

# Increase in Organochlorine Contaminant Levels in Major Water Sources of the United States in Response to the Coronavirus Pandemic

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**How to cite this paper:** Wilburn, W., Guha, S. and Beni, R. (2024) Increase in Organochlorine Contaminant Levels in Major Water Sources of the United States in Response to the Coronavirus Pandemic. *Journal of Biosciences and Medicines*, 12, 111-143.

<https://doi.org/10.4236/jbm.2024.125010>

**Received:** March 13, 2024

**Accepted:** May 13, 2024

**Published:** May 16, 2024

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## Abstract

Organochlorine contaminants, such as triclosan (TCS), are present in major water sources across the United States. These antimicrobial compounds are widely used as multipurpose ingredients in everyday consumer products. They can be ingested or absorbed through the skin and are found in human blood, breast milk, and urine samples. Studies have shown that the increased use of antimicrobial agents leads to their presence and persistence in the ecosystem, particularly in soil and watersheds. Many studies have highlighted emerging concerns associated with the overuse of TCS, including dermal irritations, a higher incidence of antibacterial-related allergies, microbial resistance, disruptions in the endocrine system, altered thyroid hormone activity, metabolism, and tumor metastasis and growth. Organochlorine contaminant exposures play a role in inflammatory responsiveness, and any unwarranted innate response could lead to adverse outcomes. The capacity of TCS and other organochlorine contaminants to induce inflammation, resulting in persistent and chronic inflammation, is linked to various pathologies, such as cardiovascular disease and several types of cancers. Chronic inflammation presents a severe consequence of exposure to these antimicrobial agents, as any changes could result in the loss of immune competence. Organochlorine contaminant levels were established by the United States Environmental Protection Agency (EPA) in 2019-2020 and have consistently increased in response to the novel coronavirus (nCoV) (COVID-19) pandemic. Our previous research examined the overuse of products containing triclosan (TCS), which led to an increase in total trihalomethane (TTHM) levels affecting the quality of our water supply. We also investigated the impact of the FDA ban that now requires pre-market approval. To comprehend the consequences of excessive antimicrobial use on water quality, we conducted an analysis of the levels of total trichloromethane

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(chloroform), a byproduct of free chlorine added to TCS, in primary water sources in metropolitan areas across the United States in 2019-2020. We repeated this analysis after the peak of the COVID-19 pandemic in 2021-2022 to examine its correlation with organochlorine exposure. Our study found that the COVID-19 pandemic, along with the increased use of antimicrobial products, has significantly raised the levels of total trihalomethanes compared to those reported in water quality reports from 2019-2020, in contrast to the reports from 2021-2022.

## Keywords

Organochlorine Contaminants, Triclosan, Trihalomethane, Chloroform, Water Quality

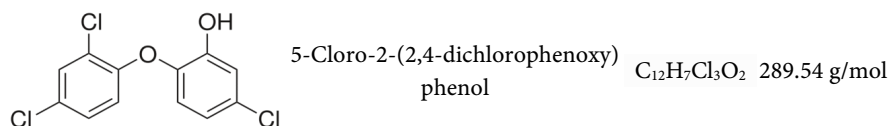
## 1. Introduction

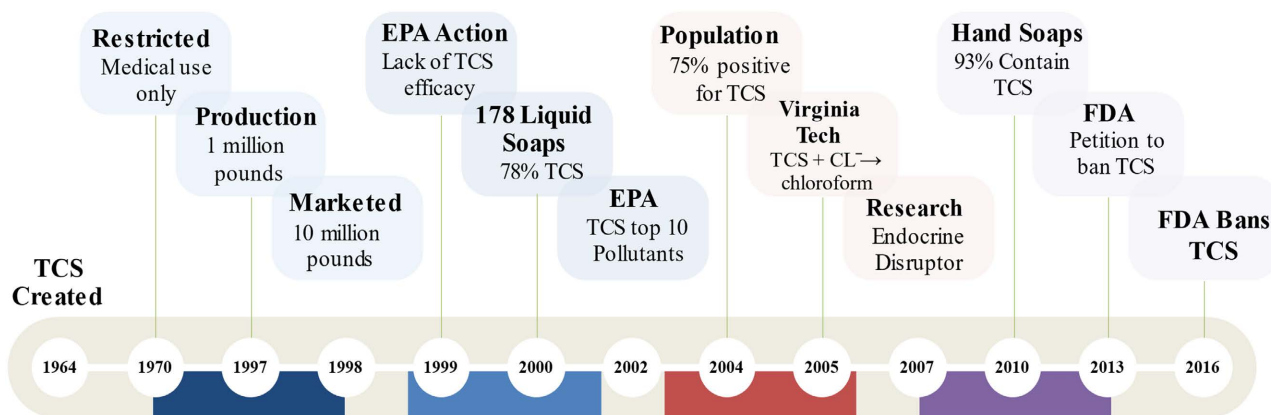
Triclosan (TCS), a chlorinated aromatic compound containing phenol and ether functional groups, is an antimicrobial and antibacterial agent in many consumer products, notably hand sanitizers and aerosol sprays. The molecular structure of TCS is displayed in **Table 1** [1] [2] [3] [4].

The mode of action of triclosan involves blocking of lipid biosynthesis by binding it with enoyl-acyl carrier protein reductase enzyme (ENR), which prevents the fatty acid synthesis required for lipid production in the microbe [5]. In a study [6], it was found that the structural features of triclosan, specifically the chlorine substituents, are linked to its susceptibility to photodegrade and produce photoproducts that are also of environmental concern. The 4-Cl substituent was predominantly responsible for triclosan's ability to photodegrade in the environment, while the 2'-Cl substituent was found to be necessary for the formation of dichlorodiphenyls and hydroxylated biphenyls as photoproducts. In the aquatic environment, triclosan is toxic to marine organisms and has the potential to affect the structure of algal communities, particularly immediately downstream of effluents from wastewater treatment facilities that treat household wastewaters [7].

TCS was first created and patented in 1964 by the Swiss to be used as surgical scrubs by hospitals and healthcare workers but entered worldwide production in 1998 as antimicrobial compounds (**Figure 1**) [8]. The United States Toxic Substances Control Act monitored the production of TCS, limiting production to

**Table 1.** Structure, names, and properties of Triclosan.





**Figure 1.** Pre-COVID-19 historical timeline for Triclosan.

approximately 1 million pounds per year; yet by 1998, production of TCS steadily increased from 1 million pounds to 10 million pounds, with an estimated global production in 2011 of approximately 14 million pounds [9] [10] [11] [12]. In 2011, United States consumers spent nearly 1 billion dollars on products containing TCS [13].

TCS use has expanded from everyday personal hygiene products, such as soaps, mouthwash, toothpaste, beauty aids, cleaning supplies, and pesticides [14] [15], becoming a significant component of other marketed consumer goods, such as kitchen utensils, trash bags, toys, diapers, bedding, and socks [15]. By 2000, TCS had been added to more than 2000 daily used consumer products [16]. Between September 2008 and September 2009, products containing concentrations of 3.5 to 17 mM of TCS as the active antimicrobial ingredient sold at a rate of 278 million 16 oz units totaling \$886 million in sales, resulting in an annual consumption of 132 million liters [10] [16]. By 2010, TCS was found in 93% of liquid, gel, bar, or foam soaps [10] [11] [16]. Some studies suggest that antimicrobial hand soaps containing TCS slightly, but significantly, reduce bacteria compared to plain soap [17]. TCS also remains in use in a majority of hand sanitizer products [13] [18].

Hand sanitizing products containing antimicrobial triclosan (TCS) were \$200 million annually pre-COVID (2020); however, a consumer surge in demand to an already robust industry globally emerged in response to the pandemic. In February 2020, when the first American death from COVID-19 occurred, hand sanitizer sales in the US increased by 300%, and by March, sales increased exponentially by an astounding 470% compared to the same week in the previous year [19] [20]. The hand sanitizer market in the United States was valued at 1.3 billion industry (US) and 6.2 billion (globally) in 2022 and is expected to grow to 1.9 billion (US) and 10.5 billion by 2030 [20].

Consumers are exposed to these organochlorine-containing products, as evidenced by numerous studies showing detectable levels of TCS in skin, urine, and blood plasma ranging from 5.0 to 0.05  $\mu\text{M}$  concentrations [21]. There remains controversy regarding whether TCS concentrations absorbed into the human

body might induce adverse effects noted in lab studies. Considering these significant findings, incorporating this antimicrobial containment into readily available consumer products, not just in soap, needs to be re-evaluated, and the biological effects of its breakdown products and metabolites need to be investigated, especially in aquatic environments.

The widespread use of TCS-containing products has given rise to the contamination of aquatic environments, most notably watersheds [2] [22] [23]. The United States Environment Protection Agency (EPA) regulates TCS as a pesticide that is generally acceptable on solid surfaces, while the United States Food and Drug Administration (FDA) regulates TCS as a drug when used in personal care items [24]. As of 2017, the EPA enacted five registration restrictions for using TCS as an active antimicrobial ingredient added to products used to slow or deter the growth of bacteria, fungi, and mildew. This commercial, institutional, and industrial restriction allows TCS use in fire hoses, dye vats, conveyor belts, and ice-making equipment, along with direct application to commercial Heating, Ventilation, and Air Conditioning (HVAC) coils to prevent microbial growth that contributes to their degradation [16] [24] [25]. Recent environmental studies show that TCS is one of the most frequently detected compounds at the highest concentrations in waterways. The risks associated with using TCS include but are not limited to water contamination, fragile aquatic ecosystems, algae toxicity, bioaccumulation in the fatty tissues of fish, and potential interference with thyroid hormone production and other endocrine functions [26]. Water treatment plants do not entirely remove TCS from treated water; thus, it becomes an unregulated contaminant of treatment plants [27].

