



# Child Lead Screening Behaviors and Health Outcomes Following the Flint Water Crisis

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## Abstract

**Background** There is little research on lead (Pb) screening behaviors and outcomes and possible health sequelae of children in Flint, Michigan in the years following the city's 2014 water crisis, which included widespread tap water contamination with elevated levels of heavy metals and other environmental contaminants.

**Methods** Between June and November 2019, we collected and analyzed cross-sectional data on Flint children's demographics and self-report of screenings of blood lead levels (BLLs) and results and various potential water contamination-related health symptoms and outcomes. We calculated descriptive statistics to summarize the prevalence of health outcomes and screenings in children, and fit multivariable models using generalized estimating equations to characterize the association between baseline traits and health symptoms and outcomes in children.

**Results** A total of 244 children (mean age  $8.6 \pm 4.8$ ) were included in the analysis. Overall, 76.6% of the children were reported to have been screened for elevated BLLs after the water source switch. In total, after the water source switch, 25.0% of children were reported as having clinician-diagnosed elevated BLLs. Overall, 43.9% of children experienced hyperactivity, 39.3% had emotional agitation, 29.1% had comprehension issues/learning delays, while 38.9% of children had skin rashes and 10.7% experienced hair loss. A child having elevated BLLs also significantly increased the odds of experiencing adverse cognitive/behavioral outcomes (comprehension issues/learning delays OR = 4.0, hyperactivity OR = 6.6, emotional agitation OR = 3.5).

**Conclusion** Child BLL screening following the crisis initiation was moderate, and BLLs and potential water contamination-related morbidity outcomes appeared heightened. Further research is needed to contextualize epidemiologic factors contributing to BLL screening patterns and results and the potential water contamination-associated sequelae observed here.

**Keywords** Child health · Class · Environmental health · Lead · Flint Water Crisis

## Abbreviations

*BLL* Blood lead level

## Introduction

On April 25, 2014, the municipal water system in the economically distressed, majority Black city of Flint, Michigan was switched from Lake Huron to the Flint River as part of a sweeping set of austerity policies advanced by the state to shore-up budgetary fissures in the city [1]. Through the early stages of Flint's water source switch, insufficient implementation of anti-corrosion controls led to widespread contamination of the water supply with environmental toxicants and bacteria, including elevated levels of lead (Pb), trihalomethanes, and the bacteria *legionella* which has been linked to upwards of 100 deaths in the city [2, 3].

Owing to residents' ongoing consumption of potentially contaminated water up through the end of 2015—this due to the government's delayed disclosure of the city water's potential issues [1, 4]—many residents in Flint, including

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children and in utero fetuses, may have been adversely exposed [5–7]. Notably, even low levels of lead exposure can severely adversely affect neurocognitive function and development and behavioral issues in young children [8–10] and can pose dire health risks to pregnant women, immunocompromised adults, and older individuals [11, 12].

Research following reports of the city’s water issues revealed that the *incidence* of BLLs of Flint children under 5 years old had increased from 2.4% (before the water source switch) to 4.9% (after the water source switch), with neighborhoods with the highest lead levels, often predominantly Black, seeing a 6.6% increase, and no increases observed immediately outside of the city [7]. Notably, however, other research showed relatively steady child BLLs across this broader time period and even modest *declines* [13–15].

Much of the existing research on the health outcomes of Flint children was conducted shortly after the water crisis began, focused on only children who were 5 years or younger, or relied on healthcare system-specific data [7, 13–16]. Accordingly, the extant research covers a potentially limited segment of Flint’s child population and reveals a vacuum in current knowledge on a potentially “latent period” of health sequelae in this group that may have been associated with the city’s contaminated water. Moreover, little is known about post-crisis child BLL screening behaviors in this population, a critical factor for secondary prevention efforts [17, 18]. Using data from a study conducted in late 2019, 5 years after Flint’s water source switch, we assessed BLL screening behaviors and potential water contamination-related health outcomes among Flint children.

## Methods

Using an observational design, we assessed lead screening behaviors and potential outcomes and sequelae associated with the water crisis in Flint, Michigan. Surveys were collected using REDCap v.9.5.36 (Nashville, TN) between June 2019 and November 2019 by three Flint residents trained in community-based data collection. Though cross-sectional studies lack randomization, they are potent in hypothesis generation, our orienting goal here, which is valuable in research on mechanistically complex health outcomes, such as lead exposure and water contamination-related sequelae [19, 20].

To further augment the rigor of the study design, we took steps to ensure adequate geographic coverage and thereby increase the likelihood of obtaining a moderately representative sample. To this end, surveys were conducted in-person at nine separate publicly accessible sites throughout Flint, at each intercardinal direction. This was also done to capture potential spatial variation in pre-crisis and post-crisis environmental exposure and overall health [7, 21]. Venue patrons

were approached by one of three recruiters and screened for eligibility. The nine public survey administration sites included locations such as public libraries, a laundromat, a fitness center, a bus station, and a café in the City of Flint, with geographical equity achieved.

To participate, caregivers had to (1) be at least 18 years of age; (2) have lived in the City of Flint for at least one full calendar year between April 25, 2014 (the date of the city’s water source switch) and the date of the survey administration; (3) be able to speak English; and (4) provide written consent. All study procedures were reviewed and approved by the Institutional Review Board at the University of Chicago. Participants were given a \$15 gift card for participating.

