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Key Points:
- In-home tap water avoidance was decreasing among U.S. children from 2007–2014, until the Flint water crisis, when tap avoidance increased
- Minority and low socioeconomic status children and adults consistently reported not drinking tap water at higher rates over time
- Children who avoided tap water were more likely to drink bottled water; not drinking tap water may capture aspects of U.S. water insecurity

Supporting Information:
- Supporting Information S1

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In-Home Tap Water Consumption Trends Changed Among U.S. Children, but Not Adults, Between 2007 and 2016

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Abstract Despite evidence that tap water is often safer and cheaper than alternative sources, tap water is avoided when perceived to be unsafe. Therefore, we conducted the first nationally representative U.S. trends analysis of in-home tap water avoidance between 2007 and 2016. We tested whether changes occurred during/after the Flint water crisis, and whether not drinking tap from one's main water source differed by age, race/ethnicity, and socioeconomic status across time. Finally, we tested whether tap water avoidance was associated with higher prevalence of bottled water consumption among children. We used data on 12,915 children and 23,139 adults from the National Health and Nutrition Examination Survey. Significant covariate-adjusted quadratic time trends were found in the prevalence of avoiding tap water with an inflection at 2013–2014 for children, but not adults. Piecewise log-binomial regressions estimated that between 2007 and 2014 each survey cycle was associated with 14% lower prevalence of not drinking tap water (prevalence ratio [PR] 0.86, 95% CI: 0.80–0.93), but in 2014–2016 a 53% (95% CI: 1.12–2.09) higher prevalence was found for children corresponding to the water crisis. Younger children, Hispanic, non-Hispanic black, and those from low socioeconomic status backgrounds had consistently higher probability of avoiding tap water over time. Children who avoided tap water had 92% higher prevalence of drinking bottled water. In 2015–2016, 78% of non-Hispanic black children who avoided tap water drank bottled water on a given day. Avoiding tap water may indicate underlying water insecurity in the United States. Efforts to address tap water distrust have critical health and economic implications.

1. Introduction

In the United States, the provision of safe tap water was one of the top public health achievements of the twentieth century (Cutler & Miller, 2005). However, aging infrastructure and several recent lead-contamination scandals have led many Americans to question the safety of tap water (Katner et al., 2018; Pieper et al., 2019) and in many cases avoid it (Doria et al., 2009; Javidi & Pierce, 2018). The Flint water crisis is the most well-publicized of the many examples of environmental injustice potentially increasing distrust of tap water, particularly among vulnerable populations with histories of a variety of injustices (Jackson, 2017; Katner et al., 2018). Despite receiving relatively late attention from the national media, by mid-2015 the Flint water crisis had sparked national headlines (Jackson, 2017), stoking public health concerns about tap water safety nationally, particularly for children of color (Hanna-Attisha et al., 2015).

Tap water avoidance has important health and economic implications (Doria, 2006). Lower consumption of tap water is associated with higher intake of sugar-sweetened beverages (Onufrak et al., 2014; Rosinger et al., 2019), higher risk of dental caries (Sanders & Slade, 2018), and excess weight gain (Schwartz et al., 2016). Moreover, tap water is significantly cheaper than alternatives like bottled water or other beverages even when buying bulk bottled water quantities (Javidi & Pierce, 2018; Natural Resources Defense Council, 1999). Tap water has tested of higher quality than bottled water in several studies (Natural Resources Defense Council, 1999; Victory et al., 2017). On the other hand, however, a national study found that U.S. children who do not drink tap water have lower prevalence of elevated lead levels (Sanders & Slade, 2018).

Previous research has found that Black and Hispanic children as well as those from lower socioeconomic status families were less likely to drink tap water in the United States (Hobson et al., 2007; Patel et al., 2013). This is often due to higher inequities in water access (Switzer & Teodoro, 2018) as well as distrust of tap water among these populations (Balazs & Ray, 2014; Patel & Schmidt, 2017).

While previous analyses have examined disparities in tap water avoidance and perceptions of drinking water safety, they have done so at single time points (Javidi & Pierce, 2018; Park et al., 2019; Pierce & Gonzalez, 2017) or by aggregating data from multiple years into a single model (Patel et al., 2013). Other studies have measured tap water avoidance more indirectly over time, for example, by examining trends in bottled water expenditures in response to water quality violations (Allaire et al., 2019; Zivin et al., 2011) or in response to the Flint water crisis (Christensen et al., 2019). However, trends in the prevalence of whether people are using the tap water in their homes over time have not been examined empirically in nationally representative data. Such data are needed to build off of this prior work using perceptions or purchasing behavior to understand how trends of in-home tap water avoidance have changed among children and adults in the United States, especially in the wake of the Flint water crisis.

Therefore, we examined national descriptive trends in prevalence of in-home tap water avoidance (i.e., not drinking tap water from one's main water source) among U.S. children and adults in the years leading up (2007–2014) to the Flint water crisis and concurrent (2015–2016) to the crisis using data from the National Health and Nutrition Examination Survey (NHANES). We hypothesized that the shock of the Flint water crisis would be associated with increased tap water avoidance among children, but not among adults, because children are the most susceptible to the negative health risks of lead in water. Additionally, early media attention surrounding the Flint water crisis highlighted the health complications for children (Hanna-Attisha et al., 2015). Second, we examined how tap water avoidance differed by age, race/ethnicity, household education, and income levels across time among children and adults. We hypothesized that those experiencing greater social disparities would avoid tap water more consistently (Balazs & Ray, 2014). Our final objective was to test whether tap water avoidance was associated with higher prevalence of bottled water consumption using 24-hr dietary recall data if there was a noted change in tap water avoidance. We hypothesized that prevalence of bottled water consumption would be higher among children who avoided tap water and among minority children in 2015–2016.

