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Boil water alerts and their impact on the unexcused absence rate in public schools in Jackson, Mississippi

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M. Kim[1], R. De Vito[2], F. Duarte[3], K. Tieskens[4], M. Luna[5], A. Salazar-Miranda[3], M. Mazzarello[3], S. Showalter Otts[6], C. Etzel[6], S. Burks[7], K. Crossley[7], N. Franzen Lee[7] & E. D. Walker[7]

The water crisis in Jackson, Mississippi, has recently made national and international headlines as a major environmental catastrophe, impacting the public health and wellbeing of residents. Here we focus on Jackson's most prevalent and vulnerable population, its children, by assessing how boil water alerts (BWAs) disrupt student learning. Using data on BWAs collected from the City of Jackson's Water/Sewer Business Administration Office between 2015 and 2021, daily school attendance data from Jackson's Public School District and community-level vulnerabilities from the American Community Survey, we add an important layer to the current conversation by analysing how BWAs disrupt student learning. After adjusting for community-level vulnerabilities, we show that each time a BWA is issued, unexcused absence rates statistically significantly increase by 1–10%. We also show statistically significant decreases in unexcused absences in schools where much of the student body receives free and reduced lunches. In a city that releases hundreds of BWAs each year, our findings highlight the urgency for addressing the root causes of the poor water quality in Jackson.

Access to clean water is a fundamental human right and is vital to community public health and wellbeing. To protect the drinking water of communities served by public water systems, the Safe Drinking Water Act (SDWA) was passed by the US Congress in 1974[1]. State regulatory agencies are responsible for enforcing the complaince of community water systems with the SDWA. However, despite these layers of oversight, there are many communities across the USA that lack access to reliable and safe drinking water[2]. Prior studies show that 2.44% of community water systems are listed as SDWA Significant Violators, which is defined as a system that has unresolved, multiple and continuing violations[3]. Further, 6.01% of permittees are listed as Clean Water Act Significant Non-compliers, which is when a system does not resolve a drinking water violation[4]. Although the precise details of which individuals are impacted by these violations are unknown, estimates are between 81 and 217 million (refs. 5,6). Contaminated drinking water has been linked to various adverse health and development outcomes in adults and children, including skin, urinary–bladder and lung cancers, gastroenteritis and both intellectual impairment and cognitive

[1]Department of Statistics, Kyungpook National University, Daegu, South Korea. [2]Department of Biostatistics, Brown University School of Public Health, Providence, RI, USA. [3]Senseable City Lab, Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, MA, USA. [4]Department of Environmental Health, Boston University School of Public Health, Boston, MA, USA. [5]Department of Geography, Salem State University, Salem, MA, USA. [6]National Sea Grant Law Center, University of Mississippi School of Law, Oxford, MS, USA. [7]Commuinty Noise Lab, Department of Epidemiology, Brown University School of Public Health, Providence, RI, USA. e-mail: erica_walker@brown.edu

Table 1 | The number of households impacted by boil water alerts and summary statistics for census block group characteristics between 2015 and 2021.

Year	Summary statistic	TV	BANHT	DIS	YOUNG	OLD	OA	LE	NC	POV	SP
2015 (*n*=12,579)	Minimum	0.70	0.00	0.04	0.02	0.01	0.00	0.00	0.00	0.02	0.09
	Median	2.14	0.94	0.11	0.25	0.10	0.03	0.01	0.09	0.17	0.30
	Maximum	3.03	1.00	0.25	0.51	0.62	0.23	0.05	0.59	0.57	0.54
	Mean (s.d.)	1.91 (0.63)	0.74 (0.34)	0.12 (0.04)	0.24 (0.10)	0.13 (0.09)	0.04 (0.04)	0.01 (0.01)	0.12 (0.10)	0.22 (0.13)	0.29 (0.12)
2016 (*n*=5,391)	Minimum	0.70	0.00	0.04	0.02	0.01	0.00	0.00	0.00	0.02	0.09
	Median	2.10	0.94	0.11	0.25	0.11	0.03	0.00	0.09	0.26	0.29
	Maximum	3.05	1.00	0.30	0.50	0.34	0.23	0.05	0.59	0.62	0.54
	Mean (s.d.)	1.95 (0.65)	0.75 (0.34)	0.12 (0.05)	0.26 (0.09)	0.13 (0.07)	0.04 (0.03)	0.01 (0.01)	0.13 (0.11)	0.24 (0.15)	0.29 (0.11)
2017 (*n*=2,784)	Minimum	0.70	0.00	0.04	0.02	0.03	0.00	0.00	0.00	0.02	0.09
	Median	2.11	0.91	0.11	0.25	0.14	0.03	0.00	0.09	0.16	0.29
	Maximum	2.89	1.00	0.30	0.45	0.34	0.23	0.05	0.43	0.62	0.49
	Mean (s.d.)	1.88 (0.62)	0.71 (0.35)	0.12 (0.05)	0.25 (0.11)	0.14 (0.09)	0.04 (0.04)	0.01 (0.01)	0.11 (0.09)	0.22 (0.13)	0.28 (0.12)
2018 (*n*=58,443)	Minimum	0.70	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.02	0.09
	Median	2.25	0.94	0.12	0.25	0.12	0.03	0.01	0.12	0.24	0.30
	Maximum	3.05	1.00	0.30	0.51	0.62	0.23	0.05	0.59	0.62	0.54
	Mean (s.d.)	2.10 (0.55)	0.83 (0.27)	0.13 (0.05)	0.24 (0.10)	0.15 (0.10)	0.04 (0.04)	0.01 (0.01)	0.14 (0.11)	0.25 (0.13)	0.31 (0.11)
2019 (*n*=9,567)	Minimum	0.70	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.02	0.09
	Median	2.22	0.94	0.11	0.25	0.09	0.03	0.00	0.12	0.30	0.33
	Maximum	3.05	1.00	0.30	0.50	0.62	0.23	0.05	0.50	0.62	0.54
	Mean (s.d.)	2.04 (0.55)	0.80 (0.29)	0.12 (0.04)	0.25 (0.10)	0.11 (0.08)	0.03 (0.03)	0.01 (0.02)	0.13 (0.09)	0.27 (0.13)	0.31 (0.10)
2020 (*n*=80,099)	Minimum	0.70	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.02	0.09
	Median	2.23	0.94	0.12	0.26	0.11	0.03	0.00	0.11	0.26	0.33
	Maximum	3.05	1.00	0.30	0.51	0.62	0.23	0.05	0.59	0.62	0.54
	Mean (s.d.)	2.13 (0.52)	0.85 (0.24)	0.13 (0.05)	0.25 (0.10)	0.14 (0.09)	0.04 (0.03)	0.01 (0.01)	0.15 (0.12)	0.25 (0.13)	0.32 (0.10)
2021 (*n*=22,679)	Minimum	0.70	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.02	0.09
	Median	2.42	0.97	0.13	0.26	0.11	0.03	0.00	0.16	0.33	0.41
	Maximum	2.95	1.00	0.30	0.46	0.42	0.13	0.05	0.59	0.62	0.49
	Mean (s.d.)	2.41 (0.35)	0.94 (0.13)	0.15 (0.04)	0.26 (0.10)	0.13 (0.08)	0.04 (0.02)	0.00 (0.01)	0.17 (0.10)	0.34 (0.12)	0.38 (0.09)

