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A Population-Based Assessment of Physical Symptoms and Mental Health Outcomes Among Adults Following the Flint Water Crisis

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Abstract Little is known about the physical and mental health outcomes of adults in the low-income, predominantly Black city of Flint, Michigan, following the city's water crisis which began in April 2014 after austerity policies led to the city switching its water source. We investigate these dynamics using data from a longitudinal community-based cohort in Flint. Between June and November 2019, surveys were administered at nine public sites across Flint. Nested models were employed to assess relationships between respondent demographics, including race/ethnicity, and self-report of clinician-diagnosed blood lead levels (BLLs) and various physical symptoms and mental health outcomes, including depression/anxiety (PHQ-4) and psychological trauma (PC-PTSD-5). Of the 331 respondents (mean age: 47.9 ± 16.5), most were women (58.6%) and Black (57.7%). In total, 10.0% self-reported elevated BLLs, with borderline significantly higher reports among Blacks ($p = 0.07$). Skin rashes (58.1% vs. 33.9%, $p < 0.01$), hair loss (45.5% vs. 30.3%, $p = 0.01$), and nausea (35.6% vs. 20.2%, $p = 0.1$) were significantly higher among Blacks versus Whites. Additionally, 29.0% and 26.3% of respondents met trauma and depression/anxiety criteria, respectively. Increasing physical symptoms was associated with psychological trauma (OR 2.1, $p < 0.01$) and depression/anxiety (OR 1.9, $p < 0.01$). In closing, Flint adults, particularly Blacks, experienced deleterious physical and mental health outcomes following the city's water crisis that appear to represent a substantial burden of excess cases. Further research is needed on how austerity impacts community health in economically distressed urban cities and ways to generate capacity to identify and curb adverse consequences.

Abbreviation
BLL   Blood lead level

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Introduction

The role of historic socioeconomic and political marginalization in the genesis of public health issues in urban communities reflects a key tenet in the fundamental causes theory (Link & Phelan, 1995). The 2014 water crisis in the low-income, predominantly Black city of Flint, Michigan, was triggered by an austerity-focused decision from an unelected, state-appointed "emergency manager" to switch the city's water source from Lake

Huron to the Flint River to lower municipal water costs [28]. The crisis was marked by widespread contamination of Flint's water supply with lead (Pb), an invisible, odorless neurotoxin, and other harmful bacteria and contaminants, including carcinogenic trihalomethanes and *Legionella*, which has since been linked to over 100 deaths in Flint [4, 39]. Mere days after the water source switch, Flint's residents began raising concerns to city officials that their tap water was discolored, odorous, and poor-tasting but were largely ignored [4, 7].

Some 5 years after the crisis' initiation and Flint's switch back to its original water source, guidance around the consumption of tap water in the city has remained ambiguous, with direction from the Environmental Protection Agency and local government and healthcare officials often at odds and contradictory [37]. Indeed, official recommendations for Flint residents have ranged from guidance to completely avoid water consumption, to use water filters, and to only use water for certain purposes, such as washing hands and brushing teeth, but not other purposes, such as drinking or bathing children [12].

The preventive public health focus in Flint has largely keyed-in on the known socio-cognitive and developmental deficits associated with lead exposure in adolescents and fetuses exposed in utero [33, 34]. This focus has derived from observed increases in blood lead levels (BLLs) among Flint children in the crisis' aftermath [14]. Far less attention has been placed on the water crisis-related impacts on Flint adults. Elevated BLLs, linked to liver, kidney, and central nervous system damage in adults [52], constitute a similarly concerning public health issue. We address this gap here, using data from an observational community-based study conducted with Flint adults. A better understanding of potential water contamination-related impacts on Flint adults could illuminate acute and chronic health consequences, and disparities therein, while also furnishing context for potential health patterns among Flint children as they age.

We further identify broader symptomatology associated with elevated bacteria and heavy metals in water, including skin rashes and hair loss, both of which have been reported in Flint post-water source switch [37] and can be physically painful, contribute to stigmatization, signal harmful underlying health conditions, and become chronic [17, 42]. We also assess patterns of emotional agitation/irritation and nausea, which have been linked to acute contamination with metals [20, 54].

Additionally, we examine mental health outcomes in the population. Excess mental health morbidity in the first year following an environmental and public health disaster is approximately 20% [5]. Further, the scope of psychological comorbidities may be amplified in racial/ethnic minority communities that already face disproportionately high levels of mental illness and trauma [16, 18], as observed in post-Hurricane Katrina in New Orleans [21].

Prior work on the Flint water crisis has focused primarily on outcomes recorded in the early years of the crisis [1, 13, 14, 48]. This narrow focus has precluded a richer understanding of physical and mental health symptoms manifesting over both acute and long-term exposure windows, specifically among adults in Flint, our focus here.

Methods

Study Overview and Design

The Flint Community Engagement Project is a longitudinal, observational community-based research project, currently in its first wave, focused on the structural antecedents and health consequences of the Flint water crisis. Surveys for this observational study were conducted in-person between June 2019 and November 2019 by two trained Flint residents. To increase the likelihood of recruiting a sample reflecting the racial/ethnic and socioeconomic diversity of Flint neighborhoods and potential spatial variation in patterns of water contamination [14, 44], surveys were administered at nine sites across the City of Flint, roughly covering each primary intercardinal direction and four of the city's seven primary zip codes (Fig. 1). The nine sites included venues such as libraries, a laundromat, a cafe, and a bus station in the City of Flint.

To be eligible to participate in the survey, individuals had to (1) be at least 18 years of age; (2) have lived in Flint for at least one full calendar year between April 25, 2014 (the date of the water source switch) and the date of the survey; (3) speak English; and (4) be able to provide written informed consent.

