Per- and Polyfluoroalkyl Substance Exposure Risks in US Carceral Facilities, 2022

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Objectives. To assess the US incarcerated population's risk of exposure to per- and polyfluoroalkyl substances (PFASs).

Methods. We assessed how many of the 6118 US carceral facilities were located in the same hydrologic unit code watershed boundaries as known or likely locations of PFAS contamination. We conducted geospatial analyses on data aggregated from Environmental Protection Agency databases and a PFAS site tracker in 2022 to model the hydrologically feasible known and presumptive PFAS contamination sites for nearly 2 million incarcerated people.

Results. Findings indicate that 5% (∼310) of US carceral facilities have at least 1 known source of PFAS contamination in the same watershed boundary and that it is at a higher elevation than the facility; also 47% (∼2285) have at least 1 presumptive source. A minimum of 990 000 people are incarcerated in these facilities, including at least 12 800 juveniles. Exposure risks faced by incarcerated youths are disproportionately underassessed.

Conclusions. The long-term impacts from potential exposures to PFAS are preventable and exacerbate health inequities among incarcerated populations. Widespread public attention to PFASs can be parlayed into broader environmental monitoring for imprisoned people. (*Am J Public Health*. 2024;114(5):501–510. https://doi.org/10.2105/AJPH.2024.307571)

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In recent decades, significant concerns have emerged about exposure to and associated health effects from per- and polyfluoroalkyl substances (PFASs). These substances, which are commonly referred to as "forever chemicals" because of their extreme environmental persistence, are among the highest priority emerging environmental health risks.[1] PFASs are the subject of major federal regulations, hundreds of state and federal legislative bills, major advocacy campaigns, interdisciplinary research initiatives, and multibillion-dollar lawsuit settlements.[1–4] Yet, because of protracted corporate secrecy, the difficulty and expense of testing, and slow governmental oversight, little is known about the health equity dimensions of PFAS exposures. The environmental conditions of carceral facilities are similarly difficult to research despite longstanding concerns about the environmental health of incarcerated populations owing to reduced exposure mitigation agency, health vulnerability, and racial inequity.[5–7] Connecting these critical issues, we assessed whether and how incarcerated people might be exposed to PFASs through drinking water, which is the most studied and regulated route of exposure for this family of chemicals.[1]

PFAS chemicals are a broad class of at least 12 000 chemicals. Sources of PFAS emissions to the environment include industrial emissions to water, air, or soil; use of fluorinated firefighting foams for training, testing, and fire response; application of contaminated sludge to agricultural lands; effluent discharges from wastewater treatment plants; emissions from incinerators or landfills handling PFAS-contaminated waste; and consumer uses.[8] Exposure to PFASs is associated with reproductive and developmental effects, multiple cancers, liver effects, and hormone disruption, and it is a key interest for state and federal regulators.[9] PFASs are particularly a concern for drinking water exposures, with an estimated 200 million US residents receiving PFAS-contaminated drinking water.[10] In March 2023, the US Environmental Protection Agency (EPA) proposed maximum contaminant levels for 6 PFAS, including health-based maximum contaminant-level goals for 2 PFASs at zero parts per trillion, indicating the toxicity of this chemical class at extremely low concentration.[11]

Despite research documenting PFASs' extreme persistence and ubiquitous exposure, the degree of potential exposure for the highly vulnerable incarcerated population remains unknown. The United States, which bears the highest total and per capita number of incarcerated people in the world, was home to almost 2 million people detained in prisons, jails, detention centers, and other carceral facilities,[12] with some 8.7 million people cycling through the nation's jails in 2022.[13] These populations are disproportionately Black, Latinx, Indigenous, low-income, and LGBTQ+ (lesbian, gay, bisexual, transgender/-sexual, queer or questioning, and all subsects), making the United States' exceedingly large number of carceral institutions an important window into how the justice system advances public health inequities.[6]

Incarceration—a key institution of structural racism in the United States—is also a major driver of morbidity and mortality in the United States,[5,7,14] so that 1 year of incarceration is estimated to reduce life expectancy by 2 years.[15] Both the physical health and mental health consequences of incarceration complicate employment and financial stability and are associated with reincarceration.[16] Furthermore, a study estimates that without the rise in incarceration from the 1980s to the mid-2000s, the life expectancy at birth in the United States would have increased 51% more than it did during that time.[7]

