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Water Supply Interruptions Are Associated with More Frequent Stressful Behaviors and Emotions but Mitigated by Predictability: A Multisite Study

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ABSTRACT: Water supply interruptions contribute to household water insecurity. Unpredictable interruptions may particularly exacerbate water insecurity, as uncertainty limits households' ability to optimize water collection and storage or to modify other coping behaviors. This study used regression models of survey data from 2873 households across 10 sites in 9 middle-income countries to assess whether water supply interruptions and the predictability of interruptions were related to composite indicators of stressful behaviors and emotional distress. More frequent water service interruptions were associated with more frequent emotional distress ($\beta = 0.49$, SE = 0.05, $P < 0.001$) and stressful behaviors ($\beta = 0.39$, SE = 0.06, $P < 0.001$). Among households that experienced interruptions, predictability mitigated these respective relationships by approximately 25 and 50%. Where the provision of continuous water supplies is challenged by climate change, population growth, and poor management, water service providers may be able to mitigate some psychosocial consequences of intermittency through scheduled intermittency and communication about water supply interruptions. Service providers unable to supply continuous water should optimize intermittent water delivery to reduce negative impacts on users, and global monitoring regimes should account for intermittency and predictability in post-2030 water service metrics to better reflect household water insecurity experiences.

KEYWORDS: *intermittent water supply, mental health, anxiety, psychosocial stress, water security*

1. INTRODUCTION

Billions of people lack safe water access[1] in both low- and high-income settings.[2] When sociotechnical infrastructure cannot provide continuous water supplies, or where such infrastructure never existed, households often face interruptions to their water supply that disrupt daily activities.[3] Even those with water piped to their homes may not enjoy a continuous water supply; nearly a billion people with piped water experience an intermittent water supply (IWS).[4] Interruptions stem from a combination of social, infrastructural, and hydrological root causes such as when demand exceeds supply due to new connections, overconsumption, leakages or other infrastructure problems,[5−7] seasonal fluctuations,[8] or politics or social exclusion.[9−12]

Some water supply interruptions can be anticipated; rotating shutoffs in a piped system to maintain system pressure can be planned and seasonal changes to water groundwater availability can be predicted with some certainty. Others are unpredictable, such as sudden failure of components, unplanned maintenance, reduced water flow due to neighbors' high water demands, or changes in rainfall patterns. The contrast between *predictable* and *unpredictable* interruptions is important, because households may experience and respond to them differently. Galaitsi et al.[13] describe three types of intermittency: *unpredictable*, *irregular*, and *unreliable*, and suggest that unpredictable interruptions are the most disruptive. But the specific implications of *unpredictable* interruptions, particularly as experienced by the users of nonpiped water sources, has received considerably less attention than the phenomenon of IWS from piped systems.[14]

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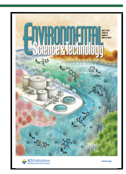

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A growing body of evidence indicates that water problems cause emotional distress and psychosocial stress.[15−19] People experience fear and worry about not having enough water to meet their daily needs, and shame related to family responsibilities or social expectations. Psychosocial stress may also lead to water-coping behaviors that cause stress and distress ("stressful coping behaviors"), such as drinking less safe water,[20] spending more on water treatment,[21] borrowing water from others and subsequently feeling indebted to them,[22] or withdrawing from social engagements.[23] These stress-inducing coping behaviors can reinforce cycles of emotional distress, but these distinctions are rare in the IWS literature despite intermittency's known adverse effects on mental health[24−26] which may be exacerbated by unpredictability. Figure 1 summarizes a conceptual model of how

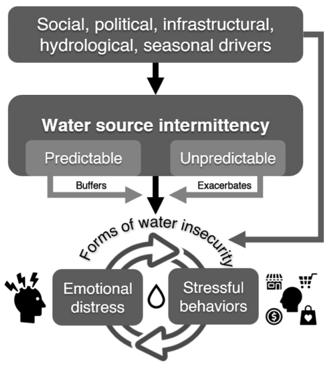

Figure 1. Conceptual model of the theorized relationships between the water source intermittency, predictability, and two forms of water insecurity, emotional distress, and stressful behaviors. (Icons created by Hanbai and Adrien Coquet of the Noun Project, CC BY 3.0.)

predictable and unpredictable forms of water source intermittency are theorized to shape mutually reinforcing emotional distress and stressful behaviors.

While it has long been a working assumption by researchers, practitioners, and policy makers that intermittent water supplies have negative consequences, few studies have specifically addressed the effects of unpredictable water supplies on mental health or attempted to empirically quantify these adverse impacts. This paper explores whether more frequent water supply interruptions are associated with higher psychosocial stress, and whether experiencing *predictable* interruptions mitigates the observed relationship. We propose two hypotheses related to intermittency and predictability of water supply and its relationship with composite indicators of *emotional distress* and *stressful behaviors*, and we test them using a multicountry data set of 10 sites from 9 countries.

- H1: Experiencing more frequent water supply interruptions (i.e., intermittency) will be associated with a *higher* frequency of (a) emotional distress, and (b) stressful behaviors, related to water insecurity.
- H2: Among the subset of households experiencing interruptions, having advanced knowledge of water supply interruptions (i.e., *predictable* intermittency) will be associated with *lower* frequency of (a) emotional distress, and (b) stressful behaviors.

By characterizing the impact of predictability on households' experience of and response to water supply interruptions, we can gain insights into the consequences of intermittency and predictability for household water insecurity. If we then quantify these relationships, we can inform operational and policy decisions in contexts where a continuous water supply is difficult to achieve. This can help operators provide water services that better meet customers' needs and inform efforts to create global indicators of water service quality to better reflect households' experience of intermittent supply.

2. METHODS

2.1. Study Sites and Data Source. The data analyzed in this study were drawn from the Household Water Insecurity Experiences (HWISE) global data set compiled from household surveys administered in 2017−2018. This parent study involved 8297 participants from 29 sites in 24 countries across sub-Saharan Africa, South America, Central America, the Middle East, Oceania, and Asia, and was originally designed to develop and validate a household-level water insecurity scale across urban, peri-urban, and rural settings.[27] Each site had a target sample of 250 households, regardless of urban classification, to have sufficient power to meet the parent study's objectives.[27,28] The site leads worked with locally

Table 1. Study Sites and Key Characteristics

region	site	sample size (n = 2873)	season of data collection	% female respondents	World Bank income classification	urbanicity classification
East Asia	Labuan Bajo, Indonesia	275	dry	44.4	lower middle income	urban and rural
South Asia	Dhaka & Chakaria, Bangladesh	505	rainy	97.0	lower middle income	urban and rural
South Asia	Pune, India[a]	179	multiple	100	lower middle income	urban and rural
South Asia	Rajasthan, India	233	dry	27.4	lower middle income	rural
Middle East	Beirut, Lebanon	565	rainy	64.2	upper middle income	urban
Middle East	Sistan and Balochistan, Iran	136	rainy	99.2	upper middle income	urban, peri-urban, and rural
Latin America	Torreón, Mexico	243	dry	72.8	upper middle income	urban
Latin America	San Borja, Bolivia	212	dry	62.8	lower middle income	urban, peri-urban, and rural
Latin America	Chiquimula, Guatemala	288	dry	85.7	lower middle income	rural
Latin America	Cartagena, Colombia	237	dry	70.6	upper middle income	urban

[a]All sites used random sampling except Pune, which used a parallel assignment, nonrandomized strategy.