### 1.1. Triclosan Toxicology

Organochlorine compounds are not acutely toxic to mammals [1] [28] [29] [30], but *in vitro* studies indicate that TCS may disturb metabolic systems and hormone homeostasis at a low concentration of 0.03 mg/L (0.1  $\mu$ M) or 0.00003% [31] [32] [33] [34] [35]. According to the FDA monograph for health care products containing TCS, the recommended limits are up to 3000 mg/L (10.36 mM) or 0.3% in oral care products (toothpaste) and leave-on, dermal care products (deodorant and lotion); 1000 - 4500 mg/L (3.45 - 15.54 mM) or 0.1% - 0.45% in wash away dermal care products (liquid hand and body soaps); and 10,000 - 30,000 mg/L (34.5 - 103.6 mM) or 1% - 3% in products used in health care settings [10] [11] [36] [37] [38].

The levels of TCS that may be present in tissues just beneath the skin following exposure to antimicrobial products that contain as much as 0.3% organochlorine compound could be greater than 10  $\mu$ M, based on findings of the absorption in human skin samples [39]. Studies have shown that TCS disrupts the thyroid hormone-dependent characteristics of metamorphosis in frogs [34] and has been shown to interfere with thyroid hormone regulation in rats [40]. Researchers found that tadpoles treated with low levels of organochlorine compounds have altered hormone-mediated development in the frog studies, while TCS ex-

posure also disrupted thyroid hormone-associated gene expression [41] [42]. Studies on frogs and rats have demonstrated that TCS can profoundly affect thyroid hormones [42]. Even though several recent studies have found concerns that TCS is an endocrine disruptor, the complete relevance of the extent to humans is still unknown [43]. Researchers at University of California—Davis recently found that TCS elevates calcium levels in cells, potentially affecting neurological function and neurodevelopment, and impairing mitochondrial function in mammalian cells [44] [45].

TCS is an endocrine disruptor that could give rise to reproductive disorders in both men and women [46]. Epidemiological studies have pointed out a possible association between TCS and infertility and neonatal birth defects [47]. There is evidence that TCS exposure may interfere with ovarian functions as well as ovarian reserve [48]. The kidney is critical in the elimination of toxins. An epidemiological investigation revealed that TCS exposure was positively associated with early kidney injury [49]. TCS exposure is also linked to thyroid function damage [50], neurodevelopmental toxicity [51], immune dysfunction [52], and cytotoxicity [53]. Cohort studies showed that TCS exposure was significantly correlated with the allergic disease in preschool children [54], and the estrogenic effect of TCS might affect the prognosis of female breast cancer [55]. Moreover, TCS exposure triggered neurotoxicity [56].

Epidemiological studies have suggested that TCS exposure may influence semen quality (sperm alignment, viability, morphology, CASA parameters) and damage sperm DNA [57]. TCS could interfere with reproductive health through oxidative stress [58], hormonal dysregulation [59], germ cell autophagy and apoptosis, steroidogenesis suppression [60], and mitochondrial dysfunction [61]. Long-term exposure to TCS might have unfavorable health effects on the liver, and it could perturb liver metabolic function, aggravate liver fibrosis, accelerate hepatocellular carcinoma development through lipid metabolism disorder [62], induce oxidative stress, facilitate mitochondrial dysfunction [63], and modulate hepatocyte apoptosis [64].

## 1.2. Inflammation and Triclosan

Since the discovery that inflammation can play a role in tumor development, scientists have shown that inflammation is present in the same areas as tumor cells, showing a connection between pro-inflammatory cells and cancer cells [65]. Inflammation can become chronic under the wrong circumstances, leading to inflammatory and autoimmune diseases. Acute inflammation occurs when tissue repair is required due to injury and helps to prevent infections [65]. Chronic inflammation occurs when pro-inflammatory and various mediators stimulate immune cells from lymphoid and myeloid lineages in blood vessels [66]. Inflammation can appear before and during malignant tumor growth and metastasis due to immune cell involvement in inflammation [66]. When immune responsiveness levels are inappropriately elevated, it causes chronic inflammation that can increase tumor invasiveness [67]. Any organochlorine TCS-induced in-

crease in pro-inflammatory responsiveness could result in chronic inflammation, which is associated with numerous pathologies, including cardiovascular disease and several types of cancers [67]-[73]. Additionally, TCS was detected in 75% of 2517 human urine samples at concentrations of 2.4 - 3790  $\mu\text{g/L}$  [74], in 61% of 90 urine samples from age 6-8-year-old girls [75], and in the range between 4.1 - 19 ng/g in human blood serum samples [76] [77]. TCS concentrations between 100 - 2100  $\mu\text{g/kg}$  of lipid were detected in 96.8% of 62 breast milk samples [78], and concentrations of TCS in breast milk were detected between 0.018 to 0.95 ng/g [76]. Lastly, TCS has been found in indoor dust ( $\sim 1.1$   $\mu\text{g/g}$ ) [79] and foods (0.02 - 0.15 ng/g) such as dairy products, vegetables, meat, fish, and egg [78].

Triclosan binds to and inactivates kinases that are necessary for endocrine and hormone processes [80] [81]. These findings, together with other data [82], support that triclosan has pleiotropic effects, where different mechanisms of action result in divergent biological outcomes. In addition, it was demonstrated that while triclosan decreased pro-inflammatory cytokine production in epithelial cells, it significantly enhanced lipopolysaccharide-induced expression of antimicrobial and immune-modulatory  $\text{h}\beta\text{D}2$  and  $\text{h}\beta\text{D}3$  proteins. The model [82] demonstrated that triclosan is not a pan-suppressor of immune activation, but rather interferes with select processes of Toll-Like Receptor (TLR) induced signaling. This finding is important because immune cell responses are necessary for wound repair/healing processes and pan-suppression of cellular responses may slow periodontal disease resolution.

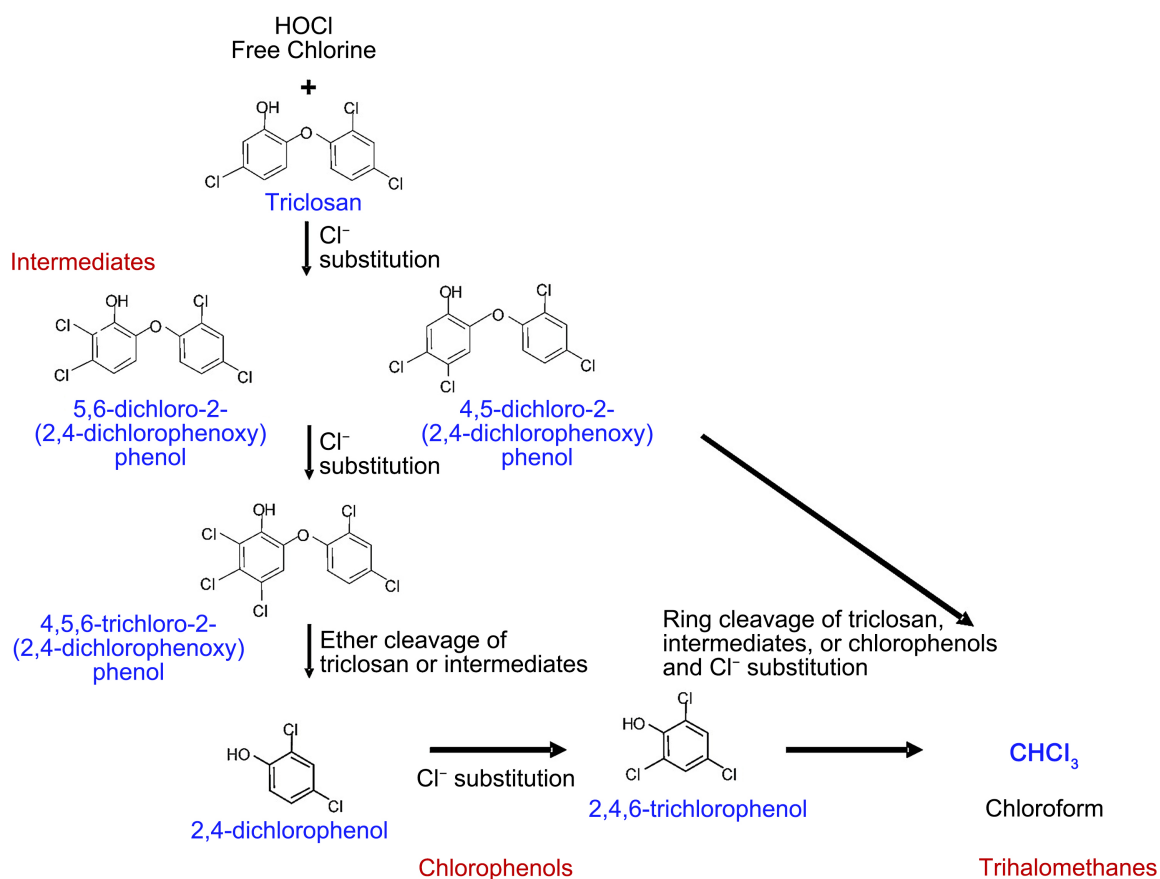
## 2. Water Contaminants and Regulations

Drinking water quality varies depending on the condition of the water source and the treatment it receives, but it must meet EPA standards and regulations. The underlying importance of water is understood, albeit violations do occur even with EPA standards in place. Once a violation occurs, it must be reported to the EPA, while the EPA is responsible for the Consumer Confidence Report (CCR) for informing consumers of the water quality [83]. The levels of contaminants found in drinking water have been studied by scientists at various agencies, such as the non-profit corporation Environmental Work Group (EWG). The EWG specializes in determining the links between tested chemical compounds found in a water source and the environmental consequences, even if the levels of the compound are within legal limits assigned by the EPA. Previous studies in our lab found a correlation between the levels of trihalomethanes (THMs), annual household income, and poverty levels [84]. Other studies showed water quality disparities regarding the level of heavy metal exposure in Tennessee's drinking water [85]. Our primary exposure to environmental hazards is unsafe drinking water. The EPA is responsible for writing regulations to enforce water quality legislation, such as the National Primary Drinking Water Regulations, the National Primary Drinking Water Regulations Implementation, and the National Secondary Drinking Water Regulations [86] [87]. However, the

EPA only requires the regulations of public drinking water systems that service at least 15 service connections or more than 25 persons [88]. The Safe Drinking Water Act of 1974 requires public drinking water systems to monitor the presence of certain contaminants at specific intervals of time and at mandatory locations to ensure compliance, allowing violations to be reported to the Safe Drinking Water Information System Federal Reporting Services (SDWIS/FED), created in 1995 [89]. However, a 2002 EPA audit found that only 62% of violations are ever reported, and states are only required to report a violation, not the contamination levels. These protocol violations leave citizens with only the knowledge of a possible violation, not the specifics of the violation [90].