Adult respondents were asked to provide information on the demographics and screening behaviors and health outcomes for any children under age 18 who had lived in the City of Flint whom they regularly provided care for, this serving as a rough proxy for children who would have been at an age during the crisis’ early phases where elevated lead exposure could have been especially detrimental [18]. Beyond providing the child’s age, race, gender, and the relationship between the child and caregiver, respondents also reported whether the child had been screened by a clinician for BLLs at any point before and/or after the water source switch, and were asked to report whether the child had subsequently been diagnosed with elevated BLLs or not. There is frequently variation in the thresholds used to determine what constitutes “elevated” BLLs [18], thus, we captured any threshold used by the child’s clinician. Of note, we further restricted the sample to children over 6 months of age with complete data on all covariates used in the analysis, while also adjusting for variation in the age of onset of each specific health outcome/symptom, to account for the age in which particular symptoms or outcomes may manifest and be clinically detectable or diagnosable.

In consideration of the widespread uptake of bottled water following the water crisis [22], we also assessed the child’s current primary drinking water source, including the options of home filtered tap water, home unfiltered tap water, water from restaurants or businesses, and bottled water (including these options for infant formula, if the child was an infant). In addition to being a risk factor for lead exposure, drinking water source/frequency is also associated with one’s likelihood of developing dental caries [23, 24].

Furthermore, respondents were asked if the child had any physical symptoms including cognitive-behavioral symptoms (comprehension issues/learning delays, hyperactivity, or emotional agitation) and physical symptoms of skin rashes or hair loss, outcomes which had been reported by residents in the weeks following the water source switch via local press and social media [25]. These symptoms were inventoried due to their pronounced likelihood of developing

following ongoing lead/water contaminant exposure [26, 27].

Due to concerns associated with recall and self-report bias and related methodological concerns [28–30], we asked respondents if the child had “regularly” experienced, *before* and *after* the date of the city’s water source switch, more of a particular symptom than would be “normal,” or typical for them (i.e., before the water source switch, if applicable). Here, we placed a specific focus on the symptom recurrence and intensity. These questions were centered around references to media reports, announcements from public officials, and government hearings, etc., to serve as memory flashpoints and reduce the likelihood of false attribution [29, 31].

Additionally, to gauge threat perception of the water crisis by caregivers [32–34], respondents were asked to what extent they agreed with this statement: “People have made the water issues (i.e. the water “crisis”/water source switch) a *bigger deal* than it really is.” We then split this variable into a binary outcome based on if the respondent Agreed/Strongly Agreed or was Neutral/Disagreed/Strongly Disagreed.

Leveraging these data, we aimed to (1) assess general patterns of self-reported child BLL screenings, BLL screening results, and various health symptoms and outcomes among individuals under 18 at the time of the survey who had lived in Flint after the water source switch (April 25, 2014); (2) assess any differences according to child age, race, gender, caregiver eligibility for public benefits (e.g., Supplemental Nutrition Assistance Program, Temporary Assistance for Needy Families, etc.) which was a proxy for income, whether the child was screened for BLLs, whether the child was diagnosed with elevated BLLs by a clinician, and the caregiver’s level of threat perception in relation to the water crisis.

To address aim 1, we produced simple descriptives and the *p*-values from bivariate associations. To address aim 2, we fit multivariable models for each health outcome, in turn, using the following predictors for all models: child age, race, gender, caregiver public benefit receipt status, child BLL screening status, whether the child was diagnosed by a clinician with elevated BLLs, and to what extent the caregiver agreed that the water crisis had been made a bigger deal than it really was. For the outcome of whether the child had been screened for BLLs, we omitted the predictors of whether the child had been screened for BLLs or diagnosed with elevated BLLs; for the outcome of whether the child was diagnosed by a clinician with had elevated BLLs, we restricted the sample to children who had been screened for BLLs (all children with elevated BLLs were screened) and omitted the predictors of whether the child was screened for BLLs and whether they were diagnosed by a clinician with elevated BLLs. For the outcomes of elevated BLLs and skin rashes, we also

omitted the predictor of whether the caregiver thought the water crisis had been made a bigger deal than it was, because models including this predictor would not converge. Similarly, the outcome of child hair loss could not be considered in multivariable models because of the small number of children who experienced this symptom. All other outcomes used the full list of predictors in the model.

We conducted sensitivity analyses to see if there were any major differences between children described by their biological parent as compared to children who were described by another individual (e.g., a grandparent, sibling, or another caregiver). Based on these sensitivity analyses, we did not identify differences based on caregiver, with effect sizes and direction largely the same. Hence, we included all children regardless of caregiver relationship in the sample to bolster statistical power.

Because the children were clustered by caregiver, with children with the same caregiver more similar than children with different caregivers, all analyses had to be adjusted to address this correlation structure. For all bivariate associations, we used an aligned rank transformed repeated-measures nonparametric ANOVA test [35] to address clustered data. For multivariable models, we used generalized estimating equations with an exchangeable correlation structure and robust standard errors to properly model the correlation among children with the same caregiver [36]. All models were logistic models, with the exception of total number of symptoms, for which a Poisson model was used. Because of the many multivariable models considered, a false-discovery rate correction was applied to *p*-values from multivariable modeling to correct for multiple testing [37]. Complete code to replicate this analysis can be found at [https://github.com/elizabethchase/Flint\\_Community\\_Engagement](https://github.com/elizabethchase/Flint_Community_Engagement). All analyses were conducted in R v. 3.6.2.

