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Disinfection Byproducts and Inorganic Contaminants in the U.S. Correctional Facility Public Water Systems

Ellen B. Bannon, Wil Lieberman-Cribbin, Raenita Spriggs, Paris B. Adkins-Jackson,
Yoshira Ornelas Van Horne, Robbie M. Parks, Seth J. Prins, and Anne E. Nigra

ABSTRACT

Background: Few studies have evaluated drinking water contaminants for people incarcerated in the United States. We predicted that community water systems (CWSs) that exclusively serve correctional facilities would report elevated contaminant concentrations compared to all other CWSs.

Methods: Concentrations of inorganic contaminants (arsenic, chromium, fluoride, nitrate, uranium) and disinfection byproducts (total trihalomethanes and haloacetic acids) were derived from routine compliance monitoring records in the U.S. Environmental Protection Agency's (EPA) Six-Year Review database. We evaluated adjusted geometric means and 90th percentile differences of 2017–2019 average concentrations of inorganic contaminants and disinfection byproducts for 194 correctional facility CWSs (serving 437,394 people) and 42,434 other CWSs. We calculated the population served by correctional facility CWSs equal to or exceeding the U.S. EPA's maximum contaminant level nationwide, by region, and by seasonal monitoring periods.

Results: In the Southwest, correctional facility CWSs reported higher arsenic concentrations (adjusted geometric mean 2.75 μg/L, 95% CI 1.46, 5.19) compared to all other CWSs (1.06 μg/L, 95% CI 1.03, 1.09; p value < 0.001) and higher adjusted 90th percentile arsenic concentrations. In fall, nationwide adjusted 90th percentile concentrations were higher for total trihalomethanes (difference 15.2 μg/L, 95% CI 11.3, 19.2) and haloacetic acids (12.3 μg/L, 95% CI 10.6, 13.9) in correctional facility CWSs compared with all other CWSs.

Conclusions: We identified regional and seasonal inequities in regulated drinking water contaminants impacting people incarcerated in the United States. Comparing our findings to those previously published, inequities in arsenic exposure for people incarcerated in the Southwest have improved since 2006, supporting that regulatory, enforcement, and legal actions have reduced exposures.

Keywords: incarceration, drinking water, environmental justice, disinfection byproducts

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Ellen B. Bannon, Raenita Spriggs, Dr. Robbie M. Parks and Dr. Anne E. Nigra are at the Department of Environmental Health Sciences, Columbia University Mailman School of Public Health, New York, New York, USA. Dr. Wil Lieberman-Cribbin is at Northwell, New Hyde Park, New York, USA. Dr. Wil Lieberman-Cribbin is at the Department of Occupational Medicine, Epidemiology and Prevention, Donald and Barbara Zucker School of Medicine at Hofstra/Northwell, Hempstead, New York, USA. Dr. Paris B. Adkins-Jackson is at the Departments of Epidemiology and Sociomedical Sciences, Columbia University Mailman School of Public Health, New York, New York, USA. Dr. Seth J. Prins is at the Department of Community Health Sciences, School of Public Health, The State University of New York, Downstate Health Sciences University, Brooklyn, New York, USA. Dr. Yoshira Ornelas Van Horne is at the Department of Environmental Health Sciences, University of California Los Angeles, Los Angeles, California, USA.

INTRODUCTION

Over 90% of United States (U.S.) residents receive some drinking water from community water systems (CWSs), federally regulated public drinking water systems that serve the same populations year-round.[1] The U.S. Environmental Protection Agency's (EPA) National Primary Drinking Water regulations set maximum contaminant levels (MCLs) for over 80 regulated contaminants, including disinfection byproducts (e.g., haloacetic acids, total trihalomethanes) and inorganic chemicals (e.g., arsenic, chromium). CWSs are required to conduct routine compliance monitoring for these contaminants.[2] Chronic exposure to regulated contaminants at levels above regulatory standards is associated with adverse health outcomes such as an increased risk of cancer, damage to the liver, kidney, or nervous system, and thyroid problems.[3] For certain contaminants (e.g., arsenic), some associations persist with chronic exposure below the regulatory standard.[4] Recent studies have identified significant environmental injustices and regional and sociodemographic inequities in regulated CWS contaminant concentrations across the United States.[5] Contaminant concentrations differ greatly by region, rurality, and by the proportion of residents that are racialized and minoritized (e.g., Black, Indigenous, Latine) and socioeconomically disadvantaged.[6] Inequities in drinking water contaminants are created and reinforced through inequities in the natural (e.g., climate change, hydrogeology), built (e.g., infrastructure, land use), and sociopolitical environments (e.g., social vulnerability, political disenfranchisement), and by the actions (or inactions) of national, state, local, and private actors.[7]

Although access to safe drinking water is recognized as a universal human right by the United Nations, vulnerable populations, such as those incarcerated in the United States, remain inadequately protected from exposure to regulated drinking water contaminants at levels relevant for health.[8] People incarcerated in the United States face compounding structural inequities, including racism (they are disproportionately racialized as Black), intergenerational impoverishment, and health disparities (they are more likely than the non-incarcerated population to have a chronic health condition).[9] For example, in the Southwestern U.S., average arsenic concentrations from 2006 to 2011 were twice as high for correctional facility CWSs (6.41 μg/L, 95% CI 3.48, 9.34) compared to all other CWSs (3.11 μg/L, 95% CI 2.97, 3.24).[10] Additionally, a quarter of correctional facility CWSs exceeded the U.S. EPA's arsenic MCL of 10 ug/L.[11] Furthermore, instances of drinking water contamination impacting people incarcerated in U.S.

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[1] US Environmental Protection Agency, "Report on the Environment: Drinking Water," US EPA, accessed August 16, 2025, https://cfpub.epa.gov/roe/indicator.cfm?i=45.

[2] Office of Water US Environmental Protection Agency, "The Standardized Monitoring Framework: A Quick Reference Guide," *Ground Water*, 2020.

[3] Office of Water US Environmental Protection Agency, "National Primary Drinking Water Regulations," Overviews and Factsheets, US EPA, November 30, 2015, https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

[4] Office of Research and Development US Environmental Protection Agency, "IRIS Toxicological Review of Inorganic Arsenic," US EPA, January 2025, https://iris.epa.gov/static/pdfs/0278_summary.pdf.

[5] Anne E. Nigra et al., "Inequalities in Public Water Arsenic Concentrations in Counties and Community Water Systems across the United States, 2006–2011," *Environmental Health Perspectives* 128, no. 12 (2020): 127001, https://doi.org/10.1289/EHP7313; Anne E. Nigra and Ana Navas-Acien, "Arsenic in US Correctional Facility Drinking Water, 2006–2011," *Environmental Research* 188 (September 2020): 109768, https://doi.org/10.1016/j.envres.2020.109768; Clare Pace et al., "Inequities in Drinking Water Quality Among Domestic Well Communities and Community Water Systems, California, 2011–2019," *American Journal of Public Health* 112, no. 1 (2022): 88–97, https://doi.org/10.2105/AJPH.2021.306561; Filippo Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11: A Cross-Sectional Study," *The Lancet Planetary Health* 6, no. 4 (2022): e320–30, https://doi.org/10.1016/S2542–5196(22)00043–2; Irene Martinez-Morata et al., "Nationwide Geospatial Analysis of County Racial and Ethnic Composition and Public Drinking Water Arsenic and Uranium," *Nature Communications* 13, no. 1 (2022): 7461, https://doi.org/10.1038/s41467–022-35185–6; Anne E. Nigra et al., "Socioeconomic Vulnerability and Public Water Arsenic Concentrations across the US," *Environmental Pollution* 313 (November 2022): 120113, https://doi.org/10.1016/j.envpol.2022.120113; Arianna Q. Tariqi and Colleen C. Naughton, "Water, Health, and Environmental Justice in California: Geospatial Analysis of Nitrate Contamination and Thyroid Cancer," *Environmental Engineering Science* 38, no. 5 (2021): 377–88, https://doi.org/10.1089/ees.2020.0315; Laurel A. Schaider et al., "Environmental Justice and Drinking Water Quality: Are There Socioeconomic Disparities in Nitrate Levels in U.S. Drinking Water?," *Environmental Health* 18, no. 1 (2019): 3, https://doi.org/10.1186/s12940–018-0442–6.