Juvenile detention is also associated with worse physical health later in life.[17] In 2019, 36 479 youths were detained or committed to a juvenile facility, and an estimated 2900 people younger than 18 years were serving time in jail.[13] Incarcerated youths are disproportionately adolescents of color, with Black youths more than 4 times as likely to be held in a juvenile facility as White youths.[18] Overrepresentation of lesbian, gay, and bisexual people in juvenile detention is driven by female lesbian, gay, and bisexual youths' detention, which is more than 3 times larger than the corresponding free population. Underlying the intersectionality of health issues facing this population, 85% of incarcerated lesbian, gay, bisexual, transgender, and gender-nonconforming incarcerated youths are people of color.[18] Between 70% and 95% of detained youth offenders have at least 1 psychiatric diagnosis,[19] yet juvenile detention and mental health services are often poorly integrated into detention facilities.

Although some mechanisms leading to health disparities for incarcerated populations, such as infectious disease, are well documented,[20] little research exists on the role of environmental contaminants. We contribute to understanding the potential environmental tributaries of the negative public health outcomes advanced by incarceration. A few studies illuminate a range of exposure routes. Toxic air releases near state prisons were found to be significantly elevated in the eastern Midwest, the Mountain region, and the Pacific region.[21] Incarcerated populations are vulnerable to heat-related mortality,[22] and EPA inspectors found a 100% violation rate across multiple hazardous waste regulations in the only known multistate prison inspection campaign.[23]

Incarcerated populations face particularly acute risks from contaminated drinking water for several reasons. First, unlike most conventional residential housing, carceral facilities can be zoned and built in industrialized areas, potentially increasing proximity to industrial exposures.[6] Second, incarcerated individuals have restricted exposure mitigation options if facilities' water becomes contaminated because of their limited or completely absent access to alternative drinking water sources or water treatment devices. Finally, because of the structural marginalization of criminalized populations, incarcerated populations have elevated chronic disease burdens that can increase an individual's risk of illness and death when facing environmental exposures.[24]

We are aware of no national studies on the drinking water quality of carceral facilities and just 2 articles on regional or subregional carceral drinking water. One study found that the water systems of carceral facilities in the US Southwest were disproportionately affected by regional exposures to arsenic.[25] Another, smaller-scale study found that a prison in California's Central Valley received drinking water violations for arsenic exceeding maximum contaminant levels for 7 years, demonstrating clear violations of the human right to water, given the health impacts of chronic arsenic exposure.[26] Although some people incarcerated in that facility could theoretically purchase uncontaminated bottled water, extremely low pay and regulated income limits for incarcerated people make this alternative water source infeasible.[26]

To evaluate this potential environmental source of health inequity in the context of acutely insufficient national testing data, we investigated possible exposure based on validated approaches to estimating drinking water contamination.[8] We modeled the hydrologically feasible PFAS drinking water exposures for the 6118 carceral facilities in the United States to determine (1) how many incarcerated people are potentially affected, and (2) where testing disparities may lead to underassessments of risk for incarcerated people and, by extension, accountability for PFAS contamination. To achieve these goals we modeled both known contamination sources[27] and, using a newly created and validated method, presumptive contamination sources.[8] We elucidate, to our knowledge, previously unknown drivers of exposure risks faced by a large structurally vulnerable population and indicate priority sites for testing.

METHODS

We conducted geospatial data analysis in R version 4.1.0 (RStudio, Boston, MA) to identify US carceral facilities in the same watershed boundary and, as a proxy for hydrological flow direction, at a lower elevation than point sources with known and likely PFAS contamination.

We identified 6118 US carceral facilities designated as not closed from the Department of Homeland Security (DHS) Prison Boundaries data set.[28] This data set records administrative data, along with polygon geometries of fence lines or building footprints, for secure detention centers in the United States, ranging in jurisdiction from federal facilities (including military facilities) to local governments.