Predictors and Outcome Construction

The primary focus of the analysis was investigating self-report of and results of being screened for BLLs and
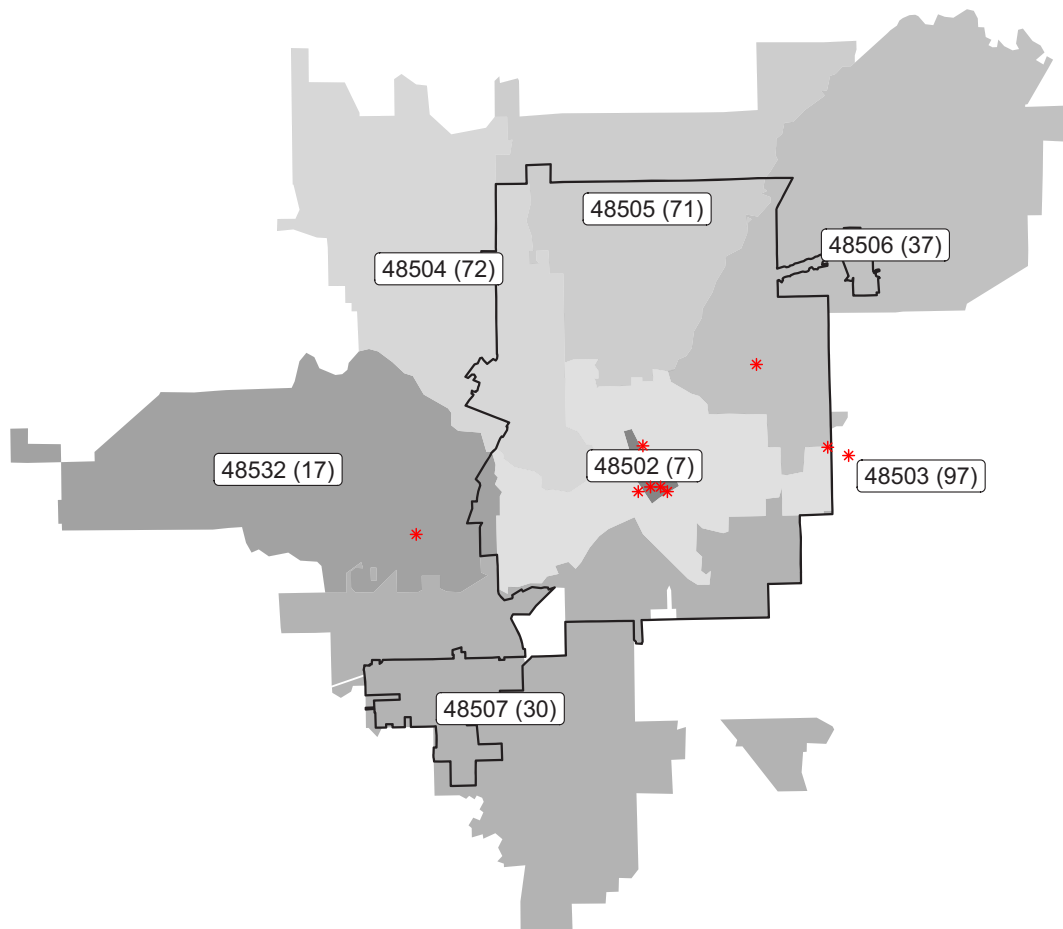
Fig. 1 Map of the seven zip codes that comprise the City of Flint, with the city boundaries outlined in Black. Zip code numbers are labeled; the number of respondents residing in that zip code is given in parentheses. Survey site locations are indicated by red stars. In total, our sample consisted of 331 residents of Flint, Michigan, who were surveyed in June–November 2019

having particular health and mental symptoms at some point before *or* after the date of the water source switch (i.e., April 25, 2014). We assessed several primary health outcomes shown to be associated with elevated lead exposure in adults, including increased emotional agitation and nausea (intestinal issues) [20, 52]. To address potential issues with recall bias [6, 9, 45], respondents were asked if they had regularly experienced, *before* and *after* the date of the city's water source switch, more emotional agitation and nausea than would be "normal" for them (i.e., prior to the water source switch), with a specific contextual emphasis on frequency and intensity of the symptom. Respondents were asked these questions, using, where appropriate, references to media attention, government hearings, etc., as memory flashpoints [9, 46]. Patterns of skin rashes and hair loss were similarly queried.

We also measured feelings of depression and anxiety, via the brief validated PHQ-4 scale [27], in view of how frequently these feelings were experienced. Responses to PHQ-4 questions ranged from "Not at all" to "Nearly every day" over the past 2 weeks. Respondents were classified as having depression or anxiety if they scored 6 or higher on the PHQ-4 [22]. Further, trauma symptomatology, in association with potential distress arising from presumed impacts, the specter of the crisis and feelings of betrayal and devaluation, was assessed using a modified version of the brief validated PC-PTSD-5 scale, with respondents classified as exhibiting "probable" trauma if they scored 3 or higher [40]. Here, respondents were asked to respond affirmatively (either "Yes" or "No") to having experienced a particular trauma-associated behavior (e.g., rumination about the water crisis) or feeling related to the water crisis.

Additionally, social network size was assessed as a potential protective factor. Social networks were measured as the individuals whom the respondent indicated they went to discuss or "vent to" [47] about the water crisis. We also assessed how much time had elapsed between the date of the water source switch (April 25, 2014) and when the respondent first became aware of or heard there were "problems" with the city's water (e.g., by noticing discolored water coming from their faucets, hearing about water issues via local news, etc.).

Statistical Analysis and Methods

We performed descriptive analyses for all pertinent outcomes and predictors, both overall and stratified by race, and studied unadjusted differences by race using Kruskal-Wallis tests [24]. Our analysis focused on nine key health-related outcomes: (1) amount of time (in months) it took to become aware of potential water quality issues following the water source switch; (2) whether or not the respondent took a blood lead test; (3) whether or not the respondent reported a clinician diagnosing them with an elevated BLL (using any threshold suggested by their clinician); (4) if they experienced skin rashes; (5) hair loss; (6) nausea; or (7) emotional agitation; (8) and what they exhibited in depression/anxiety symptomatology (PHQ-4); or (9) trauma (PC-PTSD-5). In addition, we counted respondents' overall number of potential lead and water contaminant exposure symptoms (including skin rashes, hair loss, nausea, and emotional agitation) as the 10th outcome.

For multivariable modeling, we considered the predictors age, gender, race, eligibility for public benefits, educational attainment, employment status, number of children in respondent's care, years lived in the City of Flint, size of the respondent's social network, and zip code. We did not include health insurance as a predictor because the overwhelming majority of participants (92.9%) had health insurance.

To address potential issues in causal structure [15], we fit a series of nested generalized linear models for each of our 10 outcomes, consisting of predictors of interest and necessary adjuster variables. We considered relevant pairwise interactions when the main effects were statistically significant. A complete list of the models we fit is provided in Supplementary Table 1; model choices were entirely guided by the causal diagram provided in Supplementary Figure 1. Because

effect estimation was the primary interest, no variable selection was performed. There was minor missingness in our data. To address the missing data, we used multiple imputation by chained equations. Twenty-five imputed datasets were generated using chained equations on all predictors and outcomes, then the models were fit on each imputed dataset, and then the results for each model were combined across the 25 imputed datasets using Rubin's rules [43].