## Results

Of the 331 adult respondents who participated in the study, 133 (40.2%) regularly provided care to at least one child under age 18 who lived in Flint, Michigan. The number of children per adult ranged from one to eight children, with a mean number of 2.1 ( $\pm 1.3$ ) children per adult, and 283 children total. After excluding children under 6 months, the sample size was 275 children; restricting the sample to children with complete data yielded a final sample size of 244 children. Baseline traits of these children are presented in Table 1.

The sociodemographic traits of the recruited sample were comparable to U.S. Census estimates for Flint residents in terms of race/ethnicity and general socioeconomic status (United States Census Bureau, 2019). Children were, on average, 8.6 years old ( $\pm 4.8$  years) at the

**Table 1** Baseline descriptive statistics of a sample of 244 children whose caregivers were surveyed in Flint, Michigan, June 2019–November 2019, stratified by child’s race. *P*-values come from an aligned rank transformed repeated-measures nonparametric ANOVA test

Characteristic	Overall	Black race	Other race	White race	<i>P</i> -value
<i>N</i>	244	154	45	45	
Child-caregiver relationship (%)					0.66
Child	196 (80.3)	120 (77.9)	41 (91.1)	35 (77.8)	
Grandchild	38 (15.6)	30 (19.5)	3 (6.7)	5 (11.1)	
Sister/step-sister	1 (0.4)	1 (0.6)	0 (0.0)	0 (0.0)	
Brother/stepbrother	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
Niece/nephew	5 (2.0)	0 (0.0)	1 (2.2)	4 (8.9)	
Friend’s child	1 (0.4)	1 (0.6)	0 (0.0)	0 (0.0)	
Other relationship	3 (1.2)	2 (1.3)	0 (0.0)	1 (2.2)	
Child age (mean (SD))	8.63 (4.81)	9.0 (4.8)	7.2 (4.2)	8.8 (5.2)	0.22
Child gender = male (%)	134 (54.9)	92 (59.7)	18 (40.0)	24 (53.3)	0.09
Caregiver age (mean (SD))	39.8 (12.1)	40.2 (12.4)	36.5 (10.5)	41.5 (12.1)	0.61
Caregiver gender = male (%)	73 (29.9)	43 (27.9)	17 (37.8)	13 (28.9)	0.61
Caregiver race (%)					<0.01
Black	152 (62.3)	150 (97.4)	2 (4.4)	0 (0.0)	
Other race	33 (13.5)	4 (2.6)	29 (64.4)	0 (0.0)	
White	59 (24.2)	0 (0.0)	14 (31.1)	45 (100.0)	
Caregiver education (%)					0.02
Less than high school	28 (11.5)	10 (6.5)	8 (17.8)	10 (22.2)	
High school	72 (29.5)	46 (29.9)	19 (42.2)	7 (15.6)	
Some college	92 (37.7)	64 (41.6)	15 (33.3)	13 (28.9)	
Associate’s	29 (11.9)	22 (14.3)	1 (2.2)	6 (13.3)	
College degree or more	23 (9.4)	12 (7.8)	2 (4.4)	9 (20.0)	
Caregiver eligible for public benefits (%)					0.62
Yes	181 (74.2)	114 (74.0)	39 (86.7)	28 (62.2)	
No	53 (21.7)	35 (22.7)	4 (8.9)	14 (31.1)	
Don’t know/unsure	10 (4.1)	5 (3.2)	2 (4.4)	3 (6.7)	
Caregiver employment status (%)					0.01
Employed	130 (53.3)	86 (55.8)	17 (37.8)	27 (60.0)	
Other	36 (14.8)	18 (11.7)	5 (11.1)	13 (28.9)	
Unemployed	78 (32.0)	50 (32.5)	23 (51.1)	5 (11.1)	

time of data collection. The majority were male ( $N = 134$ , 54.9%) and Black ( $N = 154$ , 63.1%), followed by White ( $N = 45$ , 18.4%) and “Other” race ( $N = 45$ , 18.4%). When looking at caregiver characteristics and weighting by the number of children in care, caregivers were, on average, 39.8 years old ( $\pm 12.1$  years). Most caregivers identified as female ( $N = 171$ , 70.1%) and were eligible for public benefits ( $N = 181$ , 74.2%). Twenty-five (10.2%) children had a caregiver who agreed/strongly agreed that the water crisis had been made a bigger deal than it was. Child race and caregiver educational attainment were significantly associated ( $p = 0.02$ ), with White children more likely to have a caregiver with educational attainment at the extremes (i.e., either a college degree or less than high school). Of note, the majority of children ( $N = 228$ , 93.4%) drank bottled water (or had it in their formula, if infants) as their primary drinking water source at the time of the survey.

## BLL Screening Rates and Results

In total, 76.6% of children ( $N = 187$ ) were screened for elevated BLLs after the water source switch, including 82.5% of Black children, 73.3% of White children, and 60.0% of Other race children (Table 2). In multivariable modeling (Table 3), male children were significantly less likely to be screened for BLLs than female children (OR = 0.6,  $p = 0.03$ ). Other race children were less significantly likely to have been screened for elevated BLLs than Black race children (OR = 0.3,  $p = 0.03$ ). A total of 25.0% of children ( $N = 61$ ) in the sample were reported to have had elevated BLLs diagnosed by a clinician after the water source switch.

