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# State-level regulation of disinfection byproducts in the United States

Jie Wang[a,†], Max G. McNally[a,†], Nicola Ulibarri[a,*], Changdeok Gim[a], Valerie A. Olson[b] and David L. Feldman[a]

[a] Department of Urban Planning & Public Policy, University of California Irvine, 300 Social Ecology I, Irvine, CA 92697, USA
[b] Department of Anthropology, University of California Irvine, 3207 Social & Behavioral Sciences Gateway, Irvine, CA 92697, USA
*Corresponding author. E-mail: ulibarri@uci.edu
†These authors contributed equally to this work.

NU, 0000-0001-6238-9056; CG, 0000-0001-7848-1404; VAO, 0000-0002-8258-3937; DLF, 0000-0003-2288-5017

## ABSTRACT

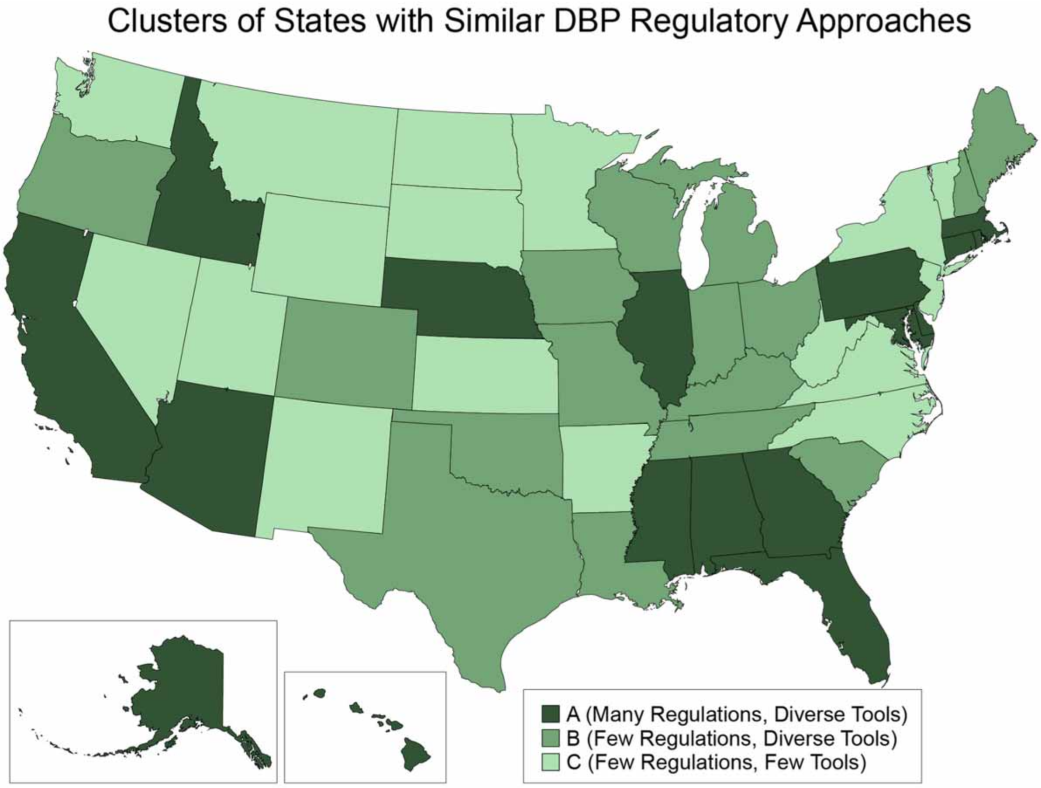
Disinfection byproducts (DBPs), residual compounds formed from the chemical disinfection of drinking water, can cause a host of damaging public health and environmental impacts. This study evaluates the landscape of regulations designed to reduce the occurrence and/or impact of DBPs, focusing on regulations issued by the US states. Drawing on a systematic search of state administrative codes and agency websites, we first identify the presence, absence, and layering of DBP-related regulations. We then evaluate the number and types of policy tools – the specific approaches required by each regulation, such as monitoring requirements, economic incentives, and required treatment technologies – to identify how DBPs are being managed and how states cluster with relatively more and less robust regulatory frameworks. Finally, we evaluate the relationship between the regulatory approach and the frequency of drinking water quality violations for DBP compounds. While most states have at least one DBP-specific regulation, these vary substantially in their comprehensiveness. The most-used policy tools (monitoring, compliance schedules, and reporting) directly reflect federal regulations; few states have adopted innovative tools such as collaboration or financial incentives. We observe no relationship between regulatory efforts and water quality violations, suggesting that current policy implementation may not adequately address the complex risk of DBPs.

**Key words:** Disinfection byproducts (DBPs), Policy analysis, Policy instruments, Water quality regulation

## HIGHLIGHTS

- This article evaluates state-level regulations to manage disinfection byproducts in the US states.
- States vary in regulatory approach, with 28 having multiple regulations and 3 having no state-level regulation.
- Most states replicate the US Environmental Protection Agency regulations, which rely on command-and-control approaches.
- Few states have adopted innovative policy tools like collaboration or financial incentives.

