level, a high percentage of households may have access to an improved source, recognized as a key target to achieve SDG 6.1, but if that access is mediated through borrowing from a neighbor's hand pump or tap, it cannot be considered as a water-secure outcome (Majuru et al., 2016). At a local level, failure to understand the dynamics of water sharing may also lead to inappropriate development interventions that upend, rather than support, secure access. Moreover, the challenging conditions faced by vulnerable households are likely to be worsened by projected changes to water availability through climate change and population growth (Konapala et al., 2020; Steffen et al., 2018). This combination of climate change and population growth may make borrowing a more important social phenomenon in coming decades, rather than a vestige of a pre-modern past when central water systems were unknown. As a global phenomenon, water sharing could potentially be harnessed to improve community resilience to natural and economic shocks (Cinner et al., 2018), but only with great care to ensure that institutions do not shirk their duties of public water provision and further shift that responsibility to residents.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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