[6] Nigra et al., "Inequalities in Public Water Arsenic Concentrations in Counties and Community Water Systems across the United States, 2006–2011"; Nigra and Navas-Acien, "Arsenic in US Correctional Facility Drinking Water, 2006–2011"; Pace et al., "Inequities in Drinking Water Quality Among Domestic Well Communities and Community Water Systems, California, 2011–2019"; Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11"; Martinez-Morata et al., "Nationwide Geospatial Analysis of County Racial and Ethnic Composition and Public Drinking Water Arsenic and Uranium"; Nigra et al., "Socioeconomic Vulnerability and Public Water Arsenic Concentrations across the US"; Tariqi and Naughton, "Water, Health, and Environmental Justice in California"; Schaider et al., "Environmental Justice and Drinking Water Quality."

[7] Carolina L. Balazs and Isha Ray, "The Drinking Water Disparities Framework: On the Origins and Persistence of Inequities in Exposure," *American Journal of Public Health* 104, no. 4 (2014): 603–11, https://doi.org/10.2105/AJPH.2013.301664.

[8] Nigra and Navas-Acien, "Arsenic in US Correctional Facility Drinking Water, 2006–2011."

[9] Laura M Maruschak et al., "Medical Problems of State and Federal Prisoners and Jail Inmates, 2011–12," Bureau of Justice Statistics, February 2015, https://bjs.ojp.gov/content/pub/pdf/mpsfpji1112.pdf.

[10] *Ibid*. Nigra and Navas-Acien.

[11] *Ibid*. Nigra and Navas-Acien.

correctional facilities have been reported in media outlets and lawsuits, including cases of drinking water contaminated with nitrate (Salinas Valley State Prison, California Institution for Women, California Institution for Men),[12] arsenic (Texas Department of Criminal Justice Wallace Pack Unit, Kern Valley State Prison),[13] manganese (Massachusetts Correctional Institution at Norfolk),[14] and raw sewage (Miami-Dade County Jail, Fulton County Jail, New Mexico Women's Correctional Facility, Logan County Jail).[15] For people who are incarcerated, drinking water exposures are of particular concern because access to alternative sources (i.e., bottled water) or point-of-use treatment systems is very limited. Other region-specific inequities in drinking water contaminants impacting people incarcerated in U.S. correctional facilities are possible but to our knowledge have not been systematically evaluated. Moreover, water system infrastructure and contaminant occurrence and concentrations are likely to be severely impacted by climate change, with more frequent and severe drought conditions, higher temperatures, and more frequent flash flooding.[16]

Our objective was to provide an updated evaluation of inequities in regulated contaminant concentrations in public water systems exclusively serving incarcerated populations nationwide, leveraging the most recently published nationwide monitoring data by the U.S. EPA (2012–2019). We compared contaminant concentrations of inorganic and disinfection byproducts in CWSs that exclusively serve correctional facilities versus all other CWSs, stratified by region for all contaminants and season for disinfection byproducts. We restricted our analysis to regulated contaminants that are commonly detected in CWS routine compliance monitoring records nationwide (arsenic, chromium, fluoride, nitrates, uranium, and two classes of disinfection byproducts, total trihalomethanes and total haloacetic acids; haloacetic acids are regulated as the sum of dichloroacetic acid, trichloroacetic acid, monochloroacetic acid, bromoacetic acid, and dibromoacetic acid). We hypothesized that contaminant concentrations would be higher for correctional facility CWSs compared to all other CWSs. For disinfection byproducts, we hypothesized that differences across correctional facility CWSs and other CWSs would be most pronounced during seasons with the highest concentrations (typically summer and fall).

METHODS

Community water system (CWS) contaminant estimates

We developed CWS-level contaminant concentration estimates for regulated contaminants using 2012–2019 routine compliance monitoring records published in the U.S. EPA's database supporting the Fourth Six-Year Review (SYR4 database), as previously described in detail.[17] In brief, the SYR4 database represents over 88% of public water systems that serve a total of 301 million people annually (92% of the total population served by public water systems nationwide).[18] In the SYR4 period (2012–2019), Georgia, Michigan, Mississippi, and New Mexico did not submit data.[19] The SYR4 data are the most recent SYR data released by the U.S. EPA.

We used 2012–2019 CWS-level contaminant concentration estimates that were previously developed by our team and published for regulated inorganic contaminants (including arsenic, chromium, fluoride, nitrate) as well as for uranium (which is regulated as a radionuclide but categorized as an inorganic contaminant for this analysis) and disinfection byproducts (total trihalomethanes and haloacetic acids).[20] We restricted our analysis to these inorganic and disinfection byproduct contaminants because these are frequently detected in CWSs across the U.S. Monitoring records include both treated (i.e.,

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[12] John Dannenberg, "Prison Drinking Water and Wastewater Pollution Threaten Environmental Safety Nationwide," Prison Legal News, November 15, 2007, https://www.prisonlegalnews.org/news/2007/nov/15/prison-drinking-water-and-wastewater-pollution-threaten-environmental-safety-nationwide/.

[13] Neal v. Director of Department of Corrections and Rehabilitations, "Case No. 1:14-Cv-02067-JLT (PC)," *United States District Court Eastern District of California*, April 9, 2015, https://truthout.org/app/uploads/2022/02/KVSP-Arsenic-Lawsuits.pdf.

[14] Panagioti Tsolkas, "Water at Massachusetts Prison Under Scrutiny from Prisoners, Advocates, Public Agencies," Prison Legal News, June 5, 2018, https://www.prisonlegalnews.org/news/2018/jun/5/water-massachusetts-prison-under-scrutiny-prisoners-advocates-public-agencies/.

[15] Dannenberg, "Prison Drinking Water and Wastewater Pollution Threaten Environmental Safety Nationwide."

[16] Nathan L. Engle, "The Role of Drought Preparedness in Building and Mobilizing Adaptive Capacity in States and Their Community Water Systems," *Climatic Change* 118, no. 2 (2013): 291–306, https://doi.org/10.1007/s10584–012-0657–4.

[17] Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11"; Office of Water US Environmental Protection Agency, "Six-Year Review 4 Compliance Monitoring Data (2012–2019)," Announcements and Schedules, US EPA, February 29, 2024, United States, https://www.epa.gov/dwsixyearreview/six-year-review-4-compliance-monitoring-data-2012–2019.

[18] Office of Water US Environmental Protection Agency, "Analysis of Occurrence Data from the Third Six-Year Review of Existing National Primary Drinking Water Regulations: Chemical Phase Rules and Radionuclides Rules," US EPA, December 2016, https://www.epa.gov/sites/default/files/2016–12/documents/810r16014.pdf; Office of Water US Environmental Protection Agency, "Data Management and Quality Assurance/Quality Control Process for the Fourth Six-Year Review Information Collection Request Dataset," US EPA, February 2024, https://www.epa.gov/system/files/documents/2024–03/syr4-data-management-and-quality-assurance_508.pdf.

[19] US Environmental Protection Agency, "Data Management and Quality Assurance/Quality Control Process for the Fourth Six-Year Review Information Collection Request Dataset."

[20] Nigra et al., "Inequalities in Public Water Arsenic Concentrations in Counties and Community Water Systems across the United States, 2006–2011"; Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11."

finished) and raw (i.e., untreated) samples. We converted all records to μg/L and then aggregated contaminant concentration estimates for each CWS within the calendar year. To best reflect concentrations distributed to consumers after potential treatment, we used only treated sample averages when the treated average concentration was lower than the raw average concentration.