2. Methods

2.1. Study Design and Data Collection

Data come from NHANES, a cross-sectional survey of the civilian, noninstitutionalized population, which uses a complex, multistage probability design. It is conducted continuously with data released in 2-year survey cycles to be nationally representative. NHANES combines in-person interviews with physical examinations in a mobile examination center. Details of survey sampling procedures and methodology are described in detail elsewhere (National Center for Health Statistics, 2015). Briefly, a proxy responded to interview questions for children aged ≤5 years; proxy-assisted interviews were conducted for children aged 6–11 years, and children aged ≥12 years responded to the question themselves. To allow for stable estimates of prevalence of health conditions and behaviors in each 2-year cycle, NHANES oversamples specific subpopulations, like Hispanic, non-Hispanic black, older adults, and low-income whites (National Center for Health Statistics, 2018).

For this analysis, we used the five most recent publicly available 2-year cycles, that is, data between 2007 and 2016. Response rates ranged between 83.1% in 2007–2008 and 64.6% in 2015–2016 for the examination component for youth aged 1–19 years. Complete data on tap water avoidance were available for 14,277 children (1,183 were excluded because they did not know the source of their tap water) and 25,294 adults (750 were excluded because they did not know the source of their tap water) from 2007–2016. We further excluded 1,362 children and 2,155 adults due to missing household income and education data. Therefore, the analytic data set consisted of 12,915 children and 23,139 adults with complete covariate information.

The National Center for Health Statistics (NCHS) conducts NHANES and it is approved by their Research Ethics Review board and then made publicly available for download without identifiers via their website.

Children aged 7–17 years provided assent and parents provided consent for children under 18, while all participants aged 18 years and over provided consent for themselves.

2.2. Dependent Variable: Tap Water Avoidance

Tap water avoidance was assessed based on questions asked during the dietary recall module: "When you [or your child] drink tap water, what is the main source of the tap water?" Is [it] the city water supply (community water supply); a well or rain cistern; a spring; or something else?" Multiple selections were not allowed. NCHS releases the responses as "Community supply," "Well or rain cistern", "Spring," or "Don't drink tap water." If individuals stated they "don't drink tap water," signifying that they did not use any of the tap water source options (including well water or spring water), we coded them as "avoided tap." This operationalization of not drinking tap water follows previous analyses (Patel et al., 2013; Sanders & Slade, 2018). Since this question is about the main source of tap water, it implies that it is the usual in-home tap source. We use the term avoided tap water to mean participants did not drink tap water for any reason (e.g., lack of access or distrust); this does not imply that participants are actively avoiding it since no follow-up responses are given by participants (this point is further elaborated on in the discussion).

As mentioned above, respondents that indicated the option "do not know" were excluded because they could not be classified as avoided tap or drank tap water since they did not indicate any other option (e.g., community supply, well/spring/rainwater, or do not drink tap water). Between 2007–2008 and 2015–2016, the percent of children who did not know their water sources varied between 5.5% and 7.6% and between 1.4% and 3.0% for adults, but did not differ significantly over time. In sensitivity analyses, we examined differences in primary water source to test whether tap water avoidance trends were consistent when disaggregating community/city and rain/well/spring water compared to those who did not drink tap water.

2.3. Dependent Variable 2: Bottled Water Intake

To estimate the percent of children who consumed bottled water on a given day, we analyzed the in-person multiple-pass 24-hr dietary recall data which was conducted in the mobile examination center by trained interviewers with assistance of caretakers for children ≤11 years old (National Center for Health Statistics, 2016). A single 24-hr dietary recall allows estimates of population means and differences between groups on a given day (Gibson, 2005). Bottled water intake was defined as consumption of greater than 0 ml or not (0 ml) of noncarbonated, unsweetened bottled water following previous analyses (Rosinger et al., 2018).

2.4. Covariates

The primary covariates used in this analysis were selected a priori from the literature as those that have been previously shown to be associated with either distrust of tap water or tap water avoidance (Javidi & Pierce, 2018; Patel et al., 2013). Being younger, of minority status, of lower income, and lower education have been shown to increase the propensity for children to avoid tap water (Patel et al., 2013). As such, age (2–5, 6–11, 12–19, 20–39, 40–59, 60+), sex (male/female), self-reported race/ethnicity (non-Hispanic [NH] white, NH black, Hispanic, or other), reference person's education level (less than high school graduate, high school graduate, some college, college graduate, or more), adult's own education level (same categories as above), and federal income to poverty ratio (FIPR) of the household (≤130%, 131–350%, >350%) were examined. FIPR is an index based on family income ratio to U.S. Department of Health and Human Services's poverty guidelines (U.S. Department of Health and Human Services, 2016).

2.5. Statistical Analyses

Analyses were conducted in Stata version 15.1 (Statacorp, College Station, TX). A two-sided P value of 0.05 was used to assess statistical significance. Statistical analyses accounted for the complex survey design of NHANES. We used the Day-1 dietary sample weights, which adjusted for oversampling, nonresponse, noncoverage, and day of week, since that is the smallest subpopulation for which all data were available and the point at which tap water avoidance and bottled water data were collected (Korn & Graubard, 2011; Rosinger & Ice, 2019). All estimates and 95% confidence intervals presented, except for sample sizes, are weighted and generated using survey commands following Korn and Graubard (Korn & Graubard, 2011).

To our first objective, to examine the prevalence of tap water avoidance across time, we assessed descriptive time trends of prevalence of not drinking tap water in log-binomial regression models with our time variable

(2-year survey cycles) as a set of indicator variables adjusted for the covariates of interest following guidance by National Center for Health Statistics (NCHS) (Ingram et al., 2018). We then used polynomial orthogonal contrasts to test the functional form of the time trend using the Stata postestimation command (contrast p. sddsrvyr, noeffects). This tests all potential functional forms for $n - 1$ time points, here (5 – 1 = 4) ranging from linear trends to quartic trends. Log-binomial models or a binomial generalized linear model with a log-link function connects the dichotomous outcome (tap water avoidance) to the predictors along with the survey sample weights (Skove et al., 1998; Wacholder, 1986). These models were chosen to estimate prevalence of avoiding tap water because this behavior was not rare (>10%) (Williamson et al., 2013). Additionally, the log-binomial model produces the least biased estimates for cross-sectional data in estimating prevalence ratios (McNutt et al., 2003; Schmidt & Kohlmann, 2008). To test if there was an inflection point during/after the Flint water crisis, we constructed piecewise [also known as joinpoint regression] log-binomial models following Ingram et al. (2018) to test differences in slope on either side of these points at 2013–2014, the survey before the Flint water crisis adjusting for the same covariates.

