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Measuring Household Water Insecurity Experiences as a Proxy for Health Outcomes in Urban Mexico

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Title: “Measuring Household Water Insecurity Experiences as a Proxy for Health Outcomes in Urban Mexico”

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ABSTRACT

This study explores the links between structural and household determinants of household water insecurity, and tested three water insecurity measures against self-reported diarrhea, dengue fever, and perceived stress in the urban context of Torreón, Mexico. We examine how the context of urban water provision is related to a new cross-culturally valid household water insecurity experiences (HWISE) scale and assessed the metric's performance as a correlate of health outcomes by assessing the relationships between three versions of the HWISE metric (the 12-item HWISE Scale, a three-item hygiene sub-score, and a three-item water worry sub-score) and self-reported diarrhea, dengue, and perceived stress. Water system intermittency, unpredictability, and seasonality were structural correlates of household water insecurity. This study also found that an experiential water insecurity scale is associated with two health outcomes, self-reported diarrhea and perceived stress, but not self-reported dengue fever. Short-form screeners may be useful for assessing certain health risks by lay survey workers in settings with limited healthcare resources, particularly in lieu of more expensive microbiological tests that require specialized training and facilities.

Strengths and Limitations of this Study

- This study applied the novel HWISE (Household Water Insecurity Experiences) Scale to demonstrate that certain dimensions of water insecurity may have stronger relationships with a given health outcome
- The study demonstrates the importance of seasonality in urban household water insecurity experiences and health outcomes.
- This study demonstrates that short-form screeners related to hygiene and stress offer efficient metrics to assess certain water insecurity health risks
- The study does not assess intra-household water insecurity or water quality

1. Introduction

Household water insecurity is more than unsafe water access: it is the interacting, co-present, and cumulative lived experiences of precarious water and hydro-social relations in the household.[1-4] While household water insecurity has been an emergent concept with various, albeit related, definitions[5], recent research has offered household water insecurity as a novel way to consider the complex relationship among water insecurity, human biology, and health.[6-15]

Critical advances seek to identify the pathways through which various experiences of household water insecurity, especially those conditions shaped by social inequality and vulnerability, contribute to adverse health effects and impede human wellbeing. Global health research in biocultural anthropology, for example, has made considerable advances in delineating the pathways and processes between water insecurity and mental or psychosocial distress.[16-22] Groundbreaking work by Wutich and Ragsdale mapped out the relationship between household water insecurity, as measured by an empirically determined experiential scale, and emotional distress in peri-urban Bolivia.[23] Studies of psychosocial distress and water insecurity have also revealed gendered differences.[24, 25] Subsequent case studies related to maternal and child health further refined our scientific understanding of the relationship between water insecurity and emotional distress.[6, 26] Sanitation, while beyond the scope of this study, has also been associated with increased gendered psycho-social distress.[27-30] Water scarcity and restriction also affect body homoeostasis, highlighting the links between maternal water intake patterns or early life water restrictions and human health states and hydration behaviors.[13] Most recently, Brewis et al. observed a positive relationship between household water insecurity and women's high blood pressure, expanding our understanding of water insecurity's biocultural effects.[31]

The complex conditions of water insecurity—diverse water delivery mechanisms, variable service quality, local variability in water storage practices, different socioeconomic structures and

community dynamics, and vector control practices—all bear on the transmission of water-borne disease. The many pathways between lack of access to clean water and disease is well-documented.[32] We also know unsafe sanitation practices and lack of environmental hygiene lead to spread of infections.[33] For example, breeding sites of *Aedes aegypti* are closely related to macro- and micro-ecological factors that are determined by human behaviors—individual, collective and institutional—and their related social, economic and political contexts.[34, 35] Yet, few studies to date have empirically linked explicit metrics of household water insecurity experiences to water-borne or water-vector diseases. One study demonstrated that high water insecurity in lowland rural areas of the Bolivian Amazon was associated with significantly higher odds of diarrhea for adults, suggesting that flooding events may exacerbate existing vulnerabilities because of displacement and deteriorated water quality.[9] But this study was conducted in a rural environment, and thus findings may not be generalizable to urban areas where the conditions of water insecurity manifest differently.

This study contributes to the growing body of empirical research that examines key relationships between correlates of household water insecurity, and between household water insecurity and health outcomes. We use the city of Torreon, in central Mexico, to explore how the context of urban water provision is related to a new cross-culturally valid household water insecurity experiences (HWISE) scale.[36] We then examined this metric's performance as a correlate of health outcomes by assessing the relationships between three versions of the HWISE metric (the 12-item HWISE Scale, a three-item hygiene sub-score, and a three-item water worry sub-score) and self-reported diarrhea, dengue, and perceived stress. Our findings offer important insights about the pathways between household water insecurity and health, as well as the potential utility and limits of the HWISE Scale and its sub-component constructs as a proxy for common health outcomes.

2. Methods

2.1 Study Region. Torreón, Coahuila, is located in the *Laguna* region of northern Mexico. The city has the largest population size among regional municipalities, with 679,288 inhabitants.[37] National statistics report that the urban households are mostly connected to public services: 96.3% connect a community water system, 99.2% have sanitation access, and 99.8% have electricity. Yet, as with many urban areas in the Global South, Torreón reportedly faces high levels water contamination in the public system.[38-40] In this case, arsenic concentration in the public water supply is above the current WHO drinking water standards.[41] Therefore, safe water availability has become a sensitive regional health concern, with water-scarcity emerging as a salient part of everyday social, economic and political discourses.

2.2 Household Survey. The survey, administered to 500 households, began with modules that solicited basic socio-economic and demographic characteristics, and self-reported hygiene and sanitation, diarrhea illness, and dengue based on WHO modules.[42, 43] Interviewees were asked if they or someone in their household had diarrhea and dengue in the past four weeks. In addition, the survey included the Household Water Insecurity Experiences (HWISE) Scale and Perceived Stress Scale (PSS-14).

The 12-item HWISE Scale was derived from the 29-item HWISE module (Version 2), in which each item elicited information using a four-week recall period and using five *a priori* frequency categories: never, rarely, sometimes, often, and always.[44] In the HWISE Scale, which probes experiential dimensions of water insecurity (Table 1), the two frequency categories of "often" and "always" were collapsed into one category, and the scores ranged from 0 to 36.[36]

The PSS is a reliable and valid screening instrument for measuring perceived stress.[45, 46] We applied the European Spanish version PSS (14-item), which demonstrates adequate reliability and internal consistency (Cronbach's α=.81) to confirm that the psychometric properties

of the scale for evaluating perceived stress are adequate (Remor 2006; Remor and Carrobles 2001). Scores ranged from 0 to 56 with higher values indicating greater perceived stress.

Table 1. Item Composition of HWISE Scale, Hygiene Sub-score, and Water Worry Sub-score

Label	Survey Item	HWISE Scale	Hygiene Sub-score	Water Worry Sub-score
Clothes	In the last 4 weeks, how frequently has there not been enough water in the household to **wash clothes**?	X		
Drink	In the last 4 weeks, how frequently has there not been **as much water to drink** as you would like for you or anyone in your household?	X		
Food	In the last 4 weeks, how frequently have you or anyone in your household had to **change what was being eaten** because there were problems with water (e.g. for washing foods, cooking, etc.)?	X		
Interruption	In the last 4 weeks, how frequently has your household water supply from your main water source been **interrupted** or **limited** (e.g. water pressure, less water than expected)?	X		
No water	In the last 4 weeks, how frequently has there been **no useable or drinkable water** whatsoever in your household?	X		
Plans	In the last 4 weeks, how frequently has you or anyone in your household had to **change schedules/plans** due to problems with your water situation, such as problems getting or distributing water within the household? (Activities that may have been interrupted include caring for others, doing household chores, etc.)	X		
Sleep	In the last 4 weeks, how frequently have you or anyone in your household gone to **sleep thirsty** because there wasn't any water to drink?	X		
Angry	In the last 4 weeks, how frequently did you or anyone in your household feel **angry** about your water situation?	X		X
Shame	In the last 4 weeks, how frequently have problems with water caused you or anyone in your household to **feel ashamed**/excluded/stigmatized?	X		X
Worry	In the last 4 weeks, how frequently did you or anyone in your household **worry** you would not have enough water for all of your household needs?	X		X
Body	In the last 4 weeks, how frequently have you or anyone in your household had to go without **washing their body** because of problems with water (e.g. not enough water, dirty, unsafe)?	X	X	
Hands	In the last 4 weeks, how frequently have you or anyone in your household had to go **without washing hands after dirty activities** (e.g., defecating or changing diapers, cleaning animal dung) because of problems with water?	X	X	
Children	In the last 4 weeks, how frequently have you or anyone in your household not **washed the faces and hands of children** because of problems with water?		X	

Note: Items classified as never (0 times), rarely (1-2 times), sometimes (3-times) and often/always (11 times or more); The score ranges are 0-36 for HWISE Scale, and 0-9 for Hygiene sub-score and Water Worry sub-score.

2.3 Data Collection and Sample Frame. Our household survey was conducted in two waves (rainy and dry season), and 250 households were selected via multi-stage cluster sample. We used census data to stratify neighborhoods based on socioeconomic status. Because the prevalence of household water insecurity is frequently correlated with water accessibility, affordability, and poor infrastructure, characteristics that are more common in lower-income communities, we used census classifications to select five low and five low-medium socio-economic status neighborhoods.[37] To minimize spatial autocorrelation, we used Google Earth images to identify the structure of each neighborhood and divide it into sampling quadrants. Within each quadrant, enumerators randomly surveyed 20–25 households. The two survey waves took place in April 2018 (dry season) and September 2018 (rainy season).

2.4 Ethics. The study received human subjects oversight through El Colegio de la Frontera Norte (COLEF) and Universidad de Coahuila-Torreon in Mexico and through the institutional review board at Texas A&M University in the United States.

2.5 Patient and Public Involvement Statement. This research was done without participant or public involvement.

2.6 Data Sharing Statement. Data are available upon reasonable request.

3. Data Analysis

3.1 Household Water and Sanitation. We computed summary and descriptive statistics for key household water and sanitation characteristics. We aggregated data on household water sources to replicate three categories used by the World Health Organization (WHO) Joint Monitoring Programme (JMP): piped water, other improved water (protected borehole), and unimproved water (water vendor, tanker truck, bottled water, bagged or sachet water, or other). We

categorized various forms of vended or packaged water into the “unimproved category” because these sources could not be verified as safely managed.

3.2 Household Water Insecurity. We calculated the 12-item HWISE Scale for each household. We then constructed a categorical variable, similar to Rosinger[9] and Jepson and Vandewalle[47], using a cut-point of 12 which reflects a household experiencing at least half of the 12 HWISE Scale items “sometimes” in the past four weeks.[36] Using this cut-point as an anchor, we defined the five categories using the HWISE Scale score: (1) *marginal insecurity* (0-3) (2) *low water insecurity* (4-11); (3) *moderate water insecurity* (12-20); (4) *high water insecurity* (21-29); (5) *extreme water insecurity* (30-36). We created ordered categories using the scale score because we wanted to identify which factors were associated with substantive changes in household water insecurity experiences, operationalized here as a change in category, rather than assess correlates of a less-meaningful one-point change in the HWISE Scale score.

3.3. Correlates of Household Water Insecurity. To assess correlates of the five-category HWISE measure, we fitted an ordinal logistic regression analysis to investigate the factors that predict household water insecurity. This model estimates the cumulative probability of being in a higher HWISE category, i.e. exhibiting a higher degree of water insecurity. We report adjusted odds ratios (OR) and 95% confidence intervals (CI) for higher water insecurity categories relative to remaining in the same category, using a significance threshold of $\alpha = 0.05$. Table 2 summarizes our independent measures, which include factors known to contribute to, or mitigate, water insecurity: gender of household head, monthly income (in US Dollars), household size (number of household members), and type of housing. We also included proxy measures for several constituents of complex water provisioning systems that shape or reflect household water decisions: intermittency, predictability, seasonality, satisfaction with current water situation, household water expenditures as a percentage of monthly income, total number of water sources,

safe water storage, primary drinking water source, and primary non-drinking water source. Prior to model fitting, we computed variance inflation factors (VIF) for our set of candidate independent variables to assess potential multicollinearity, and used a conservative VIF threshold of 4 for removing items.