We then identified 1774 known PFAS contamination sites using the PFAS Project Lab's PFAS Contamination Site Tracker.[27] These are locations where environmental monitoring has identified a specific facility or location as having PFAS contamination above laboratory detection or reporting limits. However, known PFAS contamination has been disproportionately identified in states with rigorous testing regimes and thus underrepresents the scope of contamination. Unrepresentative testing is compounded by historically high detection and reporting thresholds, geographically uneven levels of testing, exclusions of private wells from government testing programs, and disincentives to develop and report PFAS testing data in the absence of federal standards and funding.[8]

Therefore, we also identified 57 412 presumptive PFAS contamination sites using the presumptive PFAS contamination model of Salvatore et al.,[8] which identifies locations where contamination is likely and should be assumed in the absence of high-quality testing data to the contrary. This model includes 3 categories of PFAS point sources: sites that release aqueous film–forming foam (including Department of Defense sites, fire training sites, and airports), certain industrial sites, and sites related to PFAS waste (including wastewater treatments plants and landfills). PFASs are a central component of aqueous film–forming foam used in firefighting, which is widely used in suppressing fuel fires and, even more frequently, training exercises. Additionally, PFASs are used in more than 200 categories in industrial or manufacturing processes or finished goods.[29] Wastewater treatment plants and landfills are sources because they concentrate the waste stream PFAS-containing products and PFAS-contaminated water. The validation techniques in Salvatore et al.[8] show high correspondence between known and suspected sites.

We excluded a number of potentially relevant data sources from analysis because of data quality concerns. As of 2020, certain US facilities were required to report certain PFAS emissions via the Toxic Release Inventory. In 2022, 47 facilities reported PFAS emissions to the Toxic Release Inventory. We conducted separate analyses that included these point sources, and changes to our findings were negligible. We excluded this category based on our concern that the recent implementation, combined with a very small number of actual reported sites, resulted in dramatic underestimations of the total emitted PFASs.[30]

We were unable to include in our analysis data from the EPA's third Unregulated Contaminant Monitoring Rule (UCMR 3), which at the time of our analysis provided the only available nationwide data on PFAS concentration levels reported in public drinking water systems. (The next round of UCMR is ongoing through 2025.) Matching UCMR 3 data at the water system level with point data on carceral facility locations is impossible because there is no nationwide database with geolocation boundaries for all public drinking water systems. By individually checking every carceral facility in the DHS Prison Boundaries data set with EPA's Facility Registration Service, we found that only 383 carceral facilities (< 6%) have their own Safe Drinking Water Information Service ID and therefore their own public water system. Additionally, because UCMR 3 includes only public drinking water systems serving more than 10 000 and a small sample of smaller systems, virtually all carceral drinking water systems would have been excluded from UCMR 3 testing entirely.

Using the US Geological Survey's (USGS's) 12-digit hydrologic unit codes

(HUC-12), we determined the watershed boundaries for all point sources. HUC-12 s designate upstream areas of land that contribute to surface water runoff toward a specific point in a stream or other body of water and represent the smallest watershed subdivisions available via USGS's Watershed Boundary Dataset. We determined elevations for point sources via the USGS Elevation Point Query Service. We then calculated the number, percentage, and populations of carceral facilities colocated with a point source.

Throughout this article, we use the term "colocated" to refer to facilities that are in a HUC-12 with and at a lower elevation than a PFAS point source. We also identified each carceral facility's census block, using the US Census Bureau's TIGERweb API (application programming interface), and we determined whether the facility was in a rural or urban location via census block classification. We disaggregated the results by carceral facility type, whether the facility was a juvenile facility, and whether the facility was in an urban census block. To contextualize the results, we repeated all calculations using the DHS Hospitals data set,[31] which allowed us to determine the percentage of the 8013 US hospitals (excluding nursing homes and health centers) colocated with PFAS point sources.

We selected hospitals as a comparison setting because the number of US hospitals is similar to the number of US carceral facilities, although hospitals house a less racially skewed vulnerable population. Notably, exposure risks in hospitals are likely lower than those in carceral facilities, given that most hospital stays are considerably shorter than detention durations. Additionally, some hospitals use point-of-entry and point-of-use filters for infection prevention, which could mitigate PFAS exposure. The prevalence and PFAS efficacy of these filters has not been studied.

Finally, to determine priority locations for increased PFAS monitoring, we performed a series of statistical tests to determine whether there was a significant difference in proportions of certain carceral facilities near known versus presumptive PFAS contamination sites. Specifically, we determined the proportions of carcerally proximate PFAS sites that were industrial sources (vs nonindustrial) from the corpus of known sites and the corpus of presumptive sites. We used a 2-proportion z-test to determine whether there was a statistically significant difference in proportions across the 2 data sources.

