



Tap Water Avoidance Is Associated with Lower Food Security in the United States: Evidence from NHANES 2005-2018

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ARTICLE INFORMATION

Article history:

Submitted 31 January 2022

Accepted 18 July 2022

Keywords:

Food insecurity
Tap water consumption
Water insecurity
Bottled water

Supplementary materials:

Tables 3 and 4 and Figures 1, 3, and 6 are available at www.jandonline.org

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<https://doi.org/10.1016/j.jand.2022.07.011>

ABSTRACT

Background Food insecurity has profound nutritional and public health consequences. Water insecurity may exacerbate food insecurity, yet little is known about the association between water and food insecurity in the United States or other high-income countries.

Objective This study aimed to estimate how tap water avoidance, a proxy of water insecurity, covaries with food insecurity; examine how the probability of food insecurity changed by tap water avoidance between 2005 and 2018; and test how the association between tap water avoidance and food insecurity differed across income and housing statuses.

Design This was a secondary analysis of the cross-sectional 2005-2018 National Health and Nutrition Examination Survey.

Participants/setting Participants were 31,390 US adults 20 years and older.

Main outcome measures The main outcome was food insecurity, using the US Food Security Survey Module.

Statistical analyses Adjusted logistic regression models estimated how tap water avoidance was associated with the odds of food insecurity. Predicted probabilities of food insecurity over time and by income and housing status were plotted using marginal standardization.

Results Adults who avoided tap water had 21% higher odds (95% CI 1.09 to 1.34) of food insecurity compared with those who drank tap water. The probability of any food insecurity doubled between 2005-2006 and 2017-2018 and was consistently higher for tap water avoiders. Food insecurity decreased across both tap water drinkers and avoiders as income increased, but was higher among tap water avoiders at all income levels. Likewise, food insecurity was higher among renters than among homeowners but was higher among tap water avoiders in both housing groups.

Conclusions Tap water avoidance is positively associated with food insecurity in the United States, and both insecurities have increased over time. Efforts to mitigate food insecurity should simultaneously address water insecurity issues, including tap water availability and quality, as these may be a modifiable contributors to food insecurity.

J Acad Nutr Diet. 2023;123(1):29-40.

FOOD INSECURITY IS A LACK OF RELIABLE ACCESS TO nutritionally adequate and safe foods and the ability to acquire safe foods in socially acceptable ways, and may result in reduced food intake or disrupted eating patterns.¹ Food insecurity is a large and growing problem in the United States, necessitating sustained action and research.² According to the US Department of Agriculture,¹ approximately 10.5% of US households were food insecure in 2020, and the prevalence of food insecurity among adults nearly doubled between 1999 and 2016.³ Food insecurity is associated with myriad adverse psychological, nutritional, and health outcomes globally; in the United States it has been associated with higher rates of psychological stress, depression, diabetes, poor nutrition, untreated dental caries, obesity, cardiovascular disease, and all-cause mortality.³⁻⁸

Although the provision of food and/or the means to purchase food have rightfully been at the forefront of efforts to improve food security, these may not offer a complete solution. Other factors, like water quality and availability, may shape food insecurity and nutrition in myriad ways.⁹⁻¹² For example, it is nearly impossible to prepare a healthy meal without water; water is necessary for washing produce, boiling and steaming foods, and washing dishes used for meal preparation and consumption. As such, water insecurity (ie, the inability to access and benefit from sufficient, safe, trustworthy water in the home for a healthy life¹³) may be an overlooked factor that contributes to food insecurity in the United States. Water insecurity is multidimensional, but occurs when there are problems with any 1 of its 4 constituent domains (ie, availability, accessibility, use, or stability).^{9,14} Tap

water avoidance has been an insightful indicator of water problems, such as distrust in available water quality, in other analyses.¹⁵⁻¹⁷ Tap water avoidance captures the “use” domain of water insecurity, which thereby also represents availability and accessibility, as consumption is dependent on water being physically available as well as acceptable to use.⁹

Data suggest that approximately 61.4 million Americans do not drink their tap water.¹⁶ This may be due, at least in part, to problems with sufficient water quantity, quality, or affordability. For example, some Americans do not have tap water available in their homes to drink due to lack of plumbing¹⁸ or due to water that has been shut off.¹⁹ Furthermore, annually over the past 34 years, at least 9 million people in the United States lived in areas with chemical or microbial water contamination violations.²⁰ In 2014, waterborne infections in the United States led to 601,000 emergency department visits, 118,000 hospitalizations, and \$3.33 billion dollars of direct health care costs.²¹ For these reasons, people in the United States may distrust their in-home drinking water source and/or may feel water-insecure, even if they have running water at home.^{17,22,23} For example, when the city of Flint, MI switched its main water source from the Detroit River to the highly corrosive Flint River water in April 2014, residents of Flint reported avoiding their tap water because it had turned brown, stank, and affected their health negatively.²⁴ By 2015, it was confirmed that the switch created high exposures to lead among the Flint community,²⁵ which received large national attention, albeit much delayed.²⁶ This attention caused widespread distrust of tap water among many Americans outside of the Flint community as well; there was a 40% increase in tap water avoidance nationally among adults in the United States after the Flint water crisis.¹⁶

Tap water avoidance can have major ramifications for food security and nutrition. If tap water is unavailable or suspected to be contaminated, people are less likely to drink or cook with it. Not only might this hinder the ability to prepare meals at home, it may also force people to rely on prepackaged or restaurant foods, which are often more costly and less nutritious.^{27,28} Bottled water, the use of which dramatically increases after water quality violations,²⁰ is more cumbersome to obtain and cook with and is much costlier than tap water.²⁹ Thus, having to pay more for bottled water may further reduce funds available for purchasing healthy, nutritious food.

Strikingly, the intersection of water insecurity and food insecurity in the United States and other high-income countries has received minimal attention.³⁰ The research in this area has focused primarily on how food insecurity might influence beverage choices, including water intake. For example, food insecure children³¹ and adults³² in the United States were more likely to consume sugar-sweetened beverages and less likely to consume plain water than those who were food secure.

Little research has explored the reverse relationship in high-income settings, that is, how tap water consumption or avoidance shapes food insecurity. Findings in low- and middle-income countries suggest that water insecurity is strongly associated with food insecurity,³³⁻³⁵ with greater plausibility that water insecurity drives food insecurity, given its potential impact on the ability to grow and cook food, raise livestock, and engage in income-generating activities.^{9,10,36,37} Indeed, the sole longitudinal study of experiential food and water insecurity demonstrated that water insecurity preceded

RESEARCH SNAPSHOT

Research Question: How is tap water avoidance, a proxy of water insecurity, associated with food insecurity in the United States between 2005 and 2018?