Variables in columns indicate total BWA vulnerability (TV), percentage of individuals who identify as Black, Asian, Native American, Hispanic, or 2 or more races (BANHT), percentage of people with disability status (DIS), percentage of people older than 65 years (OLD), percentage of people younger than 18 years (YOUNG), percentage of people older than 65 years and living alone (OA), percentage of people with limited English (LE), percentage of households with no computer access (NC), percentage of households living in poverty (POV) and percentage of single-parent households (SP). *n* indicates the number of households impacted by boil water advisories.

decline in children[5,7–12]. Further, low-income, non-white communities are substantially more likely to have unclean water, making water quality a community public health and environmental justice issue[4,6,13–17].

Case study: Jackson, Mississippi

Nowhere is this concern more prominent than in Jackson, Mississippi, where the collapse of the city's water system has recently made national and international news headlines[18–25]. This failure represents an important and timely case study of how both current and historic intersections of race, class and infrastructure disinvestment impacts the health and wellbeing of a community's most vulnerable residents, in real time[18–25]. Specifically, we examine how these water issues impact school children enroled in the Jackson Public School District (JPSD).

The City of Jackson is Mississippi's capital and largest city and home to approximately 150,000 residents, of whom 82.5% are Black and 24.5% live in poverty[26]. At its zenith, Jackson had well over 200,000 residents in the 1980s, with white people making up over half of its population[27]. However, between 1980 and 1990, Jackson experienced a 17% decrease in white residents. From 1990 to 2000, nearly 35,000 white residents left the city, settling in surrounding suburbs, taking with them a substantial tax base and leaving behind an inability to maintain and upgrade public utilities such as roads, rubbish collection and the water system[27].

The city's water system includes two drinking water treatment plants and three wastewater treatment plants. This system covers approximately 150 square miles and services close to 200,000 people in Greater Jackson[20,28]. The city is currently subject to two enforcement

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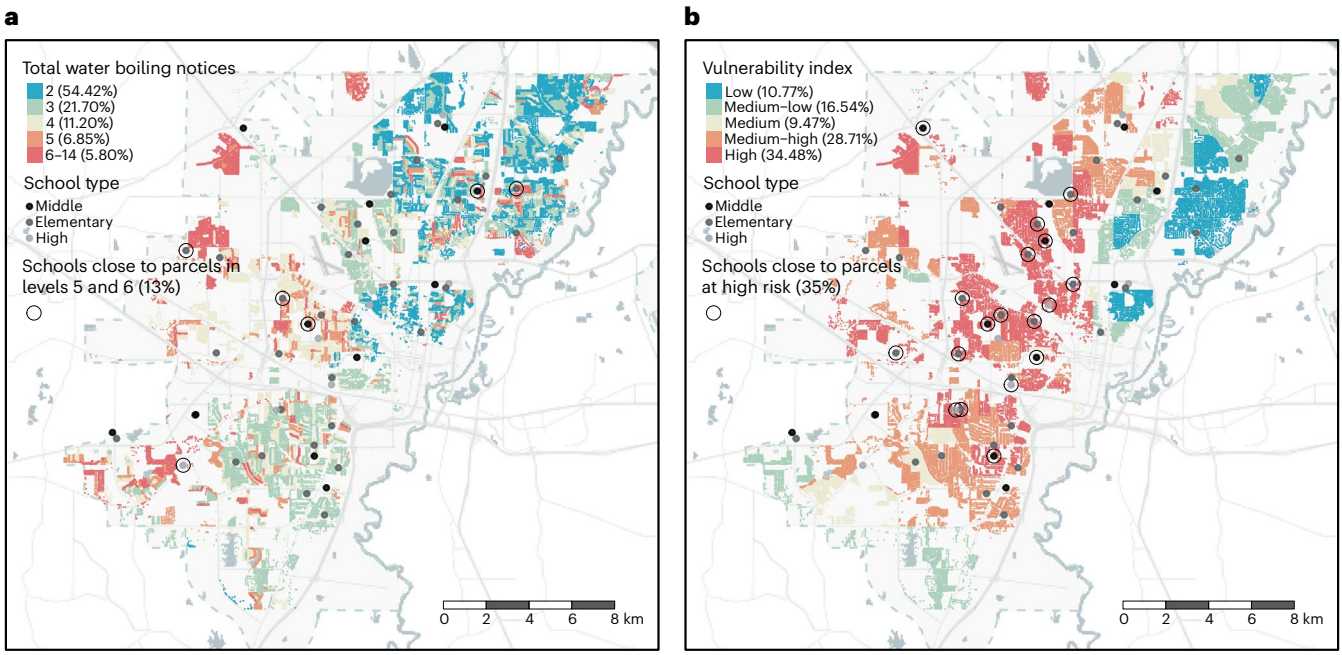

Fig. 1 | A visualization of boil water alert intensity and vulnerability in Jackson, Mississippi. a, The boil water alert intensity by parcel for Jackson, Mississippi using 2015–2021 boil water advisory data from the City of Jackson. **b**, The average total vulnerability by parcel computed using the procedure outlined in the BWA vulnerability section.

actions by the Environmental Protection Agency (EPA). The first is a consent decree, initiated in 2012 pursuant to violations of the Clean Water Act, and the second, an administrative order, was initiated in July 2021 to address SDWA violations[29,30]. On 29 November 2022, the US Department of Justice announced that the city's water system would be overseen by a third-party administrator while the city and the federal government negotiate a longer-term solution[31]. This extraordinary government enforcement action is an escalation of decades-long efforts of the EPA to ensure the city's compliance with the Clean Water Act and SDWA.