## 2.1. Contaminants in Drinking Water from Triclosan Use

Many studies have reported the occurrence of TCS and its intermediates in wastewater effluent, watersheds, and soil [91] [92]. According to the EPA, TCS is in the top 10 contaminants of emerging concern for watersheds in the United States [91] [93] [94]. Once organochlorine contaminants enter wastewater treatment plants, free chlorine exposure causes a partial or complete transformation during wastewater treatment processing before being discharged into the environment via effluent and biosolids for land application (Figure 2).



**Figure 2.** Mechanisms of TCS conversion to its intermediate products: chlorinated TCS derivatives, chlorophenols, chloroform, and trihalomethanes.

The land application of biosolids, the final products of wastewater treatment plants, can potentially route chloroform into the environment, most notably watersheds and soil (Figure 3) [95]. Organochlorine aerobic biodegradation is relatively slow, with a half-life greater than 165 days [96]. Although organochlorine contaminants in the effluent and biosolids of water resources recovery facilities are currently not regulated, the public interest has led Metropolitan Water Resources (MWR) and the EPA to monitor chloroform in the influent, effluent, and biosolids [97]. A critical comprehensive review of TCS as an environmental contaminant has been recently reported, discussing the causal effect of free chlorine chemical response to organochlorine contaminants increasing the concentration of bio-solids before land application [97]. In 2016, the United States Food and Drug Administration (FDA) issued a final rule establishing that 19 specific ingredients, including TCS, were no longer generally recognized as safe and effective [19]. However, in response to the COVID-19 pandemic, in March 2020, the FDA guidance policy for manufacturers was lifted, provided they complied with the monograph for over-the-counter topical antiseptics and other applicable requirements during the public health emergency [98].

Our research is the first to explore the effects of the COVID-19 pandemic's upsurge in antimicrobial products containing organochlorine compounds, such

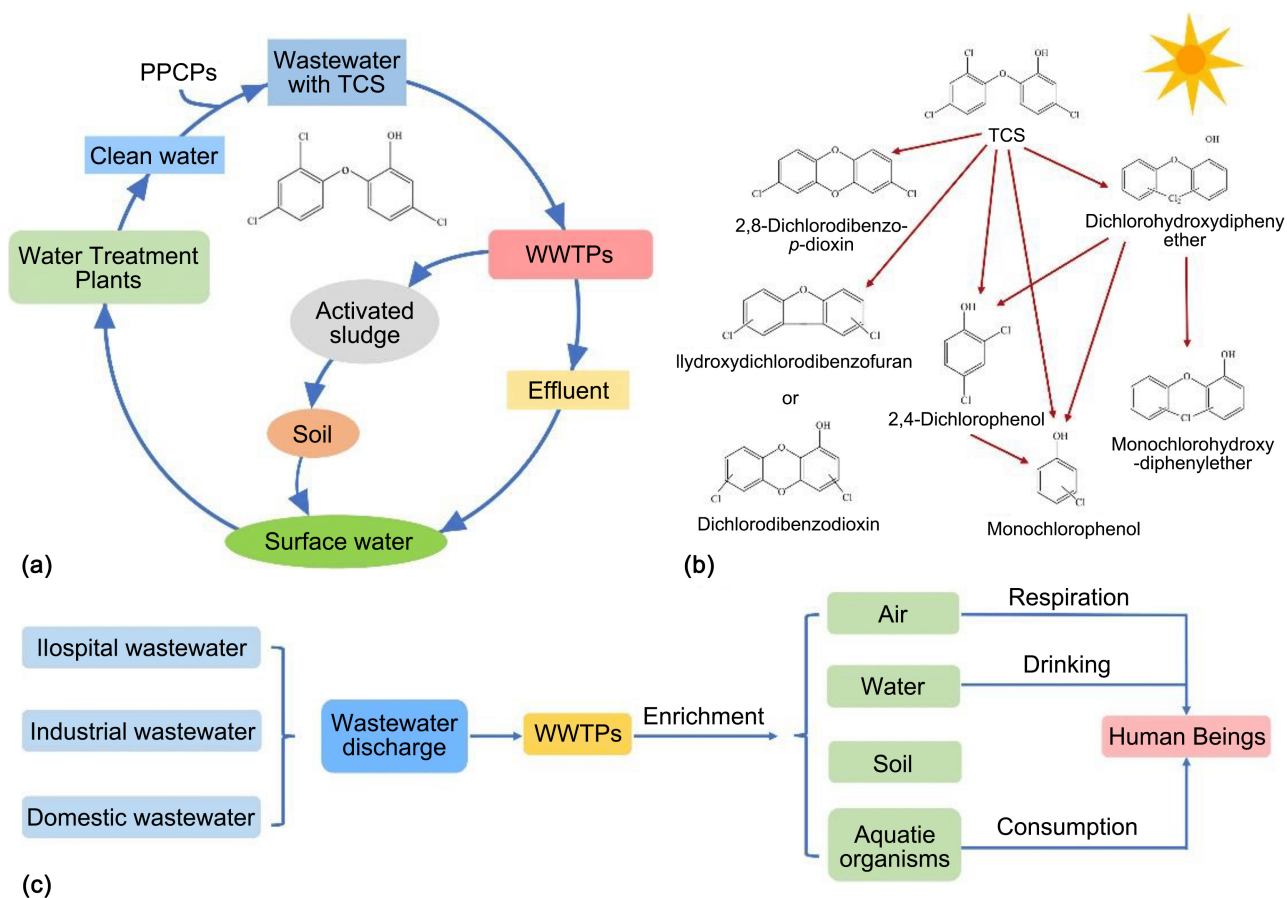


Figure 3. The fate of triclosan in the environment [43] [99].

as TCS, while investigating watershed contamination levels of total trihalomethanes (TTHM) (chloroform) across the major metropolitan water plants of the United States. Our research was on TTHM concentrations in the most densely (greater than 100,000 served) populated metropolitan city in each state from the MWR and CCR data collected during 2019-20 and again in 2021-22, in an attempt to evaluate the decline in watershed quality across the U.S. following the upsurge in the use of antimicrobial products containing TCS in response to the COVID-19 pandemic. Our report will provide timely yet informative results for initial toxicity screening on drinking water quality and risk identification that can be incorporated into a post-pandemic water resource management strategy. Exposure to TTHMs can have serious adverse health effects after prolonged exposure to higher levels of contaminants.

**Table 2** shows common water contaminants found in the drinking water supply and their relative limits, sources, and potential health risks associated with their exposure. The limits and sources for each contaminant are listed in every CCR.

## 2.2. Exposure to COVID-19 Increases Water System Exposure to TCS

Triclosan (TCS) is widely used, and its product production has significantly increased in recent years due to the pandemic. TCS is an emerging pollutant in our water systems that has attracted worldwide attention due to its toxic effects on microorganisms and aquatic ecosystems, and its concentrations in the water environment have been expected to increase since the COVID-19 pandemic outbreak [100]. Since 2020, with the widespread use of TCS, the level of TCS in the water environment has increased due to overuse from the COVID-19 pandemic [99]. Wastewater effluent is the primary source of TCS in the watershed environment (**Figure 3**). As one of the most concerning organo-chlorine contaminants in the world, TCS has also received extensive attention. In nutrient-poor aquatic or terrestrial ecosystems, the natural decay rate of TCS is prolonged [101]. However, removing TCS with the current wastewater treatment methods is difficult, due to its easy production of intermediates trihalomethanes and high maintenance costs [101] [102] [103].

**Table 2.** Common drinking water contaminants with their relative limits, sources, and potential health effects [86] [98].

Contaminants	Limits	Sources	Potential Health Effect
Residual Chlorine	4 mg/L	Disinfectant added to control pathogens	Nervous system damage, anemia, and methemoglobinemia
Trihalomethanes: chloroform, bromodichloromethane, dibromochloromethane, and bromoform	80 mg/L	By-product of water chlorination	Cancer, liver disease, kidney failure, nervous system damage, bladder cancer, colorectal cancer, adverse development, and reproductive effects during pregnancy

TCS is widely used as a synthetic, lipophilic broad-spectrum antimicrobial agent due to its antimicrobial efficacy. However, TCS detected in the aquatic environment has been recently considered one of the most damaging contaminants of human concern [104]. TCS has the potential for endocrine disruption by forming toxic by-products, such as chloroform, and the development of cross-resistance to antibiotics in aquatic environments. The by-product contaminants, including chloroform, could be carried in surface and subsurface into urban watersheds in association with migration, adsorption, and transformation processes, including photo-degradation, chemical or biological transformation in urban watershed systems [43]. Urban waters are vulnerable to contamination by normal human activities and could be polluted with a long-term impact on the urban watershed ecosystem. Urban wastewater discharge streams can be one of the major pathways for emerging organochlorine contaminants, including TCS [99].