For each contaminant, the U.S. EPA sets a compliance monitoring framework that determines how frequently CWSs must collect routine compliance monitoring samples based on contaminant type, source water type, and concentrations measured in prior compliance monitoring samples.[21] We averaged contaminant concentrations to time periods corresponding to the U.S. EPA's required compliance monitoring framework for CWSs because this approach reduces differential missingness by contaminant type, source water type, and concentrations measured in prior monitoring samples.[22] Inorganic contaminants (arsenic, chromium, fluoride, nitrates) and disinfection byproducts (total trihalomethanes, total haloacetic acids) were averaged across the most recent compliance monitoring cycle of 2017–2019, and uranium was averaged across 2008–2016 to coincide with the compliance monitoring requirements of the Radionuclide Rule.[23] To generate uranium averages for the entire 2008–2016 compliance monitoring period, we additionally incorporated uranium records from the Third Six-Year Review period (covering years 2008–2011) that we previously cleaned, compiled, and published. [24] To reflect differences across contaminants in method detection limits, we rounded arsenic, chromium, and uranium concentrations to two decimal places, disinfection byproduct concentrations to one decimal place, and fluoride and nitrate concentrations to integers.[25] Because some disinfection byproduct concentrations vary significantly with season and changes in temperature, we also evaluated average disinfection byproduct concentrations for the 2017–2019 time period stratified by season (Fall = October–December, Winter = January–March, Spring = April–June, Summer = July–September; these season periods align with U.S. EPA's quarterly compliance monitoring schedule for disinfection byproducts).[26] We merged concentration estimates with system inventory information extracted from the U.S. EPA Safe Drinking Water Information System, including counties served, the size of the population served, and source water type (surface versus groundwater).[27] We assigned the CWSs to U.S. regions (categorized in prior studies as Alaska/Hawaii, Central Midwest, Eastern Midwest, Mid-Atlantic, New England, Pacific Northwest, Southeast, Southwest, defined in Table 1).[28]

Correctional facilities

We identified correctional facility CWSs by keyword search of system names for "correction," "correct inst," "corr inst," "corr center," "corr fac," "detention," "detn," "jail," "juvenile," "incarceration," "minimum," "penitentiary," "prison," "re-entry," "sheriff," "women," "ADOC" (Arizona Department of Corrections), "ADC" (Arkansas Department of Corrections), "CDCR" (Colorado Department of Corrections), or "TDCJ" (Texas Department of Criminal Justice), and manually checked system names (e.g., "Valley State Prison").

Statistical analysis

We compared the characteristics of correctional facility CWSs versus all other CWSs in our database, including the total population served, average population served per CWS, the number of CWSs served by groundwater sources, and the number of CWSs within each U.S. region. For each contaminant, we evaluated the number and percent of CWSs with average concentrations equal to or exceeding two concentration thresholds relevant for regulation and compliance monitoring: (1) the U.S. EPA's MCL, the current regulatory standard which incorporates public health benefit, technical feasibility of reducing contaminant concentrations, and the cost of implementing more advanced treatment systems for CWSs to achieve compliance, and (2) the modal minimum reporting level set by U.S. EPA for the SYR4. The

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[21] Office of Water US Environmental Protection Agency, *Arsenic and Clarifications to Compliance and New Source Monitoring Rule: A Quick Reference Guide*, January 2001, https://eec.ky.gov/Environmental-Protection/Compliance-Assistance/DCA%20Resource%20Document%20Library/ArsenicClarificationsComplianceRuleFactSheet.pdf.

[22] Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11"; US Environmental Protection Agency, *Arsenic and Clarifications to Compliance and New Source Monitoring Rule: A Quick Reference Guide*; US Environmental Protection Agency, "National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring," Federal Register vol. 66, no. 14 (January 22, 2001): 6976, January 22, 2001, https://www.govinfo.gov/content/pkg/FR-2001-01-22/pdf/FR-2001-01-22.pdf.

[23] US Environmental Protection Agency, "The Standardized Monitoring Framework: A Quick Reference Guide"; Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11."

[24] Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11."

[25] *Ibid.* Ravalli et al.

[26] Office of Water US Environmental Protection Agency, "Occurrence Assessment for the Final Stage 2 Disinfectants and Disinfection Byproducts Rule," US EPA, December 2005, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1005ED2.txt.

[27] US Environmental Protection Agency, "Six-Year Review 4 Compliance Monitoring Data (2012–2019)"; Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11."

[28] *Ibid.* Nigra et al., "Inequalities in Public Water Arsenic Concentrations in Counties and Community Water Systems across the United States, 2006–2011"; Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11."

Table 1. Characteristics of Community Water Systems (CWSs) Exclusively Serving Correctional Facilities Versus All Other CWSs Nationwide

	Correctional facilities	*All other CWSs*
N CWSs	194	42,434
Total population served	437,394	301,680,144
Mean population served per CWS (SD)	2,255 (2,109)	7,109 (70,241)
N (%) served by groundwater	160 (82.5%)	32,163 (75.8%)
N CWSs (total population served) by region		
Alaska/Hawaii	3 (762)	457 (2,187,063)
Central Midwest	6 (12,950)	3,398 (12,218,201)
Eastern Midwest	34 (70,948)	6,522 (42,203,148)
Mid-Atlantic	33 (67,046)	5,839 (52,420,663)
New England	2 (451)	1,936 (12,076,747)
Pacific Northwest	11 (8,947)	4,851 (13,346,404)
Southeast	56 (103,221)	9,447 (77,492,013)
Southwest	49 (173,069)	9,979 (89,735,199)

Analysis was restricted to CWSs, which reported routine compliance monitoring records to the U.S. Environmental Protection Agency (U.S. EPA) for the fourth Six-Year Review (SYR4), covering years 2012–2019.

CWSs exclusively serving correctional facilities were identified via a keyword search. Regions were defined based on those used for previous analyses of inorganic contaminants: Alaska/Hawaii (AK, HI), Central Midwest (ND, SD, NE, KS, MO), Eastern Midwest (WI, IL, IN, MI, OH, MN, IA), Mid-Atlantic (PA, MD, DC, DE, NY, NJ, CT, RI), New England (MA, VT, NH, ME), Pacific Northwest (WA, OR, MT, WY, and ID), Southeast (OK, AR, LA, MS, AL, FL, GA, TN, KY, SC, NC, VA, WV), and Southwest (CA, NV, UT, CO, AZ, NM, TX).

CWSs, community water systems.

minimum reporting level reflects the lowest concentration of an analyte that can be reliably measured by a laboratory and often represents the most health protective threshold that is technically feasible given analytic limitations. For chromium and fluoride, we applied the World Health Organization's guideline for drinking water quality (WHO GDWQ) instead of the U.S. EPA's MCL because the WHO water quality value was lower and more health protective.[29]

We further evaluated the odds ratio (OR) of exceeding the U.S. EPA's MCL for correctional facility CWSs versus all other CWSs after adjusting for the size of the population served and source water type via logistic regression. We did not compute ORs unless > 5 correctional facility CWSs and > 5 other CWSs exceeded the MCL. We next compared the unadjusted arithmetic mean (true population average concentrations) and the adjusted geometric mean (adjusting for the size of the population served and source water type) of contaminant concentrations for correctional facility CWSs versus all other CWSs. We also evaluated the difference in contaminant 90th percentile concentrations comparing correctional facility CWSs versus all other CWSs after adjusting for the size of the population served and source water type via quantile regression using the "quantreg" R package. We chose 90th percentile concentrations because central measures of tendency (e.g., arithmetic and geometric means) are conservative parameters in studies of inequities in environmental exposures that mask exposures occurring at the highest ends of the distribution. These high-end exposures are the most relevant for public health exposure reduction interventions and regulatory action.[30]

Prior work indicates that inequities in U.S. public water exposures occur in regions with both a high percentage of marginalized residents reliant on public water and high concentrations of specific contaminants in drinking water.[31] Therefore, we repeated these main analyses for inorganic contaminants in the Southwest and for disinfection byproducts in the Southeast and Mid-Atlantic regions because these regions have the highest CWS concentrations of these contaminants, respectively. As an exploratory analysis, we also stratified contaminant analyses by all other regions. Finally, we calculated the total population served by correctional facility CWSs equal to or exceeding the minimum reporting level, $\frac{1}{2}$ MCL, or MCL for (1) any inorganic contaminant, (2) any disinfection byproduct, and (3) at least one inorganic contaminant and one disinfection byproduct. As concentrations of some disinfection byproducts are influenced by seasonal changes in temperature and concentrations are highest in the fall season (October–December), we

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[29] World Health Organization, ed., *Guidelines for Drinking-Water Quality*, Fourth edition incorporating the first addendum (World Health Organization, 2017).