Boil water alerts

According to a City of Jackson Distribution System Assessment released in July 2022, water line breaks occur at an average annual rate of 55 breaks per 100 miles of line, which is more than three times the Partnership for Safe Water's recommended limit of 15 breaks per 100 miles (ref. 32). When water lines break and the system loses pressure, precautionary boil water alerts (BWAs) are issued due to the risk that contaminants have entered the water system. When residents are under a boil water advisory, the Mississippi State Department of Health (MSDH) recommends that impacted residents bring water to a rolling boil for 1 min for cooking or baking; making ice cubes; taking medication; brushing teeth; bathing; washing food; mixing baby formula, food, juices or drinks; feeding pets; washing dishes and all other consumption purposes[33]. The high frequency of precautionary BWAs disrupts the operations of restaurants, stores, hospitals and schools.

BWA requirements also present physical and economic burdens for daily living activities, especially for households with school-aged children, who represent 25% of all residents in Jackson[26]. BWA issues are unpredictable, and the extra steps needed to feed and clean children in the morning before school may present an obstacle to school attendance. School attendance is an important factor leading to positive health and development for children across academic, social and behavioural domains[34]. Since 2015, the City of Jackson has released, on average, 509 BWAs per year, leading to the potential disruption of 1,098 days of school days for children attending the JPSD. In the long run, chronic absenteeism, or the overall absence from school for at least 2 weeks of school, can lead to a myriad of adverse life outcomes including poor health, poverty and an increased likelihood of interacting with the criminal justice system, with impacts on students as early as kindergarten[35–39].

Impacts on public school attendance

In this Article, we examine how BWAs impact the attendance rates—defined as the physical presence or absence of students in a school building—of schools in JPSD[34]. Specifically, we focus on the daily unexcused absence rates—defined as unscheduled or unauthorized absences from school—in elementary, middle and high schools in JPSD, to both localized and city-wide BWAs[40]. We use BWA data collected from the City of Jackson's Water/Sewer Business Administration Office between the years 2015 and 2021; the corresponding daily school attendance data gathered from the JPSD; community-level socioeconomic vulnerabilities, potential confounders, from the American Community Survey; and data to describe the unique changes to in-person instruction delivery methods due to the coronavirus disease 2019 (COVID-19) pandemic. Our findings indicate that BWAs increase unexcused absence rates by up to 10% .

Results

Table 1 presents the number of households impacted by BWAs and summary statistics for demographic characteristics at the census block group level between 2015 and 2021. The number of households impacted by BWA was largest in 2020 (80,099), followed by 2018 (58,443) and 2021 (22,679). There was a steady increase in the percentage of individuals who identify as Black (B), Asian (A), Native American (N), Hispanic (H), or 2 or more races (T), sometimes refered to as BANHT, people living in poverty and single-parent households with limited computer access who were impacted by BWAs. The total BWA vulnerability was highest in 2021 (mean 2.41, s.d. 0.35).

Figure 1 maps the total number of BWAs by parcel (panel a) and the BWA vulnerability (panel b) overlaid with the schools categorized by type. Figure 1a shows that most parcels received at least two BWAs during our study period (54.42%) and that parcels receiving the highest number of BWAs (between 6 and 14) tend to be located in West Jackson.

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Table 2 | The estimated parameters for the daily unexcused absence rates for all schools

All schools	Period 1		Period 2	
Variable	**Estimate**	***P* value**	**Estimate**	***P* value**
Intercept	**0.0477**	**$<2\times10^{-16}$***	**0.1259**	**$<2\times10^{-16}$***
Advisories				
BWA	**0.0099**	**$<2\times10^{-16}$***	**0.0096**	**0.0018***
City-wide BWAs	0.0034	0.6211	−0.0018	0.8037
COVID-19 instructional delivery				
Virtual	—	—	−0.0349	0.0646
Onsite virtual	—	—	**−0.0534**	**5.01×10^{-5}**
Hybrid virtual	—	—	0.0168	0.2036
Vulnerabilities				
Black, Asian, Native American, Hispanic, or 2 or more races	**0.0091**	**$<2\times10^{-16}$***	**0.0315**	**$<2\times10^{-16}$***
Single family	**−0.0091**	**$<2\times10^{-16}$***	**−0.0318**	**$<2\times10^{-16}$***
Disabled	**−0.0019**	**0.0002***	**0.0170**	**$<2\times10^{-16}$***
Elderly	0.0008	0.4761	**−0.0159**	**6.87×10^{-6}***
Young	−0.0001	0.7654	0.0021	0.2499
Old and living alone	**−0.0032**	**0.0020***	−0.0019	0.5624
Limited English	0.0001	0.7854	**−0.0040**	**4.67×10^{-6}***
No computer access	0.0009	0.0580	−0.0002	0.8770
People living in poverty	**0.0063**	**$<2\times10^{-16}$***	−0.0010	0.6547
Selected lag (days)	2	1		

The results of estimates for all schools are reported for unexcused absences for period 1 and 2. Note that period 1 does not have results of the variables related to the remote learning schedule for the JPSD because all schools keep an onsite method for period 1. Note that estimates in bold and *P* values with an asterisk in bold indicate statistically significant results based on a two-tailed *t*-test without adjustments for multiple comparisons.

Figure 1b shows that 34.48% of parcels are at high risk regarding BWA vulnerability and that these parcels extend throughout the city, except for parcels located in North East Jackson. Overall, 13% of schools fall close to parcels with the highest BWAs, and 35% of schools are closest to parcels with the highest BWA vulnerability risk.

Table 2 reports the estimates and the corresponding *P* value from the generalized additive model (GAM), aggregating all the schools together. In period 1, unexcused absence rates increased with the city's issue of localized and city-wide BWAs (1% and 0.3%, respectively, or 63–210 JPSD students)[41]. However, the impact of city-wide alerts on the increased unexcused absence rates is not statistically significant. In period 2, we observed similar effects.

Next, we repeat our analysis, by disaggregating 'all schools' and constructing models by school type (elementary, middle and high school) and each of the 52 individual schools in the JPSD (Fig. 2). Overall, there were no statistically significant impacts of BWAs on unexcused absence rates by school type. However, we document positive and statistically significant effects of a BWA on unexcused absence rates for specific schools. In elementary schools (Fig. 2a), this includes Bates (during the pre-pandemic period, with a 6% increase in the unexcused absence rate, impacting approximately 23 students with each alert), Boyd (post pandemic, with a 4% increase in the unexcused absence rate, impacting approximately 14 students with each alert), Key (post pandemic, with a 6% increase in the unexcused absence rate, impacting approximately 21 students) and Spann (post pandemic, with a 1% increase in the unexcused absence rate, impacting approximately five students with each alert). For Clausell elementary school, BWAs decrease unexcused absence rates by 7% pre-pandemic. We have not found any statistically significant association for any middle schools (Fig. 2b), although the BWAs tend to increase unexcused absence rates, especially for period 2. For high schools (Fig. 2c), a BWA is significantly associated with unexcused absence rates in Lanier school in period 2. From our lag analysis, the effects observed can remain for up to 2 days after an alert is issued.