Since TCS is primarily a water-borne contaminant, it is detected ubiquitously in aquatic watersheds at some of the highest concentrations among 95 organic wastewater pollutants [22] [104]. Disposal and usage of TCS-containing products resulted in chloroform-containing wastewater. About 96% of household and consumer TCS products flow down the drain [105]. TCS eventually enters wastewater treatment plants (WWTPs) where it combines with free chlorine, creating the by-product, chloroform; then 79% is biodegraded, 15% is adsorbed onto biosolids, and 6% is discharged continuously into the receiving surface watersheds [23] [106]. Total trihalomethane (chloroform) can also be released into the environment by applying biosolids to agricultural field crops and irrigating crops with treated wastewater contaminated with chloroform [23] [107] [108]. The waste from consumer goods containing organochlorine contaminant, TCS, and chloroform sludge from wastewater treatment plants is mainly sent to landfills for disposal, and chloroform is released into the environment through landfill leachate [108]. Additionally, through washing outdoor commercial or residential equipment, TCS-containing products create runoff water containing chloroform that goes directly into stormwater drain systems without treatment and flows directly into watersheds (creeks, rivers, and eventually to the bay or oceans) [43] [108].

### **2.3. Triclosan's Persistence and Bioaccumulation**

Triclosan is a multi-purpose antimicrobial agent used as a common ingredient in everyday household personal care and consumer products. The expanded use of triclosan provides a number of pathways for the compound to enter the environment and it has been detected in sewage treatment plant effluents; surface; ground and drinking water. The physico-chemical properties indicate the bioaccumulation and persistence potential of TCS in the environment. Hence, there is an increasing concern about the presence of TCS in the environment and its potential negative effects on human and animal health [109]. The bacterial

transformation product of TCS in wastewater, methyl TCS is relatively lipophilic and stable in the environment, making it more likely to bioaccumulate in fatty tissue and will not photodegrade [22].

Triclosan is highly toxic to aquatic animals and is particularly highly toxic to the algae. In a study [110], the toxicity of triclosan to a microalga was examined. The study revealed that, as the concentration of triclosan increased then algae growth declined. It was observed that conductivity also increased because of decreased “chlorophyll a” and decreased phytoplankton levels. This result indicated that triclosan exerts a marked influence on algae, which are important organisms being the first-step producers in the ecosystem; therefore, the possible destruction of the balance of the ecosystem is expected if triclosan is discharged into the environment at high levels. The bioaccumulation of triclosan in human impregnation from food exposure (in particular fish) and likely risk for human population also exists.

TCS degrades photolytically as well as through microbial action into more persistent and toxic byproducts like dioxins. Moreover, accumulation in deep water bodies or soil strata where light is not adequately available makes its degradation even more prolonged. During bioaccumulation, concentration of a chemical in the tissues of an organism is much more compared to its concentration in the ambient environment that is water and/or sediment in case of aquatic organisms [111] [112]. Incomplete removal of TCS during wastewater treatment processes leads to the continuous exposure of aquatic biota in receiving waters, which causes accumulation of TCS and its degradation products in the tissues of the organisms [26]. Accumulation of triclosan has been observed in the tissues of aquatic organisms captured from the natural water bodies as found by [1] measured TCS levels in rainbow trout in Sweden.

The bioaccumulation and slow conversion of methyl TCS in lower-level consumers could serve as potential carriers of triclosan from the environment to higher level consumers in food chain. A 120 day pond mesocosm study was conducted in order to investigate the fate of TCS in water and sediment, its bioaccumulative potential in different biota as well as the effects of TCS and its main transformation product methyl-triclosan (M-TCS) on plankton, periphyton, macrophytes, and benthos communities. Considering the high bioaccumulative potential of M-TCS in combination with the observed effects of TCS at low doses suggests that the use of triclosan, and therefore its release into the environment, should cease [113].

#### **2.4. Regulatory Measures Related to Triclosan**

Laboratory studies have raised the possibility that triclosan contributes to making bacteria resistant to antibiotics. Some data show this resistance may have a significant impact on the effectiveness of antibiotics during medical treatments. In 2015, the European Chemicals Agency (ECHA) decided to restrict the use of TCS for biocide type 1 products (human hygienic products) in the EU [114] as

safe use for humans and ecosystem health could no longer be guaranteed. Due to triclosan being hazardous to the aquatic environment and concern over hormonal effect and the potential long-term public health risk that triclosan use presents, the U.S. Food and Drug Administration issued a final rule establishing that over-the-counter consumer antiseptic wash products containing certain active ingredients—including triclosan—can no longer be marketed. Companies will no longer be able to market antibacterial washes containing triclosan because manufacturers did not demonstrate that the ingredients are both safe for long-term daily use and more effective than plain soap and water in preventing illness and the spread of certain infections [11].

The U.S. Food & Drug Administration (FDA) and the Environmental Protection Agency (EPA) have closely collaborated on scientific and regulatory issues related to triclosan. This joint effort helps to ensure government-wide consistency in the regulation of this chemical. The FDA and EPA review the effects of triclosan from two different perspectives [12]. The EPA regulates the use of triclosan as a pesticide and is in the process of updating its assessment of the effects of triclosan when it is used in pesticides. The FDA's focus is on the effects of triclosan when it is used by consumers on a regular basis in hand soaps and body washes. By sharing information, the two agencies are better able to measure the exposure and effects of triclosan and how these differing uses of triclosan may affect human health.

### 3. Materials and Methods

In this study, we conducted a full systematic review of the literature to identify primary studies that focused on investigation of water quality and the levels of organochlorine contaminants using a pre-established list of techniques and keywords. All secondary data related to levels of total trihalomethane (TTHM) concentrations were obtained from the annual water safety reports (SDWIS/FED, MWR, and CCR) for major metropolitan water plants for each state in the US [83]. Data including population and median annual household income of different household districts was obtained from the United States Census Bureau (United States Census Bureau, 2023). Histograms were used to illustrate the levels of total trihalomethanes and free chlorine in various districts across the United States. Tables were generated to record the census data (population/income/systems), number of violations, as well as total trihalomethane (TTHM) and chlorine levels. These data were readily available for public access and no permissions were required for their use. The disparities among the average household income in different districts and the organochlorine contaminants are shown using multi-variable charts.

The water quality data was then prepared for descriptive statistical analysis from secondary data related to drinking water quality divided into four districts or Federal Information Processing Standard (FIPS), identifying districts by regions, states, populations, and annual income in the US [83] [86]. Refer to dis-

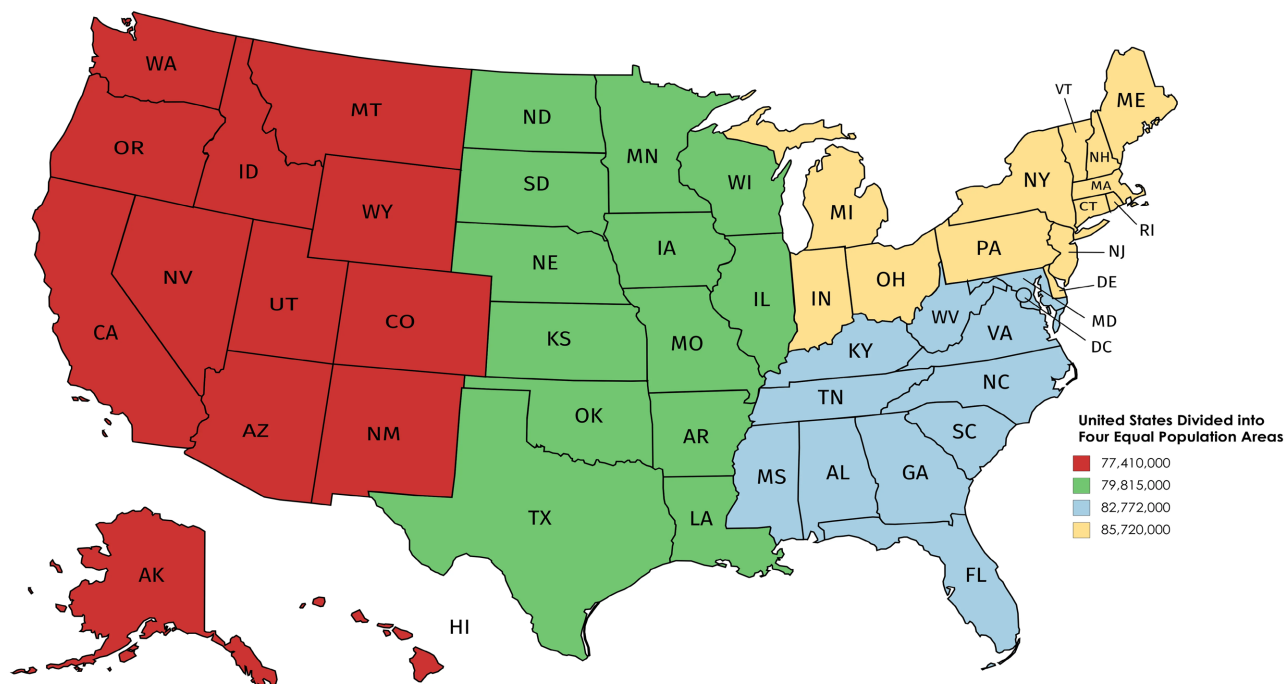
tricts (**Table 3**, **Figure 4**) for each metropolitan city in the 50 states. Data, including median annual household income and population data, was obtained from the US Census Bureau [83]. Additional information was collected by contacting water service offices to obtain information not readily available in the annual water safety reports.

