

BMJ Open Cross-sectional study to measure household water insecurity and its health outcomes in urban Mexico

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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 diarrhoea, dengue fever and perceived stress in the middle-income and low-income urban areas of Torreón, Mexico.

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

Participants 500 households selected via multistage cluster sample in selected communities. Socioeconomic status determined the selection of participant neighbourhoods; five were identified in low socioeconomic status neighbourhoods and five in low-medium socioeconomic status neighbourhoods. 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 HWISE Scale, self-reported diarrhoea, dengue fever and the Perceived Stress Scale.

Results Water system intermittency (adjusted OR (AOR) 3.96, 95% CI 2.40 to 6.54, $p<0.001$), unpredictability (AOR 2.24, 95% CI 1.34 to 3.74, $p=0.002$) and the dry season (AOR 3.47, 95% CI 2.18 to 5.52, $p<0.001$) were structural correlates of the HWISE Scale. This study also found that the HWISE Scale was associated with two health outcomes, self-reported diarrhoea (AOR 1.09, 95% CI 1.03 to 1.15, $p=0.002$) and perceived stress ($\beta=0.28$, $SE=0.07$, $t=4.30$, $p<0.001$), but not self-reported dengue fever (AOR 1.02, 95% CI 0.98 to 1.06). A 3-item hygiene subscore and a 3-item water worry subscore were also both positively associated with self-reported diarrhoea 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 specialised training and facilities.

INTRODUCTION

Household water insecurity is more than unsafe water access: it is the interacting, copresent and cumulative lived experiences of precarious water and hydrosocial relations in the household.^{1–4} While household water insecurity has been an emergent concept with

Strengths and limitations of this study

- This study employed the novel 12-item Household Water Insecurity Experiences Scale to determine the association between water insecurity experiences and health outcomes (self-reported diarrhoea, dengue, perceived stress).
- They study fits an ordinal logistic regression model 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 intrahousehold water insecurity.

various, although 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 well-being. 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 periurban 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 psychosocial distress.^{27–30} Water scarcity and restriction also affect body homeostasis, highlighting the links between maternal water intake patterns or early life water restrictions and human health states and hydration behaviours.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 waterborne disease. The many pathways between lack of access to clean water and disease are 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 macroecological and microecological factors that are determined by human behaviours—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 waterborne 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 diarrhoea for adults, suggesting that flooding events may exacerbate existing vulnerabilities because of displacement and deteriorated water quality.⁹ But the current study was conducted in an urban environment, and thus findings may not be generalisable 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 Torreón 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 3-item hygiene subscore and a 3-item water worry subscore) and self-reported diarrhoea, 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 subcomponent constructs as a proxy for common health outcomes.

METHODS

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 to a community water system, 99.2% have sanitation access and 99.8% have electricity. Yet, as with many urban areas in middle-income countries, Torreón reportedly faces high levels of 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.

Household survey

The survey, administered to 500 households, began with modules that solicited basic socioeconomic and demographic characteristics, and self-reported hygiene and sanitation, diarrhoea illness and dengue based on WHO modules.^{42,43} Interviewees were asked if they or someone in their household had diarrhoea and dengue in the past 4 weeks. In addition, the survey included the 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 4-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 14-item European Spanish version PSS, which demonstrates adequate reliability and internal consistency (Cronbach's $\alpha=0.81$) to confirm that the psychometric properties of the scale for evaluating perceived stress are adequate.^{47,48} Scores ranged from 0 to 56 with higher values indicating greater perceived stress.