The log-binomial regression has been reviewed at length elsewhere (Blizzard & Hosmer, 2006; Skove et al., 1998; Wacholder, 1986; Williamson et al., 2013) and can be written as follows:

Let $Y(0/1)$ denote the absence/presence of tap water avoidance in an individual with covariates $X = (x_1, \ldots, x_k)$.

$$\text{Then} = P(Y = 1|X) = \exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)$$

The model is defined only if $\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k < 0$ for all x_k.

Or more simply $E[Y] = e^{X\beta}$ where $x'b$ is the model's linear term.

Exponentiation of the maximum likelihood estimator (MLE) of β yields an MLE of the prevalence ratio. With the piecewise or joinpoint regression in the right side of the equation, the data are continuous at the joinpoint or breakpoint. Therefore, the right side can be parameterized following Neter (Neter et al., 1985):

$$\text{Dependent variable} = \beta_0 + \beta_1 * \text{TIME} + \beta_2 * (\text{TIME} - \text{JOINPT}) * \text{IND} + \beta\Psi + u$$

where β_0 is the intercept of the first line segment; β_1 is the slope of the first line segment; β_2 is the difference between the slopes of the first and second line segments; TIME is the observed time points for the NHANES survey cycle; JOINPT is the location of the joinpoint, that is, 2013–2014; IND is the binary variable indicating whether or not the time point falls after the joinpoint at 2013–2014; (TIME − JOINPT1) * IND1 equals 0 if the time point falls before or on the joinpoint at 2013–2014, and equals TIME − JOINPT1 if the time point falls after the joinpoint; X is a vector of covariates; and u is the error term.

We conducted a sensitivity analysis to assess changes between community/city/municipal source, well/spring/rainwater (combined due to small sample sizes), and not drinking tap water using multinomial logistic regression. This was done to further examine trends in tap water avoidance compared to trends in use of city systems and well water users. The average marginal effects and 95% confidence intervals were estimated from this model using the same covariates, and a forest plot of these effects was generated using coefplot commands (Jann, 2014).

To our second objective, to test whether those facing greater social inequalities were more likely to avoid tap water, a covariate-adjusted log-binomial regression adjusting for survey year without the piecewise term was estimated and plotted using marginal standardization for survey data to generate predicted probabilities of tap water avoidance by the four primary covariates for children and by race/ethnicity, income, and educational attainment for adults (Graubard & Korn, 1999; Muller & MacLehose, 2014).

To our third objective, to test whether avoiding tap water was associated with increased prevalence of bottled water consumption among children, we estimated log-binomial models as described above first with the same set of covariates without interaction terms. We next tested for a three-way interaction between avoiding tap water, survey year (set of indicator variables), and race/ethnicity (categorical variable) to assess whether time trends differed over time among different ethnic groups dependent on whether they avoided tap water or not. The three-way model did not converge using the log-binomial model, so we then estimated this using logistic regression. This indicated a significant three-way interaction for black children in

Table 1
Sample Size and Descriptive Characteristics of U.S. Children Aged 2–19 years, 2007–2016[a,b,c]

	2007–2008		2009–2010		2011–2012		2013–2014		2015–2016	
	[a]No. of participants	[b]Mean (SE)	[a]No. of participants	[b]Mean (SE)	[a]No. of participants	[b]Mean (SE)	[a]No. of participants	[b]Mean (SE)	[a]No. of participants	[b]Mean (SE)
Overall	2,599		2,764		2,594		2,574		2,384	
Water source:										
Municipal	1,747	68.0 (2.6)	1902	69.6 (3.3)	1851	71.4 (4.0)	1,967	77.8 (2.8)	1,693	74.3 (3.1)
Well/rain/spring	221	14.9 (2.7)	262	13.0 (3.1)	236	16.3 (4.5)	192	9.8 (2.4)	203	9.8 (3.0)
Do not drink tap	631	17.1 (1.5)	600	17.4 (2.2)	507	12.4 (1.9)	415	12.4 (1.8)	488	15.9 (2.3)
Drank bottled water	935	34.4 (2.2)	1,019	35.0 (1.8)	968	33.1 (3.6)	1,007	34.9 (2.5)	942	37.1 (2.0)
Did not drink bottled water	1,664	65.6 (2.2)	1,745	65.0 (1.8)	1,626	66.9 (3.6)	1,567	65.1 (2.5)	1,442	62.9 (2.0)
Male	1,347	50.7 (2.0)	1,454	50.9 (1.9)	1,333	51.4 (1.5)	1,303	52.4 (1.2)	1,198	50.4 (1.2)
Female	1,252	49.3 (2.0)	1,310	49.1 (1.9)	1,261	48.6 (1.5)	1,271	47.6 (1.2)	1,186	49.6 (1.2)
2–5 years	735	23.9 (1.4)	778	24.1 (1.4)	716	22.7 (1.5)	615	21.6 (1.1)	587	22.5 (1.1)
6–11 years	985	33.5 (1.0)	1,013	35.1 (1.2)	1,017	34.8 (1.2)	952	35.0 (1.5)	916	35.7 (1.2)
12–19 years	879	42.6 (2.1)	973	40.8 (1.5)	861	42.5 (1.6)	1,007	43.5 (1.9)	881	41.8 (1.9)
NH white	892	61.6 (4.0)	977	58.9 (3.9)	629	56.5 (5.0)	730	53.9 (5.3)	744	53.8 (5.9)
NH black	644	13.7 (2.5)	552	13.5 (1.0)	762	14.4 (3.3)	637	13.7 (2.3)	533	13.8 (3.4)
Hispanic	931	19.0 (3.0)	1,044	20.7 (3.6)	777	21.2 (3.3)	818	22.9 (3.7)	762	22.7 (4.2)
FIPR: ≤130%	1,168	33.1 (2.7)	1,310	34.2 (2.2)	1,241	38.9 (4.2)	1,252	37.3 (3.8)	946	30.0 (3.6)
131–350%	903	33.7 (1.8)	950	36.7 (2.2)	844	34.4 (2.7)	830	36.4 (2.9)	952	40.7 (2.9)
>350%	528	33.2 (3.1)	504	29.2 (1.7)	509	26.7 (2.9)	492	26.3 (4.1)	486	29.3 (3.8)
Less than high school	774	19.6 (2.4)	812	20.2 (1.7)	689	23.2 (1.7)	588	16.2 (2.0)	531	17.6 (3.1)
High school grad	658	25.7 (2.3)	636	20.4 (2.0)	557	18.8 (1.9)	605	24.4 (3.0)	504	19.3 (1.7)
Some college	735	29.9 (1.5)	779	30.7 (1.3)	746	31.0 (2.0)	800	31.2 (1.6)	797	34.1 (2.0)
College +	432	24.7 (3.0)	537	28.8 (2.7)	602	27.1 (2.5)	581	28.2 (3.4)	552	29.0 (3.5)