Key Findings: In the cross-sectional 2005-2018 National Health and Nutrition Examination Survey, adults who avoided tap water had 21% higher odds (95% CI 1.09 to 1.34) of experiencing food insecurity compared with those who drank tap water. The probability of food insecurity increased significantly among tap water avoiders and tap water drinkers between 2005 and 2018. However, there was a notable jump in food insecurity among tap water avoiders, which was unobserved among tap water drinkers following the 2013-2014 Flint, MI water crisis.

food insecurity in western Kenya.³⁸ Identifying whether similar trends exist in high-income settings is valuable for the development of comprehensive policies and interventions to improve food security and nutrition.

Other concurrent material needs and resource insecurities, such as low income and housing instability, may further compound food insecurity.^{39,40} For example, income is critical to procuring food and plays a role in access to food supplement programs, while renting, as opposed to owning, one's place of residence is associated with higher food insecurity.³⁹ This may be because renters' housing is less stable than that of homeowners and is often relatively costlier; unstable housing has also been associated with limited access to clean water and tap water avoidance.^{18,41,42}

Therefore, to examine the relationship between tap water avoidance and food insecurity in a high-income country, the primary aim of this article was to test how tap water avoidance, a proxy of water insecurity,⁴³ covaries with food insecurity in the United States using nationally representative data. We hypothesized that food insecurity would be more prevalent and more severe among those who avoid their tap water. The second aim of the study was to examine how the probability of food insecurity has changed by tap water avoidance between 2005 and 2018 in the United States, a period that allows comparisons of tap water avoidance before and after the onset of the Flint water crisis. The third aim of the study was to examine how the relationship between tap water avoidance and food insecurity differs by income and housing status.

METHODS

Data for this study come from the cross-sectional National Health and Nutrition Survey (NHANES), which uses a multi-stage, probability sampling design to create a nationally representative estimate of the civilian, household population in the United States every 2 years.⁴⁴ We combined the 7 available survey cycles for which there were data on the variables of interest, 2005-2006 through the 2017-2018 waves. NHANES is conducted by the National Center for Health Statistics and is approved by their Research Ethics Board. All participants provided written informed consent. All data in this article are from publicly available and de-identified datasets found online (<https://wwwn.cdc.gov/nchs/nhanes/Default.aspx>).

Outcome: Food Security

Food insecurity was measured in NHANES using the US Food Security Survey Module. This validated scale consists of 10 questions that inquire about an adult's household food security in the prior year; affirmations to each question receive a score of 1. Full details on the questions, development, definitions, and scoring are described elsewhere.^{1,45} Food security status categories were defined as full food security (score of 0, ie, no affirmative responses), marginal food security (score of 1 to 2), low food security (score of 3 to 5), and very low food security (score of 6 to 10). In primary analyses, we dichotomized food security status as either full food security (score of 0) or any degree of food insecurity (ie, affirmation of any of the food insecurity questions [scores of 1 to 10]). Because some scholars operationalize food insecurity as scores of 3 or higher,⁴⁵ we also performed a sensitivity analysis in which we instead defined food security as a score of <3 and food insecurity as a score of ≥3.

Main Exposure of Interest: Tap Water Avoidance

Experiential measures of water insecurity are less mature than those for food insecurity.⁹ Although there is burgeoning evidence that experiences of water insecurity can be measured in high-income countries,^{46–48} experiential measures in such settings are not yet widespread, and none have been implemented in nationally representative data. As such, for these analyses, we relied on a proxy of water insecurity captured by NHANES.⁴³ This primary proxy of water insecurity was tap water avoidance, that is, whether an individual reported not drinking their tap water. In the dietary recall module, participants were asked “When you drink tap water, what is the main source of the tap water?” Those who reported that their main tap water drinking source was municipal, well, or rain/cistern were coded as “drank tap water.” If respondents reported that they did not drink tap water, they were coded in the dataset as “did not drink tap” and are considered “tap water avoiders” in this study.

For robustness checks, we created 2 additional water insecurity proxy variables based on 24-hour dietary recall data; these proxies provide insight into the potential water use domain of water insecurity and are predictive of tap water avoidance.⁴³

1. Any tap water consumption on a given day. Using the NHANES total nutrients dataset,⁴⁴ we used the total tap water intake variable to classify an individual as consuming any tap water or not, dichotomized as tap water consumption >0 mL or 0 mL.
2. Exclusive bottled water consumption on a given day. Similarly, from the NHANES total nutrients dataset, we used the total bottled water intake variable to classify whether an individual exclusively consumed their plain water (ie, all water from tap and bottled sources) from noncarbonated, unsweetened bottled water, dichotomized as 100% or <100% of plain water intake coming from bottled water.

These 2 dietary measures should be interpreted as behavior on a given day, whereas not drinking one's tap water in the home is an indicator of usual avoidance.

Covariates

We focused on income and housing status as key covariates that might compound food insecurity based on existing literature.^{39,40} We measured income in our study by analyzing family income to poverty ratio (FIPR). We categorized this following prior NHANES analyses conducted by the National Center for Health Statistics between income and health and nutritional outcomes as ≤130% (at which point one qualifies for the Supplemental Nutrition Assistance Program), 131% to 350%, and >350%^{49,50}; this categorization also provides fairly equal sample sizes. We also examined FIPR as a continuous variable. We measured housing status in our study by analyzing a question about housing status in the last year, with possible response options of owning their place of residence, renting their place of residence, or having other living arrangements (eg, “couch surfing”).

Finally, we adjusted for a number of factors previously identified to be associated with food insecurity.³ These included participants' educational attainment (categorized as less than high school education, high school graduate or General Educational Development equivalent, some college completion or associate's degree, and college graduate or more), self-reported race and ethnicity (White, Black, Hispanic, or other/mixed), nativity status (born in the 50 US states and Washington, DC vs outside United States), age category (20 to 39 years, 40 to 59 years, 60 years or older), and sex (male, female).

Statistical Analysis

All analyses were conducted using survey commands and the dietary recall day 1 sample weights to account for the complex, multistage probability design of NHANES in *Stata*, version 15.1.⁵¹ These sample weights also adjust for nonresponse, day of week, oversampling, noncoverage, and loss of participants between study segments.⁵² Statistical significance was set at an α level of .05.

Models were built using data from the 31,390 adults who responded to the “source of tap water” question and had full covariate information (Figure 1; available at www.jandonline.org). Slightly more adults ($n = 32,281$) were included in the robustness analyses using the dietary recall variables as proxies for water insecurity because they included participants ($n = 891$) who were missing tap water source data.