### 3.1. Methods

The water quality data was prepared for descriptive statistical analysis and analysis of variance (ANOVA) from secondary data related to drinking water quality obtained from the annual water safety reports for the major cities of each state in the US divided into Federal Information Processing (FIP) districts [83] [86] [115]. Data, including median annual household income, was obtained from the US Census Bureau [115]. Tables were generated to record income per capita for each state (provided by the Census Bureau) along with their drinking water sources (provided by the state and local water services departments) and correlated to the levels of contaminants. The disparities between the average household income in different states and their water quality are shown using multi-variable charts. **Table 3** features the states divided into districts (West, Midwest, South, and Northeast) as reported by the US Census and the EPA being analyzed in this study, while **Figure 4** provides a map of the United States with the Census Bureau regions. Additional information for each water system was

**Table 3.** Census Bureau regions and divisions with FIPS codes for each state in the United States.

West	Midwest	South	Northeast
AK—Alaska	IL—Illinois	AL—Alabama	CT—Connecticut
AZ—Arizona	IN—Indiana	AR—Arkansas	DE—Delaware
CA—California	IA—Iowa	FL—Florida	ME—Maine
CO—Colorado	KS—Kansas	GA—Georgia	MD—Maryland
HA—Hawaii	MI—Michigan	KY—Kentucky	MA—Massachusetts
ID—Idaho	MN—Minnesota	LA—Louisiana	NH—New Hampshire
MT—Montana	MO—Missouri	MS—Mississippi	NJ—New Jersey
NV—Nevada	NE—Nebraska	NC—North Carolina	NY—New York
NM—New Mexico	ND—North Dakota	OK—Oklahoma	PA—Pennsylvania
OR—Oregon	OH—Ohio	SC—South Carolina	RI—Rhode Island
UT—Utah	SD—South Dakota	TN—Tennessee	VT—Vermont
WA—Washington	WI—Wisconsin	TX—Texas	
WY—Wyoming		VA—Virginia	
		WV—West Virginia	



**Figure 4.** Map showing the Census Bureau regions and divisions with state FIPS codes of the United States [83].

obtained from the EPA website using the Safe Drinking Water Information System (SDWIS) [116]. The SDWIS provided the primary water source, the number of violations, and the population served for each water system. The median household income, population data, and % of persons in poverty were retrieved from the US Census Bureau for 2020 [115] censuses. The data were obtained by accessing the QuickFacts website for the Census Bureau. Since the release of the 2015 census, Quick-Facts has shown the information from the current censuses. The population information is reported for 2020.

### 3.2. Statistical Analysis

An analysis of variance, ANOVA, a statistical test that compares the means of two or more data sets, would be used for significance [117]. The results of ANOVA show a significant difference between the means of the data within the given experimental setup, which means that at least one of the groups had a different mean than the others. In our research, the ANOVA was used to compare the means of the data within the water quality data reported from 2016, right before the FDA ban, with the data from March 2020, after the ban but before the beginning of the COVID-19 pandemic. The Student's t-test was then used to follow up on the findings and to identify which group pairs had significantly different means. Student's t-test is a statistical test used to compare the means of two groups (water quality data reported in 2005-2015 compared to the same data reported in 2019-2020, then finally in 2021-2022).

A significant ANOVA was followed by a pairwise analysis of control versus exposed data using Student's t-test and a p-value of less than 0.05 was consi-

dered significant. A p-value for the probability of obtaining the statistical test results if the null hypothesis is true was used. In this research, the null hypothesis is the difference between the means of the groups. A p-value of less than 0.05 means that the statistical test results are unlikely to have occurred by chance. Therefore, the results of the statistical analysis are considered to be significant. Applied to our results, a p-value of equal to or less than 0.05 means a decrease in the levels of reported TTHM could be statistically significant to the decreased production and consumer use of antibacterial products containing the organochlorine contaminant TCS from 2019-2020 after the FDA ban. Our previous research showed a significant correlation between the overuse of TCS-containing products and increased TTHM in drinking water from 2020 (after the increased use in response to COVID-19, the first required archived water quality data for TTHM levels) and 2021 (after the height of production of TCS-containing products).

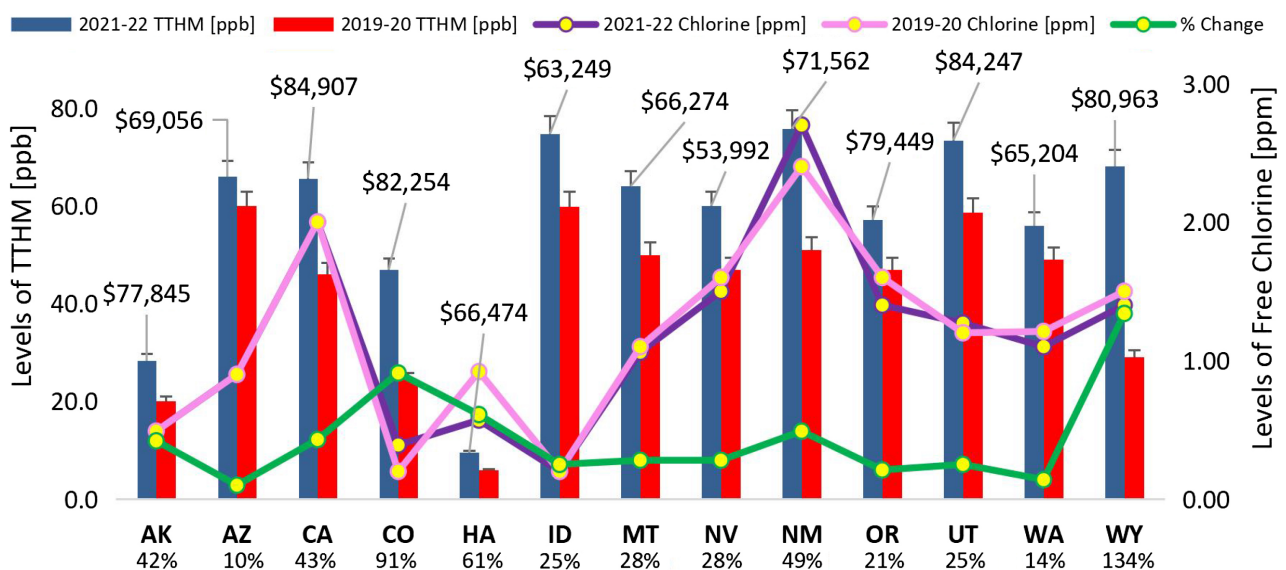
#### 4. Results and Discussion

The United States Census Bureau determined that the standard, full suite of 2016-2020 ACS 5-year data is unbiased for public release and statistical analysis for understanding the US population's social, environmental, and economic characteristics. The 2020 input data were integrated with the inputs processed using standard American Consumer Survey (ACS) methodology from 2016, 2017, 2018, and 2019 to produce the statistical analysis, according to the 2020 data from the United States Census Bureau. The nation's poverty rate decreased from 15.5 percent (2016) to 12.8 percent (2020) compared with a slight decrease of 12.4 percent in 2022, with a population percent increase of 11.4 percent or 37.2 million people, with a median income decrease of 2.9 percent from the 2019 median income of about \$69,560. According to the 2020 US Census, the US had a population of 333.29 million, which was a 7.4% increase since the last census in 2010, and an annual income level of \$67,521 before taxes, which was an annual growth rate of 3.07 percent, with approximately 6.91 percent under the federal poverty level (FPL) of the U.S. [115]. Nevertheless, ensuring access to safe drinking water poses a considerable challenge for US water systems due to aging infrastructure, impaired source water, and strained community finances. There is a correlation between recent cases of impaired water quality that have impacted lower-income communities across the country.

Based on **Table 4** and **Figure 5**, the West District of the US has an average population of 8.9 million with an average annual salary of \$72,043, +3.4 million people with a 3.2% average annual growth rate 2010-2020. The mean average levels of TTHM [ppb] (M) were  $42.2 \pm 4.7$  ppb with (SD) 16.9 ppb for 2019-2020 and (M)  $57.3 \pm 5.3$  ppb with (SD) 19.3 ppb for 2021-2022, as shown in **Table 5**. A student's t test showed statistical significance in the decrease in the levels of TTHMs between 2019-20 and 2021-22 with a *p* value of  $8.4E-4$  (2-tailed) with an average increase of 43.9% in the TTHM levels. When comparing the averages

**Table 4.** West District of the United States—US census data for the average population and annual income. The US EPA-SDWIS/FED annual data for the number of total violations, TTHM violations, and TTHM Levels reported by each state of the West District of the United States [115] [116] [118].