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recruited and trained enumerators to obtain informed consent in a local language at all sites prior to the data collection with IRB oversight from multiple institutions.[29] Survey participants included one eligible adult per household who self-identified as being knowledgeable about the household's water situation. Although the household sample was not intended to be representative of the surveyed countries or subregions, it does reflect the typical experiences of low- and middle-income households living with water insecurity across diverse contexts.

The parent study was conducted in two survey waves with the survey item assessing the predictability of water supply interruptions added in the second wave. Therefore, 13 second-wave sites were eligible for this study. Three of these 13 sites (Gressier, Haiti; Morogoro, Tanzania; and Punjab, Pakistan) were excluded because they had fewer than 50 households with complete data, which led to unstable model parameters in our preliminary analyses. These criteria resulted in a final set of 10 sites across East Asia, South Asia, the Middle East, and Latin America and the Caribbean (Table 1). The lack of sites from sub-Saharan Africa is a limitation; all but one African HWISE study site were included in the first survey wave that did not assess predictability.

The survey contained modules about the household's sociodemographic characteristics, water sources and acquisition behaviors, and different experiences related to issues such as water insecurity, food insecurity, and psychosocial health. The water insecurity module included questions about the frequency of household experiences related to water in the 4 weeks prior to the survey, and responses were categorized and coded as follows: never (0 times; coded as 0), rarely (1−2 times; 1), sometimes (3−10 times; 2), or often or always (11−20 times or more; 3). This module is the origin of our outcome measures related to psychosocial health and the exposures of interest related to intermittency and predictability. The full survey instrument and additional details about the parent study are available elsewhere.[27]

2.2. Dependent Measures. Our outcome measures were two indicators, *emotional distress* and *stressful behaviors*, each compiled from subsets of four survey items scored from 0 to 3 (Table 2). The four survey items aggregated into *emotional distress* measured the frequency of someone in the household reporting one of the following emotional states related to having insufficient water: worrying (about quantity), worrying about safety while obtaining water, shame, and anger, similar to the operationalization by Wutich and Ragsdale.[19] The four survey items aggregated into *stressful behaviors* measured how often someone in the household activated these water insecurity coping behaviors, which have been found to be stressful in prior research:[30] changing plans, missing social events, borrowing water from others, and drinking water perceived to be unsafe.

We first used principal component analysis to explore whether these two item sets exhibited unidimensionality. The Kaiser[31] rule of retaining components with eigenvalues > 1 suggested that each item set was indeed best summarized by a single component. But because each component only accounted for 59 and 56% of each respective item set's variance, we instead retained the original item scaling by computing *emotional distress* and *stressful behaviors* as the mean of each 4-item set, thus yielding two indicators with a range of 0−3. We excluded households with fewer than two valid responses from the four items. Cronbach's α suggested that there was acceptable internal reliability for both *emotional distress* (α = 0.765) and *stressful behaviors* (α = 0.715).[32]

2.3. Independent Measures. The exposures of interest were two survey items that assessed how often, in the prior 4 weeks, households experienced water supply interruptions and whether they had received notification or otherwise knew about the upcoming interruptions (i.e., predictability of interruptions). The interruptions item was scored using the same 0−3 frequency codes as described previously (never [0], rarely [1], sometimes [2], often or always [3]), and the predictability item was a binary indicator (1 = announced/scheduled, 0 = unexpected) for those households who experienced any interruptions in the past 4 weeks.

We used several additional household-level indicators to control for sociodemographic characteristics and elements of household water usage that generally shape psychosocial aspects of household water insecurity:[8,18,23,33−35]

- Number of household members ("household size"): A higher number suggests higher water demand, which can magnify experiences of water insecurity.
- Gender of household head ("female household head"): Traditional gender roles often dictate that females manage a household's water and therefore bear disproportionate burdens in their experiences of household water insecurity.
- Primary drinking water source ("water source"): The water source indicator was constructed as an ordinal variable that mapped all water sources to the hierarchy of the World Health Organization's (WHO) Joint Monitoring Programme (JMP) service ladder for drinking water,[1] ranging from 1 to 6, where higher coded values reflect a lower service level: piped source on property (coded as 1), groundwater off-premise (2), surface water or rainwater (3), tanker or small vendor (4), bottled water (5), and other (6). These rankings reflect evidence on water quality risk,[36,37] accessibility,[38,39] cost,[40] and reliability,[37] and are approaches used in other research.[37]
- Water storage: Storing water in the home is a common adaptation strategy for households who do not have a continuous water supply. Because of the positive skew in the distribution of stored water measured in liters, we generated a three-category ordinal variable for water

Table 2. Survey Item Composition of the Emotional Distress and Stressful Behaviors Scores[a]

indicator	survey items
emotional distress	1. Worried about not having enough water
	2. Worried about personal safety while obtaining water
	3. Felt shame about not having enough water
	4. Felt anger about not having enough water
stressful behaviors	1. Changed plans due to not having enough water
	2. Missed social or cultural events due to not having enough water
	3. Borrowed water from others
	4. Drank water perceived to be unsafe

[a]All items began with the phrase, "In the last 4 weeks, how frequently have you or anyone in your household..."; were scored as never (0), rarely (1), sometimes (2), often or always (3); and were averaged in each score to retain the range of 0−3.