For the first aim, multiple logistic regression models were used to test how tap water avoidance covaried with food insecurity. In the primary model (model 1), the odds of being less than fully food secure (relative to fully food secure) were estimated in relation to tap water avoidance adjusted for covariates. As a robustness check, we repeated the model with the two 24-hour dietary recall variables capturing no consumption of tap water (model 2) and exclusive bottled water consumption (model 3) on a given day. For sensitivity analyses, the logistic regression models 1 to 3 were re-estimated with food insecurity redefined as low and very low food security relative to fully or marginally food secure (models 4 to 6). Next, models 1 to 3 were re-estimated using ordered logit regression to examine the proportional odds ratio of the ordered categorical outcome variable of food security (full, marginal, low and very low, models 7 to 9).

Table 1. Descriptive characteristics of 31,390^{ab} US adults 20 years and older from the NHANES^c 2005-2018

Characteristic	%, mean ^d
NHANES survey cycle	
2005-2006	13.9
2007-2008	13.7
2009-2010	13.9
2011-2012	14.3
2013-2014	14.8
2015-2016	14.8
2017-2018	14.7
Food security status^e	
Full food security (score of 0)	76.9
Marginal food security (1-2)	9.1
Low food security (3-5)	7.6
Very low food security (6-10)	6.3
Drink tap from main water source^f	84.2
Do not drink tap from main water source^f	15.8
Drink tap on a given day^g	52.9
Did not drink tap on a given day^g	47.1
Did not drink bottled water exclusively on a given day^g	72.1
Drink bottled water exclusively on a given day^g	27.9
Sex	
Male	51.7
Female	48.3
Age category	
20-39 y	36.5
40-59 y	37.6
60+ y	25.9
Race/ethnicity	
Hispanic	13.0
Non-Hispanic Black	10.9
Non-Hispanic White	68.8
Other race/ethnicity ^h	7.3
Nativity	
% Born in US	84.6
% Born outside US	15.4
Family income to poverty ratio	
≤130%	21.6
131%-350%	35.4
>350%	43.0

(continued)

Table 1. Descriptive characteristics of 31,390^{ab} US adults 20 years and older from the NHANES^c 2005-2018 (continued)

Characteristic	%, mean ^d
Educational attainment	
Less than high school	15.0
High school graduate	23.5
Some college	31.9
College graduate and above	29.6
Housing status	
Own/bought home	68.4
Rents home	29.6
Other home status	2.0

^aUnweighted sample size.^bWithout missing covariate data and valid dietary recall status.^cNHANES = National Health and Nutrition Examination Survey.^dWeighted mean percentage for each category.^eMeasured using US Food Security Survey Module.⁴⁵^fFrom question: "What is main tap water source?"^gFrom 24-hour dietary recall.^hOther race/ethnicity category refers to other non-Hispanic races, including non-Hispanic multiracial.

For the second aim, understanding how tap water avoidance and food insecurity varied across time, we examined time trends and interactions with tap water avoidance by survey cycle. To do this, the logistic regression model 1 was re-estimated with further adjustment for survey cycle along with an interaction term between survey cycle and tap water avoidance. Following prior work,¹⁶ the 2013-2014 survey cycle was used as the reference category because it was the last data collection wave before the Flint water crisis. Marginal standardization was then used to estimate and plot predicted probabilities of any food insecurity in relation to tap water avoidance by year.⁵³ Next, the trends were re-examined using the ordered logit regression models to demonstrate how food security categories changed over time stratified by tap water avoidance.

Finally, for the third aim, potential interactions were examined between tap water avoidance and income (FIPR) and (separately) between tap water avoidance and housing status. To do this, model 1 was re-estimated with further inclusion of interaction terms for tap water avoidance by FIPR as a continuous variable; as a sensitivity test, this interaction was also tested with FIPR categories. Model 1 was then re-estimated with inclusion of interaction terms for tap water avoidance by housing status. For both models, we visualized the interactions on the predicted probability of any food insecurity using marginal standardization.

RESULTS

Approximately 76.9% of the pooled sample from 2005-2018 was considered fully food secure, and 9.1%, 7.6%, and 6.3% were considered to have marginal, low, or very low food security, respectively (Table 1). Approximately 15.8% of respondents were categorized as tap water avoiders, and the 24-hour recall

Table 2. Multiple logistic regressions examining odds of any food insecurity by water insecurity proxies, NHANES^a 2005-2018

Variable	Model 1: Food insecurity	Model 2: Food insecurity	Model 3: Food insecurity
← odds ratio (95% CI) →			
Tap water avoidance^b	1.21*** (1.09-1.34)	—	—
Did not drink any tap water on a given day ^c	—	1.30*** (1.19-1.42)	—
Exclusively drank bottled water on a given day ^c	—	—	1.20*** (1.08-1.33)
Family income to poverty ratio			
>350% (ref ^d)	1	1	1
≤130%	10.97*** (8.97-13.42)	10.84*** (8.89-13.23)	10.95*** (8.98-13.35)
131%-350%	4.69*** (3.94-5.58)	4.67*** (3.93-5.55)	4.69*** (3.95-5.57)
Housing status			
Own home (ref)	1	1	1
Rent home	2.12*** (1.90-2.37)	2.13*** (1.91-2.38)	2.14*** (1.91-2.39)
Other	1.34 (0.93-1.93)	1.33 (0.93-1.91)	1.32 (0.92-1.91)
Educational attainment			
College graduate and above (ref)	1	1	1
Less than high school	2.71*** (2.28-3.21)	2.62*** (2.21-3.11)	2.74*** (2.31-3.26)
High school graduate	2.43*** (2.04-2.89)	2.32*** (1.95-2.75)	2.40*** (2.02-2.86)
Some college	2.17*** (1.84-2.56)	2.12*** (1.80-2.48)	2.16*** (1.84-2.54)
Nativity status			
Born in United States (ref: born outside United States)	1.24*** (1.10-1.41)	1.23*** (1.09-1.40)	1.25*** (1.10-1.41)
Race/ethnicity			
NH White (ref)	1	1	1
NH Black	1.60*** (1.40-1.84)	1.57*** (1.38-1.79)	1.59*** (1.39-1.81)
Hispanic	2.15*** (1.83-2.52)	2.16*** (1.85-2.53)	2.17*** (1.85-2.54)
Other race/ethnicity	1.34*** (1.13-1.59)	1.38*** (1.17-1.63)	1.38*** (1.16-1.63)
Female (ref: male)	1.07* (0.998-1.16)	1.08** (1.01-1.16)	1.07* (0.996-1.15)
Age			
20-39 y (ref)	1	1	1
40-59 y	1.08 (0.98-1.19)	1.08 (0.98-1.19)	1.09* (0.99-1.20)
60+ y	0.51*** (0.45-0.59)	0.52*** (0.45-0.60)	0.52*** (0.45-0.60)
← n →			
Observations	31,390	32,281	32,281

^aNational Health and Nutrition Examination Survey.^bFrom question: "What is your main tap water source?"^cFrom 24-hour dietary recall.^dref = reference.* $P < .1$.** $P < .05$.*** $P < .01$.

data suggested that on a given day, 47.1% did not drink any tap water and 27.9% drank bottled water exclusively.