[30] Ravalli et al., "Sociodemographic Inequalities in Uranium and Other Metals in Community Water Systems across the USA, 2006–11"; Marie-Abele C. Bind et al., "Beyond the Mean: Quantile Regression to Explore the Association of Air Pollution with Gene-Specific Methylation in the Normative Aging Study," *Environmental Health Perspectives* 123, no. 8 (2015): 759–65, https://doi.org/10.1289/ehp.1307824.

[31] Martinez-Morata et al., "Nationwide Geospatial Analysis of County Racial and Ethnic Composition and Public Drinking Water Arsenic and Uranium."

categorized CWSs as exceeding a given threshold when either the annual or fall disinfection byproduct average was greater than or equal to the threshold value (in contrast, inorganic contaminant concentrations are largely stable across seasons).

In sensitivity analyses, we calculated the total population served by correctional facility CWSs exceeding concentration thresholds using annual disinfection byproduct averages only (instead of annual and fall averages) to categorize CWSs as exceeding the threshold. An additional sensitivity analysis calculated the number of CWSs and total population served for disinfection byproducts and inorganic contaminants exceeding concentration thresholds stratified by U.S. region for annual and fall averages. Total trihalomethanes and haloacetic acids are regulated by U.S. EPA as the sum of all individual contaminants within each group (haloacetic acids include dichloroacetic acid, trichloroacetic acid, monochloroacetic acid, bromoacetic acid, and dibromoacetic acid). We repeated our main analyses for individual trihalomethanes (bromodichloromethane, bromoform, chloroform, and dibromochloromethane) and haloacetic acids (dibromoacetic acid, dichloroacetic acid, monobromoacetic acid, monochloroacetic acid, and trichloroacetic acid) to determine if individual disinfection byproducts were driving the differences in CWS concentrations. We did not assess these individual disinfection byproducts in the main analysis because we anticipated substantial and differential missingness in the SYR4 contaminant monitoring records, given that these contaminants do not have MCLs. We additionally evaluated trends in mean concentrations over time, comparing correctional facility CWSs and all other CWSs by plotting multiple averaging periods (multiple 3-year averaging periods for inorganics, and yearly averaging periods for disinfection byproducts[32]), rather than just relying on the most recent compliance monitoring period. All data management and analysis were conducted in R version 4.4.2.

Data availability

Contaminant concentrations for the 194 correctional facility CWSs identified in this analysis are directly available in an Excel file in the Supplementary Appendix SA1.

RESULTS

From a total of 42,628 CWSs serving a total population of 302,117,538 people, we identified 194 correctional facility CWSs that served a total population of 437,394 people (Table 1, Fig. 1). Correctional facility CWSs served smaller populations (mean 2,255) than all other CWSs (mean 7,109). Correctional facility CWSs served the largest populations in the Southwest (173,069 persons across 49 CWSs) and Southeast (103,221 persons across 56 CWSs) regions. Distributions were skewed right for all inorganic contaminants and disinfection byproducts.

Nationwide, the number of correctional facility CWSs with average concentration estimates available for inorganic contaminants was n = 157 (arsenic), *n* = 154 (chromium), n = 154 (fluoride), n = 65 (uranium), and n = 134 (nitrate) (Table 2). For both the minimum reporting level and MCL thresholds, the nationwide number (%) of exceedances for correctional facility CWSs was similar to those for all other CWSs. The number (%) of correctional facility CWSs exceeding the MCL/WHO GDWQ was 2 (1.3%) for arsenic, 0 (0%) for chromium, 2 (1.3%) for fluoride, 0 (0%) for uranium, and 0 (0%) for nitrate. Nationwide, inorganic contaminant concentrations (adjusted geometric means) and exceedances were similar for both correctional facility CWSs and all other CWSs (Table 2). In the Southwest, correctional facility CWSs reported higher arsenic concentrations (adjusted geometric mean 2.75 μg/L, 95% CI 1.46, 5.19) compared to all other CWSs (1.06 μg/L, 95% CI 1.03, 1.09; *p* value <0.001), higher adjusted 90th percentile arsenic concentrations (difference 0.77, 95% CI 0.34, 1.19), and were more likely to exceed the minimum reporting level (68.3% versus 41.4%), but were not more likely to exceed the arsenic MCL (2.4% versus 2.6%) (Table 2). The unadjusted arithmetic mean 2017–2019 arsenic concentration was 1.33 μg/L higher for correctional facility CWSs compared to all other CWSs in the Southwest. In addition, correctional facility CWSs in the Southwest reported higher chromium concentrations (adjusted geometric mean 0.26 μg/L, 95% CI 0.09, 0.80) compared to all other CWSs (0.15 μg/L, 95% CI 0.14, 0.16; *p* value = 0.04). In the Southwest, adjusted 90th percentile concentrations of fluoride and uranium were significantly lower in correctional facility CWSs compared to all other CWSs. Two correctional facility CWSs in the Southwest (serving 2,010 persons) reported average concentrations exceeding at least one inorganic contaminant MCL (Supplementary Table S2).

For disinfection byproducts, the number of correctional facility CWSs nationwide with average concentration estimates available was n = 145 (annual total trihalomethanes), n = 143 (annual total haloacetic acids), n = 28 (fall total trihalomethanes), and n = 27 (fall total haloacetic acids) (Table 3). The number of correctional facility CWSs exceeding the MCL was 2 (1.4%) for annual trihalomethanes, 0 (0%) for annual haloacetic acids, 4 (14.3%) for fall trihalomethanes, and 0 (0%) for fall haloacetic acids. Annual adjusted 90th percentile total trihalomethane concentrations were lower for correctional facility CWSs compared to all other CWSs nationwide (difference –5.0 μg/L, 95% CI –5.7, –4.3). In the fall, nationwide adjusted 90th percentile concentrations were higher for both total trihalomethanes

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[32] Office of Water US Environmental Protection Agency, "Comprehensive Disinfectants and Disinfection Byproducts Rules (Stage 1 and Stage 2): Quick Reference Guide," US EPA, August 2010, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100C8XW.txt.

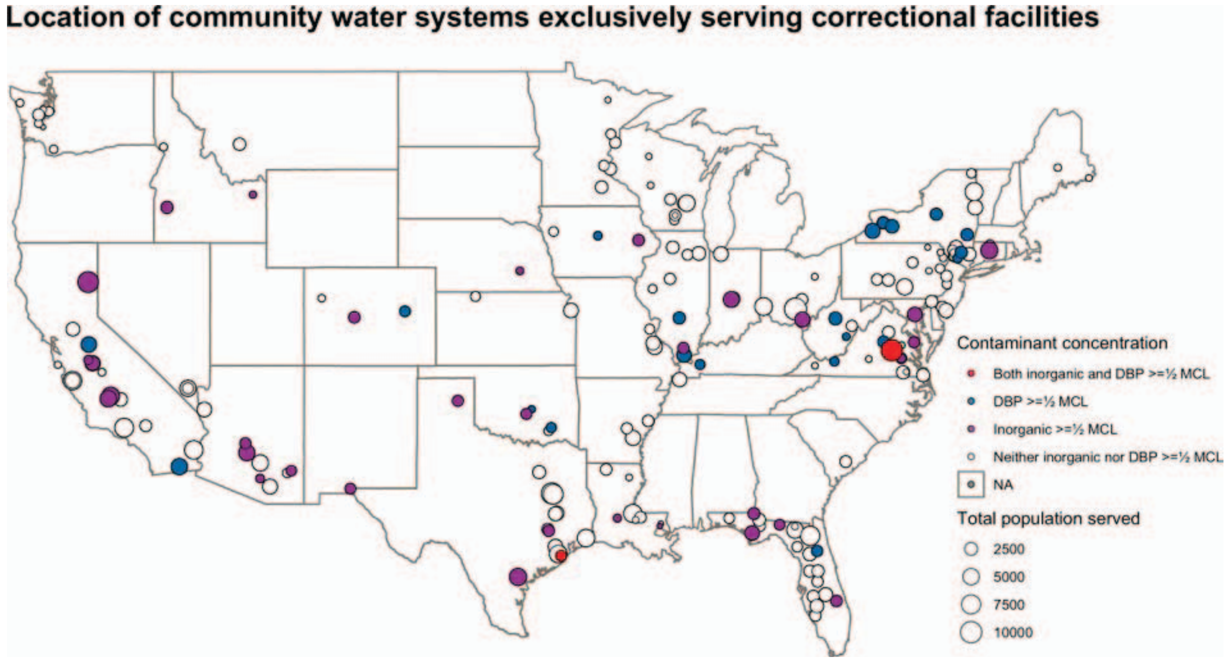

FIG. 1. Facilities are indicated by open circles. The size of the circle corresponds to the total population served by the CWS. The color of the circles indicates whether the 2017–2019 average concentrations for any disinfection byproduct (DBP, in blue), inorganic contaminant (in purple), or both (in red) were equal to or exceeding $1/2$ the maximum contaminant level (MCL). For chromium and fluoride, we applied the World Health Organization's guideline for drinking water quality (WHO GDWQ) levels as these were lower and more health protective. For disinfection byproducts, we considered CWSs to exceed the threshold when either annual or fall (October–December) average concentration values met the criteria. CWS, community water system.