## GRAPHICAL ABSTRACT




## INTRODUCTION

The chemical disinfection of drinking water has been celebrated as a defining public health success of the 20th century, helping to curtail the prevalence of, and mortality rates caused by waterborne disease. However, in addition to effectively eliminating waterborne pathogens, many commonly used disinfection agents, such as chlorine, chlorine dioxide, chloramines, and ozone, are potent oxidants that may unintentionally produce compounds that are harmful to human health (Richardson, 2003; Richardson *et al*., 2007). Disinfection byproducts (DBPs) are a class of compounds formed in water when disinfection agents react chemically with naturally occurring organic matter and anthropogenic contaminants (Villanueva *et al*., 2015; DeMarini, 2020). Epidemiological data has uncovered an association between DBPs and bladder cancer, along with potential impacts on reproductive and developmental health (Boorman, 1999; Villanueva *et al*., 2015; Li & Mitch, 2018; Kalita *et al*., 2024). Thus, DBPs have been recognized as a potential public health risk.

To limit public exposure to DBPs, the United States (US) Environmental Protection Agency (EPA) promulgated regulations for four trihalomethanes (THMs), five haloacetic acids (HAA5s), chlorite, and bromate (Richardson *et al*., 2007). Issued in 1998 and effective in 2002, the Stage 1 Disinfection Byproduct Rule (DBPR) established maximum contaminant levels (MCLs) and monitoring protocol that measured a water system's running annual averages of all collected samples (Richardson *et al*., 2007). In 2006, the Stage 2 DBPR took effect, maintaining the Stage 1 MCLs but updating monitoring procedures to measure the running annual averages of each testing location rather than merely system-wide averages, ensuring that no sample location exceeded the MCLs (Richardson *et al*., 2007). The EPA regulations govern 11 DBPs, a fraction of the 600-plus identified DBPs of concern (Gilca *et al*., 2020).

As the US is a federal system, states have authority to develop their own more stringent water quality regulations. Many states have formally adopted both the Stage 1 and 2 DBPRs into state regulations, often verbatim or by reference. Nevertheless, there remains considerable variation in how the Stage 1 and 2 DBPRs have been transcribed into state laws, and some states have created their own regulatory programs to manage DBPs. This study evaluates state-level approaches to regulating DBPs in order to map jurisdictional variation in the oversight of DBPs. More specifically, we gauge the types and quantity of regulatory and policy tools used in governing DBPs. Command-and-control regulations, which mandate specific behaviors, compliance with quality standards, or targets, can be effective at inducing compliance with the established standard; the Stage 1 and 2 DBPRs reflect a command-and-control approach. However, this approach can also encourage a race-to-the-bottom whereby reductions beyond the regulatory threshold are disincentivized (Oates & Portney, 2003). Employing a more diverse mix of tools, such as economic incentives and information-based campaigns, can incentivize more innovative and comprehensive attention to DBPs (Taylor *et al*., 2012; Cejudo & Michel, 2021). We also compare reported violations by water utilities to evaluate regions of relative non-compliance and their relationship to the regulatory approach. By comparing these variables, we hope to identify associations between policy tool types, quantity, and the likelihood of regulatory violation for DBPs.

## METHODS

This research leverages data from two primary sources at the state level. First, a web-based search was performed to compile legislation and policies on DBPs. Second, data on MCL and monitoring and reporting violations for DBPs were extracted from annual public water systems compliance reports issued by state primacy agencies that regulate drinking water. Data collected from these two sources were analyzed to inform regulatory tools and practices for managing DBPs across the country as well as to identify the prevalence of regulatory violations by state.

### Identifying and coding regulations

To create a comprehensive list of DBP regulations, we conducted targeted internet searches between September 2023 and January 2024, employing search terms 'disinfection byproducts OR DBPs + [state name]'. Additionally, a supplementary search on Westlaw identified pertinent regulations related to DBPs within states' administrative codes. Regulations that focus on general water quality, without a focus on DBP-specific chemicals, and regulations that have been repealed, were excluded from consideration, limiting inclusion criteria to current policies directly addressing DBPs (e.g., Ariz. Admin. Code §18-4-114-Disinfectant Residuals, Disinfection Byproducts, and Disinfection Byproduct Precursors) or specific types of DBPs (for example, California has specific plans and goals for individual types of DBPs, including bromate, chlorite, haloacetic acids, and trihalomethanes). Our definition of regulations includes both state legislation – typically codes of regulations and legislative statutes – as well as alternative guidance, instructions, or plans (e.g., Idaho's Implementation Guidance for the Stage 2 Disinfectants and Disinfection By-Products Rule).

Regulations obtained through the web search were coded systematically to develop a comprehensive database of policies and regulations concerning DBPs. Key information from each regulation was collected, such as the date of enactment, the specific pollutants targeted, and the responsible administrative entities. For example, in 30 states, DBP regulations are issued by environmental agencies, typically a state's Department of Environmental Protection or Department of Natural Resources. Alternatively, public health agencies, such as a state's

Department of Public Health, have issued regulations for DBPs in 13 states. In four states, both environmental and public health agencies have issued DBP-related regulations.