Aim 1: How Are Water Insecurity Proxies Associated with Food Insecurity?

Adults who avoided their tap water had 21% higher odds (odds ratio [OR] 1.21; 95% CI 1.09 to 1.34) of any food

insecurity compared with those who drank their tap water (Table 2, model 1). These relationships held when the model was re-estimated using the proxies of water insecurity from the 24-hour recall. Adults who did not drink any tap water on a given day had 30% higher odds (OR 1.30; 95% CI 1.19 to 1.42) of any food insecurity compared with adults who drank at least some tap water (model 2).

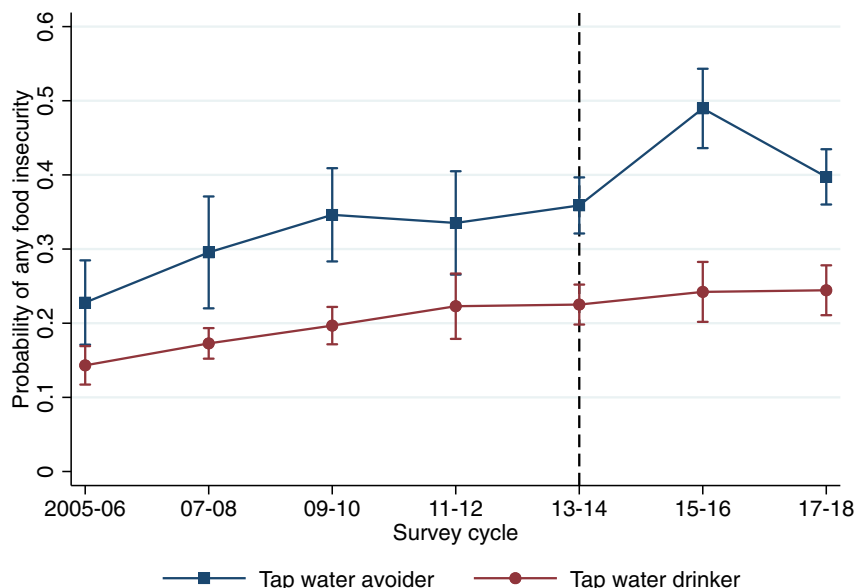


Figure 2. Predicted probability^a and 95% CI of experiencing any food insecurity^b by tap water avoidance among US adults^c in National Health and Nutrition Survey 2005-2018.^d ^aFigure generated using marginal standardization from logistic regression models adjusting for federal income poverty ratio, housing status, educational attainment, nativity status, self-reported race and ethnicity, age, and sex, and an interaction between survey cycle and tap water use. ^bAny food insecurity is defined as less than full food security. ^cn = 31,390. ^dReference line indicates the timing of the Flint water crisis in 2013-2014.

Similarly, adults who consumed bottled water exclusively on a given day had 20% higher odds (OR 1.20; 95% CI 1.08 to 1.33) of any food insecurity than those who did not consume their plain water exclusively from bottled water (model 3).

When food insecurity was dichotomized as “low” and “very low” food security vs “marginal” and “full” food security, the association between the proxies of water insecurity and food insecurity were consistent (17% to 29% higher odds) with the primary models (Table 3, models 4 to 6; available at www.jandonline.org). Finally, ordered logit regression models with 4 levels of food security status (full, marginal, low, and very low) produced similar and consistent results (Table 4, models 7 to 9; available at www.jandonline.org). Tap water avoidance was consistently positively associated with 18% to 28% higher odds of being in a more severe food insecurity category.

Aim 2: Time Trends with Tap Water Avoidance

When adjusting for survey year and the interaction between survey year and tap water avoidance, the probability of any food insecurity effectively doubled from 2005-2006 through 2017-2018 (Figure 2). The increase in food insecurity was observed among both tap water drinkers and avoiders, but was substantially higher across all years for avoiders. The predicted probability of any food insecurity among tap water avoiders increased from 22.8% (95% CI 17.1% to 28.5%) in 2005-2006 to 49% (95% CI 43.6% to 54.3%) in 2015-2016. Although this decreased in 2017-2018 to 39.7% (95% CI 36.0% to 43.5%), it was still higher in 2017-2018 among tap water avoiders compared with any year before the Flint water crisis. In contrast, among the group that drank their tap water, there was a gradual linear increase in any food insecurity from 14.3% (95% CI 11.7% to 16.9%) to 24.4% (95% CI 21.0% to 27.8%)

from 2005-2006 to 2017-2018 without any significant increases immediately before and after the Flint water crisis. In sensitivity analyses, this relationship held when food insecurity was dichotomized as “low” and “very low” food security vs “marginal” and “full” food security (Figure 3; available at www.jandonline.org).

These time trends also held when food security was modeled with 4 categories (instead of dichotomized) (Figure 4A and 4B). These models provide additional insights into how severities of food insecurity changed over time. Namely, they showed that the increase in food insecurity in 2015-2016 among tap water avoiders was driven by a rise in the proportion of adults in the low and very low food security categories, and that proportion then fell in 2017-2018.

Aim 3: Examining Interactions with Income and Housing

We examined the predicted probability of any food insecurity among tap water drinkers and avoiders at different levels of FIPR (Figure 5A). Food insecurity was higher among tap water avoiders relative to tap water drinkers at all FIPR levels, yet as income increased, food insecurity decreased across both tap water drinkers and avoiders. For example, at 150% FIPR, the predicted probability of any food insecurity for tap water drinkers was 31.5% (95% CI 29.8% to 33.1%), which decreased by approximately one-half to 15.4% (95% CI 14.1% to 16.7%) at 300% FIPR. In contrast, among tap water avoiders, the predicted probability of any food insecurity was much higher at 150% FIPR—43.5% (95% CI 41.0% to 46.1%); it decreased only by approximately forty percent to 25.4% (95% CI 23.2% to 27.8%) at 300% FIPR. These results were consistent when the interaction was tested with FIPR as a categorical variable, indicating the gap in probability of any food insecurity between tap water avoiders and tap water drinkers was widest in the