[a]Unweighted sample size. [b]Weighted means. [c]Without missing covariate data. Other race/Hispanic origin included in analyses but not shown. FIPR: Federal income poverty ratio.

2015–2016 who avoided tap water. We therefore stratified the sample by tap avoidance status and estimated log-binomial models with two-way interactions.

3. Results

3.1. Objective 1: Tap Water Avoidance Trends in Children and Adults

Overall, data were analyzed for 12,915 children aged 2–19 years without missing covariate data from 2007–2016 (Table 1) and 23,139 adults aged 20+ (supporting information Table S1). The overall percent of U.S. children avoiding tap water during the study period decreased from 17.1% in 2007–2008 to 12.4% by 2013–2014, and subsequently increased to 15.9% in 2015–2016, that is, during/after the shock. Postestimation time trend analyses following a multiple log-binomial regression indicated there were significant quadratic time trends between 2007 and 2016 ($F = 6.15$; $p = 0.015$) implying that the trends changed direction and/or magnitude (Figure 1; supporting information Table S2, Model 1). In contrast, no significant time trends (quadratic trend $F = 0.11$, $p = 0.75$; cubic trend $F = 2.89$ $p = 0.09$) were observed among adults between 2007 and 2016 (Figure S1 and Table S2, Model 2 in the supporting information).

To test the inflection point in prevalence of tap water avoidance at 2013–2014, a piecewise log-binomial regression model confirmed slope changes between 2007–2014 and 2014–2016. For each subsequent survey cycle between 2007–2008 and 2013–2014, children reported 14% lower prevalence (adjusted prevalence ratio [aPR] 0.86, 95% confidence interval [CI] 0.80–0.93; $P < 0.001$) of avoiding tap water (Figure 2; Table S3, Model 1). A significant inflection point was found at 2013–2014, and 2014–2016 was associated with 1.53 (95% CI: 1.12–2.09; $P = 0.007$) times higher prevalence of avoiding tap water among all children.

While there were no significant time trends for adults, we tested an inflection point at 2013–2014 in avoiding tap water in a piecewise log-binomial regression model since visual inspection showed a slight change in

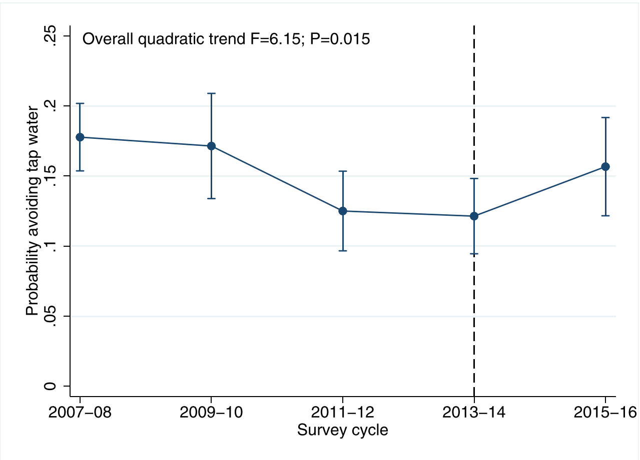

Figure 1. Covariate-adjusted trends in predicted probability and 95% confidence intervals of avoiding tap water for U.S. children aged 2–19 years, United States, 2007–2016. Note. Figure was generated using marginal standardization from covariate-adjusted log-binomial regression models adjusted for age group, race/Hispanic origin, sex, FIPR, reference person's education level, and survey cycle. Reference line indicates inflection point that was tested at 2013–2014 and beginning of Flint water crisis. Full model shown in Table S2, Model 1 in the supporting information.

trend (Figure S1a**)**. This additional analysis confirmed that there were no significant differences for adults (between 2007–2008 and 2013–2014 aPR **=** 0.97; 95% CI: 0.92–1.03; 2014–2016: aPR = 1.16, 95% CI: 0.93–1.45) **(**Table S3, Model 2).

3.2. Sensitivity Analysis of Objective 1: Primary Water Source Changes Over Time for Children

We tested whether trends in tap water avoidance were being driven by changes in municipal (i.e., community supply) or well/rainwater/spring water use (Figure 3). Piecewise multinomial regression yielded results consistent with the log-binomial estimates. Compared to the municipal supply, not drinking tap water decreased from 2007–2014 (incidence rate ratio [IRR]: 0.81, 95% CI: 0.73, 0.90; $P < 0.001$) and had a significant change in trends with a significantly elevated rate ratio in 2014–2016 (IRR: 1.80; 95% CI: 1.20, 2.71; $P = 0.005$) adjusted for the same covariates whereas well/spring/rain water use did not have a change in trends. The average marginal effects of the probability to report each primary water source of this multinomial regression model are shown in Figure 3 by the primary predictors. While the probability to avoid tap increased in 2014–2016 overall, there did not appear to be a significant decrease in municipal water use alone. Rather, it seems it was the combined reduction of both municipal and well/rain/spring water sources that may be driving these findings. In contrast, from 2007–2014, municipal water use was higher, while tap water avoidance was lower.