3.4. Household Water Insecurity and Health Outcomes. We fitted multiple logistic regression models to examine the associations between three water insecurity measures and the two binary health outcomes, self-reported diarrhea and dengue, after adjusting for covariates. We fitted multiple ordinary least squares models to examine the association between the water insecurity measures and the PSS score. The three water insecurity measures were the exposures of interest: the 12-item HWISE Scale (range 0–36), a 3-item hygiene sub-score (0–9) computed as the sum of the three hygiene-related questions, and a 3-item water worry sub-score (0–9), computed as the sum of three psycho-social distress questions (Table 1). Each model estimates the probability of a household reporting a given health outcome, using just one water insecurity measure per model. We again conducted multicollinearity assessments before fitting these models.

4. Results

4.1 Descriptive Statistics. Frequency characteristics and univariate statistics of study households (N=498) are presented in Table 2. About two-thirds of household heads were male (67.5%), and the households had 3.7 members on average. Most of the participants owned their house (83.1%) and the mean monthly income was about $335. Approximately half of the participants (49.6%) reported their water availability is intermittent and 62.8% of them had unpredictable water availability. About 70% of households were satisfied with their current water situation (completely, often, or sometimes) and an average of 3.4% of monthly income was spent on water. The participants relied on an average of two water sources, and most of the households

had unimproved water for their primary drinking water (70.5%) and primary piped water for their non-drinking water (96.6%). Over half of participants (51.2%) used safe water storage. The mean HWISE Scale score and hygiene sub-score were 7.6 and 0.97, respectively. 43% of participants reported marginal water insecurity in the households while 30% and 18.3% experienced low and moderate water insecurity, respectively. 8.8% of households experienced high and extreme water insecurity. 9.2% and 18.5% of the households reported diarrhea (GI disease) and dengue, respectively. The mean PSS score was 19.72. Bivariate relationships between household characteristics and self-reported diarrhea, dengue fever, and psychosocial stress are presented in Supplemental Material. We examined these relationships as an additional way of assessing potential multicollinearity and to guide multivariable model building.

Table 2. Descriptive Characteristics of Households (N = 498)

Characteristic	Mean ± SD or %
Female Household Head	32.5%
Household Size (number of household members)	3.7 ± 1.8
Number of Children in Household (16 years and younger)	1.2 ± 1.3
Number of Adults in Household (17 and older)	2.5 ± 1.1
Type of Housing	
Owned	83.1%
Rented	15.3%
Other	1.6%
Monthly Household Income (USD)	335.3 ± 288.2
Monthly Water Expenditures (USD, as % of Monthly Income)	3.5 ± 7.2
Intermittent water supply	49.6%
Unpredictable water supply	62.8%
Satisfaction with Current Water Situation	
Completely satisfied	23.9%
Often satisfied	16.3%
Sometimes satisfied	29.7%
Rarely satisfied	12.0%
Not at all satisfied	18.1%
Total Number of Water Sources	2.1 ± 0.7
Primary Drinking Water Source	
Piped or other improved	29.5%
Unimproved	70.5%
Primary Non-Drinking Water Source	

Piped or other improved	96.6%
Unimproved	3.4%
Secondary Drinking Water Source	
Piped or other improved	56.6%
Unimproved	45.4%
Secondary Non-Drinking Water Source	
Piped or other improved	76.6%
Unimproved	23.4%
Water Storage	
Safe Storage	51.2%
Unsafe Storage	45.6%
No Storage	3.2%
Interviewed in Dry Season	49.8%
Interviewed in Wet Season	50.2%
Household Water Insecurity Measures	
HWISE Scale score (range 0-36)	7.6 ± 7.9
Hygiene Sub-score (0-9)	0.97 ± 1.75
Water Worry Sub-score (0-9)	2.45 ± 2.44
Household Water Insecurity (five categories)	
No Water Insecurity (0-3)	43.0%
Marginal Water Insecurity (4-11)	29.9%
Moderate Water Insecurity (12-20)	18.3%
Elevated Water Insecurity (21-29)	7.6%
Extreme Water Insecurity (30-36)	1.2%
Health Outcomes	
Self-reported Diarrhea	9.2%
Self-reported Dengue Fever	18.5%
Perceived Stress Scale (PSS) Score	19.72 ± 8.98

4.2. Correlates of water insecurity

Table 3 presents the ordinal logistic regression model of the categorical HWISE Scale. Three independent measures were significantly associated with being in a higher household water insecurity category: intermittent water supply (OR=3.96, 95% CI 2.40-6.54), unpredictable water (OR=2.24, 95% CI 1.34-3.74), and the dry season (OR=3.47, 95% CI 2.18-5.52). Four independent measures were significantly associated with being in a lower household water insecurity category: monthly income (OR=0.998, 95% CI 0.996-0.999), satisfaction with current water situation (OR=0.48, 95% CI 0.40-0.57), water expenditures (% of monthly income spent on water) (OR=0.96, 95% CI 0.93-0.99), and using an unimproved primary drinking water source (OR=0.63, 95% CI 0.41-0.97).

Table 3. Ordinal Logistic Regression Model of the Categorical Household Water Insecurity Experiences (HWISE) Scale

Characteristic	OR (95% CI)
Female household head (ref: Male)	0.947 (0.628, 1.429)
Monthly income (USD)	0.998 (0.996, 0.999)***
Monthly water expenditures (USD)	0.957 (0.929, 0.986)**
Dry season (ref: Wet season)	3.467 (2.178, 5.520)***
Number of household members	1.060 (0.955, 1.175)
Intermittent water supply	3.960 (2.396, 6.544)***
Unpredictable water supply	2.239 (1.341, 3.738)**
Satisfaction with water situation	0.481 (0.403, 0.573)***
Housing type (ref: Owned)	
Rented	0.902 (0.531, 1.533)
Other	4.255 (0.919, 19.696)
Water storage (ref: no storage)	
Unsafe storage	1.813 (0.440, 7.471)
Safe storage	1.241 (0.310, 4.967)
Unimproved primary drinking water source (ref: piped or other improved)	0.628 (0.407, 0.970)*
Unimproved primary non-drinking water source (ref: piped or other improved)	1.281 (0.459, 3.570)
Unimproved secondary drinking water source (ref: piped or other improved)	0.950 (0.630, 1.433)
Unimproved secondary non-drinking water source (ref: piped or other improved)	0.820 (0.489, 1.375)

Note: * p<0.05, ** p<0.01, *** p<0.001

4.3 Health outcomes. Tables 4-6 present the results of the multiple logistic regression models of the associations between each of the three household water insecurity measures (HWISE Scale, hygiene sub-score, and water worry sub-score) as exposure of interest, and three self-reported health outcomes, controlling for household characteristics.

4.3.1 Self-reported diarrhea. The 12-item HWISE Scale score (Model 1; OR=1.09, 95% CI 1.03-1.15), the hygiene sub-score (Model 2; OR=1.38, 95% CI 1.14-1.66), and the water worry sub-score (Model 3; OR=1.33, 95% CI 1.09-1.63) were all significantly and positively associated with self-reported diarrhea (Table 4, Models 1–3). Monthly water expenditures and use of an

unimproved primary non-drinking water source were also significantly and positively associated with diarrhea, regardless of the water insecurity metric. The effect size was particularly strong for use of an unimproved primary non-drinking water source (OR ranging from 4.66-5.66), suggesting that these sources may present some opportunity for cross-contamination in the household, or perhaps are occasionally used for drinking, in either case increasing risk of diarrhea.

Table 4. Multiple Regression Models of Self-Reported Diarrhea Using Three Household Water Insecurity Measures

Characteristic	Model 1	Model 2	Model 3
	OR (95% CI)	OR (95% CI)	OR (95% CI)
HWISE Scale score	1.092 (1.033, 1.154)**		
Hygiene sub-score		1.375 (1.142, 1.655)**	
Water Worry sub-score			1.332 (1.090, 1.629)**
Female household head (ref: Male)	1.153 (0.546, 2.435)	1.151 (0.544, 2.438)	1.120 (0.530, 2.368)
Monthly income (USD)	1.001 (0.999, 1.002)	1.001 (0.999, 1.002)	1.000 (0.999, 1.002)
Monthly water expenditures (USD)	1.058 (1.022, 1.095)**	1.052 (1.017, 1.089)**	1.057 (1.021, 1.093)**
Number of household members	1.180 (0.994, 1.401)	1.194 (1.005, 1.418)*	1.172 (0.987, 1.391)
Intermittent water supply	1.274 (0.462, 3.512)	1.665 (0.624, 4.440)	1.338 (0.495, 3.615)
Unpredictable water supply	0.884 (0.333, 2.351)	1.025 (0.397, 2.642)	0.940 (0.364, 2.430)
Satisfaction with water situation	1.069 (0.781, 1.463)	1.064 (0.777, 1.455)	1.063 (0.774, 1.461)
Housing type (ref: Owned) Rented Other	 1.027 (0.377, 2.800) 0.996 (0.080, 12.366)	 1.193 (0.445, 3.198) 1.029 (0.085, 12.498)	 0.957 (0.348, 2.629) 1.253 (0.116, 13.551)
Water storage (ref: no storage) Unsafe storage Safe storage	 0.174 (0.025, 1.223) 1.041 (0.177, 6.113)	 0.209 (0.029, 1.477) 1.139 (0.192, 6.764)	 0.157 (0.022, 1.120) 0.973 (0.163, 5.796)
Unimproved primary drinking water source (ref: piped or other improved)	1.750 (0.751, 4.076)	1.954 (0.826, 4.625)	1.543 (0.665, 3.581)
Unimproved primary non-drinking water source (ref: piped or other improved)	4.687 (1.266, 17.356)*	5.667 (1.539, 20.867)**	4.660 (1.266, 17.151)*
Unimproved secondary drinking water source (ref: piped or other improved)	0.632 (0.291, 1.374)	0.602 (0.275, 1.319)	0.625 (0.288, 1.356)
Unimproved secondary non-drinking water source (ref: piped or other improved)	0.654 (0.252, 1.693)	0.532 (0.201, 1.412)	0.686 (0.266, 1.768)

Note: * p<0.05, ** p<0.01, *** p<0.001

4.3.2 Self-reported dengue fever. The HWISE Scale score, hygiene score, and water worry score were not significantly associated with dengue (Table 5, Models 4–6). Unpredictable water supply (OR ranging from 3.07-3.38) was the only variable consistently associated with self-reported dengue. This relationship may be a proxy for a particular aspect of water storage, given that our water storage measure was non-significant in all three models of self-reported dengue.

Table 5. Multiple Regression Models of Self-Reported Dengue Fever Using Three Household Water Insecurity Measures

Characteristic	Model 4	Model 5	Model 6
	OR (95% CI)	OR (95% CI)	OR (95% CI)
HWISE Scale score	1.020 (0.977, 1.064)		
Hygiene sub-score		1.074 (0.920, 1.253)	
Water Worry sub-score			1.039 (0.901, 1.198)
Female household head (ref: Male)	0.782 (0.454, 1.347)	0.782 (0.454, 1.347)	0.805 (0.466, 1.389)
Monthly income (USD)	0.999 (0.998, 1.000)	0.999 (0.998, 1.000)	0.999 (0.998, 1.000)
Monthly water expenditures (USD)	0.965 (0.909, 1.024)	0.962 (0.906, 1.022)	0.966 (0.911, 1.024)
Dry season (ref: Wet season)	1.543 (0.849, 2.804)	1.564 (0.868, 2.820)	1.615 (0.891, 2.929)
Number of household members	1.098 (0.959, 1.257)	1.099 (0.960, 1.258)	1.087 (0.949, 1.245)
Intermittent water supply	0.588 (0.296, 1.168)	0.627 (0.327, 1.204)	0.584 (0.293, 1.164)
Unpredictable water supply	3.074 (1.591, 5.939)**	3.114 (1.615, 6.005)**	3.385 (1.737, 6.594)***
Satisfaction with water situation	1.087 (0.861, 1.373)	1.077 (0.860, 1.349)	1.068 (0.844, 1.352)
Housing type (ref: Owned)			
Rented	1.027 (0.533, 1.977)	1.038 (0.539, 1.999)	1.052 (0.544, 2.034)
Other	0.396 (0.044, 3.554)	0.404 (0.045, 3.399)	0.426 (0.048, 3.803)
Water storage (ref: no storage)			
Unsafe storage	0.857 (0.205, 3.351)	0.891 (0.212, 3.740)	0.821 (0.196, 3.445)
Safe storage	0.828 (0.206, 3.328)	0.843 (0.209, 3.402)	0.811 (0.201, 3.267)
Unimproved primary drinking water source (ref: piped or other improved)	1.004 (0.557, 1.808)	1.013 (0.561, 1.831)	1.004 (0.555, 1.813)
Unimproved primary non-drinking water source (ref: piped or other improved)	1.112 (0.336, 3.678)	1.145 (0.347, 3.778)	1.108 (0.333, 3.681)
Unimproved secondary drinking water source (ref: piped or other improved)	1.298 (0.775, 2.175)	1.289 (0.769, 2.161)	1.258 (0.748, 2.117)
Unimproved secondary non-drinking water source (ref: piped or other improved)	1.665 (0.928, 2.984)	1.623 (0.901, 2.925)	1.686 (0.938, 3.031)

Note: * p<0.05, ** p<0.01, *** p<0.001

4.3.3 Self-reported perceived stress. The HWISE Score, water hygiene sub-score, and water worry score were positively and significantly associated with self-reported perceived stress (Table 6, Models 7–9). There was variation in effect size of the association with PSS between the HWISE Score (β = 0.28, t = 4.30, P < 0.001), hygiene sub-score (β = 0.56, t = 2.21, P = 0.028), and water worry score (β = 1.18, t = 5.54, P < 0.001), with the water worry sub-score having the strongest effect on PSS. Female headed households, being surveyed during the dry season, and using an unimproved secondary drinking water source were significantly and positively associated with PSS regardless of which water insecurity metric was in a given model. Monthly income, using an unimproved primary drinking water source, and using an unimproved secondary non-drinking water source were significantly and negatively associated with PSS. Model 8 also indicated water predictability and "other" housing arrangements (i.e. neither rented nor owned) were significantly and positively associated with PSS. As a sensitivity check, we fitted identical multivariable ordinal regression models of a categorical (quantile-based) PSS outcome measure; most relationships were the same to those presented in Table 6, except that the relationship between the hygiene sub-score and PSS was no longer significant (see Supplemental Materials).