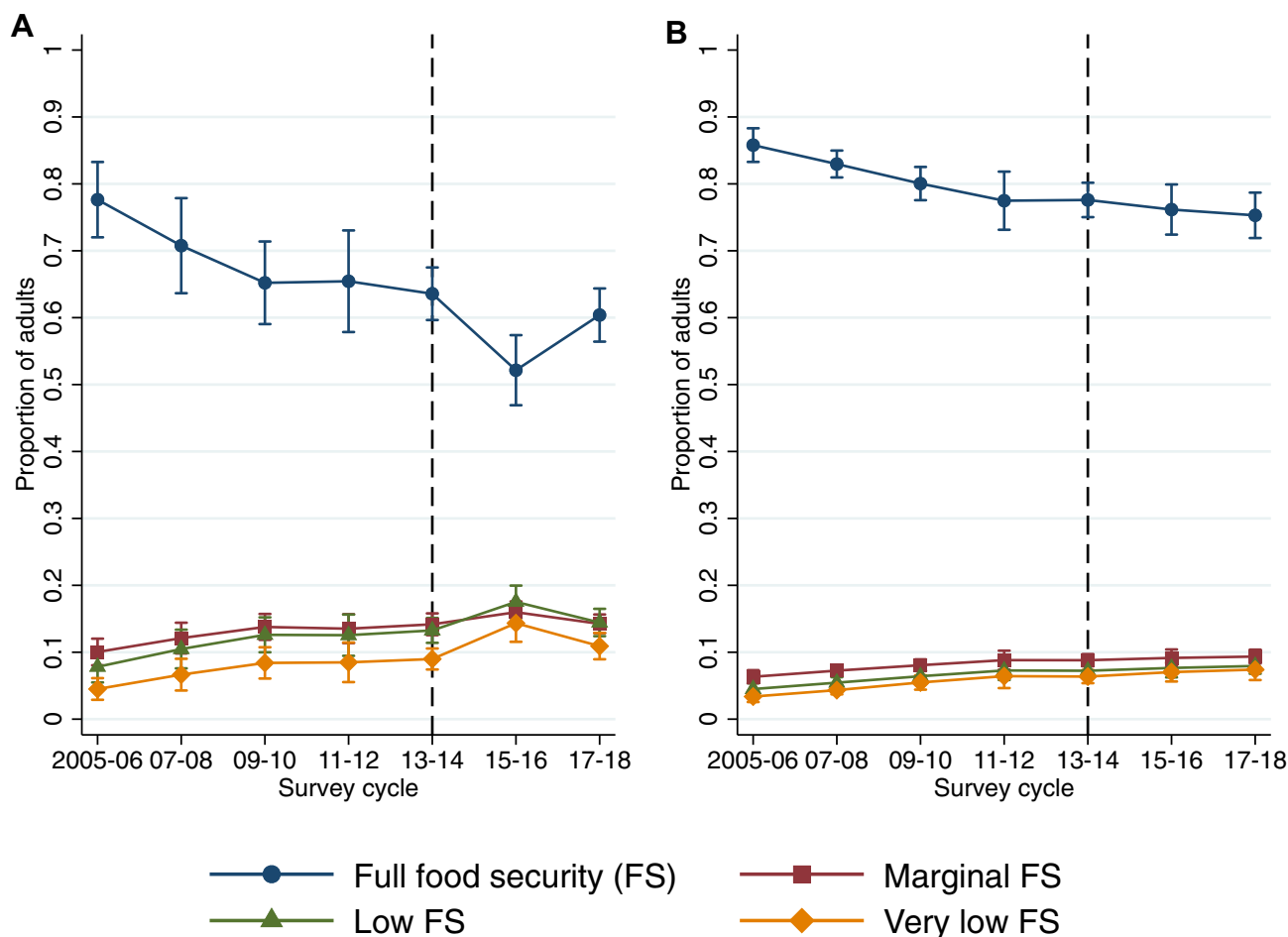


Figure 4. Change in predicted probability^a of food security category over time among (A) tap water avoiders, and (B) tap water drinkers among US adults^b in National Health and Nutrition Survey 2005-2018.^c ^aFigure generated using marginal standardization from ordered logistic regression models adjusting for federal income poverty ratio, housing status, educational attainment, nativity status, self-reported race/ethnicity, age, and sex, and survey cycle with models stratified by tap water use. ^bn = 31,390. ^cReference line indicates the timing of the Flint water crisis in 2013-2014.

middle-income group (Figure 6; available at www.jandonline.org).

When we examined the predicted probabilities of any food insecurity in relation to housing status, we observed that overall food insecurity was significantly lower among homeowners than renters (Figure 5B). However, among both owners and renters, tap water avoidance was associated with higher probability of any food insecurity. For example, there was nearly double the probability of any food insecurity among homeowners who avoided their tap water (24.3%; 95% CI 21.9% to 26.7%) compared with homeowners who drank their tap water (12.7%; 95% CI 11.7% to 13.7%) (Figure 5B). Nearly one-half of renters who avoided their tap water (49.4%; 95% CI 46.2% to 52.7%) were predicted to have food insecurity, compared with 40.9% (95% CI 38.6% to 43.3%) of renters who drank their tap water.

DISCUSSION

In this first article examining the association between proxies of water insecurity and food insecurity in nationally representative data in the United States, we found that those who

avoided their tap water had approximately 21% higher odds of experiencing any food insecurity than those who drank their tap water, as hypothesized. This relationship was observed across 3 operationalizations of tap water avoidance. To the second aim, both tap water avoidance and food insecurity increased between 2005 and 2018, and the relationship between tap water avoidance and food insecurity was stronger in recent years. Specifically, there was a significant increase in food insecurity for tap water avoiders, but not tap water drinkers, in 2015-2016 after the onset of the Flint water crisis compared with prior years. For the third aim, tap water avoidance was further associated with higher food insecurity among those with lower incomes and living in rental housing. Together, these findings suggest that tap water avoidance may be an underappreciated signifier of water problems, and tap water avoidance co-occurs with food insecurity among US adults, especially among those in lower income brackets and in less stable housing. This has important public health implications, as the known detrimental health impacts of food insecurity may be exacerbated among those who concurrently experience water insecurity.^{38,54-56}