3.3. Objective 2: Tap Water Avoidance Predictors

To our second objective, we examined how tap water avoidance varied by each of the key sociodemographic covariates (Figure 2; Table S3). As hypothesized, we found that younger children were more likely to avoid

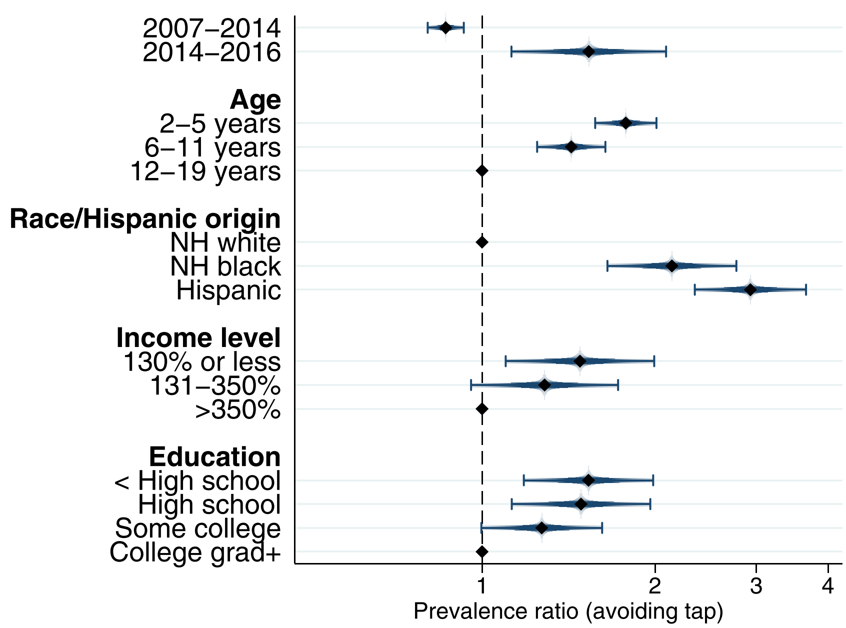

Figure 2. Forest plot of multiple piecewise log-binomial regression model assessing prevalence of avoiding tap water between 2007 and 2016 among U.S. children. Note. Model adjusts for all variables shown in addition to sex; full model shown in Table S3, Model 1.

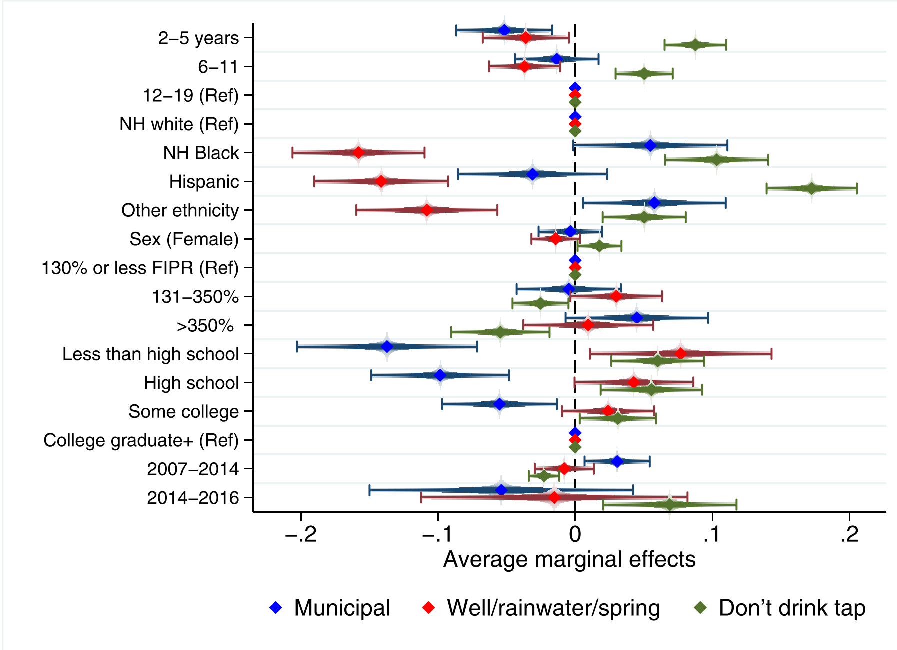

Figure 3. Forest plot of average marginal effects from piecewise multinomial logistic regression model assessing change in probability of primary water sources between 2007 and 2016 among U.S. children. Note. Model adjusts for all variables shown.

tap water. Children aged 2–5 and those aged 6–11 had 1.78 (95% CI: 1.57, 2.01) and 1.43 (95% CI: 1.25, 1.64) times higher prevalence of avoiding tap water than children aged 12–19, respectively (Table S3, Model 1). No age differences in tap water avoidance were found among adults (Table S3, Model 2).

Race/ethnicity was also strongly associated with tap water avoidance over time. NH white children were least likely to avoid tap water. Hispanic and NH black children had 2.93 (95% CI: 2.35, 3.66) and 2.14 (95% CI: 1.65, 2.77) times higher prevalence of not drinking tap water than NH white children (Table S3: Model 1). Similar results were found for adults; Hispanic and NH black adults had 2.60 (2.20, 3.06) and 2.33 (95% CI: 2.04, 2.65) times higher prevalence of not drinking tap water than NH white adults (Table S3: Model 2).

Lower family income level and education were also associated with tap water avoidance. Specifically, children from families that reported ≤130% FIPR had 48% higher prevalence (95% CI: 1.10, 1.99) than children from families who made >350% FIPR. Finally, children whose parents had less than a high school degree and only a high school degree had 1.53 (95% CI: 1.18, 1.98) and 1.49 (95% CI: 1.13, 1.96) times higher prevalence of avoiding tap water compared to children whose parents were college graduates, respectively, adjusted for covariates. Similarly, lower income and lower educational attainment were associated with higher prevalence of tap water avoidance among adults (Table S3; Model 2).

These differences in tap water avoidance held across time by age, race/ethnicity, household income, and education for children (Figures 4a–4d). Overall, the covariate-adjusted predicted probabilities of avoiding tap water for these subgroups followed the same time trends as the general population. Most notably, these aforementioned children all had consistently significantly higher prevalence of avoiding tap water than their older, NH white, high-income, and high education peers over time. In 2015–2016, the predicted probability of not drinking tap water was highest for children aged 2–5 at 21.6% (95% CI: 16.6, 26.6), 21.9% (95% CI: 17.0, 26.8) for NH black children, 31.5% (95% CI: 24.6, 38.4) for Hispanic children, 22.9% (95% CI: 18.1, 27.7) for low-income children, and 25.5% (95% CI: 19.6, 31.4) for children from households with less than a high school education (Figures 4a–4d).