(difference 15.2 μg/L, 95% CI 11.3, 19.2) and haloacetic acids (12.3 μg/L, 95% CI 10.6, 13.9) in correctional facility CWSs compared with all other CWSs. Adjusted 90th percentile concentrations were significantly higher in the Mid-Atlantic region for correctional facility CWSs, for both total trihalomethanes (difference 14.5 μg/L, 95% CI 9.6, 19.3) and haloacetic acids (difference 12.4 μg/L, 95% CI 6.7, 18.2).

In additional analyses assessing mean differences in contaminant concentrations over multiple averaging periods, we did not identify any meaningful changes in mean differences over time for either inorganics or disinfection byproducts, except for smaller disparities in arsenic concentrations in more recent years (Supplementary Fig. S2). In our exploratory analysis stratifying inorganic contaminants and disinfection byproducts by all regions, we found that fluoride was lower in correctional facility CWSs compared to all CWSs in the Eastern Midwest, and uranium was lower in correctional facility CWSs compared to all CWSs in the Southeast (Supplementary Table S3). For disinfection byproducts, we found that trihalomethanes were significantly lower in correctional facility CWSs in the Central Midwest, Eastern Midwest, and Southwest, compared to all CWSs, and haloacetic acids were lower in correctional facility CWSs in the Eastern Midwest and Southwest (Supplementary Table S4).

The total population served by correctional facility CWSs exceeding concentration thresholds using annual disinfection byproduct averages was similar to findings relying on annual and fall averages (Supplementary Table S1 and Supplementary Fig. S1). When considering CWSs exceeding the MCL with either overall averages or fall average concentrations, three correctional facility CWSs in the Southeast (serving 2,515 persons) reported exceeding at least one disinfection byproduct MCL and two correctional facility CWSs in the Mid-Atlantic (serving 2,675 persons) reported exceeding at least one disinfection byproduct MCL (Supplementary Table S2). Differences in trihalomethane concentrations were likely explained by chloroform or other individual compounds (Supplementary Table S5). Results were similar analyzing individual haloacetic acids in fall comparing correctional facilities CWS compared with all other CWSs nationwide, in the Southeast and in the Mid-Atlantic (Supplementary Table S6).

No correctional facility CWSs reported exceeding the MCLs for both a disinfection byproduct and inorganic contaminant (Fig. 2). When considering CWSs exceeding the MCL with either overall average or fall average concentrations, five CWSs (2.6%; serving 5,190 people) and four CWSs (2.1%; serving 5,570 people) reported exceeding the MCLs for either a disinfection byproduct or inorganic contaminant, respectively (Fig. 2). A total of 26 (13.4%) and 35 (18.0%) correctional facility CWSs reported exceeding $1/2$ MCL for a disinfection byproduct or inorganic contaminant, respectively, and two CWSs (1.0%) serving 11,168 people exceeded $1/2$ MCL for both a disinfection byproduct and inorganic contaminant

Table 2. Distribution of Inorganic Contaminants Comparing Community Water Systems (CWSs) Exclusively Serving Correctional Facilities versus All Other CWSs Nationwide and in the Southwest

	Nationwide		Southwest	
	Correctional facilities	*All other CWSs*	*Correctional facilities*	*All other CWSs*
Arsenic, 2017–2019				
N CWSs	157	31,109	41	8,102
N (%) ≥MRL (1 μg/L)	57 (36.3%)	8,765 (28.2%)	28 (68.3%)	3,416 (41.4%)
N (%) ≥MCL (10 μg/L)	2 (1.3%)	328 (1.1%)	1 (2.4%)	207 (2.6%)
OR (95% CI) of MCL exceedance[a]	—[f]	1.00 (reference)	—[f]	1.00 (reference)
AM (95% CI), μg/L[b]	1.73 (1.24, 2.21)	1.41 (1.37, 1.44)	3.53 (1.96, 5.11)	2.20 (2.11, 2.29)
Adjusted GM (95% CI), μg/L[c]	0.81 (0.63, 1.05)	0.70 (0.69, 0.71)	2.75 (1.46, 5.19)	1.06 (1.03, 1.09)
Kruskal–Wallis *p* value[d]	$p = 0.06$	—	$p < 0.001$	—
90th percentile difference (95% CI), μg/L[e]	0.45 (–0.69, 1.59)	(reference)	0.77 (0.34, 1.19)	(reference)
Chromium, 2017–2019				
N CWSs	154	30,286	41	7,874
N (%) ≥MRL (1 μg/L)	30 (19.5%)	5,175 (17.1%)	14 (34.1%)	1,504 (19.1%)
N (%) ≥WHO GDWQ (50 μg/L)	0 (0%)	7 (0%)	0 (0%)	6 (0.1%)
OR (95% CI) of GDWQ exceedance[a]	—[f]	—	—[f]	—
AM (95% CI), μg/L[b]	1.02 (0.51, 1.53)	0.80 (0.73, 0.86)	1.87 (0.56, 3.17)	1.05 (0.96, 1.13)
Adjusted GM (95% CI), μg/L[c]	0.14 (0.10, 0.21)	0.13 (0.13, 0.13)	0.26 (0.09, 0.80)	0.15 (0.14, 0.16)
Kruskal–Wallis *p* value[d]	$p = 0.53$	—	$p = 0.04$	—
90th percentile difference (95% CI), μg/L[e]	0.10 (–2.13, 2.33)	(reference)	3.10 (2.91, 3.30)	(reference)
Fluoride, 2017–2019				
N CWSs	154	30,935	41	7,938
N (%) ≥MRL (100 μg/L)	89 (57.8%)	19,572 (63.3%)	28 (68.3%)	6,410 (80.8%)
N (%) ≥WHO GDWQ (1,500 μg/L)	2 (1.3%)	1,241 (4.0%)	1 (2.4%)	596 (7.5%)
OR (95% CI) of GDWQ exceedance[a]	—[f]	1 (reference)	—[f]	1 (reference)
AM (95% CI), μg/L[b]	298 (234, 362)	363 (358, 369)	439 (291, 587)	493 (479, 507)
Adjusted GM (95% CI), μg/L[c]	4 (1, 11)	12 (11, 12)	29 (3, 321)	95 (87, 104)
Kruskal–Wallis *p* value[d]	$p = 0.14$	—	$p = 0.78$	—
90th percentile difference (95% CI), μg/L[e]	43 (–182, 268)	(reference)	–270 (–397, –143)	(reference)
Uranium, 2008–2016[g]				
N CWSs	65	15,404	21	4,404
N (%) ≥MRL (1 μg/L)	24 (36.9%)	5,944 (38.6%)	14 (66.7%)	2,379 (54.0%)
N (%) ≥MCL (30 μg/L)	0 (0%)	133 (0.9%)	0 (0%)	80 (1.8%)
OR (95% CI) of MCL exceedance[a]	—[f]	—	—[f]	—
AM (95% CI), μg/L[b]	1.76 (1.08, 2.43)	2.90 (2.73, 3.06)	3.06 (1.67, 4.46)	4.69 (4.22, 5.17)
Adjusted GM (95% CI), μg/L[c]	0.70 (0.47, 1.04)	0.98 (0.96, 1.01)	2.32 (0.84, 6.42)	1.51 (1.44, 1.59)
Kruskal–Wallis *p* value[d]	$p = 0.40$	—	$p = 0.57$	—
90th percentile difference (95% CI), μg/L[e]	–1.84 (–5.11, 1.43)	(reference)	–4.54 (–6.45, –2.63)	(reference)