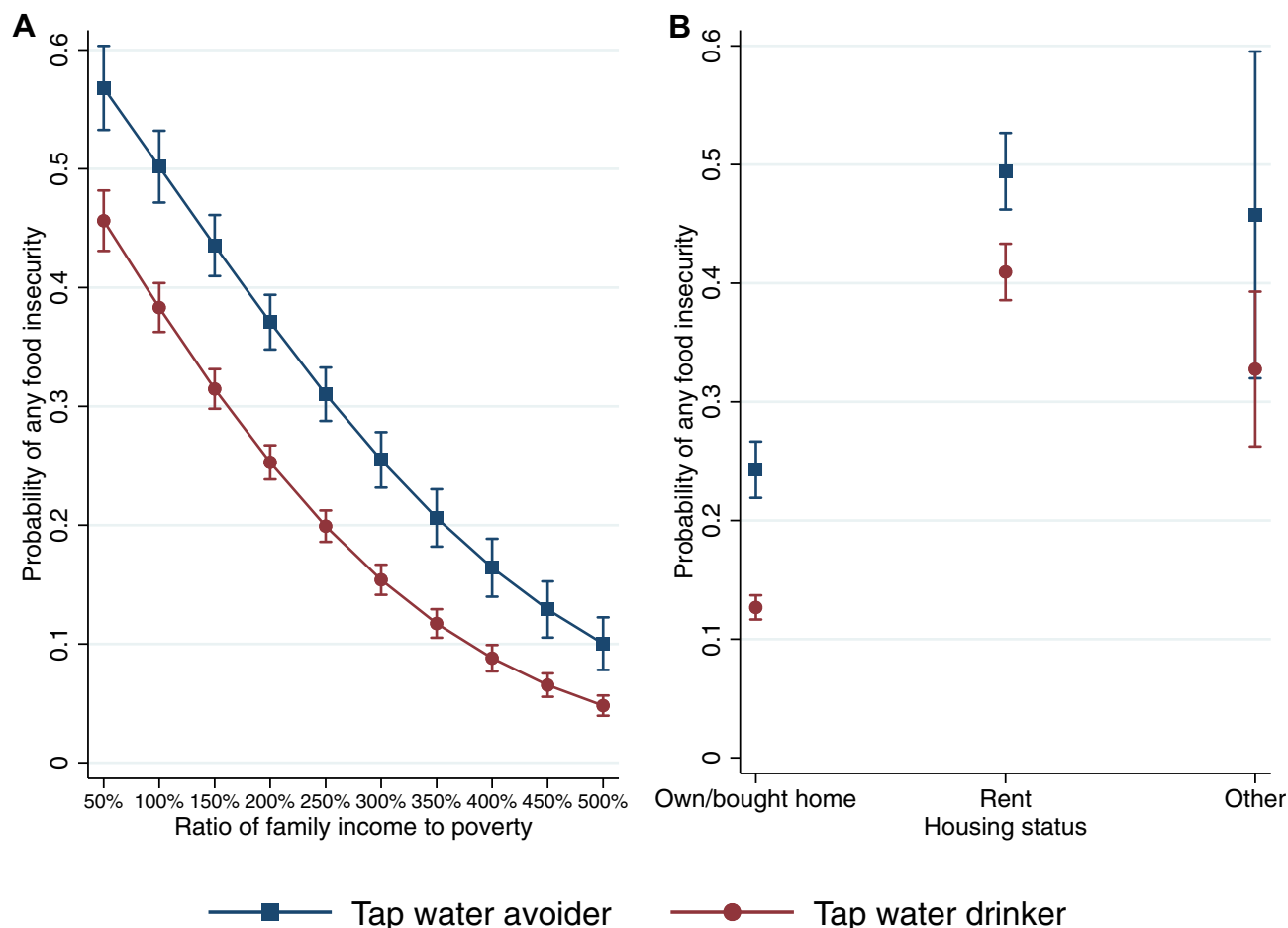


Figure 5. Predicted probability^a and 95% CIs of any food insecurity^b by tap water avoidance and (A) family income to poverty ratio, and (B) housing status among US adults in National Health and Nutrition Survey 2005-2018. ^aFigure generated using marginal standardization from logistic regression models adjusting for federal income poverty ratio, housing status, educational attainment, nativity status, self-reported race/ethnicity, age, and sex, and an interaction between family income to poverty ratio and tap water avoidance in panel A, and an interaction between housing status and tap water avoidance in panel B. ^bAny food insecurity is defined as less than full food security. ^cn = 31,390.

It is difficult to compare these findings to previous literature because the relationships between water insecurity and food insecurity are only beginning to be explored, and they have thus far been studied primarily in low- and middle-income settings.^{10,12,57} The studies examining water-related factors in relation to food insecurity in high-income settings tend to use water intake as a measure of health-related behavior, as opposed to a proxy of water quality or quantity issues. For example, French adults who consumed more plain water had higher overall dietary quality scores,⁵⁸ but this analysis did not consider availability, access, use, or reliability of food or water. Even comparisons with the observed relationships between water and food insecurity in low- and middle-income countries are difficult because our operationalization of water insecurity—tap water avoidance—is not directly comparable with experiential measures of water insecurity. For instance, in many of the settings in which household water insecurity has been associated with food insecurity,^{10,38,57,59,60} running water is not available in the home and/or the purchase of bottled water is not possible.

Nevertheless, the studies in low- and middle-income countries highlight the co-occurrence of water and food insecurities¹⁰ and the plausibility of a causal relationship between water insecurity and food insecurity.³⁸ This study builds on previous work by demonstrating that water and food insecurities can also co-occur in high-income settings.

Prior studies that have focused exclusively on either water insecurity or food insecurity have described patterns similar to those observed in these data. For example, a number of other studies have shown that tap water avoidance and/or mistrust of water in the United States has been increasing across time.^{16,17,22,29} Similarly, other research has documented recent increases in food insecurity in the United States.^{3,61}

The ability to identify previously unrecognized but modifiable drivers of food insecurity has important consequences for nutrition and public health policy and practice.² Ensuring tap water is safe, trusted, and consumed may help improve food security and/or nutritional status via several mechanisms. It could allow funds spent on bottled water to be

reallocated toward food; it could also help households feel more comfortable using water available in the home to prepare nutritious, whole-foods meals that may otherwise drain bottled water supplies too quickly (eg, preparation of whole grains and legumes). Having access to, trusting, and using tap water may also increase the types and variety of foods one can cook, as well as provide an easily available calorie- and sugar-free hydrating beverage. Finally, it may encourage more families to cook at home more often, which is generally more economical and may encourage healthier eating behaviors (and thereby better health) compared with frequent dining at restaurants.^{27,28,62}

Strengths, Limitations, and Future Directions

This study has several important strengths. First, it is based on findings from 14 years (7 waves) of cross-sectional data collection from a large, nationally representative sample. Second, we were able to operationalize tap water avoidance and food insecurity in several different ways, all of which produced consistent results. Third, the time trend analyses provide additional support that tap water avoidance is associated with higher food insecurity consistently over time. It is striking that relationships between tap water avoidance and food insecurity held when adjusting for income and housing status, and were even present at all income and housing categories. These findings suggest that at least some degree of the relationship between tap water use and food insecurity is independent of poverty and other shared causes. When adults avoid tap water, they often switch to more costly bottled water, which increases their expenditures on water.²⁹ This additional expense may be particularly problematic for those who spend high proportions of their incomes on high rents, thus reducing money that could be allocated on food.