To assess the potential for spatial correlation, we conducted Moran's I tests for spatial correlation on the zip code level for all outcomes, both unadjusted and adjusted for race, sex, and age [31]. Results are given in Supplementary Table 2. These tests showed little evidence of residual spatial correlation beyond what was accounted for by race, sex, and age, so we did not pursue a spatial random effects analysis. Instead, we used a spatial fixed effects analysis, using zip code as a predictor in all models. For all modeling, we collapsed the geographically contiguous zip codes of 48502 and 48503 and the geographically contiguous zip codes of 48507 and 48532 due to small sample sizes in these zip codes.

Because of the large number of models fit, we used the false discovery rate (FDR) threshold to assess the significance of our model results and thus correct for multiple testing [3]. All analyses were conducted in R version 3.6.2 (R Core Team, 2019). The code used to conduct this analysis can be found at https://github.com/elizabethchase/Flint_Community_Engagement. Study procedures were approved by the Institutional Review Board at the University of Chicago. Respondents provided written consent and were given a $15 gift card for completing the survey.

Results

In total, 331 individuals participated in the survey. Respondent demographics are presented in Table 1, both overall and stratified by race. Briefly, the mean age ($\pm$ SD) of respondents was 47.9 ($\pm$ 16.5) years and majority of the sample were women ($N = 194$, 58.6%). The traits of the recruited sample were comparable to U.S. Census estimates in terms of race/ethnicity and general socioeconomic status [53]. The sample was predominantly Black ($N = 191$, 57.7%) and a plurality ($N = 125$, 37.8%) had a high school degree or less. Most (62.2%) respondents indicated that they currently were eligible

for public benefits, and 60.1% (N = 199) were single. Overall, 45.6% of the sample participants (N = 151) were employed. Black and other race individuals were significantly less likely to have completed a college degree than Whites ($p < 0.01$) and were more likely to be eligible for public benefits ($p = 0.06$). Most respondents lived in zip code 48503 followed by zip code 48504 (Fig. 1). On average, respondents had lived in Flint for an average of 34.3 ($\pm$ 19.1) years and had lived in the city in the immediate periods after the switch. The average amount of time that respondents indicated had passed since they first became aware of a potential problem with their tap water was 4.9 ($\pm$ 6.1) months.

Lead Screening, BLLs, and Physical Health Symptoms and Outcomes

Descriptive statistics on lead, physical health symptoms, and other outcomes, both overall and stratified by race, are presented in Table 2. A total of 119 (39.7%) respondents indicated that they had a BLL screening at some point *after* the water source was switched (i.e., at some point between April 25, 2014 and the survey date). Of these respondents, 31 (10.3%) indicated that a clinician had diagnosed them with elevated BLLs *after* April 25, 2014 (the date of the water source switch). In univariable analysis, Whites were significantly less likely to have been screened for BLLs than Blacks (25.7% vs. 47.6%, $p = 0.01$), and White respondents were less likely to report elevated BLLs than Black respondents (4.6% vs. 13.6%, $p = 0.07$).

In model results (Table 3), once we adjusted for other demographic characteristics; however, there were few significant predictors of the length of time to noticing/hearing about there being a problem with their tap water, whether or not the respondent received BLL screening, or had elevated BLLs. Whites were less likely to be screened for elevated BLLs (OR 0.4, $p = 0.06$) and to report elevated BLLs (OR 0.4, $p = 0.47$) than Blacks. Furthermore, men were less likely than women to be screened for blood lead (OR 0.5, $p = 0.11$).

Respondents had an average of 1.7 ($\pm$ 1.4) self-reported symptoms out of the four assessed symptoms (skin rashes, hair loss, nausea, and emotional agitation). Skin rashes were the most commonly reported symptom, with almost half the sample reporting skin rashes—more than would be considered normal for them—after the water source switch. Blacks were significantly more likely to report skin rashes (58.1% vs. 33.9%, $p < 0.01$),

hair loss (45.5% vs. 30.3%, $p = 0.01$), nausea (35.6% vs. 20.2 %, $p = 0.1$), and emotional agitation (44.0% vs. 30.3%, $p = 0.04$) than Whites, and Blacks had a significantly higher total number of symptoms than Whites (1.9 vs. 1.2, $p < 0.01$).

After fitting multivariable models to adjust for confounders (Table 3), there were several significant predictors of symptoms. Whites were significantly less likely to report skin rashes than Blacks (OR 0.4, $p = 0.03$), even when adjusting for other predictors. Men were significantly less likely than women to report hair loss (OR 0.3, $p < 0.01$), and for each additional month before noticing there was a problem with the water, the odds of subsequently reporting hair loss increased by 10% ($p = 0.01$). Respondents who were eligible for public benefits were 2.6 times as likely to report agitation ($p = 0.03$) as respondents who were not eligible for public benefits. In addition, there was evidence of an association between all the symptoms; reporting nausea increased the odds of reporting rashes 3.5 times ($p = 0.01$), the odds of reporting hair loss 2.6 times ($p = 0.06$), and the odds of reporting agitation 4.0 times ($p = 0.01$), while reporting rashes, hair loss, or agitation all significantly increased the odds of reporting nausea.

Viewing the symptoms in total, and adjusting for confounders, being a man reduced the reported number of symptoms by 30% ($p = 0.01$). White respondents reported 30% fewer symptoms than Black respondents ($p = 0.02$), while respondents who were eligible for public benefits reported 40% more symptoms than respondents who were not eligible for benefits ($p = 0.02$). In addition, individuals who reported elevated BLLs had 1.5 times as many symptoms on average as respondents who did not report elevated BLLs ($p = 0.03$).

Mental Health, Anxiety, and Trauma

Descriptive statistics on mental health/anxiety outcomes, as measured by the PHQ-4 [27], can be found in Table 2. Eighty-seven (26.3%) individuals were classified as exhibiting depressive or anxious symptoms. In modeling results in which we adjusted for confounders (Table 3), individuals who reported "Other" employment (neither employed, unemployed, or retired) had 5.4 times the odds of experiencing depression/anxiety as employed individuals ($p = 0.02$). Increasing symptoms was a significant predictor of experiencing depression/anxiety. For each additional symptom, the odds of depression/anxiety increased 1.9 times ($p < 0.01$).