We performed a sensitivity analysis to understand how the unexcused absence rate was affected when both households and schools were under a BWA. The estimates and the corresponding 95% confidence intervals (CIs) remained mostly from the models presented in Table 1 and Fig. 2.

Discussion

The causes of absenteeism are multi-dimensional and exist within individual, family and school domains[42]. We add to the existing literature by focusing specifically on environmental factors such as localized and city-wide BWAs, which can have impacts across all three domains. Using publicly available data at the level of census block, we were able to control for a variety of neighbourhood-level factors that could confound the relationship between BWAs and unexcused absence rates[39]. These include people living in poverty, social isolation, single-parent households, households with limited-to-no-computer access, those who speak English less than well, the disabled and the elderly (as they are also more likely to be heads of households in Mississippi)[43–46]. Our findings show that, after adjusting for these confounding factors and the unique impact COVID-19 had on instructional delivery, we observe statistically significant increases in unexcused absence rates in JPSD during and proceeding a BWA. We found that a BWA contributes to an approximately 1–10% increase in unexcused absence rates in JPSD, impacting between 210 and 2,100 students with each issue. During the 454 alerts issued in 2020, there were between 95,000 and 9.5 million individual days of school lost by students in JPSD. These impacts were most prevalent in elementary and high schools and these students came from communities where there is a high prevalence of single-family, individuals who identify as Black, Asian, Native American, Hispanic, or 2 or more races and household living in poverty. These effects were prevalent for up to 2 days after an alert was released.

A breakdown of our findings suggests that the burdens of BWAs are borne by students at a handful of schools. In all the individual schools that experienced a statistically significant increase in unexcused absences during a BWA, their student body was 96–99.5% non-white. Contrastingly, a couple of schools experienced an increase in student attendance during BWAs, suggesting a protective effect. For example, one school where this trend was observed was Clausell Elementary School, located in South Jackson, where the entire student body receives free and reduced lunch assistance[47].

Our findings are consistent with previous studies examining how environmental factors such as temperature[48] and air pollution[38] can negatively impact absenteeism. Like our findings, in these studies, exposure to environmental hazards increased absenteeism both during and well after an event. As previous studies have also shown, both short-term and chronic school absences can lead to an increased probability of high school dropout, social disengagement, substance use, suicide ideation, criminal arrests, reduced adult economic wellbeing and decreased life expectancy[37,49–53]. In the JPSD where nearly one-quarter of its current population is school-aged youths whose current dropout rates are higher than state goals, and graduation rates are well below state goals, our findings are particularly concerning, especially given that these impacts on students can start as early as kindergarten[36].

Historical factors for a current situation

The water infrastructure issues in Jackson are long standing, with rumblings of concern dating back to over a century ago when city officials

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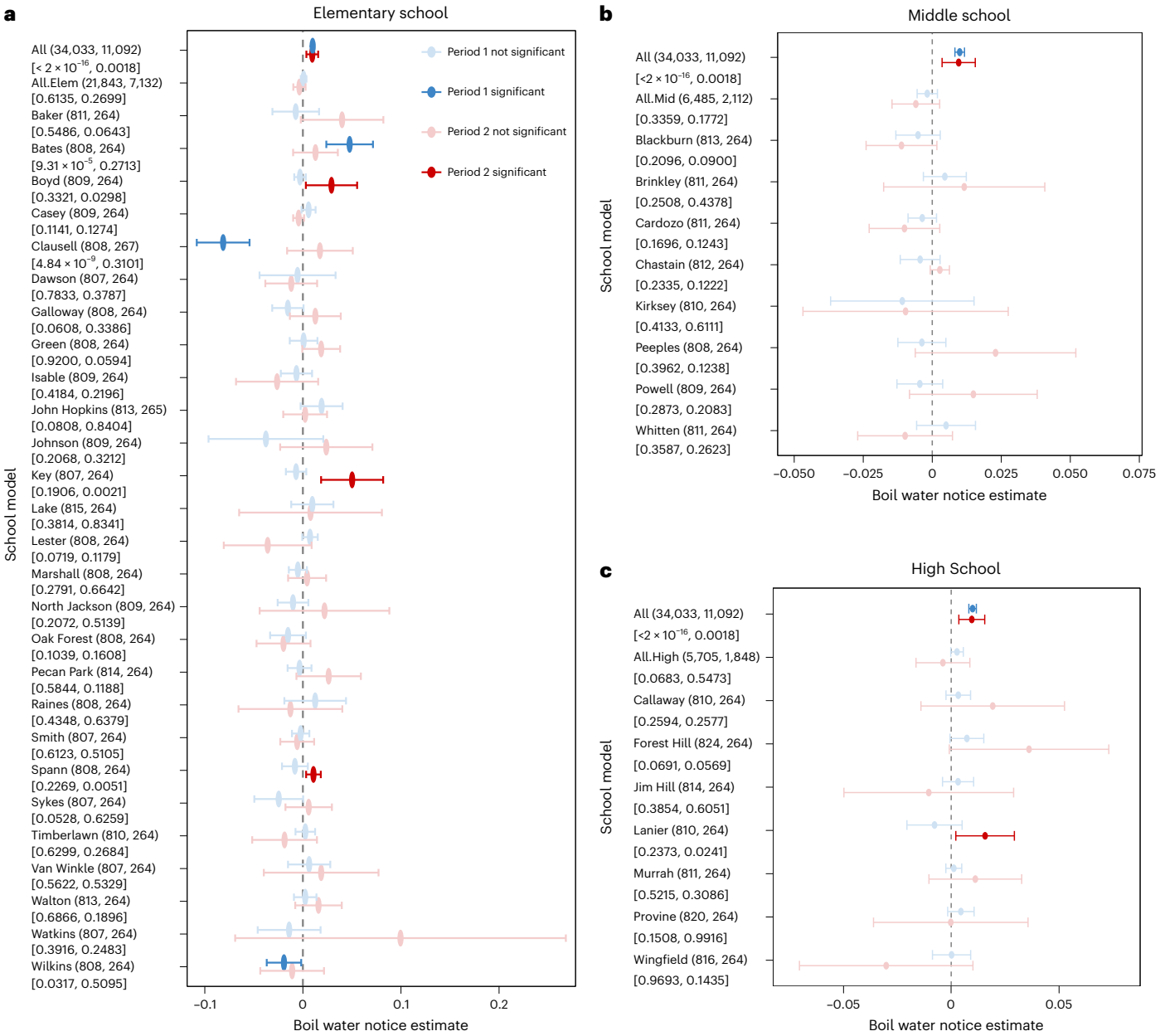