One of the limitations of this study is the fact that our 3 proxies of water insecurity are just that—proxies; experiences with water insecurity were not measured as robustly as experiences with food insecurity were, that is, with a validated scale. Although NHANES does not ask respondents why they did not drink their in-home tap water or why they drank bottled water exclusively, the 3 proxies we used have been found to be useful and predictive indicators of water insecurity.⁴³ The tap water avoidance measure is likely capturing differences in availability of safe and acceptable tap water, trust in tap water, and organoleptic preferences for drinking tap water. It is not possible to ascertain what portion of the findings correspond to each of the 3 motives, which could be an interesting avenue for future research, with implications for the most effective policy response. A second limitation is that, despite adjustment for a variety of socioeconomic covariates known to be a shared cause of both water insecurity and food insecurity, it is possible that residual confounding remains. A third limitation is the fact that, because the data are cross-sectional, it is not possible to assess directionality or establish causality. Although prior work suggests that water insecurity more likely precedes food insecurity, the reverse is also possible.^{9,38}

There are several ways to advance this nascent line of research.^{30,43} First, order of onset needs to be established: Does water insecurity precede food insecurity in high-income countries? Currently, this is unknown. Furthermore, intervention studies are needed to establish causality. Can interventions that

increase tap water consumption subsequently change food insecurity? Does food insecurity improve when water security and trust in tap water is established? Or are food insecurity and tap water avoidance related because of other shared causal factors, like economic disadvantages, social inequities, and limited access to resources in general?

Second, research measuring outcomes along potential pathways between water insecurity and food insecurity is necessary for understanding both how these two phenomena are related and how interventions may best mitigate their harmful impacts on health and well-being. This includes data about cooking avoidance and/or the inability to wash produce due to water issues, as well as money spent on water and whether purchasing water from outside the home reduces food purchases or limits food choices.^{9,12} The different reasons tap water is avoided and how each relate to food insecurity would also be useful for guiding policy decisions and interventions. Past work has found that water contamination events in the United States, like the Flint water crisis, lead to increased bottled water purchases in the affected area,²⁰ but little is known about whether or how water contamination events drive dietary decisions, including food purchase and preparation. For example, ultra-processed foods or fast food may be purchased and consumed more frequently when water for food preparation is scant or untrusted.⁶³

Third, water insecurity should be better measured in the United States and in other high-income countries.^{23,30,37} The use of experiential measures that distinguish between domains of water insecurity will help to better unpack the relationship with food insecurity. Experiential measures of water insecurity have been validated for low- and middle-income countries^{64–66}; work is ongoing to validate them in high-income countries. In the interim, there are other proxies for water insecurity available in other datasets for immediate exploration, including dietary recalls, plumbing poverty, and water shutoffs.^{18,19,23}

Fourth, finer-grain data tied to housing status and location will help unpack the heterogeneous relationship between water insecurity and food insecurity and how contamination events affect insecurities. Although renting was associated with higher odds of food insecurity in our study, homeowners dealing with water issues, particularly water contamination events, may face hardships as well. In cases like the Flint water crisis, housing becomes devalued, leading individuals to be trapped in place.⁶⁷ Future work should examine whether relationships between water insecurity and food insecurity are stronger in the cities and towns where water crises happened, and whether there are ripple effects beyond.

Finally, as research has demonstrated that the COVID-19 pandemic has exacerbated food insecurity in the United States,⁶⁸ it will be important to further test whether and how water insecurity and food insecurity were linked during the COVID pandemic.

CONCLUSIONS

Food insecurity is a known multifactorial nutritional and public health problem in the United States, but the potential for water insecurity to co-occur or exacerbate food insecurity among Americans has been overlooked. This is the first study to bring together these two constructs using nationally representative data to examine how they covary in the United

States. Our study suggests that those who avoid tap water, a proxy for water insecurity, had a higher probability of being food insecure; this relationship held across time, income levels, and housing status. Future research is needed to understand the reasons for tap water avoidance and measure other domains of water insecurity in relation to food insecurity. Efforts to mitigate food insecurity should consider whether water access and/or water quality plays a role in food insecurity, and/or whether it is indicative of other marginalizations. Water security is an important public health goal in and of itself, this importance is reinforced by its potential as a barrier to achieving food security.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

FUNDING/SUPPORT

A.Y. Rosinger was supported by the Ann Atherton Hertzler Early Career Professorship funds and Penn State's Population Research Institute (NICHD P2CHD041025). S. L. Young was supported by a fellowship from the Carnegie Foundation. The funders had no role in the research or interpretation of results.

ACKNOWLEDGEMENT

The authors thank the Water, Health, and Nutrition Laboratory and the Household Water InSecurity Experiences-Research Coordination Network (HWISE-RCN) for their intellectual vibrancy.

AUTHOR CONTRIBUTIONS

A.Y. Rosinger, H. J. Bethancourt, and S. L. Young conceptualized the paper. A.Y. Rosinger constructed the dataset and analyzed the data and drafted the manuscript with contributions from H. J. Bethancourt and S. L. Young. All authors critically revised and edited the manuscript and approved the final version.

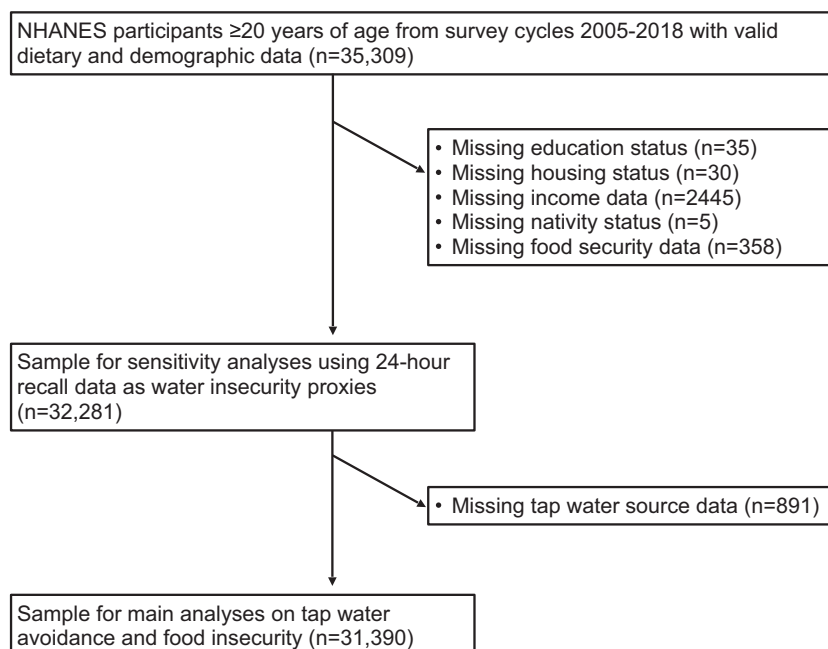


Figure 1. Flow chart of analytical samples derived among US adult participants in National Health and Nutrition Survey (NHANES) 2005-2018.