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Table 3. Frequency Statistics of All Dependent and Independent Measures and Bivariate Correlations with the Emotional Distress and Stressful Behaviors Scores[a]

characteristic and range	*n*	mean or frequency	standard deviation	correlation with emotional distress	correlation with stressful behaviors
			Dependent Measures		
emotional distress score (0−3)	2873	1.05	0.91		
stressful behaviors score (0−3)	2873	0.78	0.77		
			Independent Measures		
interruptions (0−3)†	2873	1.29	1.19	0.64***	0.53***
predictability (%)§[b]	1778	34%	0.47	−0.21***	−0.21***
household size (1−27)‡	2828	4.92	2.51	0.14***	0.14***
female head of household (%)§	2857	32%	0.47	0.01	−0.03
primary drinking water source (1−6)†	2868	2.44	1.28	0.06**	0.05**
water storage (1−3)†	2586	2.37	0.75	−0.05**	−0.08***
social status (1−10)†	2803	6.49	2.23	0.30***	0.31***
water status (1−10)†	2797	6.22	2.72	0.52***	0.44***
urban site (%)§	2842	57%	0.50	−0.00	−0.04
dry season (%)§	2873	52%	0.50	0.31***	0.31***

[a]Bivariate measure of association: †Spearman's Rank Correlation; ‡Pearson's Correlation; §Point-Biserial Correlation. $*P < 0.05$; $**P < 0.01$; $***P < 0.001$. [b]This question was only asked if intermittency > 0 (n = 1797 participants).

storage quantity based on natural breaks in the distribution: <21 L (coded as 1), 21−239 L (2), and >240 L (3).

- MacArthur Scale of Subjective Social Status ("social status"),[41] which asks the respondent to select 1 of 10 rungs on a ladder graphic (coded from 1 to 10) that best corresponds to their perceived social standing within the community. Respondents who report lower social status (who were reverse-coded to have higher values for this variable) were expected to be more vulnerable to water insecurity stressors.
- A modified version of the MacArthur Scale of Subjective Social Status that uses the same 10-rung ladder graphic to probe a household's perceived water situation relative to other community members ("water status"). Again, higher values indicated lower perceived status.
- Urbanicity ("urban" vs all other classifications): Urbanicity tends to influence the types of water sources and systems available at a given site, with respondents in urban communities expected to have access to more water source options than those in peri-urban or rural communities, thus reducing their vulnerability to water insecurity stressors.
- Seasonality ("dry season" vs all other seasons): respondents interviewed during the dry season—when water supplies may be limited, more distant from home, or more expensive—were expected to be more vulnerable to water insecurity stressors.

2.4. Statistical Analyses. We began by analyzing descriptive statistics and rates of missingness for each independent measure, assessing the correlation matrix of all indicators to check for potential collinearity concerns, and assessing bivariate relationships between each independent measure and *emotional distress* and *stressful behaviors*. We computed Pearson's correlation for the continuous independent measure (household size), Spearman's rank correlations for ordinal independent measures (intermittency, primary drinking water source, water storage rank, social status, and water status), and point−biserial correlations for binary independent measures (predictability, female head of household, urbanicity, seasonality).

We then fitted two separate linear multivariable regression models to assess the relationships between water supply intermittency with (1) *emotional distress*, and (2) *stressful behaviors*, controlling for household characteristics, and with standard errors clustered by study site. We used the structural equation model command "sem" in Stata for the multivariable analysis because the method is well suited for handling missing data.[42,43] We used the maximum likelihood with missing values estimation method, which assumes that any missing data were missing at random, to simulate missing data using full information maximum likelihood for our analytical sample of 2873 households across 10 sites. Finally, we fitted two additional models with the subset of 1797 households that experienced any level of intermittency (i.e., intermittency > 0) and added the predictability indicator to assess the association of predictability with *emotional distress* and *stressful behaviors* independent of intermittency. As a robustness check, we computed all four models with the interruptions item operationalized in two ways. We modeled *interruptions* as an ordinal variable to interpret the effect for each frequency level of interruptions, and then modeled *interruptions* as a continuous variable to facilitate an overall comparison of effect size with the binary predictability item. Given the variety of levels of measurement in our indicators, we reported all model results using standardized regression coefficients to simplify comparison of model coefficients within a given model.

All statistical analyses were performed in Stata v16 (StataCorp, College Station, TX) and interpreted with a statistical significance threshold of $\alpha \leq 0.05$. Ethical oversight of the analysis was provided by the institutional review board at the University of Miami through an interinstitutional agreement with Northwestern University. Oversight of the original data collection is described elsewhere.[29]

3. RESULTS

3.1. Descriptive and Bivariate Analyses. Frequency statistics [mean and standard deviation (SD)] for all independent measures are presented in Table 3, along with a measure of each indicator's bivariate correlation with the *emotional distress* and *stressful behaviors* scores. More frequent

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Table 4. Linear Regression Models of the Relationships between Water Supply Interruptions and Emotional Distress and Stressful Behaviors Scores, Controlling for Household Characteristics (n = 2873)[a]

	model 1: emotional distress score			model 2: stressful behaviors score		
characteristic	β	RSE	95% CI	β	RSE	95% CI
interruptions (0–3)	0.487***	0.054	0.381–0.593	0.391***	0.060	0.273–0.508
household size (1–27)	0.066**	0.023	0.022–0.111	0.069*	0.032	0.005–0.132
female head of household	0.020	0.020	−0.019 to 0.059	−0.013	0.015	−0.043 to 0.018
primary drinking water source (1–6)[b]	0.039	0.049	−0.058 to 0.135	0.047	0.053	−0.056 to 0.151
water storage (1–3)	−0.173***	0.033	−0.238 to −0.108	−0.181***	0.040	−0.259 to −0.103
social status (1–10)[b]	0.031	0.036	−0.039 to 0.101	0.069*	0.035	0.001–0.138
Water status (1–10)[b]	0.292***	0.028	0.238–0.346	0.228***	0.037	0.156–0.300
urban site	0.093	0.075	−0.055 to 0.240	0.083	0.088	−0.090 to 0.256
dry season	0.103	0.089	−0.071 to 0.277	0.136	0.076	−0.012 to 0.285

[a]*P < 0.05; **P < 0.01; ***P < 0.001. Model 1: R^2 = 0.51; model 2: R^2 = 0.39. β = standardized coefficient; RSE = robust standard error; 95% CI = 95% confidence interval. [b]Higher values indicate lower source quality and social/water status.

Table 5. Linear Regression Models of the Relationships between Water Supply Interruptions and Predictability, and Emotional Distress and Stressful Behaviors Scores, Controlling for Household Characteristics (n = 1797)[ab]

	model 1: emotional distress score			model 2: stressful behaviors score		
characteristic	β	RSE	95% CI	β	RSE	95% CI
interruptions (0–3)[b]	0.373***	0.058	0.260–0.486	0.249***	0.036	0.179–0.319
predictability[b]	−0.094***	0.023	−0.138 to −0.049	−0.120**	0.036	−0.191 to −0.049
household size (1–27)[b]	0.048	0.037	−0.025 to 0.121	0.042	0.042	−0.039 to 0.124
female head of household	0.036	0.027	−0.016 to 0.089	−0.001	0.019	−0.039 to 0.037
primary drinking water source (1–6)	0.005	0.057	−0.107 to 0.116	0.006	0.055	−0.102 to 0.113
water storage (1–3)	−0.160***	0.036	−0.230 to −0.090	−0.158***	0.026	−0.210 to −0.106
social status (1–10)	0.014	0.049	−0.083 to 0.111	0.0526	0.045	−0.036 to 0.141
water status (1–10)	0.264***	0.044	0.177–0.351	0.256***	0.024	0.209–0.303
urban site	0.191*	0.096	0.003–0.378	0.175	0.095	−0.011 to 0.362
dry season	0.163*	0.076	0.013–0.313	0.122*	0.059	0.006–0.238