Fig. 2 | Estimates and 95% CIs of the BWA covariates for the outcome unexcused absence rate. a–**c**, Estimates on the basis of the models for elementary schools (**a**), middle schools (**b**) and high schools (**c**) for period 1 (blue) and 2 (red) are reported. 'All', 'All.Elem', 'All.Mid' and 'All.High' indicate all schools, all elementary schools, all middle schools and all high schools, respectively. Each graph considers all the schools together. Dots represent point estimates of the GAM, and error bars illustrate their 95% CIs. The *y*-axis label indicates 'school name (sample size for period 1, sample size for period 2)' for each school, school types and all schools, with corresponding *P* values based on a two-tailed *t*-test without adjustments for multiple comparisons as '[*P* value for period 1, *P* value for period 2]' below. Darker lines correspond to coefficients that are statistically significant ($P < 0.05$).

warned that water treatment facility upgrades were needed to accommodate Jackson's rapidly growing population[54]. Former mayors as early as 1953 and as late as 2014 all explicitly expressed concerns about the failing water systems and ran on platforms making these issues a mayoral legislative priority. However, it was a series of educational rulings—Brown versus Board of Education in 1954 and Singleton versus Jackson Municipal Separate School District rulings in 1970—that greatly impacted Jackson's current water system failures[55,56]. Up until the Supreme Court ruled that the segregation of public schools was unconstitutional, many of the neighbourhoods in North, West and South Jackson were all-white, affluent areas, and the JPSD was predominantly white and was separated by race into all Black and predominantly white schools[57]. After these two rulings, these affluent white Jackson residents migrated to nearby suburbs. What was left behind after the migration to the suburbs was a city without a substantial tax base to assist in paying for the urgently needed water system repairs and upgrades and staff. As of 2017, 96% of JPSD students are Black, and in the city of Jackson, 82.5% are Black.

As a result, Jackson is currently operating under two separate federal enforcement orders for non-compliance with federal and state laws related to water quality including sewage overflows from the wastewater system and increased levels of lead and turbidity (sediment) in drinking water[58]. Compliance costs for both orders are estimated at over US$1 billion (ref. 30). These issues are exacerbated by the impacts of increasingly frequent severe weather events that cause water main breaks and equipment damage. In the future, as climate

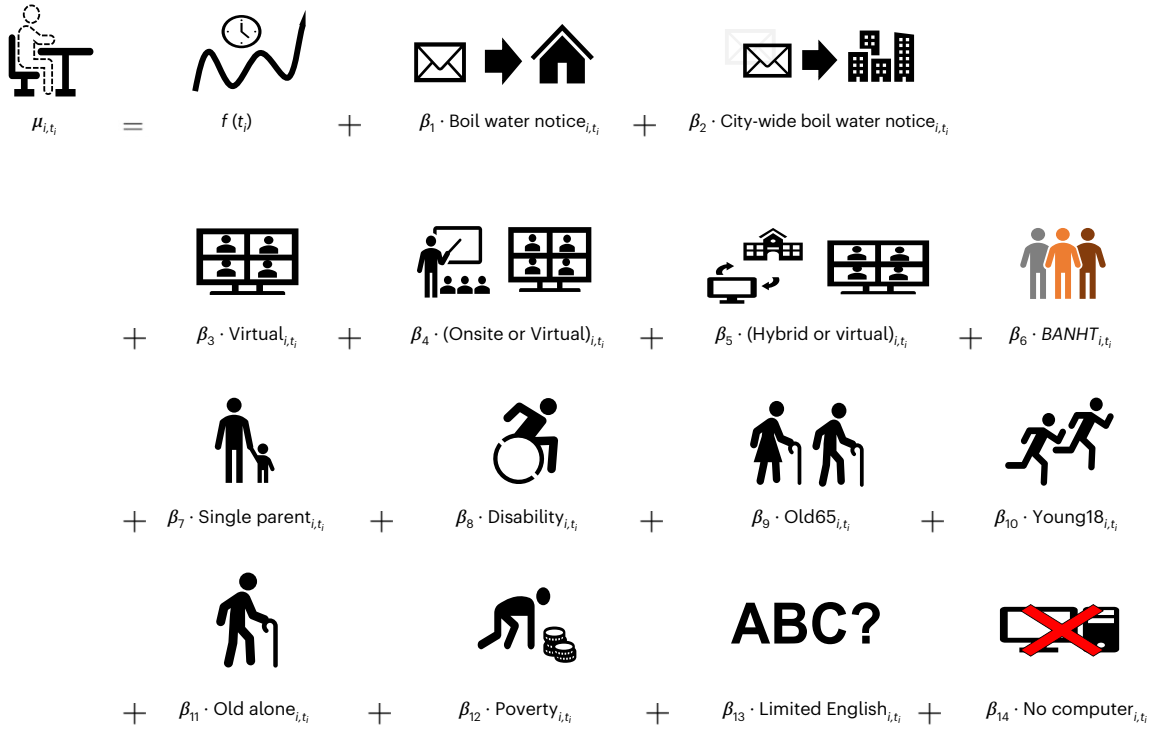

Fig. 3 | An illustration of the GAM used. The model contains a time-varying function, $f(t_i)$, of school attendance at each timepoint t_i for the ith school, and parameters of boil water notice, city-wide boil water notice, a method of instructional delivery in school and vulnerabilities. The notation, $\mu_{i,ti}$, indicates the conditional mean for unexcused absence rates given all the confounding variables and school attendance. In the model, we include a host of census block-level demographic characteristics as follows: boil water notice/advisory, city-wide boil water notice/advisory, virtual, online or virtual, hybrid or virtual, percentage of individuals who identify as Black, Asian, Native American, Hispanic, or 2 or more races (BANHT), percentage of people with disability status, percentage of people older than 65 years, percentage of people younger than 18 years, percentage of people older than 65 years and living alone, percentage of people with limited English, percentage of households with no computer access, percentage of people living in a household under poverty and percentage of single-parent households. For a time-varying function $f(\cdot)$, we considered the cubic regression spline basis function to approximate a non-parametric function.[75] See Supplementary Section Statistical Analysis for the model specification, including the details on types of models and selection of roughness parameters and knot locations. All images are drawn using icons in Microsoft PowerPoint.

change continues to influence extreme weather events, if these infrastructure problems are not quickly and equitably resolved, we anticipate compounded community impacts. Further, the EPA is currently investigating the Mississippi Department of Environmental Quality and the MSDH for allegations that the agencies discriminated against the majority Black population of the city in their funding of water infrastructure and treatment programmes, in violation of Title VI of the Civil Rights Act of 1964[59].