Table 6. OLS Models of Self-Reported Perceived Stress Using Three Household Water Insecurity Measures

Characteristic	Model 7	Model 8	Model 9
	Coef. (S.E. / t-score)	Coef. (S.E. / t-score)	Coef. (S.E. / t-score)
HWISE Scale score	0.283 (0.066 / 4.30)***		
Hygiene sub-score		0.556 (0.252 / 2.21)*	
Water Worry sub-score			1.179 (0.213 / 5.54)***
Female household head (ref: Male)	2.056 (0.794 / 2.59)*	2.071 (0.806 / 2.57)*	1.905 (0.790 / 2.41)*
Monthly income (USD)	-0.005 (0.002 / -3.25)**	-0.006 (0.002 / -3.67)***	-0.006 (0.002 /-3.42)**
Monthly water expenditures (USD)	-0.016 (0.053 / -0.31)	-0.038 (0.054 / -0.70)	-0.012 (0.053 / -0.22)
Dry season (ref: Wet season)	2.184 (0.893 / 2.45)*	2.778 (0.895 / 3.11)**	2.099 (0.879 / 2.39)*
Number of household members	-0.149 (0.206 / -0.73)	-0.116 (0.208 / -0.56)	-0.124 (0.204 / -0.61)
Intermittent water supply	-0.554 (1.028 / -0.54)	0.485 (1.005 / 0.48)	-0.879 (1.030 / -0.85)
Unpredictable water supply	1.695 (0.933 / 1.82)	2.047 (0.941 / 2.17)*	1.544 (0.929 / 1.66)
Satisfaction with water situation	-0.233 (0.346 / -0.67)	-0.585 (0.340 / -1.72)	-0.003 (0.348 / -0.01)
Housing type (ref: Owned)			
Rented	0.830 (1.020 / 0.81)	0.920 (1.035 / 0.89)	0.620 (1.024 / 0.61)
Other	4.966 (2.891 / 1.72)	5.745 (2.928 / 1.96)	4.517 (2.862 / 1.58)
Water storage (ref: no storage)			
Unsafe storage	-1.327 (2.124 / -0.62)	-0.978 (2.158 / -0.45)	-1.414 (2.105 / -0.67)
Safe storage	-0.132 (2.078 / -0.06)	-0.108 (2.111 / -0.05)	-0.196 (2.058 / -0.10)
Unimproved primary drinking water source (ref: piped or other improved)	-3.481 (0.865 / -4.02)***	-3.656 (0.880 / -4.16)***	-3.754 (0.861 / -4.36)***
Unimproved primary non-drinking water source (ref: piped or other improved)	1.222 (2.059 / 0.59)	1.439 (2.088 / 0.69)	1.184 (2.040 / 0.58)
Unimproved secondary drinking water source (ref: piped or other improved)	1.664 (0.778 / 2.14)*	1.733 (0.790 / 2.19)*	1.560 (0.777 / 2.01)*
Unimproved secondary non-drinking water source (ref: piped or other improved)	-2.711 (0.93 / -2.91)**	-2.880 (0.949 / -3.03)**	-2.629 (0.925 / -2.84)**

Note: Coef. – coefficient; S.E. – Standard Error; * p<0.05, ** p<0.01, *** p<0.001

5. Discussion

This study explored the links between household characteristics and household water insecurity, and tested three water insecurity measures against self-reported diarrhea, dengue fever, and perceived stress in the urban context of Torreón, Mexico. We found a set of seasonal and structural factors to be associated with higher household water insecurity, with intermittent water supply and seasonality exerting the strongest effects, and water insecurity declining for those at

higher income levels. We also found that although the 12-item HWISE Scale was associated with self-reported diarrhea and perceived stress, 3-item sub-scores for hygiene and water worry yielded much stronger associations with these outcomes, suggesting that construct-specific water insecurity scales may be effective screeners of certain health issues. The remainder of this section discusses each of the main findings in turn, and reflects upon the utility and limits of the HWISE Scale.

5.1 Correlates of household water insecurity. The OLR model indicated that intermittent water supply (IWS) had the strongest relationship with higher household water insecurity among all of the characteristics tested. IWS is an important characteristic of domestic water provision in low and middle-income countries across the globe. While access to piped water has increased over the past decade, water supplied through these networks may not provide continuous or reliable water.[48] Causes of IWS are complex, ranging from systemic failures and disrepairs to governance practices and policies.[49-52] Negative outcomes of intermittency are unequal across the system.[53] In some cases, IWS is a water management strategy during drought, or IWS is caused by system failure because of overexpansion. In Mexico, for example, 5.8 percent of water customers with a water supply experience discontinuous service during normal operation.[54] Water pressure drops and water-loss incidents increase during and immediately after the periods IWS events, thus increasing water contamination risk through intrusion or backflow.[55, 56]

We should not be surprised, then, that IWS increases the odds of household water insecurity. IWS, by default or by policy, impairs or compromises experiences of water service, water quality, and water delivery. Behavioral responses to IWS include increased water storage, and that response, in turn, increases risk of water quality contamination, thereby undermining the efficacy of piped water for public health outcomes. The impact of IWS on water quantity also limits personal hygiene, clothes washing, and even requires people to change their daily plans to adapt to the water situation.

Unpredictability, that is, water service that does not supply certain quantity of water on an expected timeline, has similar effects as IWS. Unpredictable water provision prevents household planning for disruptions, which also increases water worry and other disruptions to everyday life which further exacerbate water insecurity.[57] Thus, we are not surprised that unpredictable water supply increased the odds for households to increase in water insecurity, as observed in other contexts.[58-61]

We did not anticipate a strong seasonal signal because 92.8% of the households had connections to a community water system, which is commonly presumed to mitigate seasonal variation. But our results indicated that the dry season positively correlates with household water insecurity. There are three possible explanations. Reliance on non-piped water for drinking may be highly variable during the dry season, although this explanation is contradicted by the finding that households with unimproved water as primary source of drinking water were 37 percent less likely to move in to a higher water insecurity category. A second explanation is that piped water system performance is highly variable across then seasons due to changes in supply. However, Torreon draws its urban water supply from groundwater sources. While the region experiences a perpetually dropping water table, the water source is protected from seasonal changes because urban wells use more energy to draw from deeper depths.[40] A third, and most likely explanation, is that water supplies are unable to meet higher water demands during the dry season, and thus a range of water supply problems may increase, and thus odds of increasing water insecurity are greater.

We anticipated that income, satisfaction with water situation, water storage capacity, and number of water sources would have decreased the likelihood of water insecurity. Households with higher monthly incomes were less likely to experience water insecurity; for every additional $100 in monthly income, a household was 20% more likely to be in a lower HWISE Scale category. The relationship between satisfaction with one's water situation and lower water insecurity reflects how people are cognizant of water insecurity. Water storage and number of

water sources were not significant, yet households that rely on unimproved primary sources of drinking water (e.g., rainwater collection, water vendors, tanker trucks, bottled water, sachet water) were 37% less likely to increase water insecurity. The local context may explain this unanticipated result. Households regularly sought other drinking sources due to fears of arsenic contamination in the city's water supply. Purchasing water outside the piped network may offer residents a perceived safer drinking water option, and one that is more reliable even if more expensive. In addition, this result may also explain why Torreón households that spend a higher proportion of their income on water were more likely to have lower water insecurity, in contrast with the positive relationship between water expenditures and water insecurity observed globally.[62]

5.2 Household water insecurity as proxy for health risk. The 12-item HWISE Scale score was positively associated with self-reported diarrhea and perceived stress. The relationship between household water insecurity experiences and diarrhea presents a potential new proxy for drinking water quality, a characteristic that has traditionally been assessed by microbiological field tests with greater financial and time costs.[63] The relationship between water insecurity and psychosocial health is consistent with results from recent studies and adds to a growing literature that recognizes the dual mental and physical health burdens of water insecurity.

The hygiene sub-score was also positively associated with self-reported diarrhea with a much stronger signal than the full HWISE Scale (37% vs. 9% more likely to report diarrhea). Although this is consistent with the sub-score ranges being one-fourth that of the HWISE Scale (0–9 vs. 0–36), this suggests an important tradeoff of the full HWISE Scale: in trying to unidimensionally represent the complicated construct of water insecurity, it is less useful for identifying specific health issues that may be a consequence of specific constructs of water insecurity, such as insufficient water quantity. We observed a similar effect with the water worry sub-score, which yielded approximately four times the effect on diarrhea and perceived stress

than the HWISE Scale. The significant relationship between the water worry sub-score and diarrhea particularly underscores the intricate relationship between dimensions of water insecurity and human biology that have attracted recent attention.[14] Although the true utility of the three-item hygiene and water worry sub-scores requires reassessment in different contexts, these tools may be promising screeners for lay workers to rapidly assess risk of waterborne illness and water-related stress and anxiety through the simultaneous evaluation of household water insecurity.

None of the water insecurity metrics were associated with self-reported dengue fever. Unpredictability of water supply was the only household or water system characteristic that was positively associated with self-reported dengue fever. Adaptation to unpredictable water access often involves water storage, and unsafe storage is a risk factor for *Aedes aegypti* breeding and subsequent dengue transmission. Our storage variable, which characterized water storage as safe, unsafe, or none, was not associated with dengue. Given the inherent bias of households self-reporting the nature of their water storage, we refitted the OLR model using a binary storage variable that indicated any form of storage vs. none. The model results were virtually identical, so it is possible that unpredictability leads to a certain type of water storage (or other behavior) and thus captures all the variation in self-reported dengue fever. Future studies of water insecurity and *Aedes*-transmitted diseases such as dengue should explore the interaction of unpredictability and water storage. This result also highlights the limitations of the HWISE Scale, the contents of which do not appear to be an appropriate proxy for dengue fever risk, despite being associated with other health outcomes.

The primary and secondary drinking water source measures, which serve as proxies for JMP water access ladder categories, were unexpectedly not associated with self-reported diarrhea or dengue. While water sources may influence water quality parameters, this result demonstrates how the experience of water insecurity may lead to household adaptation that consequently mitigates a particular health risk. Second, intermittency was not associated with any health outcome, despite how intermittency places water quality at greater risk. We suggest that

considerable reliance on non-piped water may buffer the negative impacts of intermittency in Torreón.

5.3 Household water insecurity metrics

Our findings offer important insights about the possible correlates of household water insecurity and the relationship between different constructs of household water insecurity and common health outcomes. First, primary drinking water source, which is a frequently used as a proxy of water quality and, consequently, waterborne disease risk, was neither associated with household water insecurity, nor correlated with diarrhea or dengue.