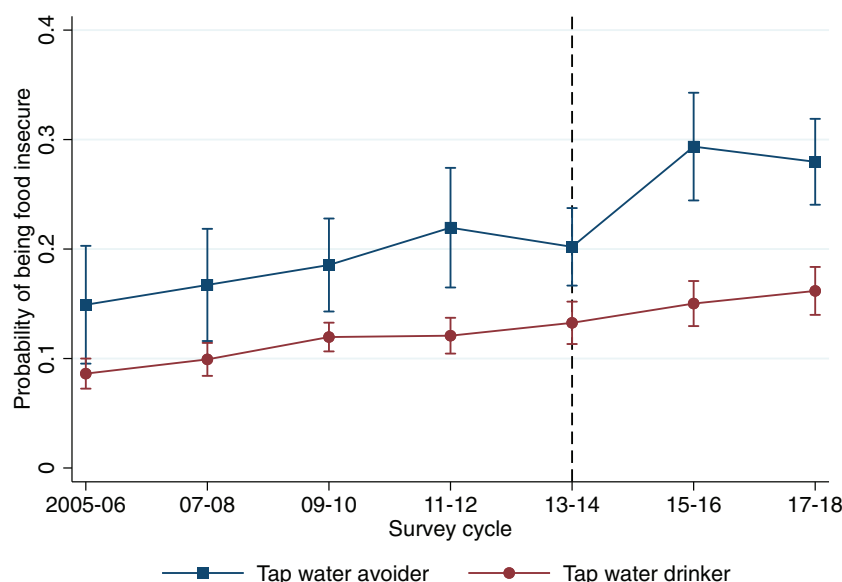


Figure 3. Predicted probability^a and 95% CI of experiencing food insecurity^b by tap water avoidance among US adults^c in National Health and Nutrition Survey 2005-2018.^d ^aFigure generated using marginal standardization from logistic regression models adjusting for federal income poverty ratio, housing status, educational attainment, nativity status, self-reported race and ethnicity, age, and sex, and an interaction between survey cycle and tap water use. ^bFood insecurity is defined as low and very low food security. ^cn = 31,390. ^dReference line indicates the timing of the Flint water crisis in 2013-2014.

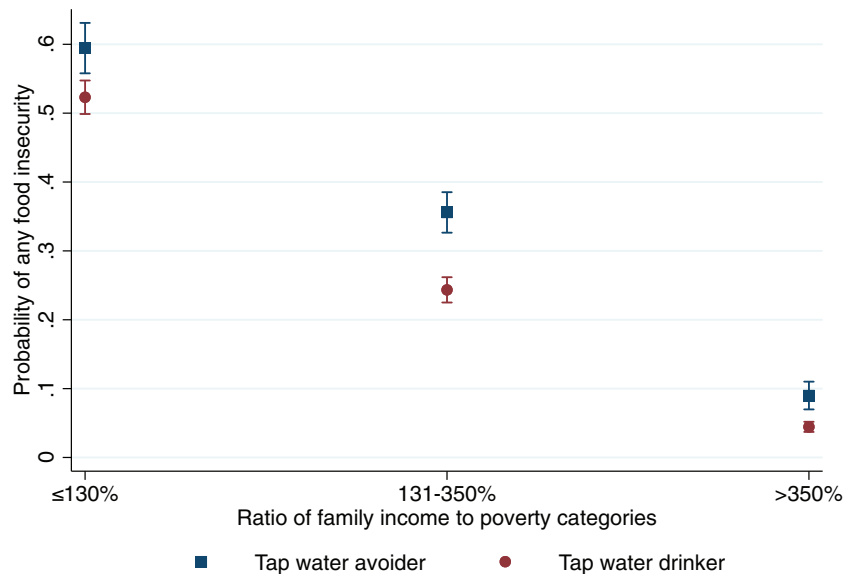


Figure 6. Predicted probability^a and 95% CIs of any food insecurity^b by tap water avoidance and family income to poverty ratio categories among US adults in National Health and Nutrition Survey 2005-2018. ^aFigure generated using marginal standardization from logistic regression models adjusting for federal income poverty ratio, housing status, educational attainment, nativity status, self-reported race/ethnicity, age, and sex, and an interaction between family income to poverty ratio categories and tap water avoidance. ^bAny food insecurity is defined as less than full food security. ^cn = 31,390.

Table 3. Multiple logistic regressions^a examining odds of food insecurity (low and very low food security) compared with food security (full and marginal) by water insecurity proxies, NHANES^b 2005-2018

Variable	Model 4: Food insecurity	Model 5: Food insecurity	Model 6: Food insecurity
	← odds ratio (95% CI) →		
Tap water avoidance ^c	1.17** (1.02-1.33)	—	—
Did not drink any tap water on a given day ^d	—	1.29*** (1.16-1.44)	—
Exclusively drank bottled water on a given day ^d	—	—	1.19*** (1.06-1.33)
	← n →		
Observations	31,390	32,281	32,281

^aModels adjusted for federal income to poverty ratio, housing status, educational attainment, nativity status, self-reported race/ethnicity, age, and sex.

^bNHANES = National Health and Nutrition Examination Survey.

^cFrom question: "What is main tap water source?"

^dFrom 24-hour dietary recall.

**p < .05.

***p < .01.

Table 4. Multiple ordered logistic regressions^a examining odds of food security status by water insecurity proxy, NHANES^b 2005-2018

Variables	Model 7: Food insecurity	Model 8: Food insecurity	Model 9: Food insecurity
	← odds ratio (95% CI) →		
Does not drink one's tap water ^c	1.18*** (1.07-1.30)	—	—
Did not drink any tap water on a given day ^d	—	1.28*** (1.17-1.40)	—
Exclusively drank bottled water on a given day ^d	—	—	1.18*** (1.07-1.30)
	← n →		
Observations	31,390	32,281	32,281

^aModels adjusted for federal income to poverty ratio, housing status, educational attainment, nativity status, self-reported race/ethnicity, age, and sex.

^bNHANES = National Health and Nutrition Examination Survey.

^cFrom question: "What is your main tap water source?"

^dFrom 24-hour dietary recall.

*** $P < .01$.