After compilation, DBP legislation and policies for each state were screened by the two lead authors to evaluate policy tools employed in regulating DBPs. Policy tools or instruments are specific regulatory techniques utilized by the government to implement their policies (Howlett, 1991). Governments select a wide range of tools to shape mechanisms through which regulations are delivered, influence the behavior of stakeholders to align with environmental and societal interests, and achieve overarching policy objectives. Command-and-control approaches, economic incentives, and information-based instruments are three common categories of policy tools that are employed to induce a targeted group to undertake actions they might not have otherwise pursued (Taylor *et al.*, 2012; Ulibarri *et al.*, 2022). With the emergence of new governance modes like network governance (Salamon, 2002), there are growing approaches that emphasize the role of third-party entities in providing public services, like mutual agreement, network building, and joint problem solving (Campbell *et al.*, 2004; Taylor *et al.*, 2012). When deciding on the tools to address environmental issues, governments grapple with several considerations, including determining the scope of regulation, seeking economically efficient solutions, striking a balance between water quality objectives and economic and public health priorities, and exploring innovative policy instruments capable of adapting to emerging challenges (Shortle & Horan, 2001; Ward, 2007; Taylor *et al.*, 2012; Gallaher *et al.*, 2013).

While previous studies have proposed various ways to classify policy tools in environmental regulations to help analyze regulatory practices (Campbell *et al.*, 2004; Taylor *et al.*, 2012), the task of characterizing and categorizing these tools remains challenging due to the multifaceted nature of individual instruments and their often blurred distinctions (Salamon, 2002). Therefore, we used an inductive approach to generate types of policy tools specifically tailored for regulating DBPs within each regulation. In instances where a particular policy tool was referenced multiple times within a regulation, it was only tallied once. This screening process led to the identification of 16 distinct types of policy tools. For a comprehensive list of DBP policy tools, along with their definitions and examples, see Supplementary Table S1.

### DBP violations

Additionally, the study analyzed state public drinking water annual compliance reports to consolidate records of regulatory violations pertaining to DBPs. These reports are issued annually by the state agency delegated with primary enforcement responsibility under the Safe Drinking Water Act (SDWA) (42 U.S.C. § 300g-3 (c)(3)(A)(i)). The state agency compiles regulatory violations from the three types of public water systems (PWSs): community water systems (CWSs), non-transient, non-community water systems (NTNC), and transient non-community water systems (TNC). Once violations are tabulated, the reports are published to the state agency's website with links posted on the EPA's website (EPA, 2024).

Public drinking water annual compliance reports typically divide violations into two types: MCL violations and monitoring and reporting violations. Additionally, some reports tabulate treatment technique violations; however, these are not universally adopted across all reports analyzed and did not receive further consideration for this study. In these annual compliance reports, under each category of violation, the gross number of violations is recorded along with the number of PWS in violation. Furthermore, the gross number of violations and number of systems in violation was further delineated by types of DBP: total THMs (TTHMs), HAA5s, chlorite, bromate, or non-specified DBPs.

While the EPA mandates that annual drinking water compliance reports be made available to the public, there were varying degrees of accessibility among the states. Most states provided functioning links to the EPA which led directly to a state agency's website containing the annual drinking water compliance report. Typically, the report displayed was for the most current reporting year (2022), but dozens of states also provided reports from previous years as well. However, for several states, links provided to the EPA led to the correct state agency's website but not to the intended reports. In many instances, these state agency websites were hard to navigate and not user-friendly, making it challenging to find the desired reports. Moreover, reports from several states with incorrect links were unable to be found within the state agency's website. Likewise, Florida, Illinois, Montana, and Utah did not have a link, functioning or non-functioning, on the EPA's website. Searches on their respective state agency websites proved unfruitful for Florida, Illinois, and Utah. To address these missing reports, each state agency was contacted directly inquiring about the availability of the annual drinking water compliance reports for 2021 and 2022.

Additionally, there was a lack of consistency among states when it came to recording and tabulating instances of regulatory violations pertaining to DBPs. While most states adopted the EPA format of documenting the number of MCL and monitoring and reporting violations incurred as well as the number of PWS in violation, a small number of states recorded all violations incurred by each type of PWS, without delineating which violations were specifically for DBPs. Likewise, several states displayed the number of DBP violations in graphical or text formats, rather than the widely used tabular approach. This made it impossible to discern the exact number of DBP violations. Due to these inconsistencies, data for New York and Maine were not viable for analysis.

Of the 17 states contacted for missing reports or data inconsistencies, 7 responded and provided the requested violation data. Ultimately, usable data from 42 and 44 states was obtained for 2021 and 2022, respectively (see Supplementary Table S2 for specific sources).

### Analysis

To reveal overall patterns of instrument uses for regulating DBPs and their variations across states, we conducted a hierarchical cluster analysis (HCA) to differentiate states into common groups. HCA is a common statistical method employed to classify data into groups based on similarities between observations. In this paper, states were categorized into distinct clusters based on similarities across three indicators, including the number of DBP regulations, the count of policy tools, and the diversity of tool types. In HCA, we used Ward's minimum variance method, which minimizes the total within-cluster variance by iteratively merging the pair of clusters with the smallest between-cluster distance. Supplementary Figure S1 shows the clustering process through a dendrogram, showing how 50 states successively converged into clusters until a single cluster was formed. A line was drawn through the dendrogram to illustrate the point at which three clusters were determined.

To evaluate the performance of DBP regulatory efforts, we computed the mean frequency of each of the two DBP violation types (MCL violations and monitoring and reporting violations) for the years 2021 and 2022, and explored their distribution across various state clusters. Additionally, Pearson correlations were calculated to assess the association between regulatory efforts and each of the two types of DBP violations. This analysis seeks to determine whether there is a statistically significant connection between the level of regulatory efforts and an observable reduction of DBP violations.