The need for better data infrastructure

Beyond Jackson's water infrastructure issues, there is a non-existent data infrastructure for residents, public health officials and local leaders on the community health impacts of poor water. In this study, we treated BWA as a real-time approximation for community water quality. However, these alerts can also be viewed as a real-time assessment of Jackson's lacking community information systems and local government poor responsiveness to environmental issues. Existing studies that have surveyed residents affected by BWAs showed that when issued, they reach 76–97% of affected persons[60]. It is recommened that water systems experiencing a BWA share a press release to local media outlets (television, radio and local newspapers) detailing the reason for the BWA and safe practices the public should follow[61]. For smaller, more localized emergencies, local water systems are encouraged to 'notify them (those affected) by personal contact, door-hangers, or notes taped to their doors'. Despite these recommendations, BWAs can only be consistently found on MSDH and the City of Jackson's website. Access to these alerts requires internet connectivity, which is still out of reach for 44% of Mississippi's residents, especially Black residents, who make up most of Jackson's population[62,63].

If/when a BWA reaches an affected household in Jackson, they rarely describe the cause of the issue or provide residents with information about what contaminants are expected to be in the water. While directions to boil water may reduce harmful levels of bacteria such as *Escherichia coli*, boiling can increase the concentrations of heavy metals, such as lead. The City of Jackson exceeded the EPA's action level for lead in 2017, and the MSDH currently continues to urge households with young children and pregnant women to take precautions[64]. We are not aware of any protocols for alerting residents of lead contamination. Further, on the boil water advisories we collected, there were no additional instructions noting necessary precautions to take in households with lead-contaminated water. Strict adherence to boil water advisories in households with lead-contaminated water can compound health impacts, especially in women and children. The City of Jackson has taken action to reduce the risk of lead contamination by implementing new corrosion control methods; however, the effectiveness of those measures is negatively impacted by the ongoing system-wide infrastructure challenges.

Conclusions

Our study demonstrates that Jackson's water system failures have wide-ranging effects that impact the city's children and their educational attainment. Each BWA represents a notable hindrance for children being able to consistently attend school. Improving the city's water infrastructure and eliminating the causes of BWAs should be its most

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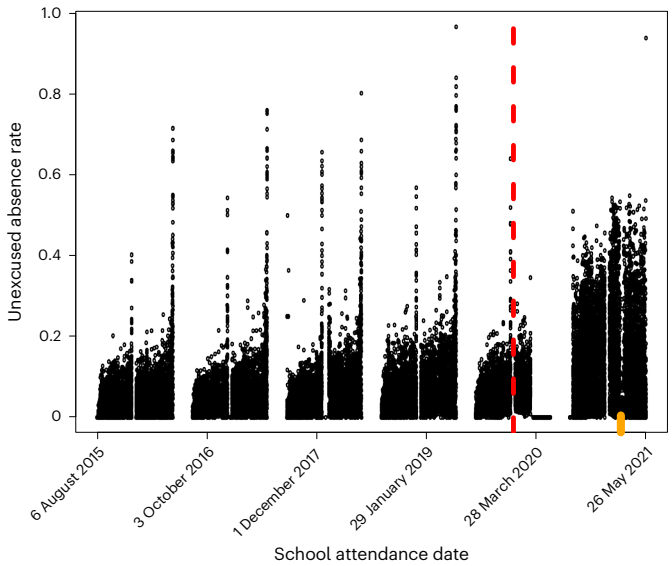

Fig. 4 | The distribution of unexcused absence rates by school attendance date during our study period between 2015 and 2021. The red line indicates the end of period 1 and the beginning of period 2, corresponding to the COVID-19 transition. The observed gaps represent school holidays or breaks. The unexcused absence rate shows different non-linear dynamic patterns during our study period. In particular, the unexcused absence rate has extreme peaks before holidays or breaks. The unexcused absence rate further increases after instructional delivery changed due to the COVID-19 global pandemic. These unexcused absence rate patterns demonstrate the importance of considering two time periods, one before COVID-19 and the other after COVID-19. The orange rug, displayed as a mark along the *x* axis, indicates the school attendance date around 20 February 2021, with a huge drop in unexcused absence rate.

pressing priority. For improving BWA communications, we suggest that municipalities pursue more personal means of contacting residents, such as social media posts, leaving voicemails or conducting door-to-door outreach when resources allow it. Furthermore, we recommend that the MSDH republish a sample press release for local water systems to follow and require its use. The sample press release available on the MSDH website is outdated and is not consistently used by water systems. Such a press release should include information about the cause of the BWA, the population impacted, the public schools impacted and what precautions to take. Additionally, designing and maintaining accessible, consistent and reliable information systems for water-related issues should also be a priority for the city. While our study has considerable strengths, we also have several limitations that should be considered. First, our methods for estimating the number of people per address affected by BWAs (using dasymetric population mapping of census 2010 population counts at census block level proportional to the building footprint area on the basis of OpenStreetMap (OSM) building footprints linked to each residential parcel) may have inaccurately estimated the true number of people impacted. Second, as mentioned previously, the causes of absenteeism are multi-dimensional and exist within individual, family and school domains[42]. In our analysis, we only took into account vulnerabilities at the community level and did not consider individual and family factors. Next steps in our research include moving beyond school- and neighbourhood-level measures and factors and to individual- and household-level measures and factors that may better describe the impacts of BWAs on unexcused absences such as household income, parental/guardian employment status, parental/guardian educational attainment and so on. We also only considered unexcused absences but could also consider additional and educational outcomes such as reading comprehension, grades and test scores[65]. We would also like to examine impacts beyond the school system and into the community, such as economic impacts, health impacts and psychological impacts. Further, we only focused on Jackson and did not consider surrounding communities who are also serviced by the city's water supply. As a result, we are not able to compare our findings with nearby communities.

While our study only focuses on Jackson, we believe our findings will be beneficial in other cities currently struggling with poor water infrastructure and will shed light on the multitude of issues incessant BWAs can bring about[66–68]. Our study also shows that, even in the face of limited data, we can unearth meaningful associations between BWAs and unexcused absences.