(*continued*)

Table 2. (Continued)

	Nationwide		Southwest	
	Correctional facilities	*All other CWSs*	*Correctional facilities*	*All other CWSs*
Nitrate, 2017–2019				
N CWSs	134	29,859	43	8,772
N (%) ≥MRL (100 µg/L)	75 (56.0%)	18,015 (60.3%)	26 (60.5%)	5,356 (61.1%)
N (%) ≥MCL (10,000 µg/L)	0 (0%)	76 (0.3%)	0 (0%)	57 (0.6%)
OR (95% CI) of MCL exceedance[a]	—[f]	—	—[f]	—
AM (95% CI), µg/L[b]	808 (582, 1,033)	1,067 (1,046, 1,089)	1,035 (590, 1,481)	1,176 (1,127, 1,225)
Adjusted GM (95% CI), µg/L[c]	39 (14, 108)	48 (46, 51)	71 (12, 442)	92 (84, 100)
Kruskal–Wallis p value[d]	$p = 0.30$	—	$p = 0.89$	—
90th percentile difference (95% CI), µg/L[e]	–413 (–1,330, 504)	(reference)	–560 (–1,760, 640)	(reference)

The MRL reflects the lowest concentration of an analyte that can be reliably measured by a laboratory. In this analysis, we used the modal MRL reported across all CWSs as defined by U.S. EPA for the Fourth Six-Year Review. We chose the WHO GDWQ when the value was lower and more health protective than the U.S. EPA MCL. States in the Southwest include CA, NV, UT, CO, AZ, NM, and TX.

[a] Adjusted for source water type and size of the population served, via logistic regression.

[b] Unadjusted.

[c] Adjusted for source water type and population size served.

[d] Non-parametric Kruskal–Wallis p value comparing the contaminant distribution for correctional facility CWSs versus all other CWSs.

[e] Difference in 90th percentile concentrations for correctional facility CWSs versus all other CWSs adjusted for source water type and size of the population served, via quantile regression using the "quantreg" package.

[f] Inadequate number (<5) in both groups exceeding the regulatory threshold.

[g] Uranium is regulated as a radionuclide and averages reflect the 2008–2016 monitoring period established by the Radionuclides Rule.

AM, arithmetic mean; CI, Confidence Interval; GM, geometric mean; MCL, maximum contaminant level set by the United States Environmental Protection Agency (U.S. EPA); MRL, minimum reporting level; OR, odds ratio; WHO GDWQ, World Health Organization Guidelines for drinking water quality.

Table 3. Distribution of Disinfection Byproduct (DBP) Contaminants Comparing Community Water Systems (CWSs) Exclusively Serving Correctional Facilities versus All Other CWSs Nationwide, in the Southeast, and in the Mid-Atlantic, 2017–2019

	Nationwide-Annual		*Nationwide-Fall*		*Southeast-Fall*		*Mid-Atlantic-Fall*	
	Correctional facilities	*All other CWSs*	*Correctional facilities*	*All other CWSs*	*Correctional facilities*	*All other CWSs*	*Correctional facilities*	*All other CWSs*
Total trihalometdanes								
N CWSs	145	22,417	28	8,792	9	3,001	9	1,161
N (%) ≥MRL (1 μg/L)	124 (85.5%)	20,492 (91.4%)	26 (92.9%)	8,637 (98.2%)	9 (100%)	2,976 (99.2%)	8 (88.9%)	1,138 (98%)
N (%) ≥MCL (80 μg/L)	2 (1.4%)	355 (1.6%)	4 (14.3%)	435 (4.9%)	2 (22.2%)	222 (7.4%)	2 (22.2%)	44 (3.8%)
OR (95% CI) of MCL exceedance[a]	—[f]	1 (reference)	—[f]	1 (reference)	—[f]	1 (reference)	—[f]	1 (reference)
AM (95% CI), μg/L[b]	19.6 (16.0, 23.2)	26.4 (26.1, 26.7)	45.7 (32.8, 58.6)	41.0 (40.4, 41.5)	59.0 (25.8, 92.3)	46.7 (45.6, 47.8)	54.2 (34.2, 74.3)	40.9 (39.6, 42.1)
Adjusted GM (95% CI), μg/L[c]	5.7 (3.9, 8.4)	7.3 (7.1, 7.4)	8.9 (2.4, 33.3)	18.7 (17.9, 19.6)	12.5 (3.5, 44.9)	30.9 (29.0, 33.0)	27.1 (1.6, 472.2)	8.0 (7.1, 9.0)
Kruskal–Wallis *p* value[d]	$p < 0.001$	—	$p = 0.48$	—	$p = 0.44$	—	$p = 0.06$	—
90th percentile difference (95% CI), μg/L[e]	−5.0 (−5.7, −4.3)	(reference)	15.2 (11.3, 19.2)	(reference)	87.2 (−289.4, 463.7)	(reference)	14.5 (9.6, 19.3)	(reference)
Total haloacetic acids								
N CWSs	143	21,981	27	8,714	9	3,035	9	1,135
N (%) ≥MRL (1 μg/L)	109 (76.2%)	18,291 (83.2%)	25 (92.6%)	8,471 (97.2%)	9 (100%)	2988 (98.5%)	8 (88.9%)	1,098 (96.7%)
N (%) ≥MCL (60 μg/L)	0 (0%)	150 (0.7%)	0 (0%)	184 (2.1%)	0 (0%)	83 (2.7%)	0 (0%)	24 (2.1%)
OR (95% CI) of MCL exceedance[a]	—[f]	—	—[f]	—	—[f]	—	—[f]	—
AM (95% CI), μg/L[b]	9.8 (7.7, 11.9)	14.0 (13.8, 14.2)	28.8 (21.8, 35.7)	22.9 (22.5, 23.2)	32.6 (21.4, 43.8)	27.3 (26.7, 28.0)	34.1 (18.5, 49.7)	22.7 (21.8, 23.7)
Adjusted GM (95% CI), μg/L[c]	3.0 (2.1, 4.2)	2.9 (2.9, 3.0)	4.7 (1.3, 16.2)	8.0 (7.6, 8.4)	6.4 (3.5, 11.8)	12.7 (11.9, 13.6)	16.7 (1.1, 248.6)	3.5 (3.0, 4.1)
Kruskal–Wallis *p* value[d]	$p < 0.001$	—	$p = 0.05$	—	$p = 0.19$	—	$p = 0.06$	—
90th percentile difference (95% CI), μg/L[e]	−2.2 (−7.3, 2.8)	(reference)	12.3 (10.6, 13.9)	(reference)	8.1 (−47.1, 63.2)	(reference)	12.4 (6.7, 18.2)	(reference)

Kruskal–Wallis *p* value refers to non-parametric Kruskal–Wallis tests comparing the distribution of contaminants for correctional facilities versus all other CWSs. The MRL reflects the lowest concentration of an analyte that can be reliably measured by a laboratory. We used the modal MRL (1 μg/L) for specific trihalomethanes and haloacetic acids reported across all CWSs as defined by U.S. EPA for the Fourth Six-Year Review. States in the Southeast include OK, AR, LA, MS, AL, FL, GA, TN, KY, SC, NC, VA, and WV. States in the Mid-Atlantic include PA, MD, DC, DE, NY, NJ, CT, and RI. For disinfection byproducts, we considered CWSs to exceed the threshold when either annual or fall (October–December) average concentration values met the criteria. Fall estimates are derived from monitoring records taken from October to December.

[a] Adjusted for source water type and size of the population served, via logistic regression.

[b] Unadjusted.

[c] Adjusted for source water type and size of the population served.

[d] Non-parametric Kruskal–Wallis *p* value comparing the contaminant distribution for correctional facility CWSs versus all other CWSs.

[e] Difference in 90th percentile concentrations for correctional facility CWSs versus all other CWSs adjusted for source water type and size of the population served, via quantile regression using the “quantreg” package.

[f] Inadequate number (<5) in both groups exceeding the regulatory threshold.

(Fig. 1, Fig. 2). These 2 CWSs were located in Virginia and Texas (Fig. 1).