Data collection and sample frame

Our household survey was conducted in two waves (rainy and dry seasons), and 250 households were selected via multistage cluster sample. We used census data to stratify neighbourhoods 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 socioeconomic status neighbourhoods.³⁷ To minimise spatial autocorrelation, we used Google Earth images to identify the structure of each neighbourhood and divide it into sampling quadrants. Within each quadrant, enumerators randomly surveyed 20–25 households. The two survey waves took

Table 1 Item composition of HWISE Scale, hygiene subscore and water worry subscore

Label	Survey item	HWISE Scale	Hygiene subscore	Water worry subscore
Clothes	In the last 4 weeks, how frequently has there not been enough water in the household to <i>wash clothes</i> ?	X		
Drink	In the last 4 weeks, how frequently has there not been <i>as much water to drink</i> 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 <i>change what was being eaten</i> because there were problems with water (eg, for washing foods, cooking, and so on)?	X		
Interruption	In the last 4 weeks, how frequently has your household water supply from your main water source been <i>interrupted or limited</i> (eg, water pressure, less water than expected)?	X		
No water	In the last 4 weeks, how frequently has there been <i>no useable or drinkable water</i> whatsoever in your household?	X		
Plans	In the last 4 weeks, how frequently has you or anyone in your household had to <i>change schedules/plans</i> 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, and so on.)	X		
Sleep	In the last 4 weeks, how frequently have you or anyone in your household gone to <i>sleep thirsty</i> 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 <i>angry</i> 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 <i>feel ashamed/excluded/stigmatised</i> ?	X		X
Worry	In the last 4 weeks, how frequently did you or anyone in your household <i>worry</i> 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 <i>washing their body</i> because of problems with water (eg, 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 <i>washing hands after dirty activities</i> (eg, 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 <i>washed the faces and hands of children</i> because of problems with water?		X	

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 subscore and water worry subscore. HWISE, Household Water Insecurity Experiences.

place in April 2018 (dry season) and September 2018 (rainy season).

Patient and public involvement

This research was done without participant or public involvement.

DATA ANALYSIS

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 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 categorised various forms of vended or packaged water

into the ‘unimproved category’ because these sources could not be verified as safely managed.

Household water insecurity

We calculated the 12-item HWISE Scale for each household. We then constructed a categorical variable, similar to Rosinger⁹ and Jepson and Vandewalle,⁴⁹ using a cut-point of 12 which reflects a household experiencing at least half of the 12 HWISE Scale items ‘sometimes’ in the past 4 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, operationalised here as a change in category, rather than assess correlates of a less meaningful one-point change in the HWISE Scale score.

Correlates of household water insecurity

To assess the correlates of the five-category HWISE measure, we fitted an ordinal logistic regression (OLR) model to investigate the factors that predict household water insecurity. This model estimates the cumulative probability of being in a higher HWISE category, that is, exhibiting a higher degree of water insecurity. We report adjusted ORs and 95% CIs for higher water insecurity categories relative to remaining in the same category, using a significance threshold of $\alpha=0.05$. Table 2 summarises our independent measures, which include factors known to contribute to, or mitigate, water insecurity: gender of household head, monthly income (in US\$), 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.

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 diarrhoea 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 subscore (0–9) computed as the sum of the three hygiene-related questions and a 3-item water worry subscore (0–9) computed as the sum of three psychosocial 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.

RESULTS

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

Table 2 Descriptive characteristics of households ($n=498$)

Characteristic	Mean±SD or %
Female household head	32.50%
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	83.10%
Rented	15.30%
Other	1.60%
Monthly household income (US\$)	335.3±288.2
Monthly water expenditures (US\$, as % of monthly income)	3.5±7.2
Intermittent water supply	49.60%
Unpredictable water supply	62.80%
Satisfaction with current water situation	
Completely satisfied	23.90%
Often satisfied	16.30%
Sometimes satisfied	29.70%
Rarely satisfied	12.00%
Not at all satisfied	18.10%
Total number of water sources	2.1±0.7
Primary drinking water source	
Piped or other improved	29.50%
Unimproved	70.50%
Primary non-drinking water source	
Piped or other improved	96.60%
Unimproved	3.40%
Secondary drinking water source	
Piped or other improved	56.60%
Unimproved	45.40%
Secondary non-drinking water source	
Piped or other improved	76.60%
Unimproved	23.40%
Water storage	
Safe storage	51.20%
Unsafe storage	45.60%
No storage	3.20%
Interviewed in dry season	49.80%
Interviewed in wet season	50.20%
Household water insecurity measures	
HWISE Scale score (range 0–36)	7.6±7.9
Hygiene subscore (0–9)	0.97±1.75
Water worry subscore (0–9)	2.45±2.44
Household water insecurity (five categories)	
No water insecurity (0–3)	43.00%
Marginal water insecurity (4–11)	29.90%