Our research team is also committed to constructing accessible and reliable data and mapping repositories and environmental health literacy tools and are currently building a data visualization, 'Mississippi Boiling: The Countdown', to engage the community both within Jackson and across the world about our findings. As part of our community engagement activities, we are currently in the field in Jackson, Mississippi, testing tap water quality for pH, dissolved oxygen, turbidity and per- and polyfluoroalkyl substances[69], and have developed a real-time data portal and reporting tool where local residents can view water quality levels by city, ZIP code and household (via an individualized report that they can access through the portal). We have also released an activity book called 'From the Ground to the Glass' for both children and adults that walks residents through the process of how drinking water moves from its source to their glass. We believe that the combined effect of a well-functioning water system, a well-informed population, and a well-maintained community information system will serve to not only improve community public health but also provide residents of Jackson with the information needed to hold elected officials accountable. In summation, these efforts will serve to reduce the number of barriers a young child in Jackson has to overcome.

Methods

Data collection

BWA data. Information about all BWAs in Jackson is from a freedom of information request from the City of Jackson's Water/Sewer Business Administration Office. BWAs include 2,547 notices between 2015 and 2021. The data consist of notices for the entire city, specific neighbourhoods or ZIP codes, whole streets, numbered sections of streets and even single addresses. Only BWAs issued in 2015 have information on the length of time the notice was in place. As the number of people impacted by each BWA varied considerably, BWAs were linked with impacted individual residential addresses using the tax assessor's parcel data of Hinds County 2021 and OSM building footprint data. We filtered the tax assessor's parcel data for residential parcels (at least one of the building types or land use types indicated residentially) and linked each notice with the associated parcels on the basis of street names and house numbers. Alerts for entire neighbourhoods or ZIP codes were linked with all addresses in the neighbourhood or ZIP code; notices for entire streets were linked to all addresses with the matching street name, and notices with a range of street numbers of a specific street were linked with corresponding addresses that fell within the range. BWA street names were cleaned and adjusted iteratively, that is, all alerts were matched or a reason for no possible match was established (for example, outside of Hinds County or non-residential addresses only). From the original data set, 2,146 alerts were successfully matched to parcel addresses, while 401 (15.7%) BWAs were not matched and thus excluded, yielding 191,748 address-specific BWAs for inclusion in the analysis. Additionally, we included 360,983 address notices associated with nine city-wide BWAs sent out to each address in the city of Jackson on the following dates: 3 May 2015, 10 March 2016, 4 January 2018, 30 November 2018, 24 January 2020, 14 February 2020, 16 February 2021, 18 February 2021 and 30 April 2021. We estimated the number of people per address affected by BWAs using dasymetric population mapping of census 2010 population counts at census block

level proportional to the building footprint area on the basis of OSM building footprints linked to each residential parcel[70].

School attendance data. The JPSD is the second largest school district in Mississippi and serves 21,000 students. Daily school attendance data (enrolment and unexcused absences) were collected for each of the district's 52 schools, including 31 elementary schools, 10 middle schools and 7 high schools, from January 2015 to October 2021. The district's four special programme schools were not included. In our analysis, we define the daily unexcused absences rate as the number of daily unexcused absences divided by the number of daily enrolments for each school.

Instruction delivery during COVID-19. To account for how differences in absences may be confounded by changing instruction due to COVID-19, we obtained instruction delivery methods and corresponding dates during the COVID-19 global pandemic from JPSD. Three types of remote learning occurred (virtual, either onsite or virtual, and either hybrid or virtual) for the JPSD are considered as follows: virtual for all schools from 16 March 2020 to 22 May 2020, and from 10 August 2020 to 18 December 2020, and either onsite or virtual for elementary schools, and either hybrid or virtual for middle and high schools from 19 January 2021 to 26 May 2021.

School zoning data. Zoning information was collected to associate each exposed household with the elementary, middle and high school children were zoned. School zoning information was obtained from JPSD as a series of pdf files with lists of street names and ZIP codes and their associated schools. These lists of streets were parsed, corrected and standardized to match census Topologically Integrated Geographic Encoding and Referencing/Line county-based road names for 2020 using the R packages tigris (version 1.6.1) (ref. 71) and postmastr (version 0.1.0.9000) (ref. 72). These standardized street names and their respective elementary, middle and high school assignments were matched to census road shapefiles on the basis of the street name and ZIP code. Most listed street names (98%) and their respective school assignments were successfully matched with census roads. Census roads within the ZIP codes covered by the JPSD that did not have a listed school assignment were assigned to the physically nearest elementary, middle and high school. Individual property parcels affected by BWAs were matched to their assigned elementary, middle and high schools using the same methodology, parsing and standardizing street names to join the Jackson Public School assignment lists to BWA parcel addresses. Most BWA parcels (95%) and their respective school assignments were successfully matched on the basis of the street name and ZIP code. Parcel addresses that could not be matched on the basis of the street name and ZIP code and those with multiple matching school assignments were assigned to the physically nearest elementary, middle and high school.

BWA vulnerability. The demographic information that described potential community-level vulnerabilities that may confound the relationship between BWAs and school absence rates were collected from the American Community Survey 5 year estimates (2016–2020) at the census block group level[73]. No individual-level or identifiable data were used. These variables include households living in poverty (percentage of people living in a household with an income under the nationally defined poverty rate), race/ethnicity (percentage of individuals who identify as Black, Asian, Native American, Hispanic, or 2 or more races), single-parent household (percentage of male- or female-headed household with no spouse present), elderly (percentage of people older than 65 years), young (percentage of people younger than 18 years), access to information (percentage of people speaking English less than well and percentage of households having access to a personal computer or other device with internet access), disability (percentage of people with disability status) and social isolation (percentage of people older than 65 years and living alone). We calculate a vulnerability score by summing the percentages of the above-mentioned variables for each census block group.

Statistical analysis. We utilized a GAM with the identity link function and Gaussian distribution. An illustration of the model is shown in Fig. 3, where the outcome is the daily unexcused absence rates. A non-parametric, time-varying function $f(\cdot)$ is used to estimate school attendance at each timepoint (typically day) for the ith school. The parameters, $\beta_k, k = 1,\ldots,14$, for each covariate are included in the model.