**Table 2** Descriptive statistics on health outcomes for a sample of 244 children whose caregivers were surveyed in Flint, Michigan, June 2019–November 2019, stratified by child’s race. *P*-values come from an aligned rank transformed repeated-measures nonparametric ANOVA test

Outcome	Overall	Black race	Other race	White race	<i>P</i> -value
N (%)	244 (100.0)	154 (63.1)	45 (18.4)	45 (18.4)	
Screened for BLLs after April 25, 2014 (%)	187 (76.6)	127 (82.5)	27 (60.0)	33 (73.3)	0.14
Had elevated BLLs after April 25, 2014 (%)	61 (25.0)	41 (26.6)	11 (24.4)	9 (20.0)	0.83
Skin rashes after April 25, 2014 (%)	95 (38.9)	66 (42.9)	18 (40.0)	11 (24.4)	0.17
Hair loss after April 25, 2014 (%)	26 (10.7)	19 (12.3)	3 (6.7)	4 (8.9)	0.37
Comprehension issues/learning delays after April 25, 2014 (%)	71 (29.1)	50 (32.5)	8 (17.8)	13 (28.9)	0.22
Hyperactivity after April 25, 2014 (%)	107 (43.9)	75 (48.7)	17 (37.8)	15 (33.3)	0.36
Emotional agitation after April 25, 2014 (%)	96 (39.3)	73 (47.4)	11 (24.4)	12 (26.7)	0.08
Total symptoms after April 25, 2014 (mean (SD))	2.6 (2.0)	2.9 (1.9)	2.1 (1.9)	2.2 (2.0)	0.13

**Table 3** Odds/risk ratios and 95% confidence intervals from multi-variable models fit with generalized estimating equations in a sample of 244 children whose caregivers were surveyed in Flint, Michigan, June 2019–November, 2019. Findings for which the false-discovery rate adjusted *p*-value is less than 0.05 are bolded and marked with an asterisk

Predictor	Outcome: got screened for BLLs	Outcome: had elevated BLLs	Outcome: skin rashes	Outcome: hyperactivity	Outcome: emotional agitation	Outcome: total symptoms
Child: male (ref. Child: female)	<b>0.6 (0.4, 0.9)*</b>	1.4 (1, 2.2)	1 (0.6, 1.6)	<b>2.2 (1.2, 4)*</b>	0.8 (0.4, 1.4)	1 (0.9, 1.2)
Child: age	1 (0.9, 1.1)	1 (0.9, 1)	1 (0.9, 1.1)	<b>1.1 (1, 1.2)*</b>	1.1 (1, 1.1)	1 (1, 1)
Child: Other race (ref. child: Black race)	<b>0.3 (0.1, 0.8)*</b>	1.8 (0.7, 4.8)	1.3 (0.4, 3.6)	0.5 (0.2, 1.3)	0.4 (0.1, 1)	0.9 (0.7, 1.1)
Child: White race (ref. child: Black race)	0.8 (0.3, 2.1)	1 (0.4, 2.8)	0.5 (0.2, 1.1)	1.1 (0.5, 2.5)	0.5 (0.2, 1.4)	0.9 (0.7, 1.1)
Caregiver: eligible for public benefits (ref. caregiver: not eligible for public benefits)	1.7 (0.8, 3.8)	1.2 (0.5, 3.1)	1.6 (0.7, 3.8)	1.9 (0.9, 4)	<b>5.3 (2.2, 12.5)*</b>	<b>1.4 (1.1, 1.6)*</b>
Caregiver agrees: water crisis was made a “bigger deal” than it really was	0.5 (0.1, 1.9)			<b>0.3 (0.1, 0.8)*</b>	0.5 (0.1, 2.3)	0.7 (0.5, 1)
Child: screened for BLLs after April 25, 2014 (ref. child: not screened for BLLs after April 25, 2014)			1.6 (0.8, 3.2)	1.4 (0.6, 3.3)	1.3 (0.6, 3.1)	<b>2.6 (1.8, 3.8)*</b>
Child: had elevated BLLs (ref. child: non-elevated BLLs)			<b>3.4 (1.7, 6.7)*</b>	<b>4 (2.1, 7.7)*</b>	<b>3.5 (1.6, 7.6)*</b>	<b>2 (1.7, 2.3)*</b>

\*Statistically significant at *p*<0.05

Each column corresponds to a different model (outcome given as column header; predictors given as rows). All models were logistic mixed models (null value odds ratio = 1.0), with the exception of the outcome of total symptoms, which was a linear mixed model (null value linear effect = 0.0). Note that the model for the outcome of elevated BLLs was restricted to the 187 children whose BLLs were screened by a clinician



## Cognitive and Behavioral Outcomes

Overall, 71 children (29.1%) were reported to have experienced comprehension issues/learning delays after the water source switch (Table 2). Further, 107 children (43.9%) were reported to have experienced hyperactivity after the water source switch. A total of 96 children (39.3%) were reported to have experienced emotional agitation after the water source switch, with Black children having borderline significantly higher rates (Black: 47.4%, White: 26.7%, Other: 24.4%,  $p=0.08$ ).

Children whose caregiver was eligible for public benefits were at a heightened risk of having comprehension issues/learning delays (OR = 1.9,  $p=0.11$ ), hyperactivity (OR = 2.9,  $p=0.02$ ), and emotional agitation (OR = 5.3,  $p<0.01$ ) (Table 3). A child having elevated BLLs diagnosed by a clinician also significantly increased the odds of experiencing adverse cognitive/behavioral outcomes (comprehension issues/learning delays OR = 4.0, hyperactivity OR = 6.6, emotional agitation OR = 3.5,  $p<0.01$  for all outcomes). Caregivers were significantly more likely to report comprehension issues/learning delays and hyperactivity in male than in female children (comprehension issues/learning delays OR = 2.2,  $p=0.02$ ; hyperactivity OR = 2.2,  $p=0.01$ ); older children were significantly more likely to be reported to have comprehension issues/learning delays than younger children (per year of age, comprehension issues/learning delays OR = 1.1,  $p=0.03$ ). In addition, having a caregiver who agreed/strongly agreed that the water crisis had been made a bigger deal than it was significantly decreased the odds of the caregiver reporting that the child had comprehension issues/learning delays (OR = 0.3,  $p=0.02$ ).