State		2020			2019-2020			2021-2022		
		Census Data		Systems	Violations	Chlorine	TTHM	Chlorine	TTHM	% Change
		Population	Income		Total	[ppm]	[ppb]	[ppm]	[ppb]	
AK	Alaska	5,696,966	\$77,845	6706	137,133	0.49	20.0	0.49	28.3	42%
AZ	Arizona	2,901,707	\$69,056	15,611	143,478	0.90	60.0	0.90	66.0	10%
CA	California	20,689,846	\$84,907	60,867	71,279	2.00	46.0	2.00	65.6	43%
CO	Colorado	9,665,530	\$82,254	15,053	52,823	0.20	24.6	0.39	46.9	91%
HA	Hawaii	4,512,989	\$84,857	1241	1325	0.92	5.9	0.57	9.5	61%
ID	Idaho	5,075,813	\$66,474	8302	46,320	0.20	59.9	0.20	74.7	25%
MT	Montana	3,141,331	\$63,249	12,978	66,233	1.10	50.0	1.06	64.0	28%
NV	Nevada	8,765,136	\$66,274	6464	14,546	1.60	47.0	1.50	60.0	28%
NM	New Mexico	3,699,347	\$53,992	10,145	40,312	2.40	51.0	2.70	75.8	49%
OR	Oregon	4,010,497	\$71,562	14,219	119,569	1.60	47.0	1.40	57.1	21%
UT	Utah	7,188,955	\$79,449	10,208	59,000	1.20	58.7	1.27	73.4	25%
WA	Washington	28,223,188	\$84,247	13,598	126,893	1.21	49.0	1.10	56.0	14%
WY	Wyoming	7,497,727	\$65,204	6186	15,158	1.50	29.1	1.40	68.1	134%



**Figure 5.** West District of the United States—US Census Data for the average population and annual income. The US EPA-SDWIS/FED annual data for the number of total violations, TTHM violations, and TTHM Levels reported by each state of the West District of the United States. Note. % is the net change increase in TTHM levels from 2019-2020 to 2021-2022 [115] [116] [118].

**Table 5.** West District of the United States-statistical descriptive data for the averages reported by the states of the West District. Note. Red indicates an increased % change in TTHM levels from pre-COVID 2019-2020 to post-COVID 2021-2022.

	2020			2019-2020			2021-2022		
	Census Data			Violations	Cl <sup>-</sup>	TTHM	Cl <sup>-</sup>	TTHM	TTHM
<i>Statistics</i>	<i>Population</i>	<i>Income</i>	<i>Systems</i>	<i>Total</i>	[ppm]	[ppb]	[ppm]	[ppb]	% Change
<b>Mean (M)</b>	8,879,670	\$72,042	15,028	74,395	1.18	42.17	1.15	57.34	43.9%
<b>Standard Error</b>	2.2E+6	2794	4283	13,292	0.18	4.69	0.19	5.34	0.09
<b>Variance</b>	6.0E+13	9.4E+7	2.1E+8	2.1E+9	0.43	289.61	0.48	371.11	0.12
<b>Standard Deviation (SD)</b>	7.8E+6	9679.4	14837.9	46048.1	0.66	16.93	0.69	19.26	0.35

(n-103) for 2019-2020 with those for 2021-2022, the decrease in TTHM levels was found to be statistically significant  $p$  value of 0.043 (2-tailed ANOVA).

Based on **Table 4** and **Figure 5**, the West District of the US has an average population of 8.9 million with an average annual salary of \$72,043, +3.4 million people with a 3.2% average annual growth rate 2010-2020. The mean average levels of TTHM [ppb] (M) were  $42.2 \pm 4.7$  ppb with (SD) 16.9 ppb for 2019-2020 and (M)  $57.3 \pm 5.3$  ppb with (SD) 19.3 ppb for 2021-2022, as shown in **Table 5**. A student's t test showed statistical significance in the decrease in the levels of TTHMs between 2019-20 and 2021-22 with a  $p$  value of  $8.4E-4$  (2-tailed) with an average increase of 43.9% in the TTHM levels. When comparing the averages (n-103) for 2019-2020 with those for 2021-2022, the decrease in TTHM levels was found to be statistically significant  $p$  value of 0.043 (2-tailed ANOVA).

Based on **Table 6** and **Figure 6**, the Midwest District of the US has an average population of 5.2 million with an average annual salary of \$66,383, -410 thousand people with a 3.0% average annual growth rate 2010-2020. The mean average levels of TTHM [ppb] (M) were  $25.4 \pm 5.0$  ppb with (SD) 17.3 ppb for 2019-2020 and (M)  $38.0 \pm 5.6$  ppb with (SD) 19.3 ppb for 2021-2022, as shown in **Table 7**. A student's t-test showed statistical significance in the increase in the levels of TTHMs between 2019-2020 and 2021-2022 with a  $p$  value of  $9.6E-3$  (2-tailed) and an average increase of 85.6% in the TTHM levels. When comparing the averages (n-95) for 2019-2020 with 2021-2022, the increase in TTHM levels was found to be statistically significant  $p$  value of  $7.21E-4$  (2-tailed ANOVA).

Based on **Table 8** and **Figure 7**, the South District of the US has an average population of 8.0 million with an average annual salary of \$59,173, +350 thousand people with a 2.9% average annual growth rate 2010-2020. The mean average levels of TTHM [ppb] (M) were  $41.1 \pm 3.6$  ppb with (SD) 13.6 ppb for 2019-2020 and (M)  $56.8 \pm 4.2$  ppb with (SD) 15.6 ppb for 2021-2022, as shown in **Table 9**. A student's t-test showed statistical significance in the increase in the levels of TTHMs between 2019-2020 and 2021-2022 with a  $p$  value of 0.048

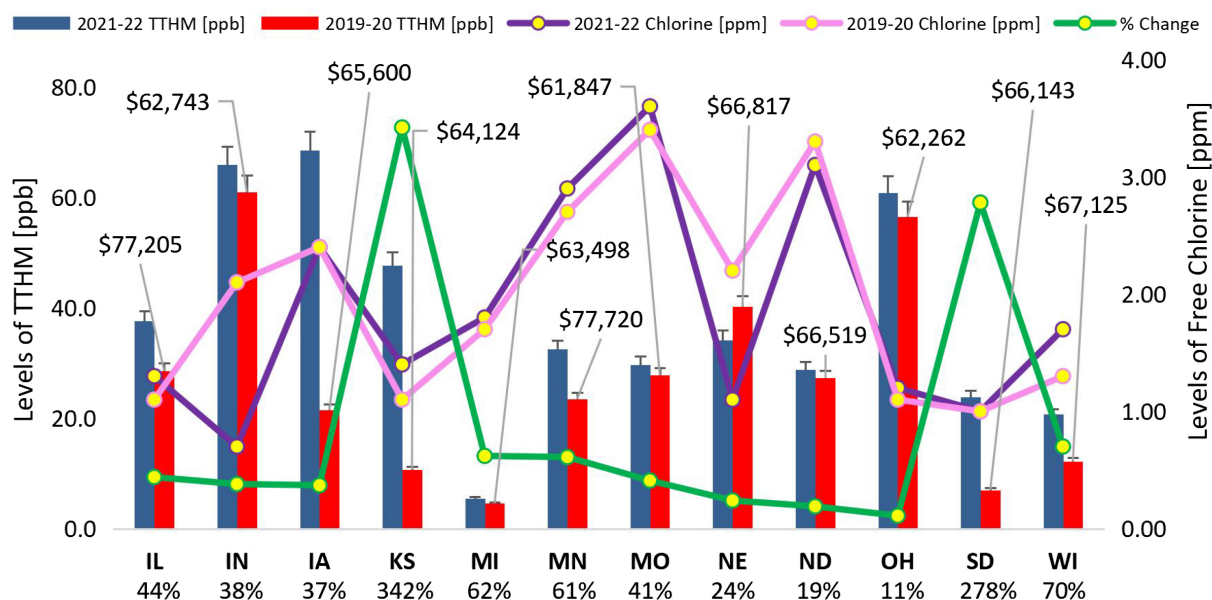
(2-tailed) and an average increase of 53.6% in the TTHM levels. When comparing the averages (n=137) for 2019-2020 with 2021-2022, the increase in TTHM levels was found to be statistically significant *p* value of 8.86E-3 (2-tailed ANOVA).

**Table 6.** Midwest District of the United States—US Census Data for the average population and annual income. The US EPA-SDWIS/FED annual data for the number of total violations, TTHM violation, and TTHM levels reported by each state of the Midwest District of the United States [115] [116] [118].

		2020			2019-2020			2021-2022		
		Census Data			Violations	Chlorine	TTHM	Chlorine	TTHM	
State		Population	Income	Systems	Total	[ppm]	[ppb]	[ppm]	[ppb]	% Change
IL	Illinois	12,506,244	\$72,205	32,614	76,309	1.1	26.2	1.3	37.6	44%
IN	Indiana	5,461,969	\$62,743	18,784	82,993	2.1	48.0	0.7	66.0	38%
IA	Iowa	2,951,224	\$65,600	18,258	25,659	2.4	50.0	2.4	68.5	37%
KS	Kansas	2,828,391	\$64,124	11,349	18,304	1.1	10.8	1.4	47.7	342%
MI	Michigan	8,735,388	\$63,498	22,083	73,588	1.7	3.4	1.8	5.5	62%
MN	Minnesota	5,012,820	\$77,720	35,547	10,301	2.7	20.2	2.9	32.5	61%
MO	Missouri	5,589,463	\$61,847	21,770	44,439	3.4	21.1	3.6	29.7	41%
NE	Nebraska	1,705,357	\$66,817	9677	12,373	2.2	27.5	1.1	34.2	24%
ND	N. Dakota	709,655	\$66,519	2943	4013	3.3	24.3	3.1	28.8	19%
OH	Ohio	10,914,524	\$62,262	32,098	84,957	1.1	55.0	1.2	60.8	11%
SD	S. Dakota	814,159	\$66,143	4310	23,270	1.0	6.3	1.0	23.8	278%
WI	Wisconsin	5,027,143	\$67,125	34,404	82,289	1.3	12.2	1.7	20.7	70%

**Table 7.** Midwest District of the United States—statistical descriptive data for the averages reported by the states of the Midwest District. *Note.* Red indicates an increased % change in TTHM levels from pre-COVID 2019-2020 to post-COVID 2021-2022.