To assess the spatial independence of facilities, we ran a spatial bootstrap test based on the Moran I statistic and found the spatial autocorrelation of the type of facilities to be very weak ($I = 0.08$). Our analysis thus assumes that point locations are independent and identically distributed. In addition, for both juvenile and nonjuvenile facilities, we tagged each facility we determined to be colocated with a suspected PFAS contamination source but not a known contamination source as "presumed only." Using a permutation test, we tested the null hypothesis that whether a facility is juvenile or adult makes no difference when it comes to the proportion of facilities where colocation with a PFAS source was presumed only. Permutation tests only presume the exchangeability of observations, an assumption that these data meet.

RESULTS

We found that 310 (5%) active US carceral facilities have at least 1 known source of PFAS contamination in the same watershed boundary and at a higher elevation than the facility (Figure 1). At least 150 000 people are incarcerated in these facilities, including at least 2200 juveniles. Calculations of the size of affected populations are significantly underestimated because 31% of all active carceral facilities are missing population data. Missing population data are biased toward juvenile carceral facilities, with 50% of juvenile carceral facilities missing population data compared with 27% of adult carceral facilities. Proximity to known PFAS contamination sites is likely the tip of the iceberg when it comes to risks of PFAS exposure. Nearly half (47%) of all active US carceral facilities have at least 1 presumptive source of PFAS contamination in the same watershed boundary and at a higher elevation than the facility. At least 990 000 people are incarcerated in those facilities, including at least 12 800 juveniles.

These values are similar to the percentages of hospitals colocated with a source of PFAS contamination: 6% of hospitals are colocated with a known source, and 56% are colocated with a presumptive source. Disaggregating the results by urban versus rural location, we determined that 66% of urban carceral facilities and 24% of nonurban carceral facilities are colocated with a presumptive source, whereas 64% of urban hospitals and 23% or nonurban hospitals are colocated with a presumptive source. This suggests the importance of considering urbanity when investigating facilities' PFAS exposure risks.

Many carceral facilities face cumulative PFAS exposures: 1874 (31%) active facilities have more than 1 presumptive source of PFAS contamination in the same watershed boundary and at a higher elevation than the facility, and