## RESULTS

One hundred individual DBP regulations from 47 states were identified (see Supplementary Table S3 for a list of regulations and Figure 1 for a map of DBP regulations by state). Notably, we did not find DBP-specific regulations in Arkansas, Minnesota, and Nevada. Among the states with identified regulations, the mean was 2.1 regulations and mode was 1; California led with 10 regulations, followed by Illinois with 7, and Pennsylvania with 4. Comprehensiveness also varied among these regulations. While some states offered detailed descriptions outlining disinfection byproduct requirements, others provided more concise directives. For example, Montana's

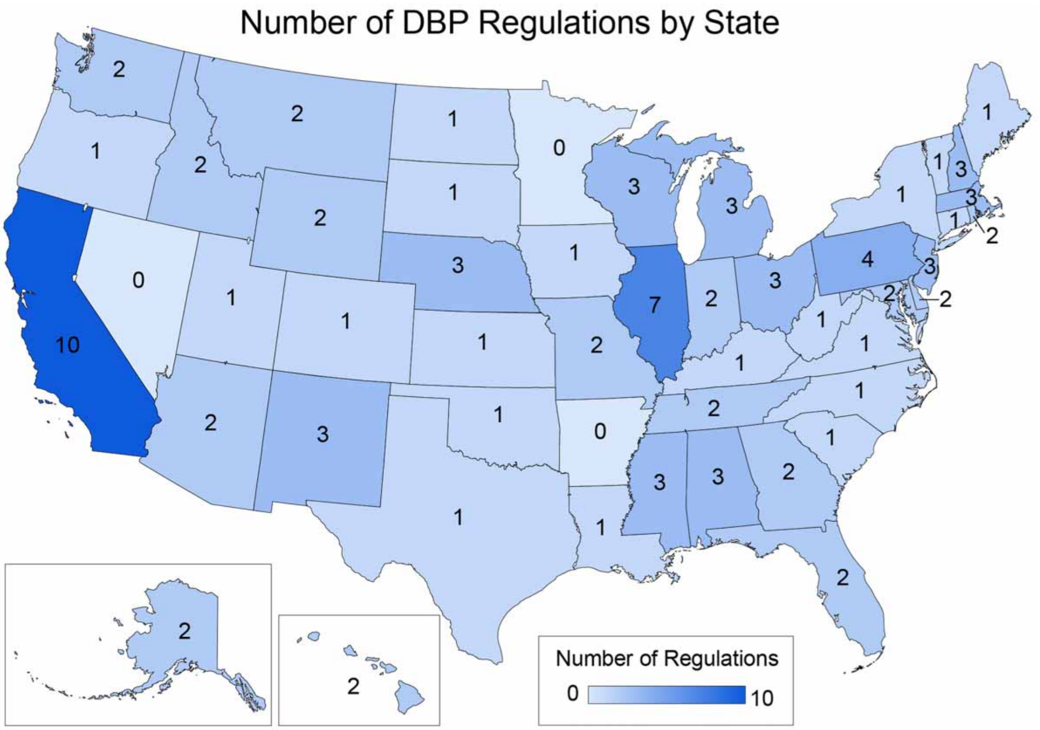



**Fig. 1** | Number of DBP regulations by state.

Administrative Rules simply state that it 'adopts and incorporates by reference 40 CFR Part 141, subpart V, which sets forth the requirements for monitoring and other requirements for achieving compliance with maximum contaminant levels based on running annual averages for disinfection byproducts' (Administrative Rules of Montana 17.38.213).

## Policy tools to manage DBPs

Through the inductive coding process, we identified 16 types of policy tools utilized for regulating DBPs (Figure 2). Monitoring and compliance schedules emerged as the most prevalent tools, employed by 39 states (78%), followed by reporting and recordkeeping in 37 states (74%), and treatment technology in 33 states (66%). These tools reflect the EPA's Stage 1 and 2 DBPR, which set forth national standards for DBPs in PWS drinking water supplies. Both stages lean heavily upon traditional command-and-control policy tools such as promulgating rules, criteria setting (i.e., MCLs), monitoring as well as reporting and recording the prevalence of DBPs, prescribing analytical methods, lab certification, and compliance schedules. Ultimately, these tools form the bulk of approaches adopted by state regulations.

In contrast, we found relatively little use of tools that are not contained in the DBPRs. The sole instance of financial incentives to support DBP control efforts was in Pennsylvania, where PENNVEST's low-cost financial assistance was mentioned to ensure residents have access to safe drinking water, including controlling DBPs (PA. CODE CH. 109 31 Pa.B. 3895). Likewise, the only use of collaboration as a tool was California's *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary*, which encourages the use of