## Physical Health Symptoms

A total of 95 children (38.9%) were reported to have had skin rashes (more than was “regular” for them) after the water source switch (Table 2). In total, 26 children (10.7%) were reported to have had hair loss after the water source switch. Having elevated BLLs significantly increased a child’s risk of having skin rashes (OR = 3.4,  $p<0.01$ ).

On average, children experienced 2.6 health symptoms (counting both cognitive/behavioral *and* physical symptoms) after the water source switch. In multivariable models, child’s gender, race, and age did not have an effect on the total number of symptoms experienced. However, children whose caregiver was eligible for public benefits, on average, had 1.4 times as many symptoms as those not eligible for public benefits, a significant difference ( $p=0.01$ ). Moreover, children who had their BLLs screened after the water source switch, on average, had 2.6 times as many total symptoms (cognitive/behavioral and physical) as children who did not have their BLLs screened ( $p<0.01$ ), while children

who were diagnosed with elevated BLLs had 2.0 times as many total symptoms as children who were not diagnosed with elevated BLLs ( $p<0.01$ ).

## Discussion

Findings from this cross-sectional analysis of a racially diverse, community-based sample of Flint children illustrate potentially heightened levels of lead exposure and broad patterns of morbidity potentially associated with the city’s 2014 water contamination crisis. In total, 76.6% of the children in our sample were screened for elevated BLLs after the water source switch. In assessing this figure, the hypothesis-generation utility of our cross-sectional study is potentially instructive [19, 20]. Our observation of moderately high but not robust BLL screening, and of male children having lower rates of screening versus female children, is of concern in the context of prevention, as it highlights that a substantial number of Flint children, many of whom may be at an already-elevated risk due to immunological conditions, may not have been screened for elevated BLLs following the crisis. What is more, this pattern may have manifested despite frequent calls by government and public health officials following the crisis for families to get their children screened [38].

Considering the fundamental cause paradigm, the theory that health disparities persist largely due to structural and systemic forces [39], multiple factors, including institutional distrust or limited threat perception [19, 20], may explain these our screening outcomes. More proximal factors potentially contributing to these suppressed screenings could include families having diminished logistical ability to obtain a screening (e.g., due to transportation issues, etc.), having limited familiarity with local healthcare options, or having a lack of health literacy corresponding to an understanding of the need to get their children screened for BLLs, knowledge on lead chelation techniques, etc. [38, 40, 41] It is also possible that some caregivers were simply unaware of whether their children had been screened for lead levels (e.g., as part of routine wellness visits), signaling insufficient provider-patient communication [42]. Accordingly, an emphasis on improving parental awareness/education and shared decision-making in relation potential environmental hazard exposure is critical [43, 44].

Overall, 25.0% of children in the sample were reported as having been diagnosed by a clinician with elevated BLLs at some point after the water source switch. We further found that elevated BLLs increased a child’s odds of having comprehension issues/learning delays, hyperactivity, and emotional agitation, consistent with the literature on links between BLL and adverse cognitive/behavioral outcomes [8, 45–47]. We also found that comprehension issues/learning delays and hyperactivity were more common in male

than in female children (and, as previously shown, males' BLL screening rates were lower), supporting evidence on the gendered manifestation of these outcomes [48–51]. Though suggestive of an alarming “excess” burden of cases, these estimates must be partly tempered both due to our lack of a random sample and our reliance on self-report. At the same time, in consideration of the notion of “perceived health,” it is vital to recognize that one's mere *perception* that their health has been impacted—by some particular exposure or somatic development—can have a dramatic impact on their wellness, feelings of self-efficacy, and their health attitudes and subsequent health behaviors [52–55]. Moreover, of note, BLL interpretations vary based on the cutpoint used, and there is currently no known safe level of exposure to lead [38, 56]. Hence, the medical and cultural valences of having elevated, potentially hazardous BLLs, or being “lead poisoned,” are fluid.

Because our study considered multiple potential screenings since the crisis began, we, in essence, captured multiple potential lead exposure windows that could have occurred in the years after the water source switch as the matter began receiving formal government attention [41]. Rigorous, publicly accessible epidemiologic surveillance along these lines is necessary. The CDC's voluntary Flint Lead Exposure Registry is poised to help maintain this level of surveillance of Flint child health outcomes over time (Ettinger, Hanna-Attisha, et al., 2019,[38]. However, for the previously highlighted reasons related to institutional distrust, limited health literacy, and diminished threat perception, both enrollment and long-term engagement among Flint residents may be substantially curtailed.

Continuing, at the aggregate symptom level, summing elevated BLLs, comprehension issues/learning delays, hyperactivity, emotional agitation, skin rashes, and hair loss, we found that children whose caregiver was eligible for public benefits experienced higher rates of emotional agitation and hyperactivity, and more overall symptoms than children whose caregiver was not eligible for public benefits. We further observed that Black children, compared to White and Other race children, had higher rates of emotional agitation. Taken in tandem, these findings signal that lower-income and Black children in Flint may have experienced a greater overall burden of water contamination-related morbidity in the years following the water crisis, with disproportionate exposure to non-potable water (e.g., due to their neighborhoods having underserviced water infrastructure) likely being at play.