Instead, our study indicates that characteristics related to *how* people accessed water. In particular, water service's temporal dimensions such as water intermittency and predictability—were associated with higher water insecurity scores.[60] This is important because it further demonstrates that the water insecurity is not only about the kind of water but about the variegated and relational flow of water between people and water systems that shape the experience of water insecurity.[4] Intermittency and unpredictability are often tied to infrastructure, as they are indicators of water governance performance. Our results highlighting how intermittency and unpredictability are related to water insecurity adds to the emerging evidence that water governance influences household water insecurity.[64]

The relationship between seasonality and health outcomes is less clear, but our study offers some potential pathways that should be tested in future research on how seasonality shapes urban household water insecurity. Our results underscore how researchers cannot assume that access and use of community water systems will necessarily buffer households from seasonality-induced insecurities. Climate change predictions for this region suggest reduced precipitation, higher temperatures, and more extreme precipitation events, all of which may further amplify season signals that increase water insecurity experiences and adversely affect human health.

Our study also highlights both the usefulness and applicability of the HWISE Scale and its limits for potentially signaling different adverse health outcomes. We demonstrated that the HWISE Scale was significantly correlated with diarrhea and perceived stress, but not dengue fever. This is an important finding because it supports the theory that the experience of water insecurity is shaped by multiple dimensions that may operate differently across populations in space and time.[65] This study demonstrate that although different water insecurity measures may be associated with the same health outcomes, certain dimensions of water insecurity may have stronger relationships with a given health outcome (e.g., water worry and PSS; hygiene and diarrhea). This finding suggests that shorter, construct-specific sub-scores, rather than the full 12-item HWISE Scale, may be a useful proxy for certain community- and household-level health risks. The range of health risks that could be detected by short-form, construct-oriented water insecurity sub-scores—the kinds of scales that can be implemented by lay community members without medical training or via mobile devices—remains a potentially fruitful area of future research.

There are two key limitations of this study. First, we were not able to assess intra-household water insecurity, which is emerging as an important research area. We recognize the gendered experience of water insecurity, age differences, complex social relationships, and differentiated labor that are involved in domestic water management all shape experiences of insecurity.[24, 25, 66-69] These issues were beyond the scope of our research design, but remain important research opportunities. Second, our study did not sample the same households in the wet and dry seasons; rather we sampled the same neighborhood with different households. While our analysis is ecologically sound, we advocate for a longitudinal household study that could capture the specific seasonal changes to better assess linkages between climate, water insecurity, and health.

Finally, the HWISE Scale offers an efficient, robust, and innovative metric for cross-cultural and unidimensional characteristics household water insecurity. Household water insecurity

experiences in Torreón can be quantitatively compared to experiences elsewhere. Yet, Wutich[15] notes that water insecurity is often a locally, culturally, and geographically unique phenomenon that operates at specific scales. The HWISE Scale does not include items about water quality, which may be an essential driver of water insecurity in some communities. For example, well-known arsenic contamination of public supply likely influences water behaviors and trade-offs to mitigate the risk. Reliance on unprotected sources in Torreón may convey a sense of security as the perception of arsenic exposure risk may be lowered even if other contaminant pathways arise through unprotected sources and requisite water storage. There are other strategies to address these differences[5], such as a household water insecurity index[65], regional scales[67], or use of subdomains[70], may be necessary to examine how water insecurity sub-scores correlate with health and other outcomes.

6. Conclusion

This case study of lower-income communities in Torreón, Mexico, identified water system intermittency, unpredictability, and seasonality as structural correlates of household water insecurity. This study also found that an experiential water insecurity scale is associated with two health outcomes, self-reported diarrhea and perceived stress, but not self-reported dengue fever. Short-form scales may be appropriate screeners of health issues that can be completed by lay workers in settings with limited healthcare resources, particularly in lieu of more expensive microbiological tests that require specialized training and facilities. This work contributes to the growing body of empirical research that has tested explicit metrics of household water insecurity. We observed that the experience of water insecurity is directly related to human health, though these types of social measures may only be useful for a limited set of health issues. Our use of the HWISE Scale provides opportunities for replication and regional comparisons, and we encourage future research about the extent to which different short-form water insecurity scales might serve as low-cost proxies of different human health burdens.

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Supplemental Table 1. Bivariate Relationships between Household Characteristics and the Categorical HWISE Scale and Self-Reported Health Outcomes

Characteristics	Categorical HWISE Scale	Diarrhea	Dengue Fever	Perceived Stress
	Odds Ratio (95% Confidence Interval)			
Female household head (ref: Male)	1.427 (1.009, 2.018)*	1.375 (0.736, 2.567)	0.782 (0.475, 1.287)	1.746 (1.193, 2.555)**
Monthly income (USD)	0.997 (0.996, 0.998)***	0.999 (0.998, 1.001)	0.999 (0.998, 1.000)	0.998 (0.998, 0.999)***
Monthly water expenditures (USD)	1.005 (0.982, 1.028)	1.036 (1.006, 1.067)*	0.981 (0.937, 1.027)	1.005 (0.980, 1.030)
Dry season (ref: Wet season)	1.552 (1.121, 2.148)**	†	1.124 (0.714, 1.767)	1.978 (1.385, 2.825)***
Total number of household	1.120 (1.024, 1.225)*	1.274 (1.101, 1.475)**	1.147 (1.020, 1.290)*	1.018 (0.924, 1.120)
Intermittent water supply	13.626 (9.113, 20.37)***	2.031 (1.077, 3.829)*	1.135 (0.721, 1.785)	2.012 (1.408, 2.875)***
Unpredictable water supply	5.661 (0.388, 8.25)***	1.757 (0.886, 3.485)	2.465 (1.446, 4.202)**	1.552 (1.077, 2.238)*
Satisfaction with water situation	0.364 (0.313, 0.424)***	0.808 (0.649, 1.006)	0.949 (0.807, 1.116)	0.784 (0.689, 0.893)***
Housing type (ref: Owned)				
Rented	1.086 (0.692, 1.705)	1.004 (0.431, 2.339)	1.094 (0.589, 2.027)	0.849 (0.520, 1.386)
Other	6.505 (1.305, 32.420)*	1.414 (0.169, 11.796)	0.635 (0.077, 5.241)	2.831 (0.565, 14.189)
Number of water sources	0.712 (0.565, 0.897)**	0.934 (0.608, 1.434)	1.272 (0.925, 1.748)	0.394 (0.298, 0.523)***
Water storage (ref: no storage)				
Unsafe storage	3.345 (1.035, 10.805)*	0.256 (0.049, 1.319)	0.955 (0.260, 3.505)	0.907 (0.329, 2.502)
Safe storage	3.527 (1.094, 11.372)*	1.151 (0.251, 5.277)	1.005 (0.275, 3.665)	1.198 (0.436, 3.292)
Unimproved primary drinking water source (ref: piped or other improved)	0.532 (0.374, 0.757)***	0.953 (0.493, 1.843)	1.151 (0.694, 1.909)	0.356 (0.237, 0.535)***
Unimproved primary non-drinking water source (ref: piped or other improved)	1.064 (0.421, 2.685)	4.471 (1.501, 13.316)**	1.887 (0.648, 5.495)	2.351 (0.816, 6.774)

Unimproved secondary drinking water source (ref: piped or other improved)	0.712 (0.513, 0.988)*	0.496 (0.257, 0.954)*	1.326 (0.842, 2.087)	0.900 (0.632, 1.282)
Unimproved secondary non-drinking water source (ref: piped or other improved)	0.676 (0.454, 1.006)	0.780 (0.365, 1.667)	1.571 (0.950, 2.598)	0.370 (0.239, 0.573)***

Note: * p<0.05, ** p<0.01, *** p<0.001

† Seasonality was omitted from the diarrhea model because no diarrhea cases were reported in the wet season

Supplemental Table 2. Multiple Regression Models of Self-Reported Perceived Stress (quantile) Using Three Household Water Insecurity Measures

Characteristic	Model 7	Model 8	Model 9
	OR (95% CI)	OR (95% CI)	OR (95% CI)
HWISE Scale score	1.062 (1.030, 1.094)***		
Hygiene sub-score		1.108 (0.989, 1.241)	
Water Worry sub-score			1.300 (1.176, 1.436)***
Female household head (ref: Male)	1.409 (0.987, 2.012)	1.408 (0.987, 2.008)	1.378 (0.961, 1.974)
Monthly income (USD)	0.999 (0.998, 0.999)**	0.999 (0.998, 0.999)**	0.999 (0.998, 0.999)**
Monthly water expenditures (USD)	0.997 (0.973, 1.022)	0.993 (0.969, 1.018)	0.998 (0.973, 1.023)
Dry season (ref: Wet season)	1.712 (1.144, 2.561)**	1.969 (1.321, 2.934)**	1.684 (1.128, 2.514)*
Number of household members	0.983 (0.893, 1.083)	0.989 (0.897, 1.090)	0.984 (0.893, 1.084)
Intermittent water supply	0.925 (0.583, 1.470)	1.194 (0.770, 1.852)	0.847 (0.528, 1.359)
Unpredictable water supply	1.511 (0.989, 2.308)	1.601 (1.051, 2.439)*	1.491 (0.972, 2.288)
Satisfaction with water situation	0.942 (0.805, 1.102)	0.870 (0.747, 1.012)	0.999 (0.852, 1.173)
Housing type (ref: Owned)			
Rented	1.283 (0.807, 2.041)	1.344 (0.848, 2.131)	1.185 (0.737, 1.904)
Other	3.403 (0.973, 11.898)	3.949 (1.124, 13.877)*	3.229 (0.922, 11.304)
Water storage (ref: no storage)			
Unsafe storage	0.755 (0.290, 1.970)	0.816 (0.315, 2.109)	0.754 (0.291, 1.952)
Safe storage	0.914 (0.360, 2.321)	0.926 (0.368, 2.331)	0.902 (0.358, 2.273)
Unimproved primary drinking water source (ref: piped or other improved)	0.418 (0.280, 0.623)***	0.402 (0.270, 0.600)***	0.397 (0.265, 0.595)***
Unimproved primary non-drinking water source (ref: piped or other improved)	1.432 (0.596, 3.441)	1.498 (0.625, 3.593)	1.438 (0.599, 3.451)

Unimproved secondary drinking water source (ref: piped or other improved)	1.520 (1.063, 2.173)*	1.558 (1.090, 2.226)*	1.475 (1.028, 2.117)*
Unimproved secondary non-drinking water source (ref: piped or other improved)	0.590 (0.391, 0.890)*	0.573 (0.379, 0.866)**	0.586 (0.387, 0.887)*

Note: * p<0.05, ** p<0.01, *** p<0.001

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Title: A cross-sectional study in urban Mexico to measure household water insecurity and its health outcomes

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ABSTRACT

Objective: To assess the links between structural and household determinants of household water insecurity and test three water insecurity measures against self-reported diarrhea, dengue fever, and perceived stress in the middle and low-income urban areas of Torreón, Mexico.

Design: Cross-sectional household survey conducted in two waves (rainy and dry season).

Participants: 500 households selected via multi-stage cluster sample in selected communities. Socio-economic status determined the selection of participant neighborhoods; five were identified in low socio-economic status neighborhoods and five in low-medium socio-economic status neighborhoods. We examine how the context of urban water provision is related to a new cross-culturally valid household water insecurity experiences (HWISE) scale.

Primary outcome measures: The Household Water Insecurity Experiences Scale (HWISE Scale), self-reported diarrhea, dengue fever, and the perceived stress scale.

Results: Water system intermittency (AOR 3.96, 95% CI 2.40 to 6.54, $P < .001$), unpredictability (AOR 2.24, 95% CI 1.34 to 3.74, $P = .002$), and the dry season (AOR 3.47, 95% CI 2.18 to 5.52, $P < .001$) were structural correlates of the HWISE Scale. This study also found that the HWISE Scale was associated with two health outcomes, self-reported diarrhea (AOR 1.09, 95% CI 1.03 to 1.15, $P = .002$) and perceived stress ($\beta = .28$, standard error = 0.07, $t = 4.30$, $P < .001$), but not self-reported dengue fever (AOR 1.02, 95% CI 0.98 to 1.06). A three-item hygiene sub-score and a three-item water worry sub-score were also both positive associated with self-reported diarrhea and perceived stress.

Conclusion: Short-form screeners of water insecurity may be useful for assessing certain health risks by lay survey workers in settings with limited healthcare resources, particularly in lieu of more expensive microbiological tests that require specialized training and facilities.