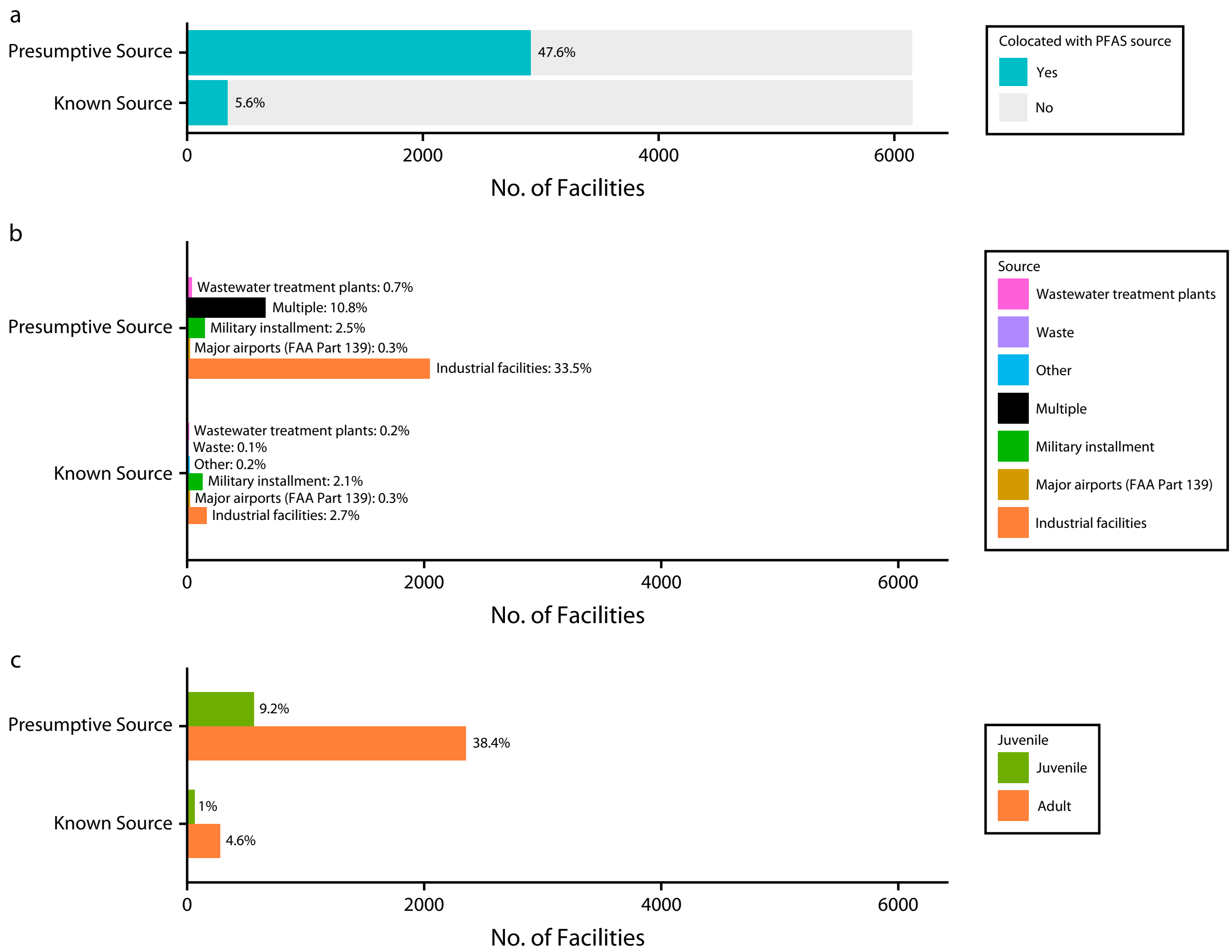

FIGURE 1— Carceral Facilities Colocated With Known and Presumptive Per- and Polyfluoroalkyl Substance (PFAS) Contamination Sources (a) Overall, (b) by Source, and (c) by Juvenile Carceral Facilities: United States, 2022

Note. FAA = Federal Aviation Administration. Percentages indicate the percentage of the total carceral facilities in the same watershed boundary and at a lower elevation than PFAS contamination sites. "Waste" and "other" are not included as categories of presumptive PFAS contamination. "Multiple" is not included as a category of known PFAS contamination.

800 (13%) have more than 5 presumptive sources of PFAS contamination meeting these criteria (Table 1).

Industrial sources are the most frequent presumptive PFAS contamination source to be colocated with carceral facilities (Figure 2), with 2658 (43%) active carceral facilities having at least 1 presumptive PFAS industrial source in the same watershed boundary and at a higher elevation than the facility. Of the presumptive PFAS contamination sources colocated with carceral facilities, 93% were industrial facilities, whereas of the known colocated PFAS contamination sources, 54% were industrial facilities. A *z*-score test indicates a statistically significant difference in proportions across the 2 groups ($P < .01$), highlighting the disproportionate lack of testing at industrial sources compared with other sources, such as military sites and waste sites.

The majority of individuals incarcerated in colocated facilities are in state- and county-run facilities, with at least 480 000 individuals incarcerated in colocated state-run facilities and at least 410 000 in county-run facilities.

Juvenile facilities are disproportionately colocated with presumptive PFAS contamination sites, with 56% of juvenile facilities in the same watershed boundary and at a lower elevation than a presumptive PFAS contamination site and 46% of nonjuvenile facilities meeting these criteria. Furthermore, 65% of locally run juvenile facilities and 62% of county-run juvenile facilities have

TABLE 1— Carceral Facilities in the Same Watershed Boundary and at a Lower Elevation Than Per- and Polyfluoroalkyl Substance (PFAS) Contamination Sites: United States, 2022

Measure	Total Carceral Facilities, No. (%)	Total Carceral Population, No. (Low Estimate)	Juvenile Carceral Facilities, No. (%)	Juvenile Carceral Population (Low Estimate)
Known sources of PFAS contamination				
≤ 1	310 (5.0)	152 595	57 (5.7)	2 287
2–5	79 (1.3)	32 902	11 (1.1)	460
> 5	10 (0.2)	5 443	3 (0.2)	225
Presumptive sources of PFAS contamination				
≤ 1	2 885 (47.2)	995 768	558 (55.5)	12 872
2–5	1 874 (30.6)	666 748	394 (39.2)	9 169
> 5	800 (13.1)	327 339	175 (17.4)	4 106