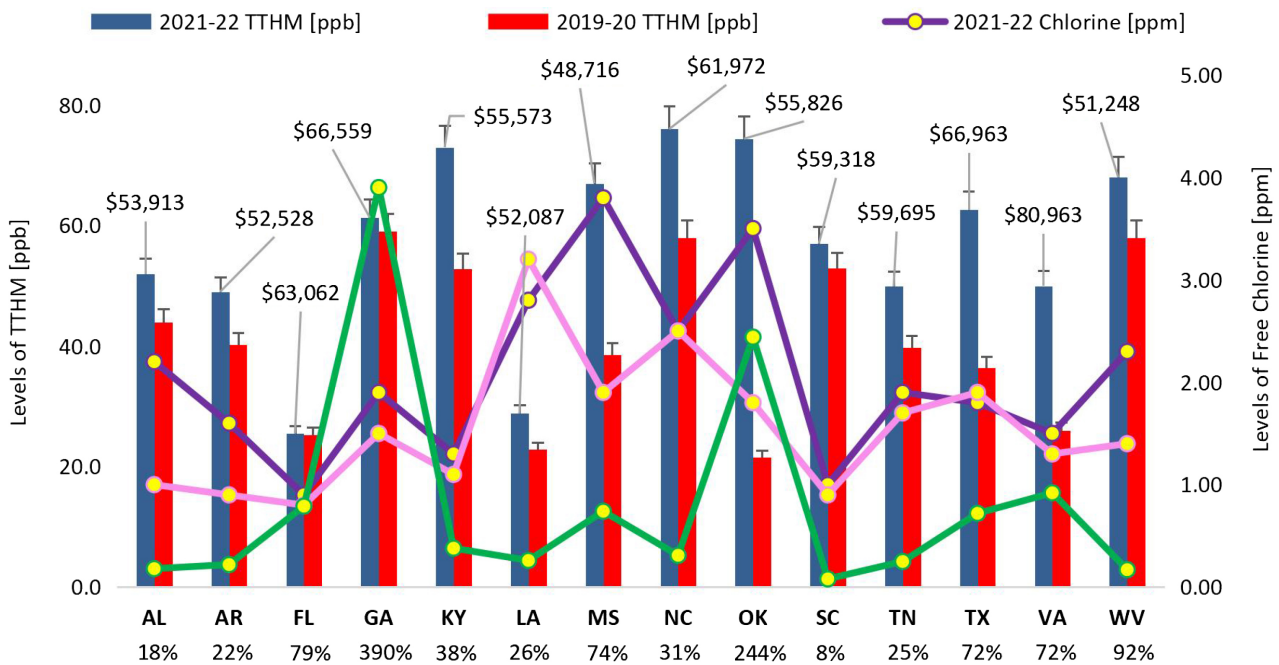
		2020			2019-2020			2021-2022		
		Census Data			Violations	Cl <sup>-</sup>	TTHM	Cl <sup>-</sup>	TTHM	TTHM
Statistics		Population	Income	Systems	Total	[ppm]	[ppb]	[ppm]	[ppb]	% Change
<b>Mean (M)</b>		5,188,028	\$66,383	20,319	44,875	1.95	25.42	1.85	37.98	+85.6%
<b>Standard Error</b>		1.1E+6	1314	3352	9429	0.25	4.98	0.27	5.56	0.31
<b>Variance</b>		1.5E+13	2.1E+7	1.4E+6	1.1E+9	0.76	298.19	0.87	371.25	1.15
<b>Standard Deviation (SD)</b>		3.8E+6	4553.6	11614.9	32662.4	0.87	17.27	0.93	19.27	1.07



**Figure 6.** Midwest District of the United States—US Census data for the average population and annual income. The US EPA-SDWIS/FED annual data for the number of Total Violations, TTHM Violation, and TTHM Levels reported by each state of the Midwest District of the United States. Note. % is the net change increase in TTHM levels from 2019-2020 to 2021-2022 [115] [116] [118].

**Table 8.** South District of the United States—US census data for the average population and annual income. The US EPA-SDWIS/FED annual data for the number of total violations, TTHM violation, and TTHM levels reported by each state of the South District of the United States [115] [116] [118].

	State	2020			2019-2020			2021-2022		
		Census Data		Systems	Violations Total	Chlorine [ppm]	TTHM [ppb]	Chlorine [ppm]	TTHM [ppb]	% Change
<b>AL</b>	Alabama	5,696,966	\$53,913	7557	8757	1.0	44.0	2.2	52.0	18%
<b>AR</b>	Arkansas	2,901,707	\$52,528	4793	14,255	0.9	40.2	1.6	49.0	22%
<b>FL</b>	Florida	20,689,846	\$63,062	18,346	52,157	0.8	25.3	0.9	25.5	79%
<b>GA</b>	Georgia	9,665,530	\$66,559	14,258	34,913	1.5	59.0	1.9	61.3	4%
<b>KY</b>	Kentucky	4,512,989	\$55,573	2730	17,895	1.1	52.8	1.3	73.0	38%
<b>LA</b>	Louisiana	5,075,813	\$52,087	12,562	19,841	3.2	22.9	2.8	28.8	26%
<b>MS</b>	Mississippi	3,141,331	\$48,716	10,304	133,139	1.9	38.6	3.8	67.0	74%
<b>NC</b>	N. Carolina	8,765,136	\$61,972	29,476	146,744	2.5	58.0	2.5	76.0	31%
<b>OK</b>	Oklahoma	3,699,347	\$55,826	10,825	54,382	1.8	21.6	3.5	74.4	244%
<b>SC</b>	S. Carolina	4,010,497	\$59,318	6067	11,299	0.9	52.9	1.0	57.0	8%
<b>TN</b>	Tennessee	7,188,955	\$59,695	7291	11,895	1.7	39.8	1.9	49.9	25%
<b>TX</b>	Texas	28,223,188	\$66,963	112,250	149,969	1.9	36.4	1.8	62.6	72%
<b>VA</b>	Virginia	7,497,727	\$80,963	21,973	36,034	1.3	26.0	1.5	50.0	92%
<b>WV</b>	W. Virginia	1,576,588	\$51,248	6366	51,205	1.4	58.0	2.3	68.0	17%



**Figure 7.** South District of the United States—US census data for the average population and annual income. The US EPA-SDWIS/FED annual data for the number of total violations, TTHM violations, and TTHM levels reported by each state of the South District of the United States. Note. % is the net change increase in TTHM levels from 2019-2020 to 2021-2022 [115] [116] [118].

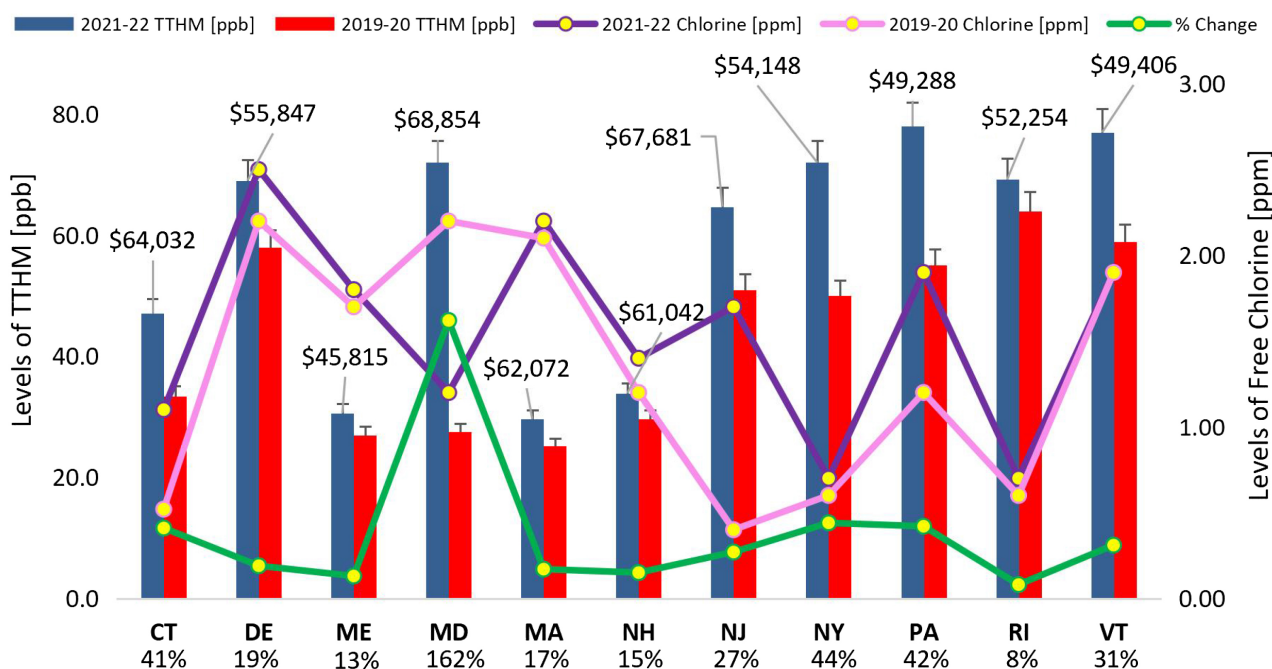
**Table 9.** South District of the United States—statistical descriptive data for the averages reported by the states of the South District. Note. Red indicates an increased % change in TTHM levels from pre-COVID 2019-2020 to post-COVID 2021-2022.