Additional temporal considerations. We implemented the GAM method for two time periods. The first period reflects the attendance date between 5 August 2015 and 31 December 2019, and the second period extends from 1 January 2020 to 26 May 2021. We partitioned the data in this way for two reasons. First, we wanted to account for differences in the number of households impacted by the BWA at different timepoints, which was 15% larger in 2020 and 2021 relative to previous years (Table 1). Second, we aim to estimate different patterns of unexcused absence rates before and after 1 January 2020, related to the remote/hybrid learning strategies implemented by the JPSD during the COVID-19 global pandemic (Fig. 4). All confounders included in the model—except for school attendance date and dummy variables—are standardized. The computations were implemented using the R package mgcv (version 1.8-40) (ref. 74).

Lag effects. The BWA data we collected from Jackson had information on their duration for the year 2015 only. In 2015, a BWA lasted, on average, approximately 2 days. We assumed this duration as our best approximation for how long BWAs last across all years. To account for the potential lag effect of BWAs, we consider three lag periods: (1) the notice date, (2) the notice date and the following day and (3) the notice date and two subsequent days. Among these three lag periods, one is selected for each model on the basis of the Bayesian information criterion measure as described in the Supplementary Section Statistical Analysis. Following, the value of the variable 'BWA' is 1 if the school attendance date is within the chosen period and 0 otherwise. Additionally, we create a dummy variable related to the city-wide BWA equal to 1 if the school attendance date matched with the city-wide boil water notices dates defined previously, and 0 otherwise. The BWAs and all the vulnerability variables are pre-processed to be included in the model (Supplementary Fig. 1).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The data that support the findings of this study are available on request from the corresponding author (E.D.W.). The data are not publicly available due to a need to obtain permission from JPSD before sharing.

Code availability

The code that supports the findings of this study is available on request from the corresponding author (E.D.W.).

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Author contributions

Conceptualization E.D.W. Data curation E.D.W., K.T. and M.L. Formal analysis M.K., R.D.V., F.D., K.T., M.L., A.S.-M., M.M. and E.D.W. Investigation M.K., R.D.V., F.D., A.S.-M., M.M. and E.D.W. Methodology M.K., R.D.V., F.D. and E.D.W. Project administration E.D.W., R.D.V. and F.D. Resources E.D.W., F.D. and R.D.V. Software E.D.W., R.D.V. and F.D. Supervision E.D.W., F.D. and R.D.V. Validation E.D.W., M.L., K.T., F.D. and R.D.V. Visualization F.D., A.S.-M., M.M. and M.K. Writing—original draft M.K., R.D.V., F.D., K.T., M.L., A.S.-M., M.M., S.S.O., C.E., S.B., B.H., K.C., N.F.L. and E.D.W. Writing—review and editing M.K., R.D.V., F.D., K.T., M.L., A.S.-M., M.M., S.S.O., C.E., S.B., B.H., N.F.L., J.B., A.P.C., K.C. and E.D.W.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s44221-023-00062-z.

Correspondence and requests for materials should be addressed to E. D. Walker.

Peer review information *Nature Water* thanks Joshua Childs and the other, anonymous, reviewers for their contribution to the peer review of this work.

Ethics and Inclusion Statement This research has included local researchers throughout the research process, from its study design to the authorship of publications. E.D.W., the senior and corresponding author, was born and raised in Jackson, Mississippi. Further, two co-authors are from the University of Mississippi, and have actively worked on water quality issues across the state. We worked with the JPSD, routinely updated them of our progress, shared our findings with the JPSD and shared all data with them, including all GIS maps we created from the pdfs of JPSD data. The roles and responsibilities were agreed to beforehand, and we adopted an 'open' draft workspace, where all authors were allowed to write, edit and revise sections, in real time.

Global code of conduct for research in resource-poor settings This research included Mississippi-based partnerships and collaborations. Further, we are committed to sharing our data with the City of Jackson and the Jackson Public School District.

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Corresponding author(s): Erica D Walker

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Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☒	☐	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☒	☐	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	ArcGIS, R
Data analysis	Statistical analysis was coded in R and mapping was conducted in ArcGIS using Python.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The data that support the findings of this study are available on request from the corresponding author [EDW]. The data are not publicly available due to a need to obtain permission from JPSD before sharing.

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Using information about all BWA in Jackson is from a Freedom of Information request from the City of Jackson's Water/Sewer Business Administration Office, from 2015 - 2021; daily school attendance data (enrollment and unexcused absences) for each of the Jackson Public School District's 52 schools, including 31 elementary schools, 10 middle schools, and 7 high schools; instruction delivery methods and corresponding dates during the COVID-19 global pandemic from JPSD; school zoning information (as a series of pdf files with lists of street names and ZIP codes and their associated schools); and community-level vulnerabilities that may confound the relationship between BWA and school absence rates from the ACS 5 -year estimates (2016-2020) at the census block group level, we examined the relationship between boil water advisories and unexcused absences in the City of Jackson, Mississippi.
Research sample	We used all data collected. The sample size was every parcel, school, and boil water alert in Jackson, between 2015 and 2021.
Sampling strategy	We used all data available to us. There was no sampling strategy.
Data collection	Co-Authors ML and KT, SB, NFL, and EW were all involved in obtaining data, transcribing data (when appropriate) and mapping data
Timing and spatial scale	We collected data from 2015 - October 2021 for the entire City of Jackson, Mississippi.
Data exclusions	From the original data set, 2,153 alerts were successfully matched to parcel addresses, while 494 (15%) BWAs were not matched and thus excluded yielding 191,748 address-specific BWAs for inclusion in the analysis.
Reproducibility	We have carefully documented our steps in the METHODS section and will share all data and code so that our findings can reproduced by anyone who is interested.
Randomization	N/A
Blinding	N/A

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☐	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Dual use research of concern

Policy information about dual use research of concern

Hazards

Could the accidental, deliberate or reckless misuse of agents or technologies generated in the work, or the application of information presented in the manuscript, pose a threat to:

No	Yes
☒	☐ Public health
☒	☐ National security
☒	☐ Crops and/or livestock
☒	☐ Ecosystems
☒	☐ Any other significant area

Experiments of concern

Does the work involve any of these experiments of concern:

No	Yes
☒	☐ Demonstrate how to render a vaccine ineffective
☒	☐ Confer resistance to therapeutically useful antibiotics or antiviral agents
☒	☐ Enhance the virulence of a pathogen or render a nonpathogen virulent
☒	☐ Increase transmissibility of a pathogen
☒	☐ Alter the host range of a pathogen
☒	☐ Enable evasion of diagnostic/detection modalities
☒	☐ Enable the weaponization of a biological agent or toxin
☒	☐ Any other potentially harmful combination of experiments and agents