DISCUSSION

This study evaluated the distribution of seven regulated public water contaminants for CWSs exclusively serving correctional facilities in the United States. Similar to our prior study evaluating 2006–2011 monitoring data, correctional facility CWSs in the Southwest reported higher arsenic concentrations compared to all other CWSs.[33] However, the magnitude of this difference was greatly attenuated in more recent monitoring data from 2017 to 2019 (unadjusted arithmetic mean difference: 1.33 µg/L for 2017–2019, and 5.25 µg/L for 2006–2011), supporting that additional regulatory and enforcement efforts since 2011 have been successful in reducing drinking water arsenic disparities for populations incarcerated in the Southwest. We unexpectedly observed lower 90th percentile concentrations of uranium and fluoride in correctional facility CWSs in the Southwest. There were also significantly higher 90th percentile concentrations of trihalomethanes and haloacetic acids for correctional facility CWSs during the fall monitoring season, when concentrations are the highest nationwide. Our findings support prior observations that larger disparities in drinking water contaminants occur at the higher ends of the exposure distribution.

Our findings support that exposure to disinfection byproducts through CWSs is widespread throughout the United States.[34] Disinfection byproducts are formed when reactive disinfectants such as chlorine interact with organic matter and other precursors.[35] Formation of these byproducts is dependent on various environmental and operational factors, including the type and concentration of disinfectant used, contact and residence time, water temperature, pH, and the amount of organic matter and other precursors such as bromide present in water.[36] Some disinfection byproduct concentrations are heavily influenced by season—warmer water temperatures in the summer and fall are associated with an increase in dissolved organic matter, partially due to increased microbial activity.[37] These factors likely explain the significantly higher disinfection byproduct concentrations estimated for CWSs during the fall monitoring season, especially in the Southeastern U.S.

Disinfection byproducts occur as complex mixtures and are often studied as classes (e.g., total trihalomethanes and total haloacetic acids) because of the large number of individual disinfection byproducts (over 600 identified). The U.S. EPA currently only sets MCLs for bromate (10 µg/L), chlorite (1,000 µg/L), total trihalomethanes (80 µg/L), and total haloacetic acids (60 µg/L, regulated as the sum of dichloroacetic acid, trichloroacetic acid, monochloroacetic acid, bromoacetic acid, and dibromoacetic acid).[38] For the individual disinfection byproducts comprising each class, the MCL goal values (which consider only public health benefit) range from 0 µg/L (for possible human carcinogens bromate, bromodichloromethane, and dichloroacetic acid) to 800 µg/L (for chlorite).[39] Extensive epidemiological evidence has evaluated the association between trihalomethanes measured in water and colorectal and bladder cancers, with effect measure modification by age, sex, and genetic susceptibility (especially *CYP2E1* and *GSTT1*).[40] Other cancer sites are less extensively studied.[41] Trihalomethanes have been widely studied in epidemiological analyses

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[33] *Ibid*. Nigra and Navas-Acien.

[34] Danielle N. Medgyesi et al., "Drinking Water Disinfection Byproducts, Ingested Nitrate, and Risk of Endometrial Cancer in Postmenopausal Women," *Environmental Health Perspectives* 130, no. 5 (2022): 057012, https://doi.org/10.1289/EHP10207; Cristina M. Villanueva et al., "Overview of Disinfection By-Products and Associated Health Effects," *Current Environmental Health Reports* 2, no. 1 (2015): 107–15, https://doi.org/10.1007/s40572–014-0032-x; Rupal Sinha et al., "A Review on Trihalomethanes and Haloacetic Acids in Drinking Water: Global Status, Health Impact, Insights of Control and Removal Technologies," *Journal of Environmental Chemical Engineering* 9, no. 6 (2021): 106511, https://doi.org/10.1016/j.jece.2021.106511.

[35] Shahid Parvez et al., "Exposure Characterization of Haloacetic Acids in Humans for Exposure and Risk Assessment Applications: An Exploratory Study," *International Journal of Environmental Research and Public Health* 16, no. 3 (2019): 471, https://doi.org/10.3390/ijerph16030471.

[36] Katrin Doederer et al., "Factors Affecting the Formation of Disinfection By-Products during Chlorination and Chloramination of Secondary Effluent for the Production of High Quality Recycled Water," *Water Research* 48 (January 2014): 218–28, https://doi.org/10.1016/j.watres.2013.09.034; Bixiong Ye et al., "Factors Influencing Disinfection By-Products Formation in Drinking Water of Six Cities in China," *Journal of Hazardous Materials* 171, nos. 1–3 (2009): 147–52, https://doi.org/10.1016/j.jhazmat.2009.05.117.

[37] Elias Munthali et al., "Drivers of Variability in Disinfection By-Product Formation Potential in a Chain of Thermally Stratified Drinking Water Reservoirs," *Environmental Science: Water Research & Technology* 8, no. 5 (2022): 968–80, https://doi.org/10.1039/D1EW00788B.

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[39] *Ibid*. US Environmental Protection Agency.

[40] S Richardson et al., "Occurrence, Genotoxicity, and Carcinogenicity of Regulated and Emerging Disinfection by-Products in Drinking Water: A Review and Roadmap for Research," *Mutation Research/Reviews in Mutation Research* 636, nos. 1–3 (2007): 178–242, https://doi.org/10.1016/j.mrrev.2007.09.001; Tarik Benmarhnia et al., "Heterogeneity in the Relationship between Disinfection By-Products in Drinking Water and Cancer: A Systematic Review," *International Journal of Environmental Research and Public Health* 15, no. 5 (2018): 979, https://doi.org/10.3390/ijerph15050979; Kenneth P. Cantor et al., "Polymorphisms in *GSTT1*, *GSTZ1*, and *CYP2E1*, Disinfection By-Products, and Risk of Bladder Cancer in Spain," *Environmental Health Perspectives* 118, no. 11 (2010): 1545–50, https://doi.org/10.1289/ehp.1002206.

[41] Emilie Helte et al., "Exposure to Drinking Water Trihalomethanes and Risk of Cancer: A Systematic Review of the Epidemiologic Evidence and Dose–Response Meta-Analysis," *Environmental Health Perspectives* 133, no. 1 (2025): 016001, https://doi.org/10.1289/EHP14505.

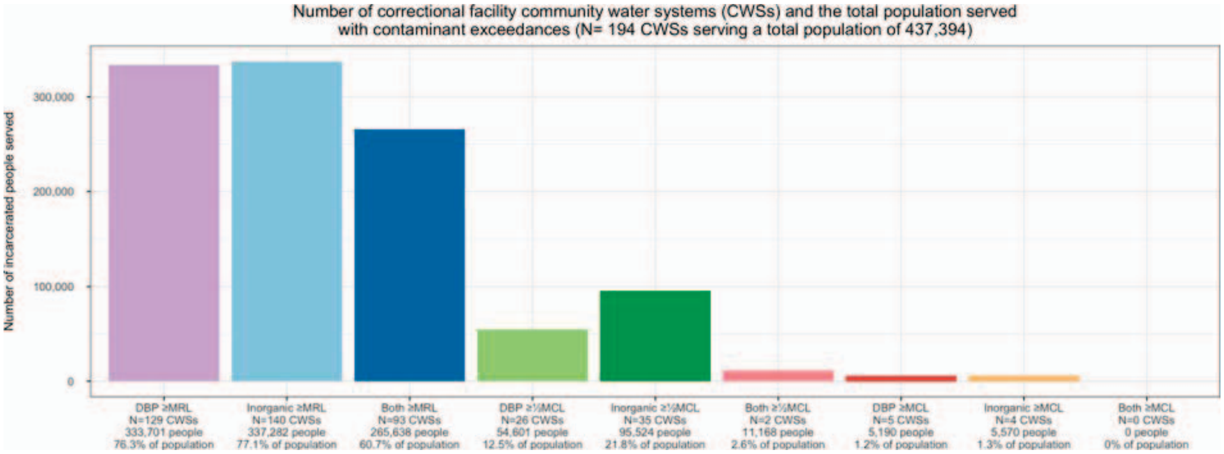

FIG. 2. For disinfection byproducts, we considered CWSs to exceed the threshold when either annual or fall (October–December) average concentration values met the criteria. DBP, disinfection byproduct (either total trihalomethanes, total haloacetic acids, or both); MCL, maximum contaminant level set by the U.S. Environmental Protection Agency; MRL, minimum reporting level.