Also of note, the vast majority of children in our sample drank bottled water as their primary drinking water source (including in infant formula). Due to the limited fluoridation in bottled water, this forecasts potential increases in dental caries in Flint's youth population [23, 24], calling attention to the need for upstream prevention efforts targeting dental

hygiene practices. Given legitimated concerns over water quality in America, particularly in racial/ethnic minority and low-income communities in the country, tap water avoidance among some caregivers, and thus children, is not uncommon [57, 58]. Of note, Congress recently approved a \$55 billion bipartisan water infrastructure bill [59, 60]. However, infrastructure upgrades alone will not motivate communities who are accustomed to—or who may merely perceive having—limited water potability to regularly use their tap water for drinking. Thus, public policies corresponding to addressing water potability must be reinforced by earnest public outreach consistently demonstrating the tap water's safety and further supplemented by education campaigns on the broad benefits of tap water consumption.

This analysis has some limitations. First, this was an observational study, and participants in the study were not randomly selected. Nevertheless, by recruiting at nine separate sites throughout Flint, we were able to obtain broad geographic coverage inclusive of the racial/socioeconomic diversity in the city, cohering closely to recent U.S. census estimates. Second, the health symptoms were collected via caregiver self-report for the child and hence did not incorporate clinical verification. Moreover, to the matter of standardization, we did not determine which specific BLL thresholds were used, a matter of ongoing clinical contestation that further reflects the intricacies of measuring lead given its half-life, both from the standpoint of effectiveness and efficiency, and accordingly predicting or correlating the impacts of lead exposure [59, 61]. Third, recall bias is possible, given that the water crisis' initiation was several years before the initiation of our survey administration. Nonetheless, our assessment ultimately allowed for a salient hypothetical assessment of the potential effect of residents' prolonged exposures to the city's contaminated water supply. Furthermore, a variety of other factors, including exposures to lead in lead-based paints (which is common in older homes in low-income communities), as well as lead in dust and soil [62, 63], may have contributed to the elevated BLLs and attendant health symptoms and outcomes observed here. Future work in this space should incorporate clinical assessment and assess homes and neighborhoods for potential concomitant environmental risk factors. Fourth, our study was partly constrained by sample size: Specifically, because of the clustered design of the study, in which multiple children sometimes shared a caregiver, our sample had diminished statistical power. A follow-up study with a larger sample of children (in separate/unrelated homes) may be able to locate other associations.

In conclusion, we find substantive observational evidence that calls attention to the need for additional epidemiologic surveillance of morbidity among Flint children, particularly among Black and low-income children in the city, that might correspond to the water crisis. Moreover,

our findings provide insights into potential BLL screening patterns in the city and suggest that a substantial portion of the child population was potentially not screened for BLLs, reflecting a cleavage in preventive efforts. Comprehensive, accessible, and trusted community-based interventions are needed to get upstream of potential barriers to child BLL screening in the city and in other socioeconomically underserved communities across the U.S. to prevent or mitigate adverse environment-related health outcomes.

**Author Contribution** Jerel Ezell contributed to the study design, data collection, and manuscript writing and revisions.

Sanvi Bhardwaj contributed to the manuscript writing and revisions.

Elizabeth Chase contributed to the data analysis and manuscript writing and revisions.

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## Declarations

**Consent to Participate** IRB approval for this study was obtained from the University of Chicago (IRB18-0111). Participants provided consent to participate.