[a]*P < 0.05; **P < 0.01; ***P < 0.001. Model 1: R^2 = 0.39; model 2: R^2 = 0.28. β = standardized coefficient; RSE = robust standard error; 95% CI = 95% confidence interval. [b]Higher values indicate lower source quality and social/water status.

water supply interruptions were positively correlated with emotional distress (ρ = 0.64, P < 0.001) and stressful behaviors scores (ρ = 0.53, P < 0.001), while predictability was negatively correlated with these scores (r = −0.21, P < 0.001 for each). Among the remaining household characteristics, only water storage—a key adaptation behavior to water insecurity—was associated with lower *emotional distress* (ρ = −0.05, P < 0.01) and *stressful behaviors* scores (ρ = −0.08, P < 0.001). Larger household size, a safer primary drinking water source, lower social status, lower water status, and being interviewed during the dry season were all positively correlated with higher *emotional distress* and *stressful behaviors* scores.

3.2. Multivariable Analysis. The multivariable models assessing the relationship between the frequency of water supply interruptions and the *emotional distress* and *stressful behaviors* scores are presented in Table 4. We observed similar positive relationships between each of these scores and interruption frequency, controlling for household characteristics, in support of our first hypothesis. We present results of the models with interruptions operationalized as a continuous variable for ease of interpretation relative to other terms in the model. See Table S1 in the Supporting Information for an additional model with interruptions operationalized as an ordinal variable. We interpret the standardized coefficients in these models as a 1 SD unit increase in a given independent measure resulting in β SD units increase in the emotional distress or stressful behaviors score.

In model 1, experiencing more frequent interruptions was associated with a higher *emotional distress* score (standardized beta [β] = 0.49, robust standard error [RSE] = 0.05, P < 0.001). Household size (β = 0.07, RSE = 0.02, P = 0.004) and water status (β = 0.29, RSE = 0.03, P < 0.001) were also associated with a higher *emotional distress* score, while water storage was associated with a lower *emotional distress* score (β = −0.17, RSE = 0.03, P < 0.001). The model's coefficient of determination (R^2) was 0.51, suggesting that the model explained about 51% of the variation in *emotional distress*.

In model 2 and consistent with findings for emotional distress, experiencing more frequent interruptions was associated with a higher *stressful behaviors* score (β = 0.39, SE = 0.06, P < 0.001). Household size (β = 0.07, RSE = 0.03, P = 0.034), social status (β = 0.07, RSE = 0.04, P = 0.046), and water status (β = 0.23, RSE = 0.04, P < 0.001) were all associated with a higher *stressful behaviors* score, while water storage was associated with a lower *stressful behaviors* score (β = −0.18, RSE = 0.04, P < 0.001). The coefficient of determination for this model was 0.39.

In both models in Table 4, experiencing more frequent interruptions also produced the largest standardized coefficients in each model relative to other known correlates of water-related distress. The coefficients for interruptions (0.49 and 0.39) were 66−71% higher than those for water status (0.29 and 0.23), and double the magnitude of the coefficients for water storage (−0.17 and −0.18), a key adaptive behavior for mitigating water insecurity.

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The multivariable models assessing the relationship between predictability of interruptions and the *emotional distress* and *stressful behaviors* scores are presented in Table 5. These models were fitted to the subset of 1797 households that reported experiencing interruptions at least once in the past 4 weeks and with interruptions operationalized as a continuous variable (see Table S2 in the Supporting Information for additional models with interruptions operationalized as an ordinal variable). We observed similar relationships between each of these scores and the indicators for predictability, controlling for intermittency, and other household characteristics, in support of our second hypothesis.

In model 1, experiencing more frequent interruptions was associated with a higher *emotional distress* score ($\beta = 0.37$, RSE $= 0.06$, $P < 0.001$) and the predictability of those service interruptions was associated with a lower *emotional distress* score ($\beta = -0.09$, RSE $= 0.02$, $P < 0.001$). These relationships suggest that water service predictability mitigated approximately 25% of the relationship between interruptions and *emotional distress*. In addition, low water status ($\beta = 0.26$, RSE $= 0.04$, $P < 0.001$), urban location ($\beta = 0.19$, RSE $= 0.10$, $P = 0.046$), and the dry season ($\beta = 0.16$, RSE $= 0.08$, $P = 0.033$) were all associated with a higher *emotional distress* score, while water storage was associated with a lower *emotional distress* score ($\beta = -0.16$, RSE $= 0.04$, $P < 0.001$). The model's coefficient of determination was 0.39.

In model 2, experiencing more frequent interruptions was associated with a higher *stressful behaviors* score ($\beta = 0.25$, RSE $= 0.04$, $P < 0.001$) and the predictability of those service interruptions was associated with a lower *stressful behaviors* score ($\beta = -0.12$, RSE $= 0.04$, $P = 0.001$). These relationships suggest that water service predictability mitigated approximately 50% of the relationship between interruptions and *stressful behaviors*. In addition—and similarly to the corresponding model of *emotional distress*—water status ($\beta = 0.26$, RSE $= 0.02$, $P < 0.001$) and the dry season ($\beta = 0.12$, RSE $= 0.06$, $P = 0.04$) were associated with a higher *stressful behaviors* score, while water storage was associated with a lower *stressful behaviors* score ($\beta = -0.16$, RSE $= 0.03$, $P < 0.001$). The coefficient of determination for this model was 0.28.

The two models containing the predictability item also produced larger coefficients for experiencing more frequent interruptions, relative to the remaining covariates. In the model of *emotional distress*, interruptions produced the largest coefficient (0.37), which was approximately 40% higher than water status (0.26), and the coefficient of predictability (−0.09) approached that of water storage (−0.16). In the model of *stressful behaviors*, the coefficient for interruptions (0.25) was comparable to that of water status (0.26), whereas predictability (−0.12) was comparable in magnitude to water storage (−0.16) and seasonality (0.12).

Table S2 (Supporting Information) contains the robustness check of the models in Table 5, but with interruptions operationalized as an ordinal variable. All of the covariate relationships and coefficients of determination are nearly identical, and the directions of the associations between interruptions, predictability, and the *emotional distress* and *stressful behaviors* scores are consistent with Table 5, providing additional evidence of the role of predictability. The models in Table S2 provide separate model coefficients for households who reported experiencing interruptions *sometimes*, and *often* or *always*, relative to those who reported them *rarely*. In these models, water service predictability mitigated nearly 54% of the relationship between interruptions and *emotional distress*, and 100% of the relationship between interruptions and *stressful behaviors*, among households who reported interruptions *sometimes*. Predictability mitigated 21% of the relationship between interruptions and *emotional distress*, and 41% of the relationship between interruptions and *stressful behaviors*, among households who reported interruptions *often or always*.