Continued

Table 2 Continued

Characteristic	Mean±SD or %
Moderate water insecurity (12–20)	18.30%
Elevated water insecurity (21–29)	7.60%
Extreme water insecurity (30–36)	1.20%
Health outcomes	
Self-reported diarrhoea	9.20%
Self-reported dengue fever	18.50%
Perceived Stress Scale (PSS) score	19.72±8.98

HWISE, Household Water Insecurity Experiences.

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 subscore were 7.6 and 0.97, respectively. Forty-three per cent 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 diarrhoea (gastrointestinal disease) and dengue, respectively. The mean PSS score was 19.72. Bivariate relationships between household characteristics and self-reported diarrhoea, dengue fever and psychosocial stress are presented in online supplemental material. We examined these relationships as an additional way of assessing potential multicollinearity and to guide multi-variable model building.

Correlates of water insecurity

Table 3 presents the OLR model of the categorical HWISE Scale. Three independent measures were significantly associated with being in a higher household water insecurity category: intermittent water supply (IWS) (OR 3.96, 95% CI 2.40 to 6.54, $p<0.001$), unpredictable water (OR 2.24, 95% CI 1.34 to 3.74, $p=0.002$) and the dry season (OR 3.47, 95% CI 2.18 to 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 to 0.999, $p<0.001$), satisfaction with current water situation (OR 0.48, 95% CI 0.40 to 0.57, $p<0.001$), water expenditures (% of monthly income spent on water) (OR 0.96, 95% CI 0.93 to 0.99, $p=0.004$) and using an unimproved primary drinking water source (OR 0.63, 95% CI 0.41 to 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 to 1.429)
Monthly income (US\$)	0.998 (0.996 to 0.999)***
Monthly water expenditures (US\$)	0.957 (0.929 to 0.986)**
Dry season (Ref: Wet season)	3.467 (2.178 to 5.520)***
Number of household members	1.060 (0.955 to 1.175)
Intermittent water supply	3.960 (2.396 to 6.544)***
Unpredictable water supply	2.239 (1.341 to 3.738)**
Satisfaction with water situation	0.481 (0.403 to 0.573)***
Housing type (Ref: Owned)	
Rented	0.902 (0.531 to 1.533)
Other	4.255 (0.919 to 19.696)
Water storage (Ref: No storage)	
Unsafe storage	1.813 (0.440 to 7.471)
Safe storage	1.241 (0.310 to 4.967)
Unimproved primary drinking water source (Ref: Piped or other improved)	0.628 (0.407 to 0.970)*
Unimproved primary non-drinking water source (Ref: Piped or other improved)	1.281 (0.459 to 3.570)
Unimproved secondary drinking water source (Ref: Piped or other improved)	0.950 (0.630 to 1.433)
Unimproved secondary non-drinking water source (Ref: Piped or other improved)	0.820 (0.489 to 1.375)

* $P<0.05$; ** $p<0.01$; *** $p<0.001$.

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 subscore and water worry subscore) 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 subscore analyses using the same units (ie, a 1-unit change in any scale).

Self-reported diarrhoea

The 12-item HWISE Scale score (model 1; OR 1.09, 95% CI 1.03 to 1.15, $p=0.002$), the hygiene subscore (model 2; OR 1.38, 95% CI 1.14 to 1.66, $p=0.001$) and the water worry subscore (model 3; OR 1.33, 95% CI 1.09 to 1.63, $p=0.005$) were all significantly and positively associated with self-reported diarrhoea (**table 4**, models 1–3). Monthly water expenditures and use of an unimproved primary