Strengths and Limitations of this Study

- This study employed the novel 12-item HWISE (Household Water Insecurity Experiences) Scale to determine the association between water insecurity experiences and health outcomes (self-reported diarrhea, dengue, perceived stress).
- They study fits an ordinal logistic regression analysis to investigate the factors that predict household water insecurity.
- The study fits multiple logistic regression models and an ordinary least squares model to examine the associations between three water insecurity measures and health outcomes.
- This study does not determine the role of objective water quality measurements on health outcomes.
- The study does not examine intra-household water insecurity.

1. Introduction

Household water insecurity is more than unsafe water access: it is the interacting, co-present, and cumulative lived experiences of precarious water and hydro-social relations in the household.[1-4] While household water insecurity has been an emergent concept with various, albeit related, definitions[5], recent research has offered household water insecurity as a novel way to consider the complex relationship among water insecurity, human biology, and health.[6-15]

Critical advances seek to identify the pathways through which various experiences of household water insecurity, especially those conditions shaped by social inequality and vulnerability, contribute to adverse health effects and impede human wellbeing. Global health research in biocultural anthropology, for example, has made considerable advances in delineating the pathways and processes between water insecurity and mental or psychosocial distress.[16-22] Groundbreaking work by Wutich and Ragsdale mapped out the relationship between household water insecurity, as measured by an empirically determined experiential scale, and emotional distress in peri-urban Bolivia.[23] Studies of psychosocial distress and water insecurity have also revealed gendered differences.[24, 25] Subsequent case studies related to maternal and child health further refined our scientific understanding of the relationship between water insecurity and emotional distress.[6, 26] Sanitation, while beyond the scope of this study, has also been associated with increased gendered psycho-social distress.[27-30] Water scarcity and restriction also affect body homoeostasis, highlighting the links between maternal water intake patterns or early life water restrictions and human health states and hydration behaviors.[13] Most recently, Brewis et al. observed a positive relationship between household water insecurity and women's high blood pressure, expanding our understanding of water insecurity's biocultural effects.[31]

The complex conditions of water insecurity—diverse water delivery mechanisms, variable service quality, local variability in water storage practices, different socioeconomic structures and

community dynamics, and vector control practices—all bear on the transmission of water-borne disease. The many pathways between lack of access to clean water and disease is well-documented.[32] We also know unsafe sanitation practices and lack of environmental hygiene lead to spread of infections.[33] For example, breeding sites of *Aedes aegypti* are closely related to macro- and micro-ecological factors that are determined by human behaviors—individual, collective and institutional—and their related social, economic and political contexts.[34, 35] Yet, few studies to date have empirically linked explicit metrics of household water insecurity experiences to water-borne or water-vector diseases. One study demonstrated that high water insecurity in lowland rural areas of the Bolivian Amazon was associated with significantly higher odds of diarrhea for adults, suggesting that flooding events may exacerbate existing vulnerabilities because of displacement and deteriorated water quality.[9] But this study was conducted in an urban environment, and thus findings may not be generalizable to rural areas where the conditions of water insecurity manifest differently.

This study contributes to the growing body of empirical research that examines key relationships between correlates of household water insecurity, and between household water insecurity and health outcomes. We use the city of Torreon, in central Mexico, to explore how the context of urban water provision is related to a new cross-culturally valid household water insecurity experiences (HWISE) scale.[36] We then examined this metric's performance as a correlate of health outcomes by assessing the relationships between three versions of the HWISE metric (the 12-item HWISE Scale, a three-item hygiene sub-score, and a three-item water worry sub-score) and self-reported diarrhea, dengue, and perceived stress. Our findings offer important insights about the pathways between household water insecurity and health, as well as the potential utility and limits of the HWISE Scale and its sub-component constructs as a proxy for common health outcomes.

2. Methods

2.1 Study Region. The cross-sectional study lasted one year, and it was conducted in the city of Torreón, Coahuila, which is located in the *Laguna* region of northern Mexico. The city has the largest population size among regional municipalities, with 679,288 inhabitants.[37] National statistics report that the urban households are mostly connected to public services: 96.3% connect a community water system, 99.2% have sanitation access, and 99.8% have electricity. Yet, as with many urban areas in the Global South, Torreón reportedly faces high levels water contamination in the public system.[38-40] In this case, arsenic concentration in the public water supply is above the current WHO drinking water standards.[41] Therefore, safe water availability has become a sensitive regional health concern, with water-scarcity emerging as a salient part of everyday social, economic and political discourses.

2.2 Household Survey. The survey, administered to 500 households, began with modules that solicited basic socio-economic and demographic characteristics, and self-reported hygiene and sanitation, diarrhea illness, and dengue based on WHO modules.[42, 43] Interviewees were asked if they or someone in their household had diarrhea and dengue in the past four weeks. In addition, the survey included the Household Water Insecurity Experiences (HWISE) Scale and Perceived Stress Scale (PSS-14). Study size was based on the HWISE Scale protocol.

The 12-item HWISE Scale was derived from the 29-item HWISE module (Version 2), in which each item elicited information using a four-week recall period and using five *a priori* frequency categories: never, rarely, sometimes, often, and always.[44] In the HWISE Scale, which probes experiential dimensions of water insecurity (Table 1), the two frequency categories of "often" and "always" were collapsed into one category, and the scores ranged from 0 to 36.[36]

The PSS is a reliable and valid screening instrument for measuring perceived stress.[45, 46] We applied the European Spanish version PSS (14-item), which demonstrates adequate reliability and internal consistency (Cronbach's α=.81) to confirm that the psychometric properties

of the scale for evaluating perceived stress are adequate (Remor 2006; Remor and Carrobles 2001). Scores ranged from 0 to 56 with higher values indicating greater perceived stress.

Table 1. Item Composition of HWISE Scale, Hygiene Sub-score, and Water Worry Sub-score

Label	Survey Item	HWISE Scale	Hygiene Sub-score	Water Worry Sub-score
Clothes	In the last 4 weeks, how frequently has there not been enough water in the household to **wash clothes**?	X		
Drink	In the last 4 weeks, how frequently has there not been **as much water to drink** as you would like for you or anyone in your household?	X		
Food	In the last 4 weeks, how frequently have you or anyone in your household had to **change what was being eaten** because there were problems with water (e.g. for washing foods, cooking, etc.)?	X		
Interruption	In the last 4 weeks, how frequently has your household water supply from your main water source been **interrupted** or **limited** (e.g. water pressure, less water than expected)?	X		
No water	In the last 4 weeks, how frequently has there been **no useable or drinkable water** whatsoever in your household?	X		
Plans	In the last 4 weeks, how frequently has you or anyone in your household had to **change schedules/plans** due to problems with your water situation, such as problems getting or distributing water within the household? (Activities that may have been interrupted include caring for others, doing household chores, etc.)	X		
Sleep	In the last 4 weeks, how frequently have you or anyone in your household gone to **sleep thirsty** because there wasn't any water to drink?	X		
Angry	In the last 4 weeks, how frequently did you or anyone in your household feel **angry** about your water situation?	X		X
Shame	In the last 4 weeks, how frequently have problems with water caused you or anyone in your household to **feel ashamed**/excluded/stigmatized?	X		X
Worry	In the last 4 weeks, how frequently did you or anyone in your household **worry** you would not have enough water for all of your household needs?	X		X
Body	In the last 4 weeks, how frequently have you or anyone in your household had to go without **washing their body** because of problems with water (e.g. not enough water, dirty, unsafe)?	X	X	
Hands	In the last 4 weeks, how frequently have you or anyone in your household had to go **without washing hands after dirty activities** (e.g., defecating or changing diapers, cleaning animal dung) because of problems with water?	X	X	
Children	In the last 4 weeks, how frequently have you or anyone in your household not **washed the faces and hands of children** because of problems with water?		X	

Note: Items classified as never (0 times), rarely (1-2 times), sometimes (3-times) and often/always (11 times or more); The score ranges are 0-36 for HWISE Scale, and 0-9 for Hygiene sub-score and Water Worry sub-score.

2.3 Data Collection and Sample Frame. Our household survey was conducted in two waves (rainy and dry season), and 250 households were selected via multi-stage cluster sample. We used census data to stratify neighborhoods based on socioeconomic status. Because the prevalence of household water insecurity is frequently correlated with water accessibility, affordability, and poor infrastructure, characteristics that are more common in lower-income communities, we used census classifications to select five low and five low-medium socio-economic status neighborhoods.[37] To minimize spatial autocorrelation, we used Google Earth images to identify the structure of each neighborhood and divide it into sampling quadrants. Within each quadrant, enumerators randomly surveyed 20–25 households. The two survey waves took place in April 2018 (dry season) and September 2018 (rainy season).

2.4 Ethics. The study received human subjects' oversight through El Colegio de la Frontera Norte (COLEF) and Universidad de Coahuila-Torreon in Mexico and through the institutional review board at Texas A&M University in the United States.

2.5 Patient and Public Involvement Statement. This research was done without participant or public involvement.

3. Data Analysis

3.1 Household Water and Sanitation. We computed summary and descriptive statistics for key household water and sanitation characteristics. We aggregated data on household water sources to replicate three categories used by the World Health Organization (WHO) Joint Monitoring Programme (JMP): piped water, other improved water (protected borehole), and unimproved water (water vendor, tanker truck, bottled water, bagged or sachet water, or other). We categorized various forms of vended or packaged water into the "unimproved category" because these sources could not be verified as safely managed.

3.2 Household Water Insecurity. We calculated the 12-item HWISE Scale for each household. We then constructed a categorical variable, similar to Rosinger[9] and Jepson and Vandewalle[47], using a cut-point of 12 which reflects a household experiencing at least half of the 12 HWISE Scale items "sometimes" in the past four weeks.[36] Using this cut-point as an anchor, we defined the five categories using the HWISE Scale score: (1) *marginal insecurity* (0-3) (2) *low water insecurity* (4-11); (3) *moderate water insecurity* (12-20); (4) *high water insecurity* (21-29); (5) *extreme water insecurity* (30-36). We created ordered categories using the scale score because we wanted to identify which factors were associated with substantive changes in household water insecurity experiences, operationalized here as a change in category, rather than assess correlates of a less-meaningful one-point change in the HWISE Scale score.

3.3. Correlates of Household Water Insecurity. To assess correlates of the five-category HWISE measure, we fitted an ordinal logistic regression analysis to investigate the factors that predict household water insecurity. This model estimates the cumulative probability of being in a higher HWISE category, i.e. exhibiting a higher degree of water insecurity. We report adjusted odds ratios (OR) and 95% confidence intervals (CI) for higher water insecurity categories relative to remaining in the same category, using a significance threshold of $\alpha = 0.05$. Table 2 summarizes our independent measures, which include factors known to contribute to, or mitigate, water insecurity: gender of household head, monthly income (in US Dollars), household size (number of household members), and type of housing. We also included proxy measures for several constituents of complex water provisioning systems that shape or reflect household water decisions: intermittency, predictability, seasonality, satisfaction with current water situation, household water expenditures as a percentage of monthly income, total number of water sources, safe water storage, primary drinking water source, and primary non-drinking water source. Prior to model fitting, we computed variance inflation factors (VIF) for our set of candidate independent

variables to assess potential multicollinearity, and used a conservative VIF threshold of 4 for removing items.

3.4. Household Water Insecurity and Health Outcomes. We fitted multiple logistic regression models to examine the associations between three water insecurity measures and the two binary health outcomes, self-reported diarrhea and dengue, after adjusting for covariates. We fitted multiple ordinary least squares models to examine the association between the water insecurity measures and the PSS score. The three water insecurity measures were the exposures of interest: the 12-item HWISE Scale (range 0–36), a 3-item hygiene sub-score (0–9) computed as the sum of the three hygiene-related questions, and a 3-item water worry sub-score (0–9), computed as the sum of three psycho-social distress questions (Table 1). Each model estimates the probability of a household reporting a given health outcome, using just one water insecurity measure per model. We again conducted multicollinearity assessments before fitting these models.