Table 1 Baseline characteristics of 331 residents from Flint, MI, gathered in June–November 2019

Characteristic N	Overall 331	Black race 191	Other race 31	White race 109	P value
Age (mean (SD))	47.9 (16.5)	47.6 (16.2)	46.0 (16.4)	48.8 (17.1)	0.68
Gender (N (%))					0.7
Woman	194 (58.6)	114 (59.7)	18 (58.1)	62 (56.9)	
Man	136 (41.1)	77 (40.3)	13 (41.9)	46 (42.2)	
Transgender woman	1 (0.3)	0 (0.0)	0 (0.0)	1 (0.9)	
Education (N (%))					< 0.01
Less than high school	24 (7.3)	10 (5.2)	4 (12.9)	10 (9.2)	
High school	101 (30.5)	66 (34.6)	12 (38.7)	23 (21.1)	
Some college	100 (30.2)	60 (31.4)	10 (32.3)	30 (27.5)	
Associates	47 (14.2)	30 (15.7)	2 (6.5)	15 (13.8)	
College degree or more	59 (17.8)	25 (13.1)	3 (9.7)	31 (28.4)	
Employment status (N (%))					0.18
Employed	151 (45.6)	98 (51.3)	15 (48.4)	38 (34.9)	
Unemployed	78 (23.6)	45 (23.6)	7 (22.6)	26 (23.9)	
Retired	71 (21.5)	35 (18.3)	6 (19.4)	30 (27.5)	
Other	28 (8.5)	11 (5.8)	3 (9.7)	14 (12.8)	
Missing	3 (0.9)	2 (1.0)	0 (0.0)	1 (0.9)	
Eligible for/receives public benefits (N (%))					0.06
Yes	206 (62.2)	125 (65.4)	20 (64.5)	61 (56.0)	
No	109 (32.9)	58 (30.4)	7 (22.6)	44 (40.4)	
Don't know/unsure	16 (4.8)	8 (4.2)	4 (12.9)	4 (3.7)	
Marital status (N (%))					0.19
Married	66 (19.9)	34 (17.8)	6 (19.4)	26 (23.9)	
Separated	66 (19.9)	32 (16.8)	9 (29.0)	25 (22.9)	
Single (never married)	199 (60.1)	125 (65.4)	16 (51.6)	58 (53.2)	
Number of children in care (mean (SD))	0.9 (1.3)	0.9 (1.5)	1.2 (1.3)	0.6 (1.0)	0.03
Years lived in Flint (mean (SD))	34.3 (19.1)	38.5 (16.8)	27.2 (19.5)	29.0 (21.0)	< 0.01
Network size (mean (SD))	3.0 (2.2)	3.1 (2.0)	2.9 (2.3)	3.0 (2.6)	0.89

Results are presented overall and stratified by race; p values come from unadjusted Kruskal-Wallis tests to compare differences by race

Ninety-six (29.0%) individuals exhibited symptoms of trauma. Once again, individuals who reported "Other" employment were substantially more likely to report trauma (OR = 6.6, $p = 0.01$), and the number of symptoms was a significant predictor of trauma symptomatology (OR 2.1, $p < 0.01$).

Discussion

To our knowledge, this is the first study using a cross-sectional, community-based sample to assess self-reported BLLs and water contamination-related symptoms and mental health outcomes among adults in Flint following the water crisis. Overall, our study highlights a substantial burden of elevated BLLs in the aftermath of the crisis and a multitude of health impacts among Flint adults that could be associated with the city's water contamination, and some notable differences according to race and socioeconomic status. Roughly 10% of our sample self-reported being diagnosed by a clinician with elevated BLLs in the years following the crisis, a rate substantially higher than national estimates among adults which range from 1% to 5%, depending on the BLL threshold used [50, 52]. We have a reason to suspect that our estimate may be an

Table 2 Prevalence of health and psychosocial outcomes among 331 residents from Flint, MI, gathered in June–November 2019

Outcome N	Overall 331	Black race 191	Other race 31	White race 109	P value
Screened for blood lead levels after April 25, 2014 (N (%))					0.01
Yes	131 (39.6)	91 (47.6)	12 (38.7)	28 (25.7)	
No	179 (54.1)	90 (47.1)	18 (58.1)	71 (65.1)	
Unsure	13 (3.9)	7 (3.7)	0 (0.0)	6 (5.5)	
Missing	8 (2.4)	3 (1.6)	1 (3.2)	4 (3.7)	
Elevated BLLs after April 25, 2014 (N (%))					0.07
Yes	33 (10.0)	26 (13.6)	2 (6.5)	5 (4.6)	
No	280 (84.6)	156 (81.7)	27 (87.1)	97 (89.0)	
Unsure	5 (1.5)	4 (2.1)	1 (3.2)	0 (0.0)	
Missing	13 (3.9)	5 (2.6)	1 (3.2)	7 (6.4)	
Skin rashes after April 25, 2014 (N (%))					< 0.01
Yes	159(48.0)	111 (58.1)	11 (35.5)	37 (33.9)	
No	160 (48.3)	76 (39.8)	18 (58.1)	66 (60.6)	
Unsure	5 (1.5)	2 (1.0)	1 (3.2)	2 (1.8)	
Missing	7 (2.1)	2 (1.0)	1 (3.2)	4 (3.7)	
Hair loss after April 25, 2014 (N (%))					0.01
Yes	134 (40.5)	87 (45.5)	14 (45.2)	33 (30.3)	
No	180 (54.4)	99 (51.8)	17 (54.8)	64 (58.7)	
Unsure	9 (2.7)	3 (1.6)	0 (0.0)	6 (5.5)	
Missing	8 (2.4)	2 (1.0)	0 (0.0)	6 (5.5)	
Nausea after April 25, 2014 (N (%))					0.1
Yes	102 (30.8)	68 (35.6)	12 (38.7)	22 (20.2)	
No	193 (58.3)	101 (52.9)	18 (58.1)	74 (67.9)	
Unsure	8 (2.4)	5 (2.6)	0 (0.0)	3 (2.8)	
Missing	28 (8.5)	17 (8.9)	1 (3.2)	10 (9.2)	
Emotional agitation after April 25, 2014 (N (%))					0.04
Yes	127 (38.4)	84 (44.0)	10 (32.3)	33 (30.3)	
No	163 (49.2)	84 (44.0)	20 (64.5)	59 (54.1)	
Unsure	11 (3.3)	4 (2.1)	0 (0.0)	7 (6.4)	
Total symptoms (mean (SD))	1.7 (1.4)	1.9 (1.4)	1.5 (1.7)	1.2 (1.3)	< 0.01
PTSD = Yes (%)	96 (29.0)	60 (31.4)	11 (35.5)	25 (22.9)	0.21
Depression/anxiety (%)					0.15
Yes	87 (26.3)	53 (27.7)	7 (22.6)	27 (24.8)	
No	223 (67.4)	121 (63.4)	24 (77.4)	78 (71.6)	
Missing	21 (6.3)	17 (8.9)	0 (0.0)	4 (3.7)	

Results are presented overall and stratified by race; p values come from unadjusted Kruskal-Wallis tests to compare differences by race. Total symptoms are how many skin rashes, hair loss, nausea, and emotional agitation the respondent reported. Note that PTSD is assessed by the PC-PTSD-5 and depression/anxiety is assessed by the PHQ-4

underestimate, especially among men, as more than half (54.1%) of our sample did not get screened for BLLs and thus may have unknowingly had elevated BLLs. Further, of note, significantly fewer White respondents reported getting screened for elevated BLLs. Given that this finding was not impacted by the inclusion of other factors in the model, such as eligibility for public benefits, this suggests that other factors, likely social or cultural, were at play. Specifically, White respondents may have had lower threat perception [2, 25, 51],