Note. Of all active carceral facilities, 31% were missing population data in the Department of Homeland Security's Prisons Boundaries data set. Percentages in the first column indicate the percentage out of the total carceral facilities in the country. Percentages in the third column indicate the percentage out of the total juvenile carceral facilities in the country.

presumptive PFAS exposure (Figure 3). However, the exposure risks faced by incarcerated youths are also disproportionately underassessed. Via a permutation test, we determined a statistically significant difference ($P < .01$) in the proportion of juvenile versus adult facilities documented as being near a suspected contamination source but not a known contamination source, indicating a need for further testing near juvenile facilities.

DISCUSSION

We found that nearly half of carceral facilities are near at least 1 presumptive PFAS contamination site, suggesting that the incarcerated population potentially faces a major environmental health hazard through their drinking water. By analyzing national data of environmental risks faced by the carceral population, we document the scale of potential exposure risk and inform population health research priorities and interventions. We also found information gaps associated with PFAS contamination to be disproportionate for juvenile carceral facilities and facilities near industrial sources that are presumptive PFAS contamination sources, suggesting the need for targeted testing. These spatial gaps in water monitoring both limit possibilities for regulatory action and mark epistemic inequalities[32] in knowledge investments, as data absences position incarcerated individuals in certain groups and locations to receive less attention from regulators and scientists.

Limitations

Our analysis likely significantly underestimates PFAS exposure potential because the data sets we used to identify known and presumptive contamination are conservative estimates: location of known contamination is biased toward states with rigorous PFAS testing, and the operationalization of presumptive contamination significantly underestimates sites because of limitations in publicly available and geocoded data.[8] In particular, certain states have conducted extensive testing and identified numerous PFAS contamination sites, whereas others have done no focused PFAS testing to date.

Furthermore, our analysis may misestimate drinking water exposure for carceral facilities that receive drinking water sourced from a different watershed, but no nationwide data exist linking carceral facilities' water systems with source locations. It also underestimates potential PFAS exposure by focusing exclusively on drinking water exposures, excluding other known exposure routes, including food, occupation, and inhalation exposures.[33,34] Future research should include exposure investigations of PFAS contamination in carceral facilities, including drinking water and soil sampling, and epidemiological investigations of associated health effects for incarcerated and formerly incarcerated people. Research can also locate existing studies of health status of incarcerated people and determine whether sicker populations are more highly exposed to PFASs.

Public Health Implications

Increased monitoring of carceral facility drinking water is needed to identify the

