Water Quality in Selected Small Drinking Water Systems of Missouri Rural Communities

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Abstract: Small drinking water treatment systems (serving <10,000 population) in rural communities frequently encounter multiple challenges in water quality and federal regulatory compliance, especially the disinfection byproduct (DBP) regulations, due to source water variations, limited resources, and aging infrastructures. Unlike most studies on the DBP control using synthetic water in laboratory settings, this research aimed to identify the major water quality issues confronting small systems in the state of Missouri (MO), the United States of America (USA). Three small systems were selected based on source water and geographic locations. Water samples were collected quarterly from each major treatment process during the period of May 2012 to March 2013 and analyzed to identify the treatment effectiveness and potential water quality issues in each small system. Results of water quality characterization showed that the major water quality issue in the selected small systems was the low efficiency of dissolved organic carbon (DOC) removal, especially the DOC species that are considered as the DBP precursors. Most collected water samples had a higher trihalomethane formation potential (THMFP) than the United States Environmental Protection Agency (USEPA) maximum contaminant limit (MCL) (80 μg/L). Based on the analysis of the treatment efficiency in each system, several strategies for water quality improvement were recommended, and a few of which have been implemented in the small systems, leading to improved drinking water quality and compliance with the USEPA DBP regulations. This study would provide a valuable aid to small system operators and local water authority in context of water quality improvement and the regulatory compliance.

Keywords: water quality; drinking water; disinfection byproducts; dissolved organic carbon; water treatment

1. Introduction

Drinking water treatment operation typically consists of a series of processes, including aeration, coagulation-flocculation-sedimentation, activated carbon treatment, and chlorination. Each operation targets specific impurities or contaminants and has some economical or technical limitations. For example, disinfection with various oxidants, such as chlorine, has widely been used for reducing the incidence of waterborne diseases caused by bacteria and viruses since the beginning of the 20th century [1,2]; however, the disinfectants applied not only deactivate waterborne microorganisms, but also react with substances other than pathogens present in the source water, *i.e.*, natural organic matter (NOM) or dissolved organic carbon (DOC), which leads to the formation of numerous disinfection

byproducts (DBPs) [3–6]. Most DBPs formed in drinking water are in a concentration ranging from ng/L to mg/L, and many of which are considered to be carcinogenic [7–10]. Among the toxic DBPs, trihalomethanes (THMs), a group of halogenated organic compounds including chloroform (CHCl$_3$), dibromochloromethane (CHBr$_2$Cl), bromodichloromethane (CHBrCl$_2$), and bromoform (CHBr$_3$), were first detected as a result of water chlorination in 1974 [11]. As they are often the dominant DBPs, THMs were regulated by the United States Environmental Protection Agency (USEPA) in 1979 with maximum contaminant level (MCL) of 100 µg/L for total THMs (TTHM) [12]. In 1998, the EPA tightened the regulation on THMs and issued the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR), which lowered the MCL for TTHM to 80 µg/L. In 2005, USEPA issued Stage 2 DBPR (effective in 2014) to further reduce general public exposure to DBPs and lower the potential cancer, reproductive, and developmental risks. The implementation of Stage 2 DBPR required all drinking water treatment plants in compliance with the MCL of <80 µg/L for TTHMs on the location running annual average (LRAA) [13].

According to the USEPA, 97% of drinking water treatment systems in the United States serve less than 10,000 people and are thus classified as "small systems". Most small water systems, especially in rural communities, are facing a challenge in compliance with the USEPA Stage 2 DBPR, due to source water variations, limited resources, aging infrastructures, and low cost efficiency. In order to help the small systems in compliance with the EPA DBP regulations and safeguard general public from the DBP health risks, there is an urgent need to develop cost-effective treatment technologies for DBP control in drinking water treatment facilities, especially for small rural drinking water treatment systems with limited technical and financial resources.

Objective and Scope

To better understand the current issues related to DBPs facing small drinking water treatment facilities and develop possible solutions, three small drinking water treatment systems in the rural communities in Missouri, USA, were selected as a case study. Unlike most studies on disinfection byproduct (DBP) control using synthetic water in laboratory settings, the objectives of this study were to (i) characterize water quality at each treatment process from source water to finished water; (ii) evaluate the treatment efficiency and identify major water quality issues; and (iii) make recommendations as coast-effective solutions for each system to improve drinking water quality and be in compliance with the EPA regulations. The outcomes of this study would make a valuable contribution to small system operators and local water authority for decision-making on water treatment, drinking water quality, and regulatory compliance.

2. Materials and Methods

2.1. Description of the Small Drinking Water Systems

This research was focused on the "small drinking water treatment systems" serving <10,000 population as defined by the USEPA. Three small systems were selected based on the water source, which uses groundwater, Missouri River water, and reservoirs water, respectively, representing the typical situations of source water used in the USA (~50% surface water and ~50% groundwater). The selection was also based on their water quality issues identified from our preliminary survey. The general information about the selected systems was listed in Table 1, and the treatment operation trains illustrated in Figure 1.

Table 1. Description of the three selected small drinking water systems.

Facility	Location	Population Served (As of 2011)	Yield (MGPD)	Source Water
System I	West of Missouri	~5300	0.58	Ground
System II	North of Missouri	~3900	0.22	Reservoir
System III	Center of Missouri	~8400	1.13	Missouri River

MGPD: million gallons per day.