Table 3 Adjusted odds ratios and 95% confidence intervals from multivariable models fit in a sample of 331 residents of Flint, MI, surveyed in June–November 2019

Predictor	Outcome: Time to notice/hear about water issues	Outcome: Get screened for BLLs	Outcome: Elevated BLLs	Outcome: Skin rashes	Outcome: Hair loss	Outcome: Nausea	Outcome: Emotional agitation	Outcome: Total Symptoms	Outcome: PTSD	Outcome: Depression/Anxiety
Age	1 (1, 1) p = 0.29	1 (1, 1) p = 0.65	1 (1, 1) p = 0.93	1 (1, 1) p = 0.8	1 (1, 1) p = 0.94	1 (1, 1) p = 0.71	1 (1, 1) p = 0.71	1 (1, 1) p = 0.63	1 (1, 1) p = 0.83	1 (1, 1) p = 0.8
Men	0.7 (0.5, 1) p = 0.19	0.5 (0.3, 0.9) p = 0.11	0.5 (0.2, 1.1) p = 0.33	0.6 (0.4, 1) p = 0.21	**0.3 (0.2, 0.5) p < 0.01**	0.8 (0.4, 1.3) p = 0.67	0.6 (0.4, 1.1) p = 0.33	**0.7 (0.6, 0.9) p = 0.01**	0.7 (0.4, 1.2) p = 0.54	0.9 (0.5, 1.7) p = 0.94
Other race (ref: Black race)	1 (0.6, 1.7) p = 0.98	0.8 (0.3, 1.8) p = 0.84	0.5 (0.1, 2.4) p = 0.76	0.4 (0.2, 1) p = 0.27	0.9 (0.4, 2.2) p = 0.97	1 (0.4, 2.4) p = 0.98	0.5 (0.2, 1.4) p = 0.53	0.8 (0.6, 1.1) p = 0.63	1.2 (0.5, 3) p = 0.89	0.6 (0.2, 1.5) p = 0.62
White race (ref: Black race)	1.1 (0.8, 1.6) p = 0.87	0.4 (0.2, 0.8) p = 0.06	0.4 (0.1, 1.4) p = 0.47	**0.4 (0.2, 0.7) p = 0.03**	0.4 (0.2, 0.8) p = 0.07	0.5 (0.2, 0.9) p = 0.16	0.7 (0.4, 1.4) p = 0.67	**0.7 (0.5, 0.9) p = 0.02**	0.6 (0.3, 1.2) p = 0.49	0.7 (0.3, 1.4) p = 0.66
Eligible for/receives public benefits (ref: No public benefits)	1 (0.7, 1.4) p = 0.98	1.8 (1, 3.2) p = 0.2	1 (0.4, 2.6) p = 0.98	1.5 (0.8, 2.6) p = 0.51	1.5 (0.8, 2.7) p = 0.53	2.3 (1.3, 4.3) p = 0.06	**2.6 (1.4, 4.8) p = 0.03**	**1.4 (1.1, 1.7) p = 0.02**	1.6 (0.9, 3) p = 0.41	1.6 (0.8, 3.2) p = 0.47
High school or less (ref: Associate's degree or more)	1 (0.7, 1.5) p = 0.98	1.1 (0.6, 2.1) p = 0.92	1.7 (0.6, 4.9) p = 0.71	1.1 (0.6, 2.1) p = 0.91	0.8 (0.4, 1.5) p = 0.76	0.6 (0.3, 1.2) p = 0.41	1 (0.5, 2.1) p = 0.97	0.9 (0.7, 1.2) p = 0.88	1.1 (0.6, 2.3) p = 0.91	1.4 (0.7, 2.9) p = 0.76
Some college (ref: Associate's degree or more)	1 (0.7, 1.5) p = 0.97	1.2 (0.6, 2.2) p = 0.88	1.3 (0.5, 3.8) p = 0.87	1.3 (0.7, 2.5) p = 0.76	0.9 (0.4, 1.7) p = 0.89	0.8 (0.4, 1.5) p = 0.76	1.2 (0.6, 2.4) p = 0.87	1 (0.8, 1.3) p = 0.96	1.1 (0.5, 2.1) p = 0.97	1.2 (0.6, 2.6) p = 0.87
Other employment (ref: Employed)	1.3 (0.7, 2.3) p = 0.78	1.1 (0.4, 2.8) p = 0.94	0.8 (0.1, 4.1) p = 0.92	1.2 (0.5, 3.1) p = 0.89	2.6 (1, 7) p = 0.25	1 (0.4, 2.7) p = 0.98	1.8 (0.7, 4.6) p = 0.61	1.2 (0.9, 1.7) p = 0.59	**6.6 (2.5, 17.4) p = 0.01**	**5.4 (2, 14.7) p = 0.02**
Retired (ref: Employed)	1.5 (0.9, 2.6) p = 0.41	1.6 (0.7, 3.7) p = 0.61	1.1 (0.3, 4) p = 0.98	1.1 (0.5, 2.5) p = 0.94	2 (0.8, 4.7) p = 0.41	1.5 (0.6, 3.6) p = 0.73	0.9 (0.4, 2.3) p = 0.97	1.2 (0.9, 1.6) p = 0.71	1.7 (0.7, 4.2) p = 0.61	2.2 (0.8, 5.8) p = 0.41
Unemployed (ref: Employed)	1.1 (0.7, 1.7) p = 0.88	0.7 (0.4, 1.4) p = 0.67	1.1 (0.4, 3.3) p = 0.94	1.1 (0.6, 2.1) p = 0.92	2.2 (1.1, 4.5) p = 0.16	1.1 (0.5, 2.2) p = 0.95	1.2 (0.6, 2.5) p = 0.86	1.2 (0.9, 1.5) p = 0.61	1.6 (0.8, 3.2) p = 0.53	1.9 (0.9, 3.9) p = 0.36
Number of children in care under 18	0.9 (0.8, 1.1) p = 0.67	1.1 (0.9, 1.3) p = 0.76	1.2 (1, 1.6) p = 0.39	1 (0.8, 1.2) p = 0.98	1.1 (0.9, 1.3) p = 0.88	1 (0.9, 1.3) p = 0.91	1.1 (0.9, 1.3) p = 0.74	1 (1, 1.1) p = 0.81	1.1 (0.9, 1.3) p = 0.79	1 (0.8, 1.2) p = 0.91
Years living in Flint	1 (1, 1) p = 0.79	1 (1, 1) p = 0.41	1 (1, 1) p = 0.94	1 (1, 1) p = 0.12	1 (1, 1) p = 0.83	1 (1, 1) p = 0.41	1 (1, 1) p = 0.37	1 (1, 1) p = 0.12	1 (1, 1) p = 0.89	1 (1, 1) p = 0.22