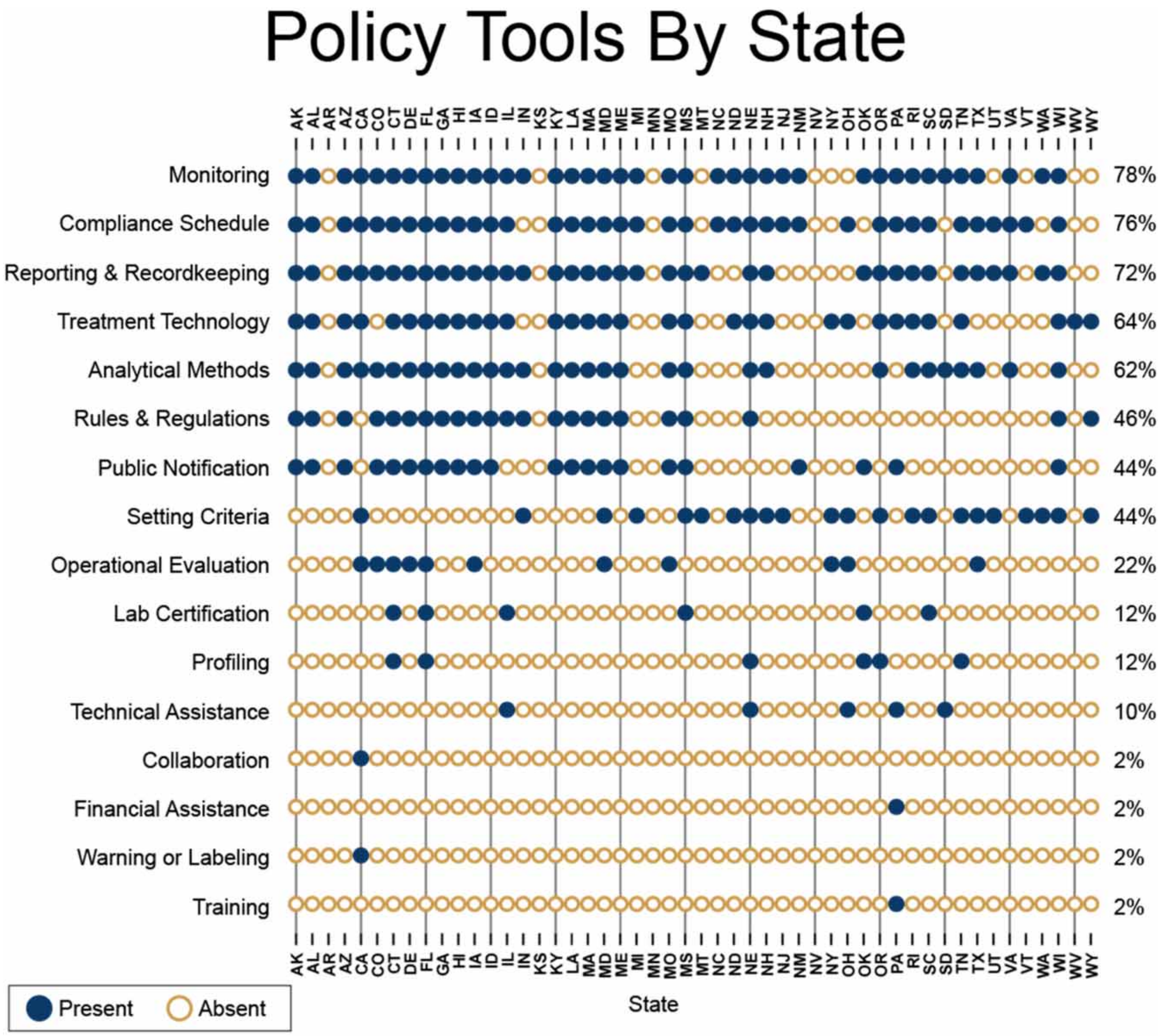



**Fig. 2** | Policy tools used by states.

'collaborative processes such as the CALFED Drinking Water Quality Program' to enhance the 'understanding of the chemical reactions which form disinfection byproducts'.

Figure 3 shows the number and types of policy tools mentioned in DBP regulations for each state. If the same policy tool was used in multiple regulations within a state, then the total occurrences of this policy tool were aggregated for that particular state. For example, if monitoring was required in two of a state's regulations, it would count as two toward *Number of Tools*, but only one toward *Number of Tool Types*.

The mean state has adopted 7.4 individual DBP policy tools. Alabama and Massachusetts stand out for employing the highest number of policy tools (15 each). We did not find any tools in four states: Arkansas, Kansas, Minnesota, and Nevada. Arkansas, Minnesota, and Nevada do not have DBP-related regulations; and Kansas incorporated the EPA's regulations by reference (40 C.F.R. 141.130–141.135), but did not reproduce them in