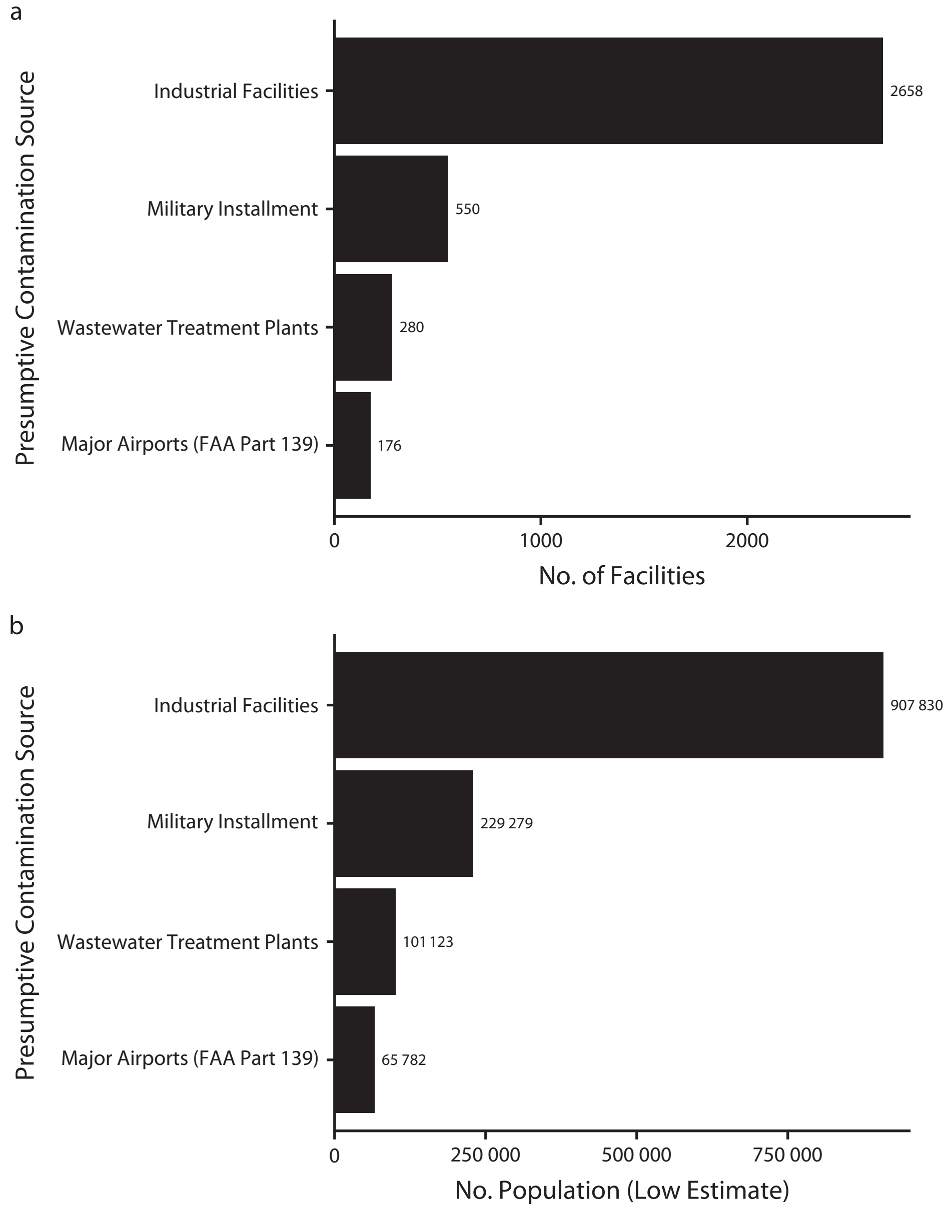

FIGURE 2— Number of (a) Carceral Facilities and (b) Population Colocated with Presumptive Per- and Polyfluoroalkyl Substance (PFAS) Contamination Sources: United States, 2022

Note. FAA = Federal Aviation Administration.

extent of PFAS contamination and potential exposure risk, and testing results should be disclosed to incarcerated populations. If drinking water is contaminated with PFASs above the EPA's proposed maximum contaminant levels, remediation would be required if and when those maximum contaminant levels are finalized. Based on our analysis, in addition to prioritizing testing of water systems serving a large number of individuals, researchers and prison decision-makers should prioritize PFAS testing of drinking water and other media (including soil and food grown onsite) at both juvenile carceral facilities and facilities near known and likely contamination sources.

Partnerships with advocacy groups concerned with carceral health are necessary to ensure that such research is conducted equitably and with meaningful involvement of incarcerated people, their families, and communities hosting