**Consent for Publication** The authors approve the content of this manuscript and agree to its publication.

**Competing Interests** The authors declare no competing interests.

## References

- 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.
- Binney ZO, Nelson KN, Chamberlain AT. Excess pneumonia mortality during a Legionnaires' disease outbreak in Flint, Michigan. 2019. MedRxiv, 19005942–19005942.
- Schwake DO, Garner E, Strom OR, Pruden A, Edwards MA. Legionella DNA markers in tap water coincident with a spike in Legionnaires' disease in Flint. *MI Environmental Science & Technology Letters*. 2016;3(9):311–5.
- Morckel V. Why the Flint, Michigan, USA water crisis is an urban planning failure. *Cities*. 2017;62:23–7.
- Craft-Blacksheare MG. Lessons learned from the crisis in Flint, Michigan regarding the effects of contaminated water on maternal and child health. *J Obstet Gynecol Neonatal Nurs*. 2017;46(2):258–66.
- Grossman DS, Slusky DJG. The impact of the Flint water crisis on fertility. *Demography*. 2019;56(6):2005–31.
- Hanna-Attisha M, LaChance J, Sadler RC, Champney Schnepf 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.
- Banks EC, Ferretti LE, Shucard DW. Effects of low level lead exposure on cognitive function in children: a review of behavioral, neuropsychological and biological evidence. *Neurotoxicology*. 1997;18(1):237–81.
- Lanphear BP, Hornung R, Khoury J, Yolton K, Baghurst P, Bellinger DC, Canfield RL, Dietrich KN, Bornschein R, Greene T, Rothenberg SJ, Needleman HL, Schnaas L, Wasserman G, Graziano J, Roberts R. Low-level environmental lead exposure and children's intellectual function: an international pooled analysis. *Environ Health Perspect*. 2005;113(7):894–9. <https://doi.org/10.1289/ehp.7688>.
- Wheeler W, Brown M. Blood lead levels in children aged 1–5 years—United States, 1999–2010. *Morb Mortal Wkly Rep*. 2013;62(13):245–8.
- Obeng-Gyasi E. Lead exposure and cardiovascular disease among young and middle-aged adults. *Medical Sciences*. 2019;7(11):103.
- Vig EK, Hu H. Lead toxicity in older adults. *J Am Geriatr Soc*. 2000;48(11):1501–6.
- Gómez HF, Borgialli DA, Sharman M, Shah KK, Scolpino AJ, Oleske JM, Bogden JD. Blood lead levels of children in Flint, Michigan: 2006–2016. *J Pediatr*. 2018;197:158–64. <https://doi.org/10.1016/j.jpeds.2017.12.063>.
- Kennedy C, Yard E, Dignam T, Buchanan S, Condon S, Brown MJ, Raymond J, Rogers HS, Sarisky J, de Castro R, Arias I, Breyse P. Blood lead levels among children aged <6 years—Flint, Michigan, 2013–2016. *Morb Mortal Wkly Rep*. 2016;65(25):650–4. <https://doi.org/10.2307/24858150> JSTOR.
- Laidlaw M, Filippelli G, Sadler R, Gonzales C, Ball A, Mielke H. Children's blood lead seasonality in Flint, Michigan (USA), and soil-sourced lead hazard risks. *Int J Environ Res Public Health*. 2016;13(4):358.
- Hanna-Attisha M, Gonuguntla A, Peart N, LaChance J, Taylor DK, Chawla S. Umbilical cord blood lead level disparities between Flint and Detroit. *Am J Perinatol*. 2021;38(S 01):e26–32.
- Curry SJ, Krist AH, Owens DK, Barry MJ, Cabana M, Caughey AB, Doubeni CA, Epling JW, Kemper AR, Kubik M. Screening for elevated blood lead levels in children and pregnant women: US Preventive Services Task Force recommendation statement. *JAMA*. 2019;321(15):1502–9.
- Spanier AJ, McLaine P, Gilden RC. Screening for elevated blood lead levels in children and pregnant women. *JAMA*. 2019;321(15):1464–5. <https://doi.org/10.1001/jama.2019.2594>.
- Levin KA. Study design III: cross-sectional studies. *Evid Based Dent*. 2006;7(1):24–5.
- Mann C. Observational research methods. Research design II: cohort, cross sectional, and case-control studies. *Emerg Med J*. 2003;20(1):54–60.
- 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.
- Ezell JM, Chase EC. A population-based assessment of physical symptoms and mental health outcomes among adults following the Flint Water Crisis. *J Urban Health*. 2021. <https://doi.org/10.1007/s11524-021-00525-2>.
- Armfield JM, Spencer AJ. Consumption of nonpublic water: implications for children's caries experience. *Commun Dent Oral Epidemiol*. 2004;32(4):283–96. <https://doi.org/10.1111/j.1600-0528.2004.00167.x>.
- Kitchens M, Owens B. Effect of carbonated beverages, coffee, sports and high energy drinks, and bottled water on the in vitro erosion characteristics of dental enamel. *J Clin Pediatr Dent*. 2008;31(3):153–9. <https://doi.org/10.17796/jcpd.31.3.115716538206100>.
- Peplow M. The Flint water crisis: how citizen scientists exposed poisonous politics. *Nature*. 2018;559(7713):180–1.
- Sankhla MS, Kumari M, Nandan M, Kumar R, Agrawal P. Heavy metals contamination in water and their hazardous effect on human health—a review. *Int J Curr Microbiol App Sci* (2016). 2016;5(10):759–66.