Table 4 Multiple regression models of self-reported diarrhoea 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 to 1.154)**		
Hygiene subscore		1.375 (1.142 to 1.655)**	
Water worry subscore			1.332 (1.090 to 1.629)**
Female household head (Ref: Male)	1.153 (0.546 to 2.435)	1.151 (0.544 to 2.438)	1.120 (0.530 to 2.368)
Monthly income (US\$)	1.001 (0.999 to 1.002)	1.001 (0.999 to 1.002)	1.000 (0.999 to 1.002)
Monthly water expenditures (US\$)	1.058 (1.022 to 1.095)**	1.052 (1.017 to 1.089)**	1.057 (1.021 to 1.093)**
Number of household members	1.180 (0.994 to 1.401)	1.194 (1.005 to 1.418)*	1.172 (0.987 to 1.391)
Intermittent water supply	1.274 (0.462 to 3.512)	1.665 (0.624 to 4.440)	1.338 (0.495 to 3.615)
Unpredictable water supply	0.884 (0.333 to 2.351)	1.025 (0.397 to 2.642)	0.940 (0.364 to 2.430)
Satisfaction with water situation	1.069 (0.781 to 1.463)	1.064 (0.777 to 1.455)	1.063 (0.774 to 1.461)
Housing type (Ref: Owned)			
Rented	1.027 (0.377 to 2.800)	1.193 (0.445 to 3.198)	0.957 (0.348 to 2.629)
Other	0.996 (0.080 to 12.366)	1.029 (0.085 to 12.498)	1.253 (0.116 to 13.551)
Water storage (Ref: No storage)			
Unsafe storage	0.174 (0.025 to 1.223)	0.209 (0.029 to 1.477)	0.157 (0.022 to 1.120)
Safe storage	1.041 (0.177 to 6.113)	1.139 (0.192 to 6.764)	0.973 (0.163 to 5.796)
Unimproved primary drinking water source (Ref: Piped or other improved)	1.750 (0.751 to 4.076)	1.954 (0.826 to 4.625)	1.543 (0.665 to 3.581)
Unimproved primary non-drinking water source (Ref: Piped or other improved)	4.687 (1.266 to 17.356)*	5.667 (1.539 to 20.867)**	4.660 (1.266 to 17.151)*
Unimproved secondary drinking water source (Ref: Piped or other improved)	0.632 (0.291 to 1.374)	0.602 (0.275 to 1.319)	0.625 (0.288 to 1.356)
Unimproved secondary non-drinking water source (Ref: Piped or other improved)	0.654 (0.252 to 1.693)	0.532 (0.201 to 1.412)	0.686 (0.266 to 1.768)

*P<0.05; **p<0.01

HWISE, Household Water Insecurity Experiences.

non-drinking water source were also significantly and positively associated with diarrhoea, 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 to 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 diarrhoea.

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 to 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.

Self-reported perceived stress

The HWISE score, water hygiene subscore 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 ($\beta=0.28$, $t=4.30$, $p<0.001$), hygiene subscore ($\beta=0.56$, $t=2.21$, $p=0.028$) and water worry score ($\beta=1.18$, $t=5.54$, $p<0.001$), with the water worry subscore 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 (ie, 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 subscore and PSS was no longer significant (see online supplemental materials).

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

p<0.01; *p<0.001.

HWISE, Household Water Insecurity Experiences.

DISCUSSION

This study explored the links between household characteristics and household water insecurity, and tested three water insecurity measures against self-reported diarrhoea, 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 IWS 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 diarrhoea and perceived stress, 3-item subscores 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 on the utility and limits of the HWISE Scale.