4. Results

4.1 Descriptive Statistics. Frequency characteristics and univariate statistics of study households (N=498) are presented in Table 2. Data from two households from the original sample of 500 were incomplete, and therefore, we removed them from the analysis. About two-thirds of household heads were male (67.5%), and the households had 3.7 members on average. Most of the participants owned their house (83.1%) and the mean monthly income was about $335. Approximately half of the participants (49.6%) reported their water availability is intermittent and 62.8% of them had unpredictable water availability. About 70% of households were satisfied with their current water situation (completely, often, or sometimes) and an average of 3.4% of monthly income was spent on water. The participants relied on an average of two water sources, and most of the households had unimproved water for their primary drinking water (70.5%) and primary

piped water for their non-drinking water (96.6%). Over half of participants (51.2%) used safe water storage. The mean HWISE Scale score and hygiene sub-score were 7.6 and 0.97, respectively. 43% of participants reported marginal water insecurity in the households while 30% and 18.3% experienced low and moderate water insecurity, respectively. 8.8% of households experienced high and extreme water insecurity. 9.2% and 18.5% of the households reported diarrhea (GI disease) and dengue, respectively. The mean PSS score was 19.72. Bivariate relationships between household characteristics and self-reported diarrhea, dengue fever, and psychosocial stress are presented in Supplemental Material. We examined these relationships as an additional way of assessing potential multicollinearity and to guide multivariable model building.

Table 2. Descriptive Characteristics of Households (N = 498)

Characteristic	Mean ± SD or %
Female Household Head	32.5%
Household Size (number of household members)	3.7 ± 1.8
Number of Children in Household (16 years and younger)	1.2 ± 1.3
Number of Adults in Household (17 and older)	2.5 ± 1.1
Type of Housing	
Owned	83.1%
Rented	15.3%
Other	1.6%
Monthly Household Income (USD)	335.3 ± 288.2
Monthly Water Expenditures (USD, as % of Monthly Income)	3.5 ± 7.2
Intermittent water supply	49.6%
Unpredictable water supply	62.8%
Satisfaction with Current Water Situation	
Completely satisfied	23.9%
Often satisfied	16.3%
Sometimes satisfied	29.7%
Rarely satisfied	12.0%
Not at all satisfied	18.1%
Total Number of Water Sources	2.1 ± 0.7
Primary Drinking Water Source	
Piped or other improved	29.5%
Unimproved	70.5%
Primary Non-Drinking Water Source	
Piped or other improved	96.6%
Unimproved	3.4%

Secondary Drinking Water Source	
Piped or other improved	56.6%
Unimproved	45.4%
Secondary Non-Drinking Water Source	
Piped or other improved	76.6%
Unimproved	23.4%
Water Storage	
Safe Storage	51.2%
Unsafe Storage	45.6%
No Storage	3.2%
Interviewed in Dry Season	49.8%
Interviewed in Wet Season	50.2%
Household Water Insecurity Measures	
HWISE Scale score (range 0-36)	7.6 ± 7.9
Hygiene Sub-score (0-9)	0.97 ± 1.75
Water Worry Sub-score (0-9)	2.45 ± 2.44
Household Water Insecurity (five categories)	
No Water Insecurity (0-3)	43.0%
Marginal Water Insecurity (4-11)	29.9%
Moderate Water Insecurity (12-20)	18.3%
Elevated Water Insecurity (21-29)	7.6%
Extreme Water Insecurity (30-36)	1.2%
Health Outcomes	
Self-reported Diarrhea	9.2%
Self-reported Dengue Fever	18.5%
Perceived Stress Scale (PSS) Score	19.72 ± 8.98

4.2. Correlates of water insecurity

Table 3 presents the ordinal logistic regression model of the categorical HWISE Scale. Three independent measures were significantly associated with being in a higher household water insecurity category: intermittent water supply (OR=3.96, 95% CI=2.40-6.54, p<0.001), unpredictable water (OR=2.24, 95% CI=1.34-3.74, p=0.002), and the dry season (OR=3.47, 95% CI=2.18-5.52, p<0.001). Four independent measures were significantly associated with being in a lower household water insecurity category: monthly income (OR=0.998, 95% CI=0.996-0.999, p<0.001), satisfaction with current water situation (OR=0.48, 95% CI=0.40-0.57, p<0.001), water expenditures (% of monthly income spent on water) (OR=0.96, 95% CI=0.93-0.99, p=0.004), and using an unimproved primary drinking water source (OR=0.63, 95% CI=0.41-0.97, p=0.036).

Table 3. Ordinal Logistic Regression Model of the Categorical Household Water Insecurity Experiences (HWISE) Scale

Characteristic	OR (95% CI)
Female household head (ref: Male)	0.947 (0.628, 1.429)
Monthly income (USD)	0.998 (0.996, 0.999)***
Monthly water expenditures (USD)	0.957 (0.929, 0.986)**
Dry season (ref: Wet season)	3.467 (2.178, 5.520)***
Number of household members	1.060 (0.955, 1.175)
Intermittent water supply	3.960 (2.396, 6.544)***
Unpredictable water supply	2.239 (1.341, 3.738)**
Satisfaction with water situation	0.481 (0.403, 0.573)***
Housing type (ref: Owned)	
Rented	0.902 (0.531, 1.533)
Other	4.255 (0.919, 19.696)
Water storage (ref: no storage)	
Unsafe storage	1.813 (0.440, 7.471)
Safe storage	1.241 (0.310, 4.967)
Unimproved primary drinking water source (ref: piped or other improved)	0.628 (0.407, 0.970)*
Unimproved primary non-drinking water source (ref: piped or other improved)	1.281 (0.459, 3.570)
Unimproved secondary drinking water source (ref: piped or other improved)	0.950 (0.630, 1.433)
Unimproved secondary non-drinking water source (ref: piped or other improved)	0.820 (0.489, 1.375)

Note: * p<0.05, ** p<0.01, *** p<0.001

4.3 Health outcomes. Tables 4-6 present the results of the multiple logistic regression models of the associations between each of the three household water insecurity measures (HWISE Scale, hygiene sub-score, and water worry sub-score) as exposure of interest, and three self-reported health outcomes, controlling for household characteristics. We use the HWISE Scale score as the independent variable in this analysis, rather than the categorical version, so that we can compare the regression coefficient with the corresponding coefficients from the HWISE sub-score analyses using the same units (i.e., a 1-unit change in any scale).

4.3.1 Self-reported diarrhea. The 12-item HWISE Scale score (Model 1; OR=1.09, 95% CI=1.03-1.15, p=0.002), the hygiene sub-score (Model 2; OR=1.38, 95% CI=1.14-1.66, p=0.001), and the

water worry sub-score (Model 3; OR=1.33, 95% CI=1.09-1.63, p=0.005) were all significantly and positively associated with self-reported diarrhea (Table 4, Models 1–3). Monthly water expenditures and use of an unimproved primary non-drinking water source were also significantly and positively associated with diarrhea, regardless of the water insecurity metric. The effect size was particularly strong for use of an unimproved primary non-drinking water source (OR ranging from 4.66-5.66), suggesting that these sources may present some opportunity for cross-contamination in the household, or perhaps are occasionally used for drinking, in either case increasing risk of diarrhea.

Table 4. Multiple Regression Models of Self-Reported Diarrhea Using Three Household Water Insecurity Measures

Characteristic	Model 1	Model 2	Model 3
	OR (95% CI)	OR (95% CI)	OR (95% CI)
HWISE Scale score	1.092 (1.033, 1.154)**		
Hygiene sub-score		1.375 (1.142, 1.655)**	
Water Worry sub-score			1.332 (1.090, 1.629)**
Female household head (ref: Male)	1.153 (0.546, 2.435)	1.151 (0.544, 2.438)	1.120 (0.530, 2.368)
Monthly income (USD)	1.001 (0.999, 1.002)	1.001 (0.999, 1.002)	1.000 (0.999, 1.002)
Monthly water expenditures (USD)	1.058 (1.022, 1.095)**	1.052 (1.017, 1.089)**	1.057 (1.021, 1.093)**
Number of household members	1.180 (0.994, 1.401)	1.194 (1.005, 1.418)*	1.172 (0.987, 1.391)
Intermittent water supply	1.274 (0.462, 3.512)	1.665 (0.624, 4.440)	1.338 (0.495, 3.615)
Unpredictable water supply	0.884 (0.333, 2.351)	1.025 (0.397, 2.642)	0.940 (0.364, 2.430)
Satisfaction with water situation	1.069 (0.781, 1.463)	1.064 (0.777, 1.455)	1.063 (0.774, 1.461)
Housing type (ref: Owned) Rented Other	 1.027 (0.377, 2.800) 0.996 (0.080, 12.366)	 1.193 (0.445, 3.198) 1.029 (0.085, 12.498)	 0.957 (0.348, 2.629) 1.253 (0.116, 13.551)
Water storage (ref: no storage) Unsafe storage Safe storage	 0.174 (0.025, 1.223) 1.041 (0.177, 6.113)	 0.209 (0.029, 1.477) 1.139 (0.192, 6.764)	 0.157 (0.022, 1.120) 0.973 (0.163, 5.796)
Unimproved primary drinking water source (ref: piped or other improved)	1.750 (0.751, 4.076)	1.954 (0.826, 4.625)	1.543 (0.665, 3.581)
Unimproved primary non-drinking water source (ref: piped or other improved)	4.687 (1.266, 17.356)*	5.667 (1.539, 20.867)**	4.660 (1.266, 17.151)*
Unimproved secondary drinking water source (ref: piped or other improved)	0.632 (0.291, 1.374)	0.602 (0.275, 1.319)	0.625 (0.288, 1.356)

Unimproved secondary non-drinking water source (ref: piped or other improved)	0.654 (0.252, 1.693)	0.532 (0.201, 1.412)	0.686 (0.266, 1.768)

Note: * p<0.05, ** p<0.01, *** p<0.001

4.3.2 Self-reported dengue fever. The HWISE Scale score, hygiene score, and water worry score were not significantly associated with dengue (Table 5, Models 4–6). Unpredictable water supply (OR ranging from 3.07-3.38) was the only variable consistently associated with self-reported dengue. This relationship may be a proxy for a particular aspect of water storage, given that our water storage measure was non-significant in all three models of self-reported dengue.

Table 5. Multiple Regression Models of Self-Reported Dengue Fever Using Three Household Water Insecurity Measures

Characteristic	Model 4	Model 5	Model 6
	OR (95% CI)	OR (95% CI)	OR (95% CI)
HWISE Scale score	1.020 (0.977, 1.064)		
Hygiene sub-score		1.074 (0.920, 1.253)	
Water Worry sub-score			1.039 (0.901, 1.198)
Female household head (ref: Male)	0.782 (0.454, 1.347)	0.782 (0.454, 1.347)	0.805 (0.466, 1.389)
Monthly income (USD)	0.999 (0.998, 1.000)	0.999 (0.998, 1.000)	0.999 (0.998, 1.000)
Monthly water expenditures (USD)	0.965 (0.909, 1.024)	0.962 (0.906, 1.022)	0.966 (0.911, 1.024)
Dry season (ref: Wet season)	1.543 (0.849, 2.804)	1.564 (0.868, 2.820)	1.615 (0.891, 2.929)
Number of household members	1.098 (0.959, 1.257)	1.099 (0.960, 1.258)	1.087 (0.949, 1.245)
Intermittent water supply	0.588 (0.296, 1.168)	0.627 (0.327, 1.204)	0.584 (0.293, 1.164)
Unpredictable water supply	3.074 (1.591, 5.939)**	3.114 (1.615, 6.005)**	3.385 (1.737, 6.594)***
Satisfaction with water situation	1.087 (0.861, 1.373)	1.077 (0.860, 1.349)	1.068 (0.844, 1.352)
Housing type (ref: Owned)			
Rented	1.027 (0.533, 1.977)	1.038 (0.539, 1.999)	1.052 (0.544, 2.034)
Other	0.396 (0.044, 3.554)	0.404 (0.045, 3.399)	0.426 (0.048, 3.803)
Water storage (ref: no storage)			
Unsafe storage	0.857 (0.205, 3.351)	0.891 (0.212, 3.740)	0.821 (0.196, 3.445)
Safe storage	0.828 (0.206, 3.328)	0.843 (0.209, 3.402)	0.811 (0.201, 3.267)
Unimproved primary drinking water source (ref: piped or other improved)	1.004 (0.557, 1.808)	1.013 (0.561, 1.831)	1.004 (0.555, 1.813)
Unimproved primary non-drinking water source (ref: piped or other improved)	1.112 (0.336, 3.678)	1.145 (0.347, 3.778)	1.108 (0.333, 3.681)

Unimproved secondary drinking water source (ref: piped or other improved)	1.298 (0.775, 2.175)	1.289 (0.769, 2.161)	1.258 (0.748, 2.117)
Unimproved secondary non-drinking water source (ref: piped or other improved)	1.665 (0.928, 2.984)	1.623 (0.901, 2.925)	1.686 (0.938, 3.031)

Note: * p<0.05, ** p<0.01, *** p<0.001

4.3.3 Self-reported perceived stress. The HWISE Score, water hygiene sub-score, and water worry score were positively and significantly associated with self-reported perceived stress (Table 6, Models 7–9). There was variation in effect size of the association with PSS between the HWISE Score (β=0.28, t=4.30, p<0.001), hygiene sub-score (β=0.56, t=2.21, p=0.028), and water worry score (β=1.18, t=5.54, p<0.001), with the water worry sub-score having the strongest effect on PSS. Female headed households, being surveyed during the dry season, and using an unimproved secondary drinking water source were significantly and positively associated with PSS regardless of which water insecurity metric was in a given model. Monthly income, using an unimproved primary drinking water source, and using an unimproved secondary non-drinking water source were significantly and negatively associated with PSS. Model 8 also indicated water predictability and "other" housing arrangements (i.e. neither rented nor owned) were significantly and positively associated with PSS. As a sensitivity check, we fitted identical multivariable ordinal regression models of a categorical (quantile-based) PSS outcome measure; most relationships were the same to those presented in Table 6, except that the relationship between the hygiene sub-score and PSS was no longer significant (see Supplemental Materials).