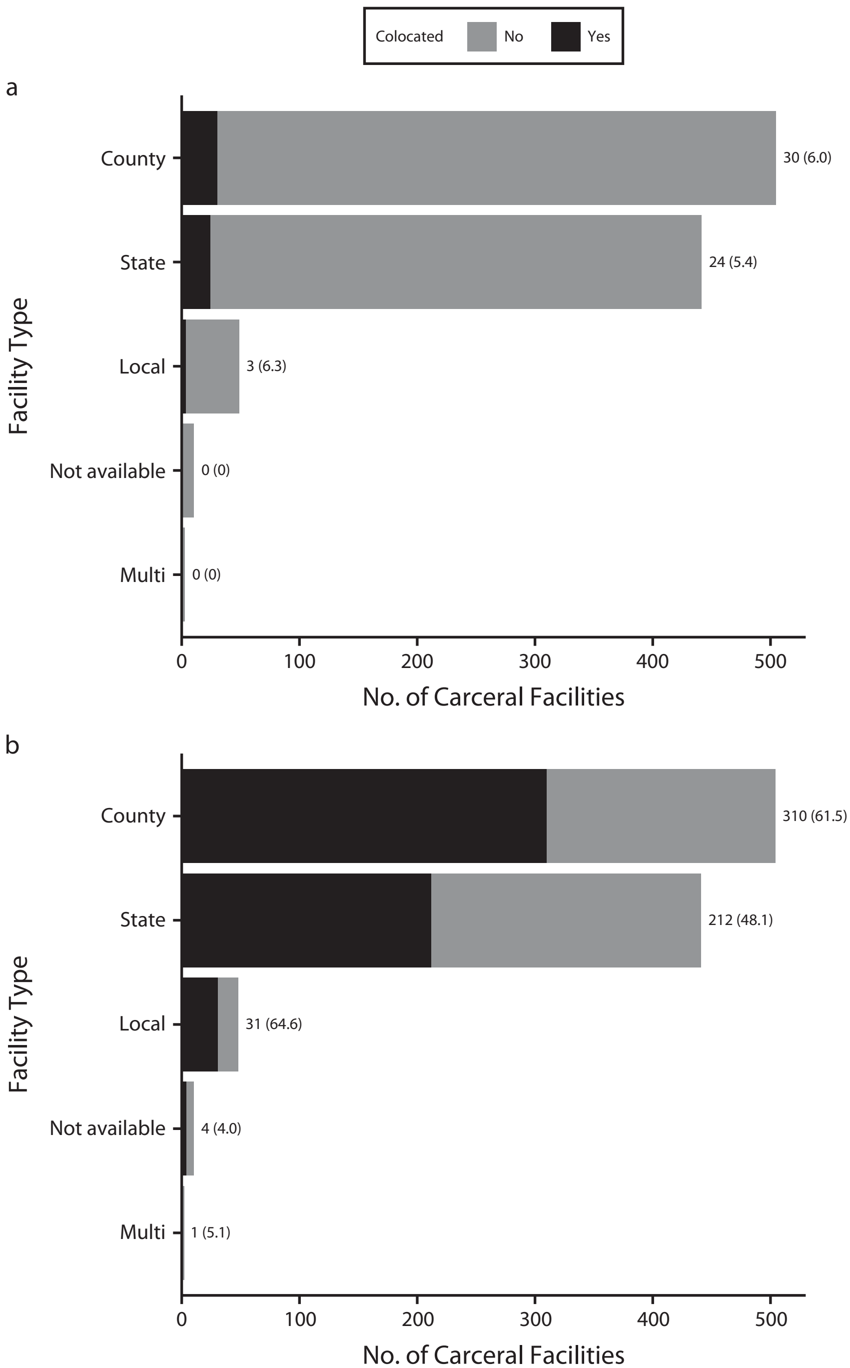

FIGURE 3— Juvenile Carceral Facilities Colocated With at Least 1 Per- and Polyfluoroalkyl Substance (PFAS) Contamination Source That Is (a) Known, or (b) Presumptive: United States, 2022

Note. Values to the right of the bars indicate the number of colocated juvenile facilities of the corresponding type with the percentage (in parentheses) of the total juvenile facilities of that type.

carceral facilities. Incarcerated people face structural barriers to raising awareness of the health inequities they face, as well as barriers in obtaining the data, monitoring, and services they need to protect themselves from PFASs and other environmental hazards. This is in stark contrast to the exceptionally rapid and widespread mobilization in the nonincarcerated population of PFAS-affected residents across the United States.

PFASs are immunosuppressants and are associated with increased COVID-19 severity and mortality.[35] In the tight confines of carceral facilities, which increase respiratory infectious disease transmission, it is imperative to reduce any factors that could exacerbate the hazards of airborne pandemics such as COVID-19. Beyond the acute infectious disease crisis that has swept the world over the past nearly 4 years, the chronic health impacts of incarceration are unequally distributed across race, gender, sexual orientation, and gender identity. The long-term effects from these potential exposures are preventable and contribute to health inequities among those who are incarcerated.

Today's widespread public, scientific, and regulatory attention to PFASs could be parlayed into broader environmental monitoring for imprisoned people. That monitoring can contribute to more attention to the overall health of this population, which is historically neglected and faces heightened likelihood for negative health outcomes. AJPH

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CONTRIBUTORS

L. Poirier led data analysis. L. Poirier and N. Shapiro conceptualized the study. D. Salvatore, P. Brown, A. Cordner, and K. Mok were responsible for data curation and validation. All authors collaboratively developed the methodology for this study and contributed to writing, reviewing, and editing.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

HUMAN PARTICIPANT PROTECTION

No protocol approval was necessary because this study did not involve human participants.

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