Correlates of household water insecurity

The OLR model indicated that 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-income 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.⁵⁰ Causes of IWS are complex, ranging from systemic failures and disrepairs to governance practices and policies.^{51–54} Negative outcomes of intermittency are unequal across the system.⁵⁵ 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% of water customers with a water supply experience discontinuous service during normal operation.⁵⁶ Water pressure drops and water loss incidents increase during and immediately after the periods of IWS events, thus increasing water contamination risk through intrusion or backflow.^{57,58}

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. Behavioural

Table 6 OLS models of self-reported perceived stress using three household water insecurity measures

Characteristic	Model 7	Model 8	Model 9
	Coefficient (SE/t-score)	Coefficient (SE/t-score)	Coefficient (SE/t-score)
HWISE Scale score	0.283 (0.066/4.30)***		
Hygiene subscore		0.556 (0.252/2.21)*	
Water worry subscore			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 (US\$)	-0.005 (0.002/-3.25)**	-0.006 (0.002/-3.67)***	-0.006 (0.002/-3.42)**
Monthly water expenditures (US\$)	-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)**

*P<0.05; **p<0.01; ***p<0.001.

HWISE, Household Water Insecurity Experiences; OLS, ordinary least squares.

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 a 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 and further exacerbates water insecurity.⁵⁹ Thus, we are not surprised that unpredictable water supply increased the odds for households to increase in water insecurity, as observed in other contexts.^{60–63}

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% 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, Torreón 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 cognisant of water insecurity. Water storage and number of water sources were not significant, yet households that rely on unimproved primary sources of drinking water (eg, rain-water 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 who 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.⁶⁴

Household water insecurity as proxy for health risk

The 12-item HWISE Scale score was positively associated with self-reported diarrhoea and perceived stress. The relationship between household water insecurity experiences and diarrhoea 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.⁶⁵ The relationship between water insecurity and psychosocial health is consistent with results from recent studies and adds to a growing literature that recognises the dual mental and physical health burdens of water insecurity.

The hygiene subscore was also positively associated with self-reported diarrhoea with a much stronger signal than the full HWISE Scale (37% vs 9% more likely to report diarrhoea). Although this is consistent with the subscore ranges being one-fourth that of the HWISE Scale (0–9 vs 0–36), this suggests an important trade-off 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 subscore, which yielded approximately four times the effect on diarrhoea and perceived stress than the HWISE Scale. The significant relationship between the water worry subscore and diarrhoea 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 3-item hygiene and water worry subscores 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 *A. aegypti* breeding and subsequent dengue transmission. Our storage variable, which characterised 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 versus none. The model results were virtually identical, so it is possible that unpredictability leads to a certain type of water storage (or other behaviour) 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 diarrhoea 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.

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 frequently used as a proxy of water quality and, consequently, waterborne disease risk, was neither associated with household water insecurity nor correlated with diarrhoea 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.⁶² This is important because it further demonstrates that the water



insecurity is about the kind of water and about the varied 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 add to the emerging evidence that water governance influences household water insecurity.⁶⁶

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 signalling different adverse health outcomes. We demonstrated that the HWISE Scale was significantly correlated with diarrhoea 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.⁶⁷ This study demonstrates 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 (eg, water worry and PSS; hygiene and diarrhoea). This finding suggests that shorter, construct-specific subscores, rather than the full 12-item HWISE Scale, may be a useful proxy for certain community-level and household-level health risks. The range of health risks that could be detected by short-form, construct-oriented water insecurity subscores—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 intrahousehold water insecurity, which is emerging as an important research area. We recognise the gendered experience of water insecurity, age differences, complex social relationships and differentiated labour that are involved in domestic water management all shape experiences of insecurity.^{24 25 68–71} 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 neighbourhood 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 of household water insecurity. Household water insecurity experiences in Torreón can be quantitatively compared with experiences elsewhere. Yet, Wutich¹⁵ 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 behaviours 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,⁶⁷ regional scales⁶⁹ or use of subdomains,⁷² which may be necessary to examine how water insecurity subscores correlate with health and other outcomes.

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 diarrhoea 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 specialised 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 sociospatial 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.⁷³ 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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Contributors WEJ and GC designed the study. WEJ developed the survey and GC, FJUS and JMM contributed to survey design. GC, JMM and FJUS supervised the survey administration and data management. JB, JS and WEJ conducted the

statistical analysis. WEJ outlined the paper. WEJ, JS and JB drafted the article. All authors reviewed and approved the final draft of the manuscript.

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