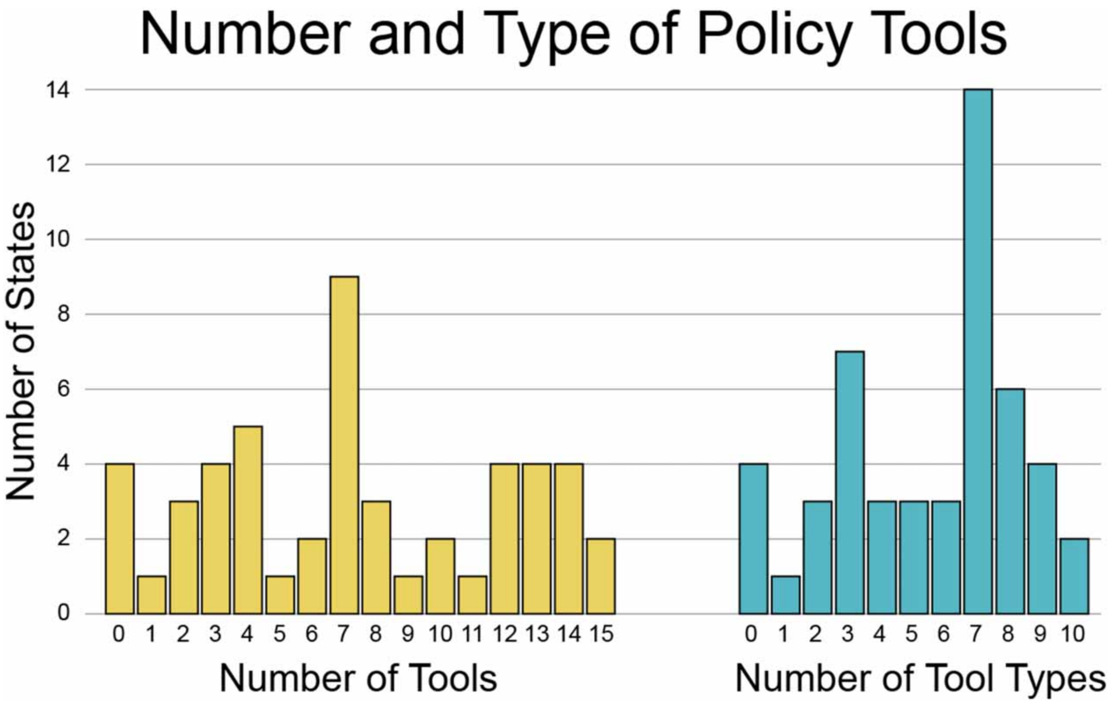



**Fig. 3** | Distribution of the number and types of policy tools used by states.

its own administrative code. Regarding the diversity of tools, states have adopted a mean of 5.5 types of DBP tools. Connecticut and Florida have incorporated the most varied array of tools in their regulations, including 10 of the 16 different types of policy tools.

In states where multiple tools of the same type are utilized, there is consistency in how these tools are used across various regulations or guidelines. For example, in Pennsylvania, the tool of monitoring is referenced in four distinct regulations. In each instance, the requirement for monitoring aligns with the stipulations outlined in 25 Pa. Code §109.3. A supplementary manual was also developed to specifically address the monitoring mandates, compliance calculations, and reporting obligations specified by these rules. The utilization of the same tool may also arise when addressing distinct pollutants. In California, for instance, analytical methods are referenced for evaluating risks to human health from exposure to four different types of DBPs.

Figure 4 presents three clusters of states that employ similar regulatory approaches, in terms of number of regulations, number of tools, and types of tools for regulating DBPs. Table 1 presents the summary of cluster variable values to inform the distinctions among the three clusters. Cluster A comprises 17 states characterized by significant regulatory efforts addressing DBPs. These states have the highest number of regulations, alongside the highest utilization of diverse policy tools. Cluster B includes 16 states and Cluster C includes 17 states. While these two clusters exhibit comparable numbers of DBP regulations, Cluster B has a higher quantity and diversity of DBP policy tools. On average, Cluster B has adopted 7.1 policy tools and 6.5 different types of policy tools, whereas Cluster C has only adopted approximately 2.3 policy tools and 2.1 tool types.