Table 6. OLS Models of Self-Reported Perceived Stress Using Three Household Water Insecurity Measures

Characteristic	Model 7	Model 8	Model 9
	Coef. (S.E. / t-score)	Coef. (S.E. / t-score)	Coef. (S.E. / t-score)
HWISE Scale score	0.283 (0.066 / 4.30)***		
Hygiene sub-score		0.556 (0.252 / 2.21)*	
Water Worry sub-score			1.179 (0.213 / 5.54)***
Female household head (ref: Male)	2.056 (0.794 / 2.59)*	2.071 (0.806 / 2.57)*	1.905 (0.790 / 2.41)*
Monthly income (USD)	-0.005 (0.002 / -3.25)**	-0.006 (0.002 / -3.67)***	-0.006 (0.002 /-3.42)**
Monthly water expenditures (USD)	-0.016 (0.053 / -0.31)	-0.038 (0.054 / -0.70)	-0.012 (0.053 / -0.22)
Dry season (ref: Wet season)	2.184 (0.893 / 2.45)*	2.778 (0.895 / 3.11)**	2.099 (0.879 / 2.39)*
Number of household members	-0.149 (0.206 / -0.73)	-0.116 (0.208 / -0.56)	-0.124 (0.204 / -0.61)
Intermittent water supply	-0.554 (1.028 / -0.54)	0.485 (1.005 / 0.48)	-0.879 (1.030 / -0.85)
Unpredictable water supply	1.695 (0.933 / 1.82)	2.047 (0.941 / 2.17)*	1.544 (0.929 / 1.66)
Satisfaction with water situation	-0.233 (0.346 / -0.67)	-0.585 (0.340 / -1.72)	-0.003 (0.348 / -0.01)
Housing type (ref: Owned)			
Rented	0.830 (1.020 / 0.81)	0.920 (1.035 / 0.89)	0.620 (1.024 / 0.61)
Other	4.966 (2.891 / 1.72)	5.745 (2.928 / 1.96)	4.517 (2.862 / 1.58)
Water storage (ref: no storage)			
Unsafe storage	-1.327 (2.124 / -0.62)	-0.978 (2.158 / -0.45)	-1.414 (2.105 / -0.67)
Safe storage	-0.132 (2.078 / -0.06)	-0.108 (2.111 / -0.05)	-0.196 (2.058 / -0.10)
Unimproved primary drinking water source (ref: piped or other improved)	-3.481 (0.865 / -4.02)***	-3.656 (0.880 / -4.16)***	-3.754 (0.861 / -4.36)***
Unimproved primary non-drinking water source (ref: piped or other improved)	1.222 (2.059 / 0.59)	1.439 (2.088 / 0.69)	1.184 (2.040 / 0.58)
Unimproved secondary drinking water source (ref: piped or other improved)	1.664 (0.778 / 2.14)*	1.733 (0.790 / 2.19)*	1.560 (0.777 / 2.01)*
Unimproved secondary non-drinking water source (ref: piped or other improved)	-2.711 (0.93 / -2.91)**	-2.880 (0.949 / -3.03)**	-2.629 (0.925 / -2.84)**

Note: Coef. – coefficient; S.E. – Standard Error; * p<0.05, ** p<0.01, *** p<0.001

5. Discussion

This study explored the links between household characteristics and household water insecurity, and tested three water insecurity measures against self-reported diarrhea, dengue fever, and perceived stress in the urban context of Torreón, Mexico. We found a set of seasonal and structural factors to be associated with higher household water insecurity, with intermittent water supply and seasonality exerting the strongest effects, and water insecurity declining for those at

higher income levels. We also found that although the 12-item HWISE Scale was associated with self-reported diarrhea and perceived stress, 3-item sub-scores for hygiene and water worry yielded much stronger associations with these outcomes, suggesting that construct-specific water insecurity scales may be effective screeners of certain health issues. The remainder of this section discusses each of the main findings in turn, and reflects upon the utility and limits of the HWISE Scale.

5.1 Correlates of household water insecurity. The OLR model indicated that intermittent water supply (IWS) had the strongest relationship with higher household water insecurity among all of the characteristics tested. IWS is an important characteristic of domestic water provision in low and middle-income countries across the globe. While access to piped water has increased over the past decade, water supplied through these networks may not provide continuous or reliable water.[48] Causes of IWS are complex, ranging from systemic failures and disrepairs to governance practices and policies.[49-52] Negative outcomes of intermittency are unequal across the system.[53] In some cases, IWS is a water management strategy during drought, or IWS is caused by system failure because of overexpansion. In Mexico, for example, 5.8 percent of water customers with a water supply experience discontinuous service during normal operation.[54] Water pressure drops and water-loss incidents increase during and immediately after the periods IWS events, thus increasing water contamination risk through intrusion or backflow.[55, 56]

We should not be surprised, then, that IWS increases the odds of household water insecurity. IWS, by default or by policy, impairs or compromises experiences of water service, water quality, and water delivery. Behavioral responses to IWS include increased water storage, and that response, in turn, increases risk of water quality contamination, thereby undermining the efficacy of piped water for public health outcomes. The impact of IWS on water quantity also limits personal hygiene, clothes washing, and even requires people to change their daily plans to adapt to the water situation.

Unpredictability, that is, water service that does not supply certain quantity of water on an expected timeline, has similar effects as IWS. Unpredictable water provision prevents household planning for disruptions, which also increases water worry and other disruptions to everyday life which further exacerbate water insecurity.[57] Thus, we are not surprised that unpredictable water supply increased the odds for households to increase in water insecurity, as observed in other contexts.[58-61]

We did not anticipate a strong seasonal signal because 92.8% of the households had connections to a community water system, which is commonly presumed to mitigate seasonal variation. But our results indicated that the dry season positively correlates with household water insecurity. There are three possible explanations. Reliance on non-piped water for drinking may be highly variable during the dry season, although this explanation is contradicted by the finding that households with unimproved water as primary source of drinking water were 37 percent less likely to move in to a higher water insecurity category. A second explanation is that piped water system performance is highly variable across then seasons due to changes in supply. However, Torreon draws its urban water supply from groundwater sources. While the region experiences a perpetually dropping water table, the water source is protected from seasonal changes because urban wells use more energy to draw from deeper depths.[40] A third, and most likely explanation, is that water supplies are unable to meet higher water demands during the dry season, and thus a range of water supply problems may increase, and thus odds of increasing water insecurity are greater.

We anticipated that income, satisfaction with water situation, water storage capacity, and number of water sources would have decreased the likelihood of water insecurity. Households with higher monthly incomes were less likely to experience water insecurity; for every additional $100 in monthly income, a household was 20% more likely to be in a lower HWISE Scale category. The relationship between satisfaction with one's water situation and lower water insecurity reflects how people are cognizant of water insecurity. Water storage and number of

water sources were not significant, yet households that rely on unimproved primary sources of drinking water (e.g., rainwater collection, water vendors, tanker trucks, bottled water, sachet water) were 37% less likely to increase water insecurity. The local context may explain this unanticipated result. Households regularly sought other drinking sources due to fears of arsenic contamination in the city's water supply. Purchasing water outside the piped network may offer residents a perceived safer drinking water option, and one that is more reliable even if more expensive. In addition, this result may also explain why Torreón households that spend a higher proportion of their income on water were more likely to have lower water insecurity, in contrast with the positive relationship between water expenditures and water insecurity observed globally.[62]

5.2 Household water insecurity as proxy for health risk. The 12-item HWISE Scale score was positively associated with self-reported diarrhea and perceived stress. The relationship between household water insecurity experiences and diarrhea presents a potential new indicator for drinking water quality problems, a characteristic that has traditionally been assessed by microbiological field tests with greater financial and time costs.[63] The relationship between water insecurity and psychosocial health is consistent with results from recent studies and adds to a growing literature that recognizes the dual mental and physical health burdens of water insecurity.

The hygiene sub-score was also positively associated with self-reported diarrhea with a much stronger signal than the full HWISE Scale (37% vs. 9% more likely to report diarrhea). Although this is consistent with the sub-score ranges being one-fourth that of the HWISE Scale (0–9 vs. 0–36), this suggests an important tradeoff of the full HWISE Scale: in trying to unidimensionally represent the complicated construct of water insecurity, it is less useful for identifying specific health issues that may be a consequence of specific constructs of water insecurity, such as insufficient water quantity. We observed a similar effect with the water worry

sub-score, which yielded approximately four times the effect on diarrhea and perceived stress than the HWISE Scale. The significant relationship between the water worry sub-score and diarrhea particularly underscores the intricate relationship between dimensions of water insecurity and human biology that have attracted recent attention.[14] Although the true utility of the three-item hygiene and water worry sub-scores requires reassessment in different contexts, these tools may be promising screeners for lay workers to rapidly assess risk of waterborne illness and water-related stress and anxiety through the simultaneous evaluation of household water insecurity.

None of the water insecurity metrics were associated with self-reported dengue fever. Unpredictability of water supply was the only household or water system characteristic that was positively associated with self-reported dengue fever. Adaptation to unpredictable water access often involves water storage, and unsafe storage is a risk factor for *Aedes aegypti* breeding and subsequent dengue transmission. Our storage variable, which characterized water storage as safe, unsafe, or none, was not associated with dengue. Given the inherent bias of households self-reporting the nature of their water storage, we refitted the OLR model using a binary storage variable that indicated any form of storage vs. none. The model results were virtually identical, so it is possible that unpredictability leads to a certain type of water storage (or other behavior) and thus captures all the variation in self-reported dengue fever. Future studies of water insecurity and *Aedes*-transmitted diseases such as dengue should explore the interaction of unpredictability and water storage. This result also highlights the limitations of the HWISE Scale, the contents of which do not appear to be an appropriate proxy for dengue fever risk in this context, despite being associated with other health outcomes.

The primary and secondary drinking water source measures, which serve as proxies for JMP water access ladder categories, were unexpectedly not associated with self-reported diarrhea or dengue. While water sources may influence water quality parameters, this result demonstrates how the experience of water insecurity may lead to household adaptation that consequently mitigates a particular health risk. Second, intermittency was not associated with any

health outcome, despite how intermittency places water quality at greater risk. We suggest that considerable reliance on non-piped water may buffer the negative impacts of intermittency in Torreón.

5.3 Household water insecurity metrics

Our findings offer important insights about the possible correlates of household water insecurity and the relationship between different constructs of household water insecurity and common health outcomes. First, primary drinking water source, which is a frequently used as a proxy of water quality and, consequently, waterborne disease risk, was neither associated with household water insecurity, nor correlated with diarrhea or dengue.

Instead, our study indicates that experiences of household water insecurity influence *how* people access and store water. In particular, water service's temporal dimensions such as water intermittency and predictability—were associated with higher water insecurity scores.[60] This is important because it further demonstrates that the water insecurity is not only about the kind of water but about the variegated and relational flow of water between people and water systems that shape the experience of water insecurity.[4] Intermittency and unpredictability are often tied to infrastructure, as they are indicators of water governance performance. Our results highlighting how intermittency and unpredictability are related to water insecurity adds to the emerging evidence that water governance influences household water insecurity.[64]

The relationship between seasonality and health outcomes is less clear, but our study offers some potential pathways that should be tested in future research on how seasonality shapes urban household water insecurity. Our results underscore how researchers cannot assume that access and use of community water systems will necessarily buffer households from seasonality-induced insecurities. Climate change predictions for this region suggest reduced precipitation, higher temperatures, and more extreme precipitation events, all of which may further

amplify season signals that increase water insecurity experiences and adversely affect human health.