	2020		2019-2020			2021-2022			% Change
	Census Data		Violations	Cl <sup>-</sup>	TTHM	Cl <sup>-</sup>	TTHM	TTHM	
Statistics	Population	Income	Systems	Total	[ppm]	[ppb]	[ppm]	[ppb]	
Mean (M)	8,046,116	\$59,173	18,914	53,034	1.56	41.11	2.07	56.75	53.6%
Standard Error	2.0E+6	2260	7443	13,758	0.18	3.63	0.23	4.17	0.17
Variance	5.6E+13	7.2E+7	7.8E+8	2.7E+9	0.68	184.32	0.74	243.51	0.38
Standard Deviation (SD)	7.5E+6	8465.5	27848.9	51,480	0.46	13.58	0.86	15.60	0.62

Based on Table 10 and Figure 8, the Northeast District of the US has an average population of 6.1 million with an average annual salary of \$57,134, +500 thousand people with a 3.0% average annual growth rate 2010-2020. The mean average levels of TTHM [ppb] (M) were  $43.6 \pm 4.5$  ppb with (SD) 15.0 ppb for 2019-2020 and (M)  $58.5 \pm 5.8$  ppb with (SD) 19.3 ppb for 2021-2022, as shown in Table 11. A student’s t-test showed statistical significance in the increase in the levels of TTHMs between 2019-2020 and 2021-2022 with a *p* value of 0.024 (2-tailed) and an average increase of 38.1% in the TTHM levels. When comparing the averages (n-137) for 2019-2020 with 2021-2022, the increase in TTHM levels was found to be statistically significant *p* value of  $1.9E-6$  (2-tailed ANOVA).

**Table 10.** Northeast District of the United States—US Census Data for the average population and annual income. The US EPA-SDWIS/FED Annual Data for the number of total violations, TTHM violations, and TTHM levels reported by each state of the Northeast District of the United States [115] [116] [118].

State		2020			2019-2020			2021-2022		
		Census Data			Violations	Chlorine	TTHM	Chlorine	TTHM	
		Population	Income	Systems	Total	[ppm]	[ppb]	[ppm]	[ppb]	% Change
<b>CT</b>	Connecticut	2,880,001	\$64,032	14,516	57,345	0.52	33.4	1.1	47.1	41%
<b>DE</b>	Delaware	974,687	\$55,847	3471	3140	2.2	58.0	2.5	69.0	19%
<b>ME</b>	Maine	929,625	\$45,815	11,721	33,484	1.7	27.0	1.8	30.6	13%
<b>MD</b>	Maryland	5,915,557	\$68,854	17,806	19,480	2.2	27.5	1.2	72.0	162%
<b>MA</b>	Massachusetts	9,802,316	\$62,072	13,329	43,124	2.1	25.2	2.2	29.6	17%
<b>NH</b>	New Hampshire	1,201,963	\$61,042	6,476	39,843	1.2	29.6	1.4	33.9	15%
<b>NJ</b>	New Jersey	9,614,776	\$67,681	17,734	81,449	0.4	51.0	1.7	64.7	27%
<b>NY</b>	New York	21,306,094	\$54,148	53,656	145,200	0.6	50.0	0.7	72.0	44%
<b>PA</b>	Pennsylvania	12,695,604	\$49,288	38,483	337,248	1.2	55.0	1.9	78.0	42%
<b>RI</b>	Rhode Island	1,128,572	\$52,254	3000	4248	0.6	64.0	0.7	69.2	8%
<b>VT</b>	Vermont	613,979	\$49,406	8287	31,709	1.9	58.9	1.9	77.0	31%



**Figure 8.** Northeast District of the United States—US Census Data for the average population and annual income. The US EPA-SDWIS/FED Annual Data for the number of total violations, TTHM violations, and TTHM levels reported by each state of the Northeast District of the United States. Note. % is the net change increase in TTHM levels from 2019-2020 to 2021-2022 [115] [116] [118].

**Table 11.** Northeast District of the United States—statistical descriptive data for the averages reported by the states of the Northeast District. *Note.* Red indicates an increased % change in TTHM levels from pre-COVID 2019-2020 to post-COVID 2021-2022.

	2020			2019-2020		2021-2022			
	Census Data			Violations	Cl <sup>-</sup>	TTHM	Cl <sup>-</sup>	TTHM	TTHM
<i>Statistics</i>	<i>Population</i>	<i>Income</i>	<i>Systems</i>	<i>Total</i>	[ppm]	[ppb]	[ppm]	[ppb]	% Change
<i>Mean (M)</i>	6,096,652	\$57,313	17,134	72,388	1.33	43.61	1.55	58.46	38.1%
<i>Standard Error</i>	2.0E+6	2,372	4689	29,089	0.22	4.53	0.18	5.79	0.13
<i>Variance</i>	4.4E+13	6.2E+7	2.4E+8	9.3E+9	0.52	225.67	0.35	369.89	0.18
<i>Standard Deviation (SD)</i>	6.6E+6	7869.4	15554.4	96479.2	0.72	15.02	0.59	19.23	0.43

**Table 12.** United States—statistical descriptive data for the averages reported for the West, Midwest, South, and Northeast Districts. *Note.* Red indicates a decreased % change in TTHM levels from 2016 to 2020.

	2020			2019-2020		2021-2022			
	Census Data			Violations	Cl <sup>-</sup>	TTHM	Cl <sup>-</sup>	TTHM	TTHM
<i>Statistics</i>	<i>Population</i>	<i>Income</i>	<i>Systems</i>	<i>Total</i>	[ppm]	[ppb]	[ppm]	[ppb]	% Change
<i>Mean (M)</i>	7,112,677	\$63,673	17,907	60,612	1.50	38.17	1.67	52.78	55.3%
<i>Standard Error</i>	9.4E+6	1,378	2656	8056	0.11	2.39	0.19	2.78	0.10
<i>Variance</i>	4.4E+13	9.3E+7	3.5E+8	3.6E+9	0.59	285.24	0.71	385.20	0.68
<i>Standard Deviation (SD)</i>	6.6E+6	9646.8	18595.1	59542.8	0.77	16.89	0.84	19.63	0.46

After compiling the secondary data, population size, annual income, and water quality for all 50 states in four districts of the US (Tables 4-11 and Figures 4-7). The average mean (M) household income was \$63,673 ± 1378, standard deviation (SD) of 9647, which was a statistically significant *df* of 428, and *p* value of 1.4E-06 (2-tailed ANOVA). The average levels of TTHM [ppb] (M) 38.2 ± 2.4 with (SD) 16.9 for 2019-2020 and (M) 52.8 ± 2.8 ppb (SD) 19.6 ppb for 2021-2022, as shown in Table 12. A student's *t* test showed statistical significance in the increase in the levels of TTHMs between pre-COVID 2019-2020 and post-COVID 2021-2022 with a *p* value of 1.4E-06 (2-tailed). When comparing the averages (*n*=569) for 2019-2020, the increase in TTHM levels was found to be statistically significant *p* value 1.3E-4, with an overall average % increase in the levels of TTHM was 55.3 percent after the increased use of products containing antimicrobial agent, triclosan (TCS) post-COVID 2021-2022 (2-tailed ANOVA).

## 5. Conclusions

Recent environmental studies show that TCS is one of the most frequently detected compounds at the highest concentrations in waterways. The risks asso-

ciated with using TCS include but are not limited to water contamination, fragile aquatic ecosystems, algae toxicity, bioaccumulation in the fatty tissues of fish, and potential interference with thyroid hormone production and other endocrine functions. Water treatment plants do not entirely remove TCS from treated water; thus, it becomes an unregulated contaminant of treatment plants. Our review assesses the impact on water quality caused by the COVID-19 pandemic on the overuse of products containing the active antiviral, antibacterial, or antimicrobial ingredient organochlorine, TCS.

Our research showed that all US states had a significant increase in the levels of TTHM in major metropolitan water plants and water sources after the pandemic. All the states showed a statistically significant increase overall in TTHM, compared to the slight decreases seen in data we compiled for 2015-2019 after the FDA issued the ban. The most significant increase in TTHM levels seen post-COVID in the West District was in Wyoming (2021-22)—68.1 ppb +134.0% compared to 29.1 ppb pre-COVID (2019). The Midwest state with the most significant increase in TTHM was South Dakota (2021-22)—23.8 ppb +278.0% compared to 6.3 ppb pre-COVID. The South District's most significant increase was seen in Oklahoma (2021-22)—74.4 ppb +244.0% compared to 21.6 ppb in pre-COVID (2019-20). Lastly, the Northeast District had the most substantial increases post-COVID, with the most significant increase in Maryland—27.5 ppb pre-COVID (2019-20), with a +162.0% increase to 72.0 ppb. Our results showed an overall average decrease of 55.3% in TTHM levels in drinking water supplies.

## Acknowledgements

We acknowledge the financial support from the Office of Research and Sponsored Programs (RSP) and the Title III Office under the supervision of Dr. Andrea Tyler of Tennessee State University. We also thank the United States water service offices for providing annual water safety reports.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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### Abbreviations and Acronyms

EPA	Environmental Protection Agency
FDA	Food and Drug Administration
SDWIS/FED	Safe Drinking Water Information System/Federal Reporting Services
CCR	Consumer Compliance Report
CDC	Centers for Disease Control and Prevention
MWR	Major Water Report
EWG	Environmental Work Group
WWTP	Wastewater Treatment Plant
DBP	Disinfectant By-Product
TCS	Triclosan
TTHM	Total Trihalomethanes