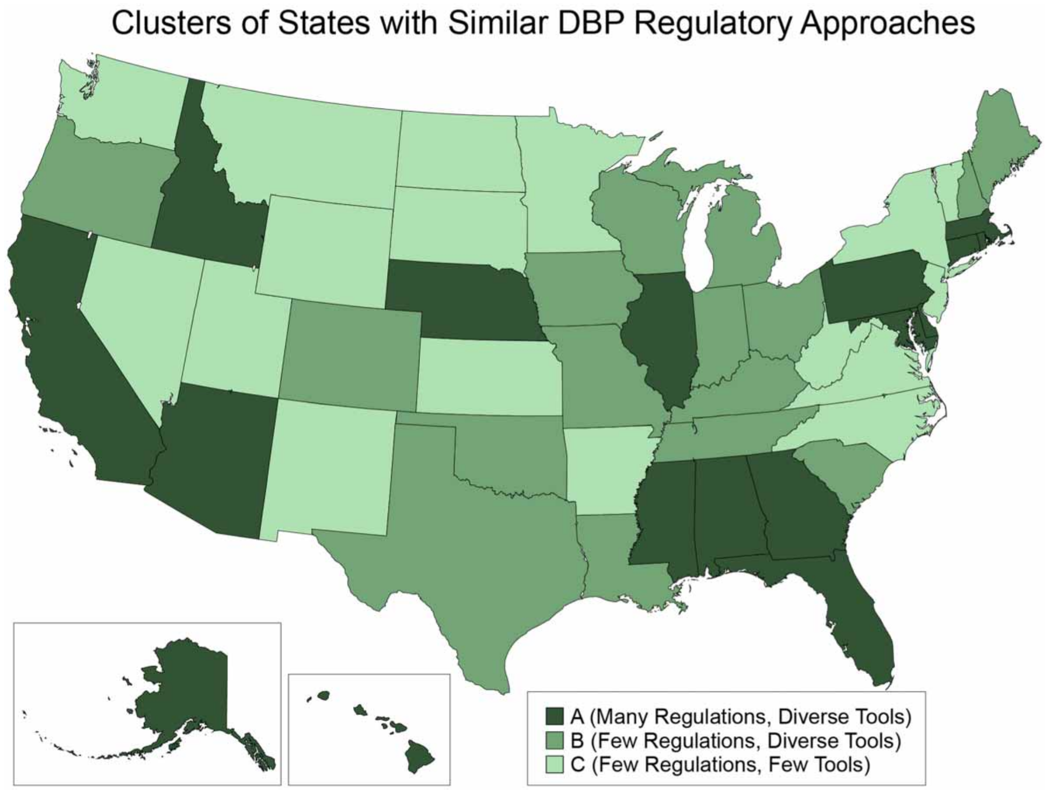



**Fig. 4** | Cluster analysis of states with similar regulatory toolkits.

**Table 1** | Mean variable values by state cluster.

| Clusters | Size | Number of regulations | Number of tools | Number of tool types |
|---|---|---|---|---|
| Cluster A | $N = 17$ | 3.2 | 12.8 | 7.9 |
| Cluster B | $N = 16$ | 1.7 | 7.1 | 6.5 |
| Cluster C | $N = 17$ | 1.2 | 2.3 | 2.1 |
| Total | $N = 50$ | 2.0 | 7.4 | 5.5 |

## DBP violations

Instances of DBP violations typically fall into one of two categories: MCL violations or monitoring and reporting violations. MCL violations for DBPs account for any exceedance of the maximum permissible level for TTHMs, HAA5s, chlorite, and bromate during regular measuring of locational running annual averages at each testing site within the service area of a PWS. Monitoring and reporting violations indicate either a failure to test water samples in a timely manner according to mandated monitoring schedules or to report findings to the state's primary agency responsible for drinking water quality.

Across the 44 states with violation data, monitoring and reporting violations occur more frequently than MCL violations. Between 2021 and 2022, the mean number of monitoring and reporting violations was 118.6 (median = 53.5) compared with 60.2 MCL violations (median = 18).

To assess the relationship between regulatory approach and violations, we compared the distribution of violations across the three regulatory clusters (Figure 5). Notably, Cluster B, which included states with multiple regulations but relatively fewer individual tools, had the highest median violations for both monitoring and reporting and MCLs, with 65.8 and 21.8 violations, respectively. Cluster C, with the least stringent regulatory regime, averaged 37.5 monitoring and reporting violations, followed by 15 for Cluster A. For MCL violations, Clusters A and C tied with 10 median violations. Additionally, ignoring outliers, Cluster B had the largest variance in both violation types, while Cluster A had the smallest.

To evaluate whether regulatory efforts meaningfully contribute to a reduction of DBPs and attainment of overarching policy goals, we calculated Pearson correlation coefficients between each of a state's regulatory efforts (number of DBP regulations, number of policy tools, and number of tool types) and both types of DBP violations (MCL violation and monitoring and reporting violations). However, with absolute values less than 0.1, none of the correlation coefficients between each regulatory effort and violation type were statistically significant. Therefore, no discernible association can be concluded between states' regulatory efforts and improved water quality outcomes observed via reductions in DBP-related violations.

## DISCUSSION

This paper evaluated the distribution of DBP regulations across the US states, investigated variations in the types and quantity of regulatory tools used in governing DBPs, and compared states' regulatory performance by measuring the number of regulatory violations. States demonstrate a considerable range in the number and comprehensiveness of regulations designed to mitigate DBPs. A thorough web-based investigation into DBP-related regulations revealed that only 47 states have established formal regulatory frameworks, with 28 states having more than one regulation and 3 states having yet to establish any state-level regulation. The degree of

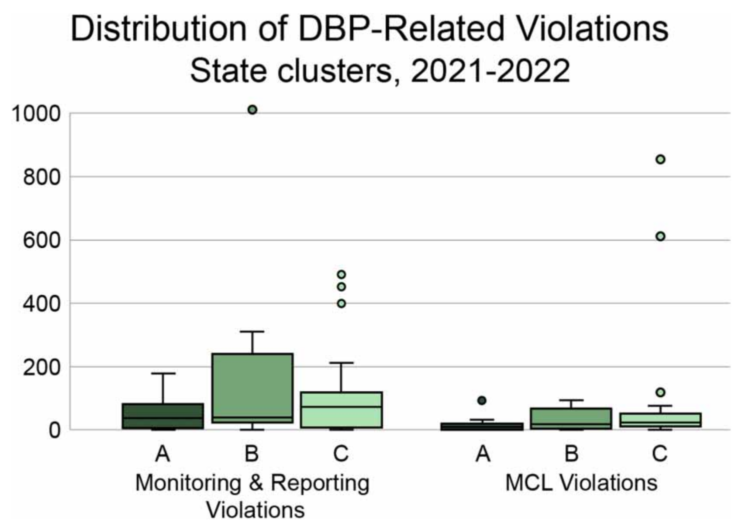



**Fig. 5** | Distribution of DBP-related violations by state cluster, 2021–2022. Left: Monitoring and reporting violations; Right: MCL violations.

comprehensiveness also varies significantly among these regulations. Some states offer detailed descriptions outlining DBP requirements, while others, like Montana, only provide succinct references to the EPA's Stage 1 and 2 DBPRs. Given that the chemical disinfection of drinking water continues to inadvertently produce compounds harmful to human health, there remains a need for states lagging behind in these initiatives to assess the urgency and significance of incorporating DBP regulatory tools into their policy agenda and issuing regulations tailored to address water quality concerns and safeguard public health. This also suggests an opportunity for tougher federal regulations, whereby states are required to conform to the EPA rules as a minimum baseline.