Table 3 (continued)

Predictor	Outcome: Time to notice/hear about water issues	Outcome: Get screened for BLLs	Outcome: Elevated BLLs	Outcome: Skin rashes	Outcome: Hair loss	Outcome: Nausea	Outcome: Emotional agitation	Outcome: Total Symptoms	Outcome: PTSD	Outcome: Depression/Anxiety
Social network size	1 (0.9, 1.1) p = 0.89	1 (0.9, 1.1) p = 0.89	1 (0.9, 1.2) p = 0.89	0.9 (0.8, 1) p = 0.54	p = 0.72	1 (0.9, 1.1) p = 0.98	1 (0.9, 1.1) p = 0.98	1 (0.9, 1) p = 0.79	1 (0.8, 1.1) p = 0.79	0.9 (0.8, 1) p = 0.41
Zip code 48504 (ref: 48502/48503)	1.1 (0.7, 1.7) p = 0.87	1.2 (0.6, 2.4) p = 0.86	1.2 (0.5, 3.3) p = 0.89	1.3 (0.6, 2.5) p = 0.82	1 (0.5, 2) p = 0.99	0.9 (0.4, 1.9) p = 0.94	1.3 (0.6, 2.8) p = 0.79	1.1 (0.8, 1.4) p = 0.87	1.9 (0.9, 3.9) p = 0.33	2 (0.9, 4.4) p = 0.32
Zip code 48505 (ref: 48502/48503)	1.1 (0.7, 1.7) p = 0.89	0.9 (0.5, 1.8) p = 0.94	0.8 (0.3, 2.3) p = 0.89	1 (0.5, 1.9) p = 0.98	0.6 (0.3, 1.3) p = 0.53	1.2 (0.6, 2.5) p = 0.87	2.4 (1.2, 5) p = 0.12	1.1 (0.9, 1.4) p = 0.79	1.4 (0.7, 2.9) p = 0.76	2.2 (1, 4.9) p = 0.23
Zip code 48506 (ref: 48502/48503)	0.9 (0.5, 1.5) p = 0.88	1.4 (0.6, 3.4) p = 0.76	0.7 (0.1, 3.7) p = 0.9	2.2 (1, 5.2) p = 0.29	2.1 (0.9, 5.1) p = 0.34	2.6 (1.1, 6.4) p = 0.2	2.1 (0.9, 5.3) p = 0.36	**1.5 (1.1, 2) p = 0.04**	1.1 (0.4, 2.8) p = 0.97	1.2 (0.4, 3.5) p = 0.91
Zip code 48507/48532 (ref: 48502/48503)	1.2 (0.7, 2) p = 0.8	1.1 (0.5, 2.5) p = 0.93	0.3 (0.1, 1.7) p = 0.53	1.2 (0.6, 2.7) p = 0.87	0.4 (0.2, 0.9) p = 0.16	1.3 (0.5, 3) p = 0.87	2.1 (0.9, 4.9) p = 0.34	1 (0.8, 1.4) p = 0.92	0.8 (0.3, 2) p = 0.89	2.1 (0.9, 5.1) p = 0.35
Elevated BLLs (ref: Normal BLLs)				3.4 (1, 11.6) p = 0.25	1.7 (0.6, 4.7) p = 0.7	2.2 (0.7, 6.8) p = 0.53	1.7 (0.6, 5.1) p = 0.71	**1.5 (1.2, 1.9) p = 0.03**	0.9 (0.4, 2.4) p = 0.97	0.6 (0.2, 1.6) p = 0.68
Screened for BLLs (ref: Not screened)				1 (0.5, 1.8) p = 0.98	1.1 (0.6, 2.1) p = 0.91	1.4 (0.7, 2.9) p = 0.72	1.1 (0.5, 2.1) p = 0.97	1.2 (1, 1.5) p = 0.25	1.1 (0.6, 2.2) p = 0.89	1.3 (0.7, 2.5) p = 0.76
Time to notice/hear about water issues				1 (0.9, 1) p = 0.67	**1.1 (1, 1.1) p = 0.01**	1 (1, 1.1) p = 0.79	1 (0.9, 1) p = 0.89	1 (1, 1) p = 0.59	1 (1, 1) p = 0.93	1 (1, 1) p = 0.97
Skin rashes (ref: No skin rashes)					2 (1.1, 3.7) p = 0.16	**3.3 (1.7, 6.5) p = 0.01**	2.5 (1.3, 5.2) p = 0.09			
Hair loss (ref: No hair loss)				2.2 (1.2, 4.2) p = 0.11		**3.1 (1.5, 6.4) p = 0.03**	1.3 (0.6, 2.6) p = 0.8			
Nausea (ref: No nausea)				**3.5 (1.8, 6.8) p = 0.01**	2.6 (1.3, 5.2) p = 0.06		**4 (2, 8.2) p = 0.01**			
Emotional agitation (ref: No emotional agitation)				2.3 (1.2, 4.4) p = 0.12	1.3 (0.6, 2.5) p = 0.82	**5.3 (2.5, 11.3) p < 0.01**				
Total symptoms									**2.1 (1.6, 2.7) p < 0.01**	**1.9 (1.5, 2.4) p < 0.01**

signaling that they did not believe the water crisis to be a serious threat to their health. Conversely, their limited screening could have reflected fatalistic views [36, 49] or beliefs that screenings were not an effective means of detecting BLLs or providing a basis for mitigation [8, 29]. Additionally, roughly half of all respondents reported skin rashes, 40% reported emotional agitation and hair loss, and approximately a third of respondents reported experiencing nausea post-crisis. Further, being Black was a significant predictor of reporting more total symptoms, suggesting that Whites experienced fewer or less pronounced symptoms.

Continuing, nearly a third of the sample reported either depression or anxiety (as measured by the PHQ-4 [27]) and/or trauma (as measured by the PC-PTSD-5 [40]), reflecting a steep and broad mental health toll potentially associated with functional impairment [22, 35]. In a study with a random sample of patients in the United States, PHQ-4 results indicated that 23.3% of patients had mild elevations, 10.6% had moderate elevations, and 4.6% had severe elevations [22]. Further, while the PC-PTSD-5 has not been conducted with a random sample, the authors of the measure conducted a study with US veterans, finding that 26.4% had probable PTSD (using a cutoff of 3) [40]. Both sets of estimates, in comparison to our results, suggest a substantially elevated burden of mental health sequelae among Flint adults.