4. DISCUSSION

This study used household data from ten sites distributed across three continents to demonstrate that a higher frequency of water supply interruptions is associated with a higher frequency of water-related emotional distress and stressful behaviors. This finding is consistent with studies that have previously reported negative psychosocial impacts of unreliable water supplies and the various ways in which households cope with unreliable supplies.[11,13,15,19,21−23,44−47] The magnitude of the associations between water supply interruptions and emotional distress and stressful behaviors was generally much larger than the associations for several covariates long known to be correlates of water-related distress, underscoring the salience of our results.

Our analysis also demonstrated that when households expected their water supply interruptions (or otherwise perceived them to be predictable), the frequency of emotional distress and stressful behaviors associated with interruptions was mitigated by 25 and 50% respectively. This mitigation effect was slightly lower for households who experienced the most frequent level of interruptions but doubled for households that only experienced occasional interruptions. These relationships were stronger than those reported in a study that examined the effect of text message notifications for resumption of water supply in India,[48,49] and suggest that information about supply interruptions—or the perception of predictability—may reduce associated negative emotions and stressful behaviors. These findings support further theory-building around potential causal relationships among water disruptions, undesirable emotions, and adaptation (or maladaptation) through coping behaviors.

4.1. Implications for Water Service Delivery. These findings suggest that in contexts where water utilities and service providers struggle to provide continuous supplies, some of the adverse impacts of intermittency may be mitigated by careful management and communication of the intermittency in a way that helps households to adapt. For example, where piped systems have resorted to IWS to serve a larger population than they were designed for, the costs of providing continuous services may be prohibitive.[50] For a fraction of the cost, better operational practices can improve the predictability of system intermittency—potentially combined with better public awareness of the timing of service interruptions—thereby reducing some of the negative impacts on users. Some cities already do this; utilities will publicize the municipal water rationing schedule so that residents know the days, or even hours, of their neighborhood's water allocation,[49,51] though the user impact ultimately depends on the utility's adherence to the schedule.

Systems designed to provide information to water users about rationing schedules explicitly acknowledge the benefits of this information for users,[48,49] assuming that such knowledge can facilitate adaptation and coping by households and communities to reduce the impact of water supply interruptions. If supply interruptions are unavoidable, users

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may prefer a supply with a lower performance (measured strictly as hours of supply per day) but with more reliable interruptions, thus implying a theoretical "predictability premium."[52] Notification systems are also predicated on utilities understanding the adequacy of the water they supply, which is not always the case. Households may be viewed by the service provider as having continuous water service even if low pressure renders that service inadequate; thereby, a continuous supply with intermittent *pressure* may unintentionally make households ineligible for notifications.

In rural contexts, information about intermittent water sources—such as groundwater sources where access fluctuates seasonally or with precipitation events—is generally spread by word-of-mouth. Sensors and mobile technology may present opportunities for notification systems that save residents time by steering them to the "best" available water source (e.g., cleanest, nearest, or fastest-flowing), but most of the sensor research for rural water systems has focused on water quality, usage patterns, or infrastructure maintenance.[53−55]

Interruption frequency was also positively associated with increased water storage, which is a ubiquitous adaptation strategy that helps households cope with service interruptions.[56,57] If a household can afford automatic pumps that sense water pressure and fill plumbed household storage tanks, then unpredictable water services may become invisible to users (to the extent of their tank size). In this fashion, households and businesses with intermittent water supplies can create their own de facto continuous supply. In lieu of this level of household infrastructure, predictable water supply interruptions may make it easier for household-level adaptation, such as more efficient timing of trips to water access points, or scheduling one's availability to turn on pumps, manually fill containers, or manage household water treatment. Future interventions could explore combining improved storage capacity, point-of-use water quality technologies, and advanced notices of water service disruption to maximize the impact.

4.2. Global Monitoring and Definition of Water Services. The distinctions between predictable and unpredictable intermittency also have important implications for global water monitoring efforts. The definition of sustainable development goal (SDG) indicator 6.1.1, "safely managed drinking water services,"—the highest level of water service defined by the WHO's JMP service ladder—includes a criterion for water access that accommodates intermittency. "Water is counted as "available when needed" if households report having "sufficient" water, or water is available "most of the time" (that is, continuously or for at least 12 h per day or 4 days per week)."[1] This indicator implies that water source intermittency—and subsequent household adaptations—may not only be *acceptable*, but within the bounds of what global elites deem to be a high quality water service.

This JMP framing may inadvertently position the intermittent supply as a norm, but our results suggest that this broad definition of "safely managed drinking water services" covers a wide range of user experiences and responses. Households who know of interruptions in advance may have a much better experience than those who do not, and household storage may be the key to intermittent water being "available when needed" within the home. If an IWS continues to qualify as a high-quality water service in the post-SDG era, then global monitoring regimes will need to account for different experiences of intermittency and household adaptation strategies to accurately quantify "available when needed."

In contexts where decentralized solutions are cost-effective approaches to clean water provision, user acceptance of these systems may also depend on passive approaches to managing intermittency that do not burden users with stressful water management or infrastructure maintenance tasks.[58,59]

4.3. Limitations and Future Research. Our findings are limited by the study data gathered by a parent study investigating multiple aspects of water insecurity but with few questions about intermittency. We do not know to what extent the survey questions about emotional distress and stressful behaviors were perceived as linked to questions about supply interruptions. We also could not distinguish between random or nonrandom interruptions or estimate their severity (e.g., an outage vs a significant drop in pressure that precipitates coping or distress), and we did not have information about the timing or duration of interruptions or households' advance knowledge of them. The responses we used to construct the scores for emotional distress and stressful behaviors were self-reported subjective measures.

Although many of the survey items used in this study were demonstrated to have cross-cultural equivalency during the construction of the HWISE scale,[29] because the data were gathered by different teams in different languages, there is also potential bias in how study participants interpreted the meaning of water source interruptions. For example, pride in effective coping with intermittency can lead to a higher stated satisfaction with intermittent water service.[60] This may lead to under-reporting of emotional distress and—consequently—water insecurity. The small number of sites that implemented the predictability survey item also limits the generalizability of our findings to similar water-insecure sites in Latin America and Asia. Attitudes and local adaptive responses to unpredictable water supplies may differ in Europe, North America, or Africa.