Similarly, trends in tap water avoidance probabilities were consistently higher over time for NH black, Hispanic, low income, and low education adults, compared to NH white, higher income, and adults with higher educational attainment (Figures 1b–1d).

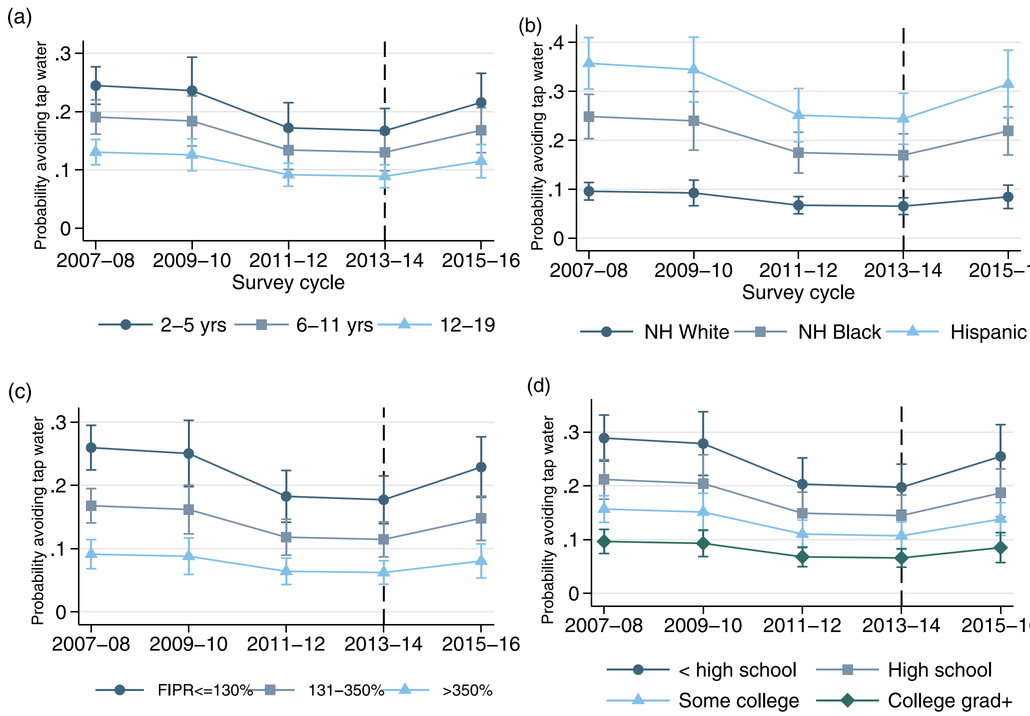

Figure 4. Covariate-adjusted trends in predicted probability and 95% confidence intervals of avoiding tap water for U.S. children aged 2–19 years, United States, 2007–2016, by (a) age group, (b) race/Hispanic origin, (c) income group, and (d) household education. Note. Figure was generated using marginal standardization from covariate-adjusted log-binomial regression models adjusted for age group, race/Hispanic origin, sex, FIPR, reference person's education level, and survey cycle. Dashed reference line indicates inflection point that was tested at 2013–2014 and beginning of Flint water crisis. NH: non-Hispanic. Other race/Hispanic origin included in analysis but not shown separately. FIPR: Federal income poverty ratio. yrs: age in years.

3.4. Objective 3: Bottled Water Intake as a Response to Tap Water Avoidance Among Children

Our third objective was to analyze the association of avoiding tap water on prevalence of bottled water consumption among children since they were the only group with a statistically significant trend change in tap water avoidance. As hypothesized, U.S. children who avoided tap water had 1.92 (95% CI: 1.77, 2.08) times higher prevalence of drinking bottled water on a given day (Table S4; Model 1). Both overall and among tap water drinkers, Hispanic and NH black children had a significantly greater prevalence of drinking bottled water (Table S4, Models 1 and 2).

Among those who avoided tap water, differences by race/ethnicity were not found in the main effects, but the time trend interaction with race/ethnicity indicated that NH black children in 2015–2016 had 51% (95% CI: 0.94–2.42) increase in prevalence of drinking bottled water relative to 2007–2008, the highest of any group (Table S4, Model 3). Using marginal standardization, we plotted these interaction models for tap water drinkers and those who avoided tap water by race/ethnicity (Figures 5a and 5b). Most importantly, NH black children who avoided tap water had a 77.9% probability (95% CI: 68.9%, 86.9%) of drinking bottled water on a given day in 2015–2016 up from 56–67% between 2007–2008 and 2013–2014 (Figure 5b). Non-Hispanic black children who avoided tap water were the only group showing such a dramatic increase in bottled water intake corresponding to the Flint water crisis.

4. Discussion

This study provides some of the first nationally representative descriptive trends of in-home tap water avoidance (i.e., not drinking tap water from one's main water source) among U.S. children and adults