Through content analysis of state DBP regulations, we identified 16 distinct policy tools utilized for regulating DBPs, with 7.3 tools utilized on average in each state. Despite this apparent diversity of tools, the majority of tools used are traditional command-and-control approaches, including required monitoring, compliance schedules, reporting and recordkeeping, treatment technology, and prescribed analytical methods. We observed limited utilization of innovative or adaptive policy tools designed to specifically address complex water quality challenges. Since the 1980s, water resource governance has increasingly emphasized multi-party coordination and collaboration, which recognizes the need for a more systematic and integrated approach involving government and non-governmental actors. The accumulation of different sources and types of knowledge and information from different actors helps with the evaluation of complex resource problems and for identifying innovative solutions to address them (Pahl-Wostl, 2007; Wang *et al.*, 2024). However, our findings reveal that only one state encourages collaboration as a distinct DBP policy tool. Other policy tools that reflect the involvement of non-state actors in regulating DBPs are mandated training (required by one state) and lab certification (required by six states); these introduce various in-house and third-party scientists, engineers, and other technical experts into the regulatory process for DBPs. The most widely used public-facing tool is public notification, which is explicitly employed by 22 states (44%) and aims to increase public access to water quality data and promote public participation. However, unidirectional notification approaches can be criticized as having limited impacts on administrative actions given that state agencies often have little incentive to respond to citizens' comments (West, 2004; Ulibarri *et al.*, 2019). For future decision-makers within state agencies, effective communicative pathways to meaningfully engage different non-state actors in the DBP regulatory process should be fully considered.

Another area of concern regarding states' regulatory efforts revolves around implementation. Despite our identification of policy tools within state-level DBP regulations, we did not assess the extent to which these tools are actually put into practice. Relatively few state regulations provided financial or technical assistance to water agencies or communities to help them comply with regulations – tools that would presumably increase implementation. The lack of association between regulatory efforts and the number of reported DBP-related violations also suggests that more regulation alone is insufficient to reduce DBPs. States with the strongest regulatory regimes (Cluster A, with more regulations and the most diverse policy tools) were relatively successful at minimizing MCL violations, but states with fewer regulations and somewhat diverse tools (Cluster B) performed the worst on average. This nonlinearity is perhaps partly because of the emerging nature of DBPs, wherein there is still a lot that is unknown about their formation as well as their health impacts (Li & Mitch, 2018; Richardson & Plewa, 2020). Nonetheless, studies exploring the implementation process of regulations and related instruments in real-world contexts would shed light on regulations' efficacy in mitigating DBPs.

We can only hypothesize why each cluster performed differently regarding violation frequency. The more regulated states (Cluster A) were better at complying with monitoring and reporting requirements, which makes sense given that more regulations likely translate into more capacity. For MCL violations, while it appears that the most regulated and least regulated states performed equally, the lack of monitoring requirements in Cluster C may mean that actual MCL violations are underreported. However, this cannot be confirmed without collecting water quality data. Regarding the larger variation in Cluster B, the main distinction between Clusters A and B is the number of tools, rather than diversity in tool types. This perhaps suggests that duplication of tools can help limit violations more reliably. Cluster B states also tend to use the full arsenal of tool types included in the DBPRs but are less likely to include any novel tools.

This study did not include an in-depth analysis of violations at the PWS level, which is an important area for future research. Most states' public drinking water compliance reports include data itemizing annual DBP violations by PWS, enabling future researchers to determine what percentage of DBP-related infractions are incurred by repeat offenders and whether those systems are habitually in non-attainment. Likewise, given that the report data also typically includes all non-DBP water quality violations, further analysis could be conducted to gauge whether PWS in violation for DBP regulations are also out-of-compliance with other water quality regulations, shedding insight into the institutional capacity of offending PWS.

## CONCLUSION

This paper identified state-level regulatory policies and tools to manage DBPs across the US and evaluated their performance by testing their association with the frequency of regulatory violations. By determining the types of policy tools used, the state agencies involved, and how regulatory efforts perform in terms of violation outcomes, this research helps discern the impact of certain regulatory practices for reducing the prevalence of DBPs in drinking water. Future research needs include examining the practical implementation of DBP regulations by regulatory agencies and PWSs, to establish the degree to which certain policy tools are operationalized, as well as analyzing DBP violation trends at the PWS level.

This work yields several policy recommendations. Most notably, the widespread variation in how states reported their violations not only challenged our data collection, but also makes more systematic monitoring of compliance more difficult. EPA could require states to adhere to more standardized reporting requirements, including listing both the total number of violations and number of PWSs in violation, disaggregating violations by chemical constituents, and posting multiple years' reports (rather than just the most recent year). Given how closely many states' regulatory regimes mirrored the DBPRs, the EPA could also consider expanding the DBPRs to include more diverse and flexible tools, especially economic incentives and inter-agency collaboration.

## ACKNOWLEDGEMENTS

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

## CONFLICT OF INTEREST

The authors declare there is no conflict.

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