Furthermore, we found that the total number of symptoms experienced was a statistically significant predictor of both depression/anxiety and trauma. This finding suggests that the magnitude of health outcomes—that is, the scope—likely contributed to greater feelings of emotional distress or anguish [10] and are consistent with one study previously reporting that perceived water quality was associated with PTSD symptoms among Flint residents [23].

Importantly, results from this work indicate that the average time that had passed from the date of the water source switch until residents became aware of potential problems with their tap water was roughly 5 months. This indicates that many residents may have unknowingly consumed tap water that was contaminated for an extended period, thus heightening their likelihood of experiencing some of the adverse health outcomes indicated in this work.

There are some limitations to this research. First, the sample was not randomly selected. However, efforts were made to ensure broad coverage of the Flint population and to capture the racial/ethnic and socioeconomic diversity in the city, by recruiting at nine separate community sites spread widely across the city. Second, data on symptoms were self-reported and thus not subject to clinical verification. Additionally, there is the possibility of recall bias, given that the initiation of the water crisis was multiple years before the data collection period. However, simultaneously, the recency of our research allowed for a salient measure of the potential impact of residents' prolonged exposures to the city's contaminated water. Also, we did not survey Flint residents who may have moved out of Flint in the immediate years after the crisis. This "out-migration" population could have differed from our sample in terms of demographic traits and/or in ways related to water crisis-related impact and risk. Nonetheless, because out-migration remained fairly steady in the years following the crisis [32], and because most adult residents in Flint have lived in the city since their birth or adolescence [32, 38], we project that this dynamic likely would not have substantively impacted our findings. Finally, it is not possible to directly link or imply causation between the symptoms reported here and the water contamination. For example, many factors, including paint and soil-based lead exposures [19, 30], may be linked to the pattern of elevated BLLs that we observed. However, this analysis provides some valuable insights into broader, excess physical and mental health outcomes experienced by Flint adults, and potential forthcoming consequences for children in the city, which are substantially beyond what would typically be estimated.

In conclusion, the acute and potentially long-term health issues highlighted in this assessment punctuate the need for continued testing of water quality in Flint and ongoing epidemiologic surveillance of the municipal water's potential instigation of new adverse health cases and exacerbation of existing adverse health outcomes. More broadly, in consideration of the fundamental causes [26] of the Flint water crisis, it is imperative that attention be paid to the broader macrosocial forces, many of which have racist and classist antecedents [11, 41], that contributed to the emergence of unsound, undemocratic austerity policies in the city prior to the crisis. It is these forces that ultimately laid the groundwork for the devaluation of Flint's water and negligence towards residents' health. Moreover, there is a stark need for more inclusivity in urban planning in the city, independent oversight, and transparency around prospective issues in community health. These foci on

macro and meso-level dynamics will be necessary to increase civic trust and, in turn, should help reduce resident distress that is derived from perceptions of deleterious institutional action and inaction.

Declarations

Conflict of Interest The authors have declare no conflicts of interest.

References

1. Abouk R, Adams S. Birth outcomes in Flint in the early stages of the water crisis. *J Public Health Policy*. 2018;*39*(1):68–85.

2. Beck KH, Frankel A. A conceptualization of threat communications and protective health behavior. *Soc Psychol Q*. 1981;44:204–17.

3. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J R Stat Soc Ser B Methodol*. 1995;*57*(1):289–300.

4. Binney, Z. O., Nelson, K. N., & Chamberlain, A. T. (2019). Excess pneumonia mortality during a Legionnaires' disease outbreak in Flint, Michigan MedRxiv, 19005942.

5. Bromet EJ. Mental health consequences of the Chernobyl disaster. *J Radiol Prot*. 2012;*32*(1):N71–5.

6. Brusco NK, Watts JJ. Empirical evidence of recall bias for primary health care visits. *BMC Health Serv Res*. 2015;*15*(1):1–8.

7. Butler LJ, Scammell MK, Benson EB. The Flint, Michigan, water crisis: a case study in regulatory failure and environmental injustice. *Environ Justice*. 2016;*9*(4):93–7.

8. Campbell C, Tran M, Gracely E, Starkey N, Kersten H, Palermo P, et al. Primary prevention of lead exposure: the Philadelphia lead safe homes study. *Public Health Rep*. 2011;*126*(1_suppl):76–88.

9. Coughlin SS. Recall bias in epidemiologic studies. *J Clin Epidemiol*. 1990;*43*(1):87–91.

10. Ezell JM, Salari S, Rooker C, Chase EC. Intersectional trauma: COVID-19, the psychosocial contract, and America's racialized public health lineage. *Traumatology*,

11. No Pagination Specified-No Pagination Specified. 2021; https://doi.org/10.1037/trm0000302.

12. Fasenfest D. A neoliberal response to an urban crisis: emergency management in Flint, MI. *Crit Sociol*. 2019;*45*(1):33–47.

13. Fortenberry GZ, Reynolds P, Burrer SL, Johnson-Lawrence V, Wang A, Schnall A, et al. Assessment of behavioral health concerns in the community affected by the Flint water crisis–Michigan (USA) 2016. *Prehosp Disaster Med*. 2018;*33*(3):256–65.

14. Grossman DS, Slusky DJG. The impact of the Flint water crisis on fertility. *Demography*. 2019;*56*(6):2005–31.

15. Hanna-Attisha M, LaChance J, Sadler RC, Champney Schnepp A. Elevated blood lead levels in children associated with the Flint drinking water crisis: a spatial analysis of risk and public health response. *Am J Public Health*. 2016;*106*(2):283–90.

16. Hernán MA, Robins JM. *Causal Inference*: What If. Boca Raton: Chapman & Hall/CRC Boca Raton, Florida 2020.

17. Hill TD, & Maimon D (2013). Neighborhood context and mental health. In *Handbook of the sociology of mental health* (pp. 479–501). Springer.

18. Hong J, Koo B, Koo J. The psychosocial and occupational impact of chronic skin disease. *Dermatol Ther*. 2008;*21*(1):54–9.

19. Hudson CG. Socioeconomic status and mental illness: tests of the social causation and selection hypotheses. *Am J Orthopsychiatry*. 2005;*75*(1):3–18.

20. Jacobs DE, Clickner RP, Zhou JY, Viet SM, Marker DA, Rogers JW, et al. The prevalence of lead-based paint hazards in US housing. *Environ Health Perspect*. 2002;*110*(10):A599–606.

21. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. *Interdiscip Toxicol*. 2014;*7*(2):60–72.