27. Whelton AJ, McMillan L, Connell M, Kelley KM, Gill JP, White KD, Gupta R, Dey R, Novy C. Residential tap water contamination following the freedom industries chemical spill: perceptions, water quality, and health impacts. *Environ Sci Technol*. 2015;49(2):813–23.
28. Brusco NK, Watts JJ. Empirical evidence of recall bias for primary health care visits. *BMC Health Serv Res*. 2015;15(1):1–8.
29. Coughlin SS. Recall bias in epidemiologic studies. *J Clin Epidemiol*. 1990;43(1):87–91.
30. 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.
31. 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.
32. Murray DR, Schaller M. Threat (s) and conformity deconstructed: perceived threat of infectious disease and its implications for conformist attitudes and behavior. *Eur J Soc Psychol*. 2012;42(2):180–8.
33. Rousseau DL, Garcia-Retamero R. Identity, power, and threat perception: a cross-national experimental study. *J Conflict Resolut*. 2007;51(5):744–71.
34. Weinman JA. Perceptions of health and illness. In *Perceptions of health & illness*. Psychology Press; 2013. p. 13–30
35. Wobbrock, J. O., Findlater, L., Gergle, D., & Higgins, J. J. (2011). The aligned rank transform for nonparametric factorial analyses using only anova procedures. 143–146.
36. Fitzmaurice GM, Laird NM, Ware JH. *Applied longitudinal analysis* (Vol. 998). John Wiley & Sons; 2012.
37. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J Roy Stat Soc: Ser B (Methodol)*. 1995;57(1):289–300.
38. Ruckart PZ, Ettinger AS, Hanna-Attisha M, Jones N, Davis SI, Breyse PN. The Flint water crisis: a coordinated public health emergency response and recovery initiative. *J Public Health Manag Pract: JPHMP*. 2019;25(Suppl 1 Lead Poisoning Prevention), S84.
39. Link BG, Phelan J. Social conditions as fundamental causes of disease. *J Health Soc Behav*. 1995;35:80–80. <https://doi.org/10.2307/2626958>.
40. Blando JD, Antoine N, Lefkowitz D. Lead-based paint awareness, work practices, and compliance during residential construction and renovation. *J Environ Health*. 2013;75(9):20–7.
41. Davis KM. Lead poisoning prevention efforts in high-risk environments: follow-up testing rates among preschool children in Flint, Michigan, 2013–2015. *J Racial Ethn Health Disparities*. 2020: 1–11.
42. Hauptman M, Bruccoleri R, Woolf AD. An update on childhood lead poisoning. *Clinical Pediatric Emergency Medicine*. 2017;18(3):181–92.
43. Légaré F, Ratté S, Gravel K, Graham ID. Barriers and facilitators to implementing shared decision-making in clinical practice: update of a systematic review of health professionals' perceptions. *Patient Educ Couns*. 2008;73(3):526–35.
44. Polivka BJ, Gottesman MM. Parental perceptions of barriers to blood lead testing. *J Pediatr Health Care*. 2005;19(5):276–84.
45. Daneshparvar M, Mostafavi S-A, Jeddi MZ, Yunesian M, Mesdaghinia A, Mahvi AH, Akhondzadeh S. The role of lead exposure on attention-deficit/hyperactivity disorder in children: a systematic review. *Iran J Psychiatry*. 2016;11(1):1.
46. Mazumdar M, Bellinger DC, Gregas M, Abanilla K, Bacic J, Needleman HL. Low-level environmental lead exposure in childhood and adult intellectual function: a follow-up study. *Environ Health*. 2011;10(1):1–7.
47. Reyes JW. Lead exposure and behavior: effects on antisocial and risky behavior among children and adolescents. *Ssrn*. 2015;53(3):1580–605. <https://doi.org/10.1111/ecin.12202>.
48. Biederman J, Mick E, Faraone SV, Braaten E, Doyle A, Spencer T, Wilens TE, Frazier E, Johnson MA. Influence of gender on attention deficit hyperactivity disorder in children referred to a psychiatric clinic. *Am J Psychiatry*. 2002;159(1):36–42.
49. Matheis M, Matson JL, Hong E, Cervantes PE. Gender differences and similarities: autism symptomatology and developmental functioning in young children. *J Autism Dev Disord*. 2019;49(3):1219–31.
50. Rucklidge JJ. Gender differences in attention-deficit/hyperactivity disorder. *Psychiatr Clin*. 2010;33(2):357–73.
51. Valla L, Wentzel-Larsen T, Hofoss D, Slinning K. Prevalence of suspected developmental delays in early infancy: results from a regional population-based longitudinal study. *BMC Pediatr*. 2015;15(1):1–8.
52. Chipperfield JG. Incongruence between health perceptions and health problems: implications for survival among seniors. *J Aging Health*. 1993;5(4):475–96.
53. Cutler MJ, Marlon JR, Howe PD, Leiserowitz A. The influence of political ideology and socioeconomic vulnerability on perceived health risks of heat waves in the context of climate change. *Weather Climate Soc*. 2018;10(4):731–46.
54. Gaskin JL, Pulver AJ, Branch K, Kabore A, James T, Zhang J. Perception or reality of body weight: which matters to the depressive symptoms. *J Affect Disord*. 2013;150(2):350–5.
55. Grogan S. Body image and health: contemporary perspectives. *J Health Psychol*. 2006;11(4):523–30.
56. Burki T. Report says 815 million children have high blood lead levels. *Lancet*. 2020;396(10248):370.
57. Patel AI, Shapiro DJ, Wang YC, Cabana MD. Sociodemographic characteristics and beverage intake of children who drink tap water. *Am J Prev Med*. 2013;45(1):75–82. <https://doi.org/10.1016/j.amepre.2013.04.001>.
58. Rosinger AY, Young SL. In-home tap water consumption trends changed among US children, but not adults, between 2007 and 2016. *Water Resour Res*. 2020;56(7), e2020WR027657.
59. Paulson JA, Brown MJ. The CDC blood lead reference value for children: time for a change. *Environ Health*. 2019;18(1):1–3.
60. Fact Sheet: The bipartisan infrastructure deal. The White House; 2021. <https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/06/fact-sheet-the-bipartisan-infrastructure-deal/>. Accessed 10 Dec 2021
61. Schaffer SJ, Campbell JR. The new CDC and AAP lead poisoning prevention recommendations: consensus versus controversy. 1994.
62. Lanphear BP, Roghmann KJ. Pathways of lead exposure in urban children. *Environ Res*. 1997;74(1):67–73. <https://doi.org/10.1006/enrs.1997.3726>.
63. Mielke HW, Reagan PL. Soil is an important pathway of human lead exposure. *Environ Health Perspect*. 1998;106(suppl 1):217–29.
64. Ettinger AS, Hanna-Attisha M, Breyse PN, Iskander JK, Thorpe P, Laird S. A renewed commitment to prevent childhood lead exposure in the post-Flint era. 2019.
65. Ettinger AS, Ruckart PZ, Dignam T. Lead poisoning prevention: the unfinished agenda. *Journal of Public Health Management and Practice: JPHMP*. 2019;25(Suppl 1 Lead Poisoning Prevention), S1.
66. United States Census Bureau. QuickFacts: Flint, Michigan. 2019.

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