This study also did not assess any objective measures of physical health or water quality, although the stressful behaviors indicator contained a perceived component, "drank water perceived to be unsafe." Potable water has long been linked to good health,[61] and even infrequent switching to unsafe water sources can undermine health gains.[62] Predictable intermittency will not *directly* reduce water-related infections related to microbial contaminants entering depressurized pipes, which is one of the main pathways linking intermittency and poor health.[63] But if residents are aware of interruptions, they can potentially avoid drinking water that is more likely to be contaminated and reserve it for nondrinking purposes. Other disease pathways for water-related diseases may be reduced through the better management of intermittency. For example, a study that observed an association between unpredictable water supply and dengue fever theorized that this relationship may have been related to mosquito breeding in water storage containers which were an adaptation to unpredictability.[25] The relationships between predictability and other well-established pathways for water-related diseases warrant further research.

To fully understand the role of predictability as a buffer from adverse health outcomes, future studies should investigate the relationships among intermittency, predictability, and a broader range of health outcomes associated with water insecurity. Additional studies could assess the relationship between predictability and specific coping behaviors and the effects of those coping behaviors on other dimensions of water insecurity. These could include gender burdens, inter- and

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intrahousehold conflict, and implications for food insecurity and nutrition. Determining the additional benefits of predictability can aid efforts to disaggregate elements of water supply reliability. This will help practitioners understand how these elements relate to different components of household water insecurity and subsequent adaptation and resilience-building responses, with longitudinal research needed to determine whether these changes over time. Because women may experience additional psychosocial stress due to their role in buffering family members against water insecurity,[64,65] future research should be conducted at the individual level to reveal any gendered impacts of supply (un)predictability.

Finally, we know little about how the timing, duration, frequency intervals, or severity of water supply interruptions affect users and household decision-making. Future studies should explore the impacts of specific types of interruptions as well as the extent to which improvements in the communication of service interruptions improve community relationships. Water service providers who cannot avoid supply intermittency may be able to leverage user-oriented predictability metrics to improve user satisfaction and communities' water security while also directly improving their operations. For example, optimizing service delivery around the least-disruptive forms of intermittency could lead to timelier bill payments and improved revenue collection. There may also be implicit cost-saving opportunities for operators in cases where fewer hours of predictable flow are more valued by users than more hours of unpredictable flow.[52] Water supply managers should thus consider the use of distress-related measures, such as those used in this study, as part of a comprehensive operational improvement and cost-savings strategy.

This study demonstrated that water supply interruptions were associated with water-related emotional distress and stressful behaviors but also that these stressful responses were less frequent if water supply interruptions were predictable. By improving the predictability of service interruptions to users, water service providers may be able to mitigate some of the negative impacts of intermittency. A finer-scale understanding of how unpredictable water supplies affect water insecurity—and in turn affect physical and mental health, livelihoods, and other aspects of well-being—would allow policy makers and practitioners to improve the effectiveness of water supply interventions and infrastructure operation. Such improvements to water supply management and communication can potentially minimize household disruptions, directly buffer users from negative mental health consequences, and promote household-level adaptations that also reduce psychosocial stress and build resilience to water insecurity.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.3c08443.

> The results of additional models using an alternate operationalization of the interruptions and outcome indicator variables to complement the results presented in Tables 4 and 5 (PDF)

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Household Water Insecurity Experiences Research Coordination Network (HWISE-RCN)

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Author Contributions

J.S., A.L.P., and P.T. conceived the study. A.L.P., P.T., and J.S. performed the analysis. P.T., J.S., and A.L.P. drafted the manuscript. All authors critically interpreted the results, revised the manuscript, and approved the final version.

Notes

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■ REFERENCES

(1) WHO/UNICEF. *Progress on Household Drinking Water, Sanitation and Hygiene 2000−2020: Five Years into the SDGs*; WHO, 2021.

(2) Meehan, K.; Jepson, W.; Harris, L. M.; Wutich, A.; Beresford, M.; Fencl, A.; London, J.; Pierce, G.; Radonic, L.; Wells, C.; Wilson, N. J.; Adams, E. A.; Arsenault, R.; Brewis, A.; Harrington, V.; Lambrinidou, Y.; McGregor, D.; Patrick, R.; Pauli, B.; Pearson, A. L.; Shah, S.; Splichalova, D.; Workman, C.; Young, S. Exposing the myths of household water insecurity in the global north: A critical review. *WIREs Water* **2020**, *7* (6), No. e1486.

(3) Smiley, S. L.; Stoler, J. Socio-environmental confounders of safe water interventions. *WIREs Water* **2020**, *7* (3), No. e1438.

(4) Bivins, A. W.; Sumner, T.; Kumpel, E.; Howard, G.; Cumming, O.; Ross, I.; Nelson, K.; Brown, J. Estimating infection risks and the global burden of diarrheal disease attributable to intermittent water supply using QMRA. *Environ. Sci. Technol.* **2017**, *51* (13), 7542−7551.

(5) Kaminsky, J.; Kumpel, E. Dry pipes: associations between utility performance and intermittent piped water supply in low and middle income countries. *Water* **2018**, *10* (8), 1032.

(6) Klingel, P. Technical causes and impacts of intermittent water distribution. *Water Supply* **2012**, *12* (4), 504−512.

(7) Simukonda, K.; Farmani, R.; Butler, D. Intermittent water supply systems: causal factors, problems and solution options. *Urban Water J.* **2018**, *15* (5), 488−500.

(8) Broyles, L. M. T.; Pakhtigian, E. L.; Rosinger, A. Y.; Mejia, A. Climate and hydrological seasonal effects on household water insecurity: A systematic review. *WIREs Water* **2022**, *9* (3), No. e1593.

(9) Lee, G. O.; Whitney, H. J.; Blum, A. G.; Lybik, N.; Cevallos, W.; Trueba, G.; Levy, K.; Eisenberg, J. N. S. Household coping strategies associated with unreliable water supplies and diarrhea in Ecuador, an upper-middle-income country. *Water Res.* **2020**, *170*, 115269.

(10) Price, H. D.; Adams, E.; Quilliam, R. S. The difference a day can make: The temporal dynamics of drinking water access and quality in urban slums. *Sci. Total Environ.* **2019**, *671*, 818−826.

(11) Tutu, R. A.; Stoler, J. Urban but off the grid: the struggle for water in two urban slums in greater Accra, Ghana. *Afr. Geogr. Rev.* **2016**, *35* (3), 212−226.

(12) Wutich, A.; Brewis, A.; Chavez, J. B. R.; Jaiswal, C. L. Water, worry, and Doña Paloma: why water security is fundamental to global mental health. *Global Mental Health*; Kohrt, B. A., Mendenhall, E., Eds.; Routledge, 2016, pp 57−72.