22. Kessler RC, Galea S, Gruber MJ, Sampson NA, Ursano RJ, Wessely S. Trends in mental illness and suicidality after Hurricane Katrina. *Mol Psychiatry*. 2008;*13*(4):374–84.

23. Kroenke K, Spitzer RL, Williams JBW, Löwe B. An ultra-brief screening scale for anxiety and depression: the PHQ-4. *Psychosomatics*. 2009;*50*(6):613–21.

24. Kruger DJ, Cupal S, Franzen SP, Kodjebacheva G, Bailey ES, Key KD, et al. Toxic trauma: household water quality experiences predict posttraumatic stress disorder symptoms during the Flint, Michigan, water crisis. *J Community Psychol*. 2017;*45*(7):957–62.

25. Kruskal WH, Wallis WA. Use of ranks in one-criterion variance analysis. *J Am Stat Assoc*. 1952;*47*(260):583–621.

26. Lawson VL, Bundy C, Belcher J, Harvey JN. Mediation by illness perceptions of the effect of personality and health threat communication on coping with the diagnosis of diabetes. *Br J Health Psychol*. 2010;*15*(3):623–42.

27. Link BG, Phelan J. Social conditions as fundamental causes of disease. *J Health Soc Behav*. 1995;*35*:80. https://doi.org/10.2307/2626958.

28. Löwe B, Wahl I, Rose M, Spitzer C, Glaesmer H, Wingenfeld K, et al. A 4-item measure of depression and anxiety: validation and standardization of the Patient Health Questionnaire-4 (PHQ-4) in the general population. *J Affect Disord*. 2010;*122*(1–2):86–95.

28. Masten SJ, Davies SH, Mcelmurry SP. Flint water crisis: what happened and why? *J Am Water Works Assoc*. 2016;*108*(12):22–34.

29. Mehta S, Binns HJ. What do parents know about lead poisoning?: The Chicago lead knowledge test. *Arch Pediatr Adolesc Med*. 1998;*152*(12):1213–8.

30. Mielke HW, Reagan PL. Soil is an important pathway of human lead exposure. *Environ Health Perspect*. 1998;*106*(suppl 1):217–29.

31. Moran PAP. Notes on continuous stochastic phenomena. *Biometrika*. 1950;*37*(1/2):17–23.

32. Morckel V, Rybarczyk G. The effects of the water crisis on population dynamics in the City of Flint, Michigan. *Cities Health*. 2018;*2*(1):69–81.

33. Muller C, Sampson RJ, Winter AS. Environmental inequality: the social causes and consequences of lead exposure. *Annu Rev Sociol*. 2018;44:263–82.

34. Needleman H. Lead poisoning. *Annu Rev Med*. 2004;*55*: 209–22.

35. Ouimette P, Wade M, Prins A, Schohn M. Identifying PTSD in primary care: comparison of the Primary Care-PTSD screen (PC-PTSD) and the General Health Questionnaire-12 (GHQ). *J Anxiety Disord*. 2008;*22*(2):337–43.

36. Oyserman D, Fryberg SA, Yoder N. Identity-based motivation and health. *J Pers Soc Psychol*. 2007;*93*(6):1011–27.

37. Pauli BJ. The Flint water crisis. *Wiley Interdiscip Rev Water*. 2020;*7*(3):e1420.

38. Pearson AL, Sadler RC, Kruger DJ. Social integration may moderate the relationship between neighborhood vacancy and mental health outcomes: initial evidence from Flint, Michigan. *Appl Res Qual Life*. 2019;*14*(4):1129–44.

39. Pieper KJ, Tang M, Edwards MA. Flint water crisis caused by interrupted corrosion control: investigating "ground zero" home. *Environ Sci Technol*. 2017;*51*(4):2007–14.

40. Prins A, Bovin MJ, Smolenski DJ, Marx BP, Kimerling R, Jenkins-Guarnieri MA, et al. The primary care PTSD screen for DSM-5 (PC-PTSD-5): development and evaluation within a veteran primary care sample. *J Gen Intern Med*. 2016;*31*(10):1206–11.

41. Pulido L. *Flint, environmental racism, and racial capitalism, Capitalism Nature Socialism*. (2016);*27*(3):1–16. https://doi.org/10.1080/10455752.2016.1213013.

42. Ricketts EJ, Brandt BC, Woods DW. The effects of severity and causal explanation on social perceptions of hair loss. *J Obs-Compul Related Disorders*. 2012;*1*(4):336–43. https://www.r-project.org/. Accessed 01-29-2021

43. Rubin DB. *Multiple imputation for survey nonresponse*. New York City: New York Wiley; 1987.

44. Sadler RC, LaChance J, Hanna-Attisha M. Social and built environmental correlates of predicted blood lead levels in the Flint water crisis. *Am J Public Health*. 2017;*107*(5):763–9.

45. Schmier JK, Halpern MT. Patient recall and recall bias of health state and health status. *Expert Rev Pharmacoecon Outcomes Res*. 2004;*4*(2):159–63.

46. Schüz J, Spector LG, Ross JA. Bias in studies of parental self-reported occupational exposure and childhood cancer. *Am J Epidemiol*. 2003;*158*(7):710–6.

47. Small ML. *Someone to talk to*. New York City: New York. Oxford: Oxford University Press; 2017.

48. Sneed RS, Dotson K, Brewer A, Pugh P, Johnson-Lawrence V. Behavioral health concerns during the Flint water crisis, 2016–2018. *Community Ment Health J*. 2020;*56*(5):793–803. 1–11

49. Straughan PT, Seow A. Fatalism reconceptualized: a concept to predict health screening behavior. *J Gend Cult Health*. 1998;*3*(2):85–100.

50. The National Institute for Occupational Safety and Health. (2019). *Adult Blood Lead Epidemiology and Surveillance (ABLES)*. https://www.cdc.gov/niosh/topics/ables/description. html. Accessed 01-29-2021

51. Tønnessen A, Mårdberg B, Weisæth L. Silent disaster: a European perspective on threat perception from Chernobyl far field fallout. *J Trauma Stress*. 2002;*15*(6):453–9.

52. Tsoi M-F, Cheung C-L, Cheung TT, Cheung BMY. Continual decrease in blood lead level in Americans: United States National Health Nutrition and examination survey 1999-2014. *Am J Med*. 2016;*129*(11):1213–8.

53. United States Census Bureau. (2019). *QuickFacts: Flint, Michigan*. https://www.census. gov/quickfacts/flintcitymichigan. Accessed 01-29-2021

54. Whelton AJ, McMillan L, Connell M, Kelley KM, Gill JP, White KD, et al. Residential tap water contamination following the freedom industries chemical spill: perceptions, water quality, and health impacts. *Environ Sci Technol*. 2015;*49*(2):813–23.