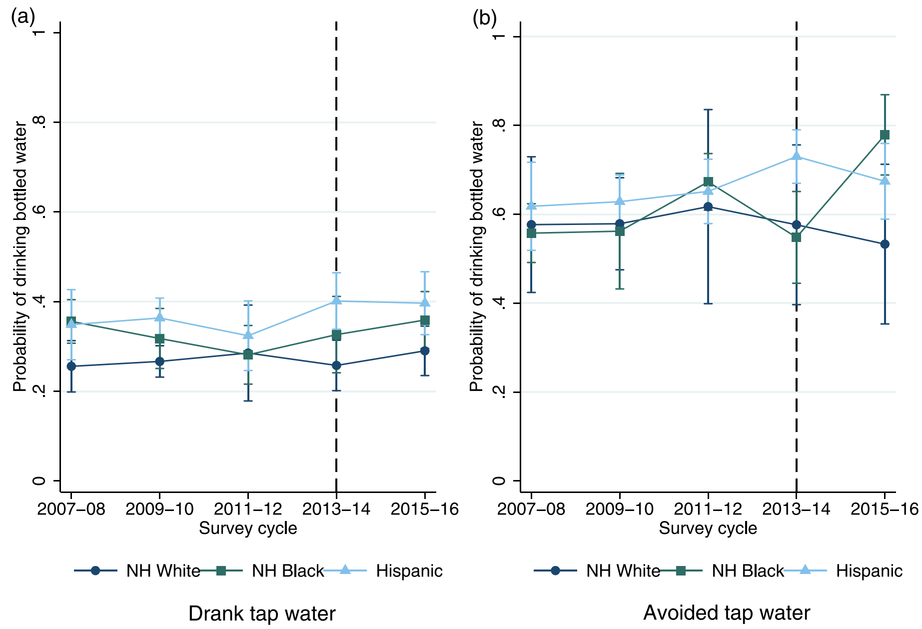

Figure 5. Covariate-adjusted predicted probability and 95% confidence intervals of drinking bottled water for U.S. children aged 2–19 years by tap avoidance and ethnicity, United States, 2007–2016. Note. Figure was generated using marginal standardization from covariate-adjusted log-binomial regression models stratified on tap drinking adjusted for age group, race/Hispanic origin, sex, FIPR, reference person's education level, and survey cycle, along with two-way interaction between ethnicity and survey cycle. Dashed reference line at 2013–2014 indicates the beginning of Flint water crisis. Full models shown in Table S4, Models 2 and 3.

between 2007 and 2016. To our first objective, we found that prevalence of tap water avoidance decreased from 2007–2014 and changed direction, increasing between 2013–2014 and 2015–2016 for children aged 2–19 years, but not among adults. The increase in tap water avoidance among children observed in 2015–2016 corresponded to the timing of the Flint water crisis but causality cannot be inferred because NHANES is cross-sectional. To our second objective, we found that children aged 2–5 years, Hispanic and NH black children, and those of low-income and low-education families, consistently had higher probabilities of avoiding tap water compared to older, NH white, and children from high-income and high-education families over time. Adults exhibited similar trends as children in tap water avoidance by self-reported race/ethnicity and socioeconomic status. These results were consistent when municipal/community water supply and well/rainwater/spring use were not aggregated. Finally, since children witnessed a change in trends of tap water avoidance over time, we tested how tap water avoidance was associated with their prevalence of bottled water consumption. We found that children who avoided tap water had nearly twice the prevalence of drinking bottled water on a given day; and that in 2015–2016, NH black children who avoided tap water had significantly elevated probability of drinking bottled water.

Perceived tap water safety is one hypothesized reason as to why children and parents avoid tap water (Pierce & Gonzalez, 2017). Reports or news of water quality violations likely change people's perceptions of tap water safety and, resultingly, their avoidance behaviors (Jackson, 2017). Previous research has demonstrated that in counties reporting water quality violations, bottled water sales (a proxy of tap water avoidance) increased by 2.3% after the first Tier 1 violation, but that in counties with repeat violations, these same effects were not present (Allaire et al., 2019). News coverage dedicated to the Flint water crisis may have affected the decisions of parents elsewhere about the safety of their own tap water through the "availability heuristic" (Tversky & Kahneman, 1974). If parents saw news about tap water being unsafe, it may have led to mental shortcuts judging the risk of their tap water and led them to avoid giving their children tap water. Since environmental exposures are particularly damaging to children's health who are still developing, it is less surprising that the change in trends corresponding to the Flint Water Crisis was witnessed among children but not adults (Bearer, 1995; Hanna-Attisha et al., 2015).

A second reason why participants might report that they do not drink tap water from their main water source is lack of access. If water is shut off by water utilities or it is intermittently unreliable due to housing problems, tap water is not available (Deitz & Meehan, 2019). Previous studies have pointed to this being a particular problem for those living in mobile home parks (Pierce & Jimenez, 2015), which disproportionately affect low-income and minority populations (Deitz & Meehan, 2019; Switzer & Teodoro, 2018). Moreover, undergoing a crisis related to tap water safety is associated with higher stress and posttraumatic stress, symptoms among those from Flint (Kruger et al., 2017). Groups who previously experienced water quality violations and historical traumas likely also avoid tap water as a result since they identify with those with whom they share characteristics (VanDerslice, 2011).

Whether not consumed because of lack of trust or access, data on in-home tap water avoidance may capture a critical component of water insecurity faced by U.S. households. Household water insecurity occurs when there are water-related issues surrounding access, affordability, adequacy, and safety (Jepson et al., 2017). Currently, there is a validated measure of household water insecurity for low- and middle-income countries (Young et al., 2019), but it has not yet been validated for high-income countries such as the United States. As such, the magnitude of household water insecurity in the United States is largely unquantified. Whether a person drinks their tap water or not may represent a simple way to capture multiple dimensions of water insecurity. In other words, avoidance of tap water indicates underlying problems related to access, affordability, adequacy, water quality and sensory issues, and/or perceived safety (Doria et al., 2009; Tosun et al., 2020), and may be a useful proxy for household water insecurity.

The present study adds to a growing literature documenting problems with tap water trust (Merkel et al., 2012; Pierce & Jimenez, 2015; Rosinger et al., 2018) and demonstrates that among U.S. children and adults tap water avoidance persistently occurs at higher levels among low-income and minority groups, and does so over time. This matters because previous research found that when adults perceive their water to be unsafe, they seek alternatives they believe to be safer but in fact may not be, such as bottled water or sugar-sweetened beverages, which may also increase economic burdens disproportionately (Javidi & Pierce, 2018). As observed in studies with adults (Javidi & Pierce, 2018; Rosinger et al., 2018), our study confirms this consequence of tap water avoidance among children over time. We found that U.S. children who do not drink their tap water have 92% higher prevalence of drinking bottled water on a given day. Critically, it is NH black children, who were most strongly affected by the Flint water crisis, that exhibited higher prevalence of bottled water consumption in 2015–2016.