Our study also highlights both the usefulness and applicability of the HWISE Scale and its limits for potentially signaling different adverse health outcomes. We demonstrated that the HWISE Scale was significantly correlated with diarrhea and perceived stress, but not dengue fever. This is an important finding because it supports the theory that the experience of water insecurity is shaped by multiple dimensions that may operate differently across populations in space and time.[65] This study demonstrate that although different water insecurity measures may be associated with the same health outcomes, certain dimensions of water insecurity may have stronger relationships with a given health outcome (e.g., water worry and PSS; hygiene and diarrhea). This finding suggests that shorter, construct-specific sub-scores, rather than the full 12-item HWISE Scale, may be a useful proxy for certain community- and household-level health risks. The range of health risks that could be detected by short-form, construct-oriented water insecurity sub-scores—the kinds of scales that can be implemented by lay community members without medical training or via mobile devices—remains a potentially fruitful area of future research.

There are two key limitations of this study. First, we were not able to assess intra-household water insecurity, which is emerging as an important research area. We recognize the gendered experience of water insecurity, age differences, complex social relationships, and differentiated labor that are involved in domestic water management all shape experiences of insecurity.[24, 25, 66-69] These issues were beyond the scope of our research design, but remain important research opportunities. Second, our study did not sample the same households in the wet and dry seasons; rather we sampled the same neighborhood with different households. While our analysis is ecologically sound, we advocate for a longitudinal household study that could capture the specific seasonal changes to better assess linkages between climate, water insecurity, and health.

Finally, the HWISE Scale offers an efficient, robust, and innovative metric for cross-cultural and unidimensional characteristics household water insecurity. Household water insecurity experiences in Torreón can be quantitatively compared to experiences elsewhere. Yet, Wutich[15] notes that water insecurity is often a locally, culturally, and geographically unique phenomenon that operates at specific scales. The HWISE Scale does not include items about water quality, which may be an essential driver of water insecurity in some communities. For example, well-known arsenic contamination of public supply likely influences water behaviors and trade-offs to mitigate the risk. Reliance on unprotected sources in Torreón may convey a sense of security as the perception of arsenic exposure risk may be lowered even if other contaminant pathways arise through unprotected sources and requisite water storage. There are other strategies to address these differences[5], such as a household water insecurity index[65], regional scales[67], or use of subdomains[70], may be necessary to examine how water insecurity sub-scores correlate with health and other outcomes.

6. Conclusion

This case study of lower-income communities in Torreón, Mexico, identified water system intermittency, unpredictability, and seasonality as structural correlates of household water insecurity. This study also found that an experiential water insecurity scale is associated with two health outcomes, self-reported diarrhea and perceived stress, but not self-reported dengue fever. Short-form scales may be appropriate screeners of health issues that can be completed by lay workers in settings with limited healthcare resources, particularly in lieu of more expensive microbiological tests that require specialized training and facilities. This work contributes to the growing body of empirical research that has tested explicit metrics of household water insecurity. The HWISE scale can support further research on how urban water problems, influenced by global urban water development models, intersect with socio-spatial inequalities and uneven health burdens experienced by low-income and underemployed populations by offering an

efficient means to triangulate these data with other relevant information.[71] We observed that the experience of water insecurity is directly related to human health, though these types of social measures may only be useful for a limited set of health issues. Our use of the HWISE Scale provides opportunities for replication and regional comparisons, and we encourage future research about the extent to which different short-form water insecurity scales might serve as low-cost proxies of different human health burdens.

Contributor Statement. WJ and GC designed the study; WJ developed survey and GC, FU, and JM contributed to survey design; GC, JM and FU supervised survey administration and data management; JB, JS, and WJ conducted the statistical analysis; WJ outlined the paper; W, JS, and JB drafted the article. All authors reviewed and approved the final draft of the manuscript.

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Supplemental Table 1. Bivariate Relationships between Household Characteristics and the Categorical HWISE Scale and Self-Reported Health Outcomes

Characteristics	Categorical HWISE Scale	Diarrhea	Dengue Fever	Perceived Stress
	Odds Ratio (95% Confidence Interval)			
Female household head (ref: Male)	1.427 (1.009, 2.018)*	1.375 (0.736, 2.567)	0.782 (0.475, 1.287)	1.746 (1.193, 2.555)**
Monthly income (USD)	0.997 (0.996, 0.998)***	0.999 (0.998, 1.001)	0.999 (0.998, 1.000)	0.998 (0.998, 0.999)***
Monthly water expenditures (USD)	1.005 (0.982, 1.028)	1.036 (1.006, 1.067)*	0.981 (0.937, 1.027)	1.005 (0.980, 1.030)
Dry season (ref: Wet season)	1.552 (1.121, 2.148)**	†	1.124 (0.714, 1.767)	1.978 (1.385, 2.825)***
Total number of household	1.120 (1.024, 1.225)*	1.274 (1.101, 1.475)**	1.147 (1.020, 1.290)*	1.018 (0.924, 1.120)
Intermittent water supply	13.626 (9.113, 20.37)***	2.031 (1.077, 3.829)*	1.135 (0.721, 1.785)	2.012 (1.408, 2.875)***
Unpredictable water supply	5.661 (0.388, 8.25)***	1.757 (0.886, 3.485)	2.465 (1.446, 4.202)**	1.552 (1.077, 2.238)*
Satisfaction with water situation	0.364 (0.313, 0.424)***	0.808 (0.649, 1.006)	0.949 (0.807, 1.116)	0.784 (0.689, 0.893)***
Housing type (ref: Owned)				
Rented	1.086 (0.692, 1.705)	1.004 (0.431, 2.339)	1.094 (0.589, 2.027)	0.849 (0.520, 1.386)
Other	6.505 (1.305, 32.420)*	1.414 (0.169, 11.796)	0.635 (0.077, 5.241)	2.831 (0.565, 14.189)
Number of water sources	0.712 (0.565, 0.897)**	0.934 (0.608, 1.434)	1.272 (0.925, 1.748)	0.394 (0.298, 0.523)***
Water storage (ref: no storage)				
Unsafe storage	3.345 (1.035, 10.805)*	0.256 (0.049, 1.319)	0.955 (0.260, 3.505)	0.907 (0.329, 2.502)
Safe storage	3.527 (1.094, 11.372)*	1.151 (0.251, 5.277)	1.005 (0.275, 3.665)	1.198 (0.436, 3.292)
Unimproved primary drinking water source (ref: piped or other improved)	0.532 (0.374, 0.757)***	0.953 (0.493, 1.843)	1.151 (0.694, 1.909)	0.356 (0.237, 0.535)***
Unimproved primary non-drinking water source (ref: piped or other improved)	1.064 (0.421, 2.685)	4.471 (1.501, 13.316)**	1.887 (0.648, 5.495)	2.351 (0.816, 6.774)

Unimproved secondary drinking water source (ref: piped or other improved)	0.712 (0.513, 0.988)*	0.496 (0.257, 0.954)*	1.326 (0.842, 2.087)	0.900 (0.632, 1.282)
Unimproved secondary non-drinking water source (ref: piped or other improved)	0.676 (0.454, 1.006)	0.780 (0.365, 1.667)	1.571 (0.950, 2.598)	0.370 (0.239, 0.573)***

Note: * p<0.05, ** p<0.01, *** p<0.001

† Seasonality was omitted from the diarrhea model because no diarrhea cases were reported in the wet season

Supplemental Table 2. Multiple Regression Models of Self-Reported Perceived Stress (quantile) Using Three Household Water Insecurity Measures

Characteristic	Model 7	Model 8	Model 9
	OR (95% CI)	OR (95% CI)	OR (95% CI)
HWISE Scale score	1.062 (1.030, 1.094)***		
Hygiene sub-score		1.108 (0.989, 1.241)	
Water Worry sub-score			1.300 (1.176, 1.436)***
Female household head (ref: Male)	1.409 (0.987, 2.012)	1.408 (0.987, 2.008)	1.378 (0.961, 1.974)
Monthly income (USD)	0.999 (0.998, 0.999)**	0.999 (0.998, 0.999)**	0.999 (0.998, 0.999)**
Monthly water expenditures (USD)	0.997 (0.973, 1.022)	0.993 (0.969, 1.018)	0.998 (0.973, 1.023)
Dry season (ref: Wet season)	1.712 (1.144, 2.561)**	1.969 (1.321, 2.934)**	1.684 (1.128, 2.514)*
Number of household members	0.983 (0.893, 1.083)	0.989 (0.897, 1.090)	0.984 (0.893, 1.084)
Intermittent water supply	0.925 (0.583, 1.470)	1.194 (0.770, 1.852)	0.847 (0.528, 1.359)
Unpredictable water supply	1.511 (0.989, 2.308)	1.601 (1.051, 2.439)*	1.491 (0.972, 2.288)
Satisfaction with water situation	0.942 (0.805, 1.102)	0.870 (0.747, 1.012)	0.999 (0.852, 1.173)
Housing type (ref: Owned)			
Rented	1.283 (0.807, 2.041)	1.344 (0.848, 2.131)	1.185 (0.737, 1.904)
Other	3.403 (0.973, 11.898)	3.949 (1.124, 13.877)*	3.229 (0.922, 11.304)
Water storage (ref: no storage)			
Unsafe storage	0.755 (0.290, 1.970)	0.816 (0.315, 2.109)	0.754 (0.291, 1.952)
Safe storage	0.914 (0.360, 2.321)	0.926 (0.368, 2.331)	0.902 (0.358, 2.273)
Unimproved primary drinking water source (ref: piped or other improved)	0.418 (0.280, 0.623)***	0.402 (0.270, 0.600)***	0.397 (0.265, 0.595)***
Unimproved primary non-drinking water source (ref: piped or other improved)	1.432 (0.596, 3.441)	1.498 (0.625, 3.593)	1.438 (0.599, 3.451)

Unimproved secondary drinking water source (ref: piped or other improved)	1.520 (1.063, 2.173)*	1.558 (1.090, 2.226)*	1.475 (1.028, 2.117)*
Unimproved secondary non-drinking water source (ref: piped or other improved)	0.590 (0.391, 0.890)*	0.573 (0.379, 0.866)**	0.586 (0.387, 0.887)*

Note: * p<0.05, ** p<0.01, *** p<0.001

TITLE- A Cross-sectional study in Urban Mexico to measure household water insecurity and its health outcomes.

STROBE Statement—checklist of items that should be included in reports of observational studies

Page and lines		Item No	Recommendation
1; 1-2	**Title and abstract**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
2, 26-47			(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
	Introduction		
2, 63-102	Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
4, 102-112	Objectives	3	State specific objectives, including any prespecified hypotheses
	Methods		
5, 116-125; 7, 157-158	Study design	4	Present key elements of study design early in the paper
5, 116-125; 7, 157-158	Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
7; 149-155	Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
n/a			(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
5, 133-142	Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
7, 155-157	Bias	9	Describe any efforts to address potential sources of bias
5, 132	Study size	10	Explain how the study size was arrived at
9, 219-220;	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why

8-9, 189-216	Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
n/a			(*b*) Describe any methods used to examine subgroups and interactions
9, 220--222			(*c*) Explain how missing data were addressed
n/a			(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
n/a			(*e*) Describe any sensitivity analyses
	Results		
Table, 2; 10	Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
n/a			(b) Give reasons for non-participation at each stage
n/a			(c) Consider use of a flow diagram
Table, 2; 10	Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
2			(b) Indicate number of participants with missing data for each variable of interest
n/a			(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
n/a	Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
n/a			*Case-control study*—Report numbers in each exposure category, or summary measures of exposure
11, Table 3; 13, Table 4; 14, Table 5; 16, Table 6			*Cross-sectional study*—Report numbers of outcome events or summary measures
11, Table 3; 13, Table 4; 14, Table 5; 16, Table 6	Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
8, 178-187			(*b*) Report category boundaries when continuous variables were categorized
n/a			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
n/a	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
	Discussion		
16, 318-328	Key results	18	Summarise key results with reference to study objectives

20, 419-421; 22, 468-477	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
23, 493-499	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
23-24, 499-509	Generalisability	21	Discuss the generalisability (external validity) of the study results
	Other information		
24, 511-513	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.