(13) Galaitsi, S. E.; Russell, R.; Bishara, A.; Durant, J. L.; Bogle, J.; Huber-Lee, A. Intermittent domestic water supply: A critical review and analysis of causal-consequential pathways. *Water* **2016**, *8* (7), 274.

(14) DuChanois, R. M.; Liddle, E. S.; Fenner, R. A.; Jeuland, M.; Evans, B.; Cumming, O.; Zaman, R. U.; Mujica-Pereira, A. V.; Ross, I.; Gribble, M. O.; Brown, J. Factors associated with water service continuity for the rural populations of Bangladesh, Pakistan, Ethiopia, and Mozambique. *Environ. Sci. Technol.* **2019**, *53* (8), 4355−4363.

(15) Stevenson, E. G. J.; Greene, L. E.; Maes, K. C.; Ambelu, A.; Tesfaye, Y. A.; Rheingans, R.; Hadley, C. Water insecurity in 3 dimensions: An anthropological perspective on water and women's psychosocial distress in Ethiopia. *Soc. Sci. Med.* **2012**, *75* (2), 392−400.

(16) Toivettula, A.; Varis, O.; Vahala, R.; Juvakoski, A. Making waves: Mental health impacts of inadequate drinking water services — From sidenote to research focus. *Water Res.* **2023**, *243*, 120335.

(17) Workman, C. L.; Ureksoy, H. Water insecurity in a syndemic context: Understanding the psycho-emotional stress of water insecurity in Lesotho, Africa. *Soc. Sci. Med.* **2017**, *179*, 52−60.

(18) Wutich, A.; Brewis, A.; Tsai, A. C. Water and mental health. *WIREs Water* **2020**, *7* (5), No. e1461.

(19) Wutich, A.; Ragsdale, K. Water insecurity and emotional distress: Coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement. *Soc. Sci. Med.* **2008**, *67* (12), 2116−2125.

(20) Daly, S. W.; Lowe, J.; Hornsby, G. M.; Harris, A. R. Multiple water source use in low- and middle-income countries: a systematic review. *J. Water Health* **2021**, *19* (3), 370−392.

(21) Cook, J.; Kimuyu, P.; Whittington, D. The costs of coping with poor water supply in rural Kenya. *Water Resour. Res.* **2016**, *52* (2), 841−859.

(22) Wutich, A.; Rosinger, A.; Brewis, A.; Beresford, M.; Young, S.; HWISE-RCN. Water sharing is a distressing form of reciprocity: Shame, upset, anger, and conflict over water in twenty cross-cultural sites. *Am. Anthropol.* **2022**, *124* (2), 279−290.

(23) Venkataramanan, V.; Collins, S. M.; Clark, K. A.; Yeam, J.; Nowakowski, V. G.; Young, S. L. Coping strategies for individual and household-level water insecurity: A systematic review. *WIREs Water* **2020**, *7* (5), No. e1477.

(24) Adams, E. A.; Stoler, J.; Adams, Y. Water insecurity and urban poverty in the Global South: Implications for health and human biology. *Am. J. Hum. Biol.* **2020**, *32*, No. e23368.

(25) Jepson, W. E.; Stoler, J.; Baek, J.; Morán Martínez, J.; Uribe Salas, F. J.; Carrillo, G. Cross-sectional study to measure household water insecurity and its health outcomes in urban Mexico. *BMJ Open* **2021**, *11* (3), No. e040825.

(26) Workman, C. L.; Miller, J. D.; Shah, S. H.; Maes, K.; Tesfaye, Y.; Mapunda, K. M. Frequency and perceived difficulty of household water experiences in Morogoro, Tanzania: Evidence of the psychosocial burden of water insecurity. *SSM Ment. Health* **2024**, *5*, 100295.

(27) Young, S. L.; Collins, S. M.; Boateng, G. O.; Neilands, T. B.; Jamaluddine, Z.; Miller, J. D.; Brewis, A. A.; Frongillo, E. A.; Jepson, W. E.; Melgar-Quiñonez, H.; Schuster, R. C.; Stoler, J. B.; Wutich, A.; HWISE Research Coordination Network. Development and validation protocol for an instrument to measure household water insecurity across cultures and ecologies: the Household Water InSecurity Experiences (HWISE) Scale. *BMJ Open* **2019**, *9* (1), No. e023558.

(28) Guadagnoli, E.; Velicer, W. F. Relation of sample size to the stability of component patterns. *Psychol. Bull.* **1988**, *103* (2), 265−275.

(29) Young, S. L.; Boateng, G.; Jamaluddine, Z.; Miller, J.; Frongillo, E.; Neilands, T.; Collins, S.; Wutich, A.; Jepson, W.; Stoler, J.; HWISE-RCN. The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. *BMJ Glob. Health* **2019**, *4* (5), No. e001750.