These findings help unpack disparities of in-home tap water use, building upon analyses in which observations are aggregated across time or studies which used bottled water sales as a proxy of tap water avoidance (Allaire et al., 2019; Christensen et al., 2019; Patel et al., 2013; Rosinger et al., 2018; Zivin et al., 2011). Examining time trends allows for an evaluation of changes across critical demographic covariates in respect to large-scale events and magnitude of changes. Future data from NHANES and other sources will allow for evaluation in the preexamination-postexamination effects of the Flint water crisis on tap water avoidance at a national level and its implications for health and economic outcomes.

Further, knowledge of these trends in tap water avoidance is important for informing public health interventions designed to increase tap water consumption, for example, uptake of water stations and campaigns to increase tap water trust (Lawman et al., 2019; Patel & Schmidt, 2017; Schwartz et al., 2016). These data can also help make the case on why investment in water infrastructure in the United States is critical.

Given the importance of safe water for physical and mental health, government and public health officials should consider how to instill confidence in tap water and address seemingly growing public mistrust of tap water to correct health disparities and inequities in water access (Lawman et al., 2019). Increasing trust of water systems through systematic water quality testing, for example, at schools and in homes, could be one strategy for reducing stress and economic burdens on parents while decreasing risk of exposure to unsafe water for children (Cradock et al., 2019). Other strategies may be to provide water filters among groups with high levels of distrust to encourage water consumption.

Finally, it will be important for future research to consider how long it takes for public confidence in tap water to rebound and what steps institutions, like water utility companies, local, state, and federal governments, can take to restore public confidence in tap water. In some cities, like Flint, Michigan, distrust of water and of local government persists (Renwick, 2019). However, other cities, like Philadelphia, are prime examples of using grassroots campaigns and randomized interventions to attempt to increase confidence in the municipal water system and encourage tap water intake (Bate, 2019; Lawman et al., 2019; Lawman et al., 2020).

5. Limitations

This study is subject to limitations. First, we cannot link decisions to avoid tap water with tap water safety (or perceptions of safety) because reasons for not drinking their tap water were not collected. However, previous research supports that distrust of tap water is associated with reduction in tap water consumption (Onufrak et al., 2014; Pierce & Gonzalez, 2017).

A second limitation is that NHANES data may not fully capture, and potentially underestimate, the effects of the water crisis due to its sampling strategy, the timing of the Flint water crisis, and differences in potential awareness of the Flint water crisis among children and adults. While the Flint water crisis began in April 2014 when the city of Flint changed its water source to the Flint River, national media attention did not begin until March 2015 and was stronger after the second half of 2015 (Jackson, 2017). NHANES is conducted continuously throughout each 2-year cycle and data are released in an aggregated batch for each survey cycle. Therefore, some participants may have been unaware of the water crisis or had different levels of exposure to that information if they were surveyed before major media coverage began in the 2015–2016 survey cycle. Relatedly, NHANES is cross-sectional and selects 30 rotating locations per cycle, which are not publicly released to preserve confidentiality. Therefore, differences in site selection across survey cycles preclude a high-resolution geographic examination of tap water avoidance over time. For example, it is not possible to test how those living closer to Flint, Michigan, responded over time compared to those living farther away, as those living closer may have stronger responses than those living in other cities (Christensen et al., 2019). However, sampling weights adjust for nonresponse, loss between screener to interview and examination, and changes across cycles to provide stable nationally representative, rather than geographic, estimates (National Center for Health Statistics, 2018).

Changes in tap water avoidance may relate to water filter use. NHANES stopped asking about whether a water filter is used in the household in 2010; therefore, this variable was not included in the analysis. However, previous analyses have shown that even when controlling for water filter use, NH black, Hispanic, and lower socioeconomic status adults were more likely to avoid tap water and were less likely to use water filters than NH white and higher socioeconomic status adults (Rosinger et al., 2018). Water filter use is not taken into account when participants are asked about the source of their home tap water. When examining characteristics of those who reported using a water filter in 2007–2010, 57.4% of those who selected well/rain/spring used water treatment; only 25.6% of people who selected municipal reported water treatment; and 13.6% of people who reported they do not drink tap water reported using water treatment. Therefore, of those who avoided tap water, only a small percentage used a water filter and so it is unlikely that the increase in 2015–2016 of tap water avoidance among children is due to an increase in water filter use.

Finally, differences in reporting across children's age groups may affect direct comparability of tap water avoidance prevalence between children of different ages. Data examining the concordance of self-report versus proxy reporting in health surveys concludes that there is generally good agreement (Sakshaug, 2014), and previous analyses of NHANES have compared estimates across age groups for children (Patel et al., 2013; Sanders & Slade, 2018). We found that younger children (proxy-reported) aged 2–5 years have the highest levels of tap water avoidance, which we hypothesized since they are the age most susceptible to potential negative health effects of water contamination and parents are most in control of their fluid intake. However, whether this finding is due to differences in tap water distrust from parents compared to older children's autonomy is not possible to untangle with these data. Nevertheless, we constructed the age bins of children in the analysis to match the reporting strategy (proxy vs. proxy-assisted vs. direct) and this did not change over time.

6. Conclusions

This study presents the first nationally representative trend analyses of in-home tap water avoidance among children and adults in the United States since the Flint water crisis. These data suggest that the trend of decreasing tap water avoidance among children reversed in 2015–2016, and began to increase, whereas this similar change did not occur among U.S. adults. Differences in not drinking one's main tap water persisted over time among those populations with historically higher levels of distrust of tap water (Pierce & Gonzalez, 2017). Finally, U.S. children who avoided tap water were significantly more likely to consume bottled water on a given day than children who drank tap water. Moreover, nearly 80% of NH black children who avoided tap water in 2015–2016 drank bottled water. While issues related to water are often overlooked in high-income countries, the prevalence of tap water avoidance, particularly among low-income and minority groups, suggests that household water insecurity is not only an issue in the United States but one with important health and economic implications.

Data Availability Statement

All data are publicly available from the CDC NHANES website under the dietary total intake Day 1 files and demographics files (https://wwwn.cdc.gov/nchs/nhanes/Default.aspx). The constructed data set and code for replication are available at openicpsr-115228 (https://doi.org/10.3886/E115228V2).

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