and have been used as markers of total disinfection byproduct exposure because they are widely prevalent and present at higher concentrations.[42] For haloacetic acids, substantial experimental evidence supports that these compounds are mutagenic, genotoxic, and carcinogenic, although epidemiological studies of the association between these compounds in drinking water with cancer outcomes in general U.S. populations are much more limited.[43] Experimental evidence also supports that individual haloacetic acids are associated with hepatoxicity (dichloroacetic acid) and birth defects and impaired fertility (dibromoacetic acid).[44]

Our findings support that people incarcerated in U.S. correctional facilities served by regulated public water systems exclusively serving correctional facilities are exposed to significantly higher concentrations of carcinogenic or possibly carcinogenic compounds (arsenic, trihalomethanes, haloacetic acids) in drinking water compared to the general U.S. population in areas and during seasons when these contaminant concentrations are generally the highest.[45] However, our exploratory analysis stratifying by other regions (with overall lower disinfection byproduct concentrations) indicated lower disinfection byproduct concentrations for correctional facility CWSs in some regions, supporting that such disparities are region-specific. The region-specific nature of these disparities could reflect regional differences in drinking water source, infrastructure, or enforcement, and supports that disparities impacting marginalized communities are often more extreme at the higher ends of the exposure distribution. Cancer is the leading cause of death for people currently incarcerated in prisons (30% of all deaths), and several studies support that people formerly incarcerated in U.S. correctional facilities experience increased cancer death rates and shorter survival times compared to the general U.S. population.[46] Further studies should evaluate nationwide disparities in carcinogenic drinking water contaminant exposures for all people incarcerated in U.S. correctional facilities and assess whether drinking water exposures are associated with cancer outcomes in these populations. There are few opportunities for people incarcerated in U.S. correctional facilities to access alternative drinking water sources or point-of-use treatment devices in the event of compromised drinking water quality.[47] Even when available for purchase, bottled water is not an affordable or sustainable option.[48]

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[42] Benmarhnia et al., "Heterogeneity in the Relationship between Disinfection By-Products in Drinking Water and Cancer."

[43] Richardson et al., "Occurrence, Genotoxicity, and Carcinogenicity of Regulated and Emerging Disinfection by-Products in Drinking Water"; Michael J. Plewa et al., "Mammalian Cell Cytotoxicity and Genotoxicity of the Haloacetic Acids, a Major Class of Drinking Water Disinfection By-products," *Environmental and Molecular Mutagenesis* 51, nos. 8–9 (2010): 871–78, https://doi.org/10.1002/em.20585; Mark G. Muellner et al., "Human Cell Toxicogenomic Analysis of Bromoacetic Acid: A Regulated Drinking Water Disinfection By-product," *Environmental and Molecular Mutagenesis* 51, no. 3 (2010): 205–14, https://doi.org/10.1002/em.20530.

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[47] *Ibid*. Nigra and Navas-Acien.

[48] Jenny Rempel et al., "The Human Right to Water: A 20-Year Comparative Analysis of Arsenic in Rural and Carceral Drinking Water Systems in California," *Environmental Health Perspectives*

Our analysis has several limitations. First, we did not evaluate water contaminant concentrations for the entire population incarcerated in the United States. Many people incarcerated in U.S. correctional facilities are served by CWSs that also serve other communities and were therefore not categorized as correctional facility CWSs in this analysis. Our findings are therefore not generalizable to incarcerated populations that share a public water system with other non-incarcerated communities. We restricted our analysis to correctional facility CWSs because we predicted that people incarcerated in U.S. correctional facilities served by these systems would be especially vulnerable to elevated drinking water contaminants because of the absence of social and political capital compared to consumers who are not incarcerated.[49] We developed CWS contaminant concentration estimates for only 194 facilities (approximately 3.0% of 6,738 correctional facilities nationwide),[50] covering a population of 437,394 (approximately 23.9% of the estimated 1,827,600 total number of incarcerated persons in 2022).[51] Future studies should assess public drinking water systems serving all correctional facilities. Because the states of Georgia, Michigan, Mississippi, and New Mexico did not submit data to the SYR4, our findings are also not generalizable to incarcerated populations in these states.

Additionally, we relied on 3-year (2017–2019) seasonal and annual average contaminant concentrations using routine compliance monitoring records collected for the U.S. EPA's SYR4 database to align these exposure estimates with EPA monitoring periods. In analyses of environmental exposure, measures of central tendency such as geometric or arithmetic means are conservative parameters that mask, underestimate, and do not reflect cumulative contaminant exposure inequities impacting the most highly exposed residents.[52] For disinfection byproducts, we find larger absolute differences in correctional CWS total trihalomethane and haloacetic acid concentrations when restricting to the fall monitoring period and when assessing adjusted 90th percentile concentrations, supporting that our findings for three-year averages and mean differences likely underestimate cumulative exposure inequities for people incarcerated in U.S. correctional facilities. Although disinfection byproduct concentrations differ within distribution systems and residence time is a strong predictor of disinfection byproduct occurrence and concentration, we were unable to account for sampling location in our analysis. Under the Disinfection Byproducts Rule, U.S. EPA requires CWSs to monitor for disinfection byproducts at sampling locations with the highest residence times. However, the compliance monitoring records included in the U.S. EPA's SYR4 database do not include information on sampling location, and to account for differential missingness, we generated average CWS values for the entire quarterly monitoring season. Our estimates for each CWS are therefore an average of all monitoring samples collected throughout a CWS's distribution system for a given monitoring period. Although we predict that this overall averaging approach has similarly underestimated inequities in seasonal and three-year average disinfection byproduct concentrations, future studies could leverage monitoring records for individual states that retain sampling location information to determine the magnitude of the bias that our approach may introduce.

CONCLUSION

The present study demonstrates that people incarcerated in U.S. correctional facilities are exposed to higher concentrations of arsenic, trihalomethanes, and haloacetic acids in drinking water compared to the general U.S. population, specifically in regions of the United States with the highest overall concentrations of these contaminants. Technical, financial, and managerial support, additional enforcement, and other immediate exposure reduction interventions should be directed to all CWSs, including correctional facility CWSs, to reduce concentrations and inequities in drinking water contaminants, particularly in regions where average contaminant concentrations are more likely to exceed MCL values for arsenic, total trihalomethanes, and haloacetic acids. Our analysis also supports that disparities in drinking water arsenic exposure for incarcerated populations in the Southwest have improved over time, suggesting that regulatory, enforcement, and legal efforts to address these exposure disparities have been successful. Further studies should assess drinking water contaminant inequities for people incarcerated in U.S. correctional facilities nationwide. Future epidemiological studies can leverage our findings to evaluate whether inequities in these water contaminants are associated with major causes of morbidity and mortality for people currently and formerly incarcerated in U.S. correctional facilities such as cancer, cardiovascular disease, liver disease, and respiratory illnesses.

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[51] Emily Buehler and Rich Kluckow, "Correctional Populations in the United States, 2022 – Statistical Tables | Bureau of Justice Statistics," accessed August 16, 2025, https://bjs.ojp.gov/library/publications/correctional-populations-united-states-2022-statistical-tables.

[52] Rempel et al., "The Human Right to Water"; Bind et al., "Beyond the Mean."

and lawsuits related to drinking water quality for people who are incarcerated in the United States. He was dedicated to improving the health and well-being of people who are currently and formerly incarcerated.

AUTHORS' CONTRIBUTIONS

E.B.: Formal analysis, writing—original draft, visualization. A.E.N.: Conceptualization, methodology, formal analysis, resources, writing—original draft, supervision, funding acquisition. R.S., P.B.A.-J., Y.O.V.H., R.M.P., S.J.P., W.L.C.: Writing—review and editing.

AUTHOR DISCLOSURE STATEMENT

The authors declare that they have no competing interests.

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SUPPLEMENTARY MATERIALS

Supplementary Data
Supplementary Appendix

Address correspondence to:
Ellen Bannon
Department of Environmental Health Sciences
Columbia University Mailman School of Public Health
722 W 168th St
11th Floor 1103A
New York, NY 10032
USA

E-mail: Ebb2170@cumc.columbia.edu