(30) Rosinger, A. Y. Water needs, water insecurity, and human biology. *Annu. Rev. Anthropol.* **2023**, *52* (1), 93−113.
(31) Kaiser, H. F. The application of electronic computers to factor analysis. *Educ. Psychol. Meas.* **1960**, *20*, 141−151.
(32) Tavakol, M.; Dennick, R. Making sense of Cronbach's alpha. *Int. J. Med. Educ.* **2011**, *2*, 53−55.
(33) Mushavi, R. C.; Burns, B. F. O.; Kakuhikire, B.; Owembabazi, M.; Vořechovská, D.; McDonough, A. Q.; Cooper-Vince, C. E.; Baguma, C.; Rasmussen, J. D.; Bangsberg, D. R.; Tsai, A. C. "When you have no water, it means you have no peace": A mixed-methods, whole-population study of water insecurity and depression in rural Uganda. *Soc. Sci. Med.* **2020**, *245*, 112561.
(34) Brewis, A.; Choudhary, N.; Wutich, A. Household water insecurity may influence common mental disorders directly and indirectly through multiple pathways: Evidence from Haiti. *Soc. Sci. Med.* **2019**, *238*, 112520.
(35) Collins, S. M.; Mbullo Owuor, P.; Miller, J. D.; Boateng, G. O.; Wekesa, P.; Onono, M.; Young, S. L. 'I know how stressful it is to lack water!' Exploring the lived experiences of household water insecurity among pregnant and postpartum women in western Kenya. *Glob. Public Health* **2019**, *14* (5), 649−662.
(36) Bain, R.; Cronk, R.; Wright, J.; Yang, H.; Slaymaker, T.; Bartram, J. Fecal contamination of drinking-water in low- and middle-income countries: A systematic review and meta-analysis. *PLoS Med.* **2014**, *11* (5), No. e1001644.
(37) Pearson, A. L.; Zwickle, A.; Namanya, J.; Rzotkiewicz, A.; Mwita, E. Seasonal shifts in primary water source type: a comparison of largely pastoral communities in Uganda and Tanzania. *Int. J. Environ. Res. Public Health* **2016**, *13* (2), 169.
(38) Howard, G.; Bartram, J. *Domestic Water Quantity, Service Level and Health*; World Health Organization: Geneva, 2003.
(39) WHO/UNICEF. *Report of the Second Consultation on Post 2015 Monitoring of Drinking-Water, Sanitation and Hygiene*; WHO/UNICEF, 2013.
(40) Soares, L. C.; Griesinger, M. O.; Dachs, J. N.; Bittner, M. A.; Tavares, S. Inequities in access to and use of drinking water services in Latin America and the Caribbean. *Rev. Panam. Salud Pública* **2002**, *11* (5−6), 386−396.
(41) Adler, N.; Stewart, J.; Psychosocial Working Group *The MacArthur Scale of Subjective Social Status*; University of California, 2007. https://sparqtools.org/mobility-measure/macarthur-scale-of-subjective-social-status-adult-version/ (accessed 09 January 2023).
(42) Allison, P. D. Missing data techniques for structural equation modeling. *J. Abnorm. Psychol.* **2003**, *112* (4), 545−557.
(43) Enders, C. K.; Bandalos, D. L. The relative performance of full information maximum likelihood estimation for missing data in structural equation models. *Struct. Equa. Model. Multidiscip. J.* **2001**, *8* (3), 430−457.
(44) Bisung, E.; Elliott, S. J. Psychosocial impacts of the lack of access to water and sanitation in low- and middle-income countries: a scoping review. *J. Water Health* **2017**, *15* (1), 17−30.
(45) Katuwal, H.; Bohara, A. K. Coping with poor water supplies: empirical evidence from Kathmandu, Nepal. *J. Water Health* **2011**, *9* (1), 143−158.
(46) Pattanayak, S. K.; Yang, J.-C.; Whittington, D.; Bal Kumar, K. C. Coping with unreliable public water supplies: Averting expenditures by households in Kathmandu, Nepal. *Water Resour. Res.* **2005**, *41* (2), W02012.
(47) Achore, M.; Bisung, E.; Kuusaana, E. D. Coping with water insecurity at the household level: A synthesis of qualitative evidence. *Int. J. Hyg. Environ. Health* **2020**, *230*, 113598.
(48) Hyun, C.; Kumar, T.; Post, A. E.; Ray, I. Engineering predictable water supply: The humans behind the tech. *Introduction to Development Engineering: A Framework with Applications from the Field*; Madon, T., Gadgil, A. J., Anderson, R., Casaburi, L., Lee, K., Rezaee, A., Eds.; Springer, 2022, pp 463−485.
(49) Kumar, T.; Post, A. E.; Ray, I. Flows, leaks and blockages in informational interventions: A field experimental study of Bangalore's water sector. *World Dev.* **2018**, *106*, 149−160.
(50) Burt, Z.; Ercümen, A.; Billava, N.; Ray, I. From intermittent to continuous service: Costs, benefits, equity and sustainability of water system reforms in Hubli-Dharwad, India. *World Dev.* **2018**, *109*, 121−133.
(51) Stoler, J.; Fink, G.; Weeks, J. R.; Otoo, R. A.; Ampofo, J. A.; Hill, A. G. When urban taps run dry: Sachet water consumption and health effects in low income neighborhoods of Accra, Ghana. *Health Place* **2012**, *18* (2), 250−262.
(52) Thomson, P.; Koehler, J. Performance-oriented monitoring for the water SDG − challenges, tensions and opportunities. *Aquat. Procedia* **2016**, *6*, 87−95.
(53) Bogdan, R.; Paliuc, C.; Crisan-Vida, M.; Nimara, S.; Barmayoun, D. Low-cost Internet-of-Things water-quality monitoring system for rural areas. *Sensors* **2023**, *23* (8), 3919.
(54) Sharpe, T.; Iribagiza, C.; Iorkumbur, E.; Coyle, J.; Fenwick, C.; Greggio, E.; Kassam, P.; Feighery, J.; Andres, L.; Thomas, E. Electronic sensors to monitor functionality and usage trends of rural water infrastructure in Plateau State, Nigeria. *Dev. Eng.* **2022**, *7*, 100100.
(55) Thomson, P. Remote monitoring of rural water systems: A pathway to improved performance and sustainability? *WIREs Water* **2021**, *8* (2), No. e1502.
(56) Kumpel, E.; Woelfle-Erskine, C.; Ray, I.; Nelson, K. L. Measuring household consumption and waste in unmetered, intermittent piped water systems. *Water Resour. Res.* **2017**, *53* (1), 302−315.
(57) Meyer, D. D. J.; Singh, S.; Singh, J.; Kumar, M.; He, M. Learning from intermittent water supply schedules: Visualizing equality, equity, and hydraulic capacity in Bengaluru and Delhi, India. *Sci. Total Environ.* **2023**, *892*, 164393.
(58) Contzen, N.; Kollmann, J.; Mosler, H.-J. The importance of user acceptance, support, and behaviour change for the implementation of decentralized water technologies. *Nat. Water* **2023**, *1* (2), 138−150.
(59) Stoler, J.; Jepson, W.; Wutich, A.; Velasco, C. A.; Thomson, P.; Staddon, C.; Westerhoff, P. Modular, adaptive, and decentralised water infrastructure: promises and perils for water justice. *Curr. Opin. Environ. Sustainability* **2022**, *57*, 101202.
(60) Huberts, A.; Palma, D.; Bernal García, A. C.; Cole, F.; Roberts, E. F. S. Making scarcity "enough": The hidden household costs of adapting to water scarcity in Mexico City. *PLoS Water* **2023**, *2* (3), No. e0000056.
(61) Bartram, J.; Baum, R.; Coclanis, P. A.; Gute, D. M.; Kay, D.; McFadyen, S.; Pond, K.; Robertson, W.; Rouse, M. J. *Routledge Handbook of Water and Health*; Routledge: London, 2015.
(62) Brown, J.; Clasen, T. High adherence is necessary to realize health gains from water quality interventions. *PLoS One* **2012**, *7* (5), No. e36735.
(63) Kumpel, E.; Nelson, K. L. Intermittent water supply: prevalence, practice, and microbial water quality. *Environ. Sci. Technol.* **2016**, *50* (2), 542−553.
(64) Baguma, D.; Hashim, J. H.; Aljunid, S. M.; Loiskandl, W. Safe-water shortages, gender perspectives, and related challenges in developing countries: The case of Uganda. *Sci. Total Environ.* **2013**, *442*, 96−102.
(65) Maxfield, A. Testing the theoretical similarities between food and water insecurity: Buffering hypothesis and effects on mental wellbeing. *Soc. Sci. Med.* **2020**, *244*, 112412.

https://doi.org/10.1021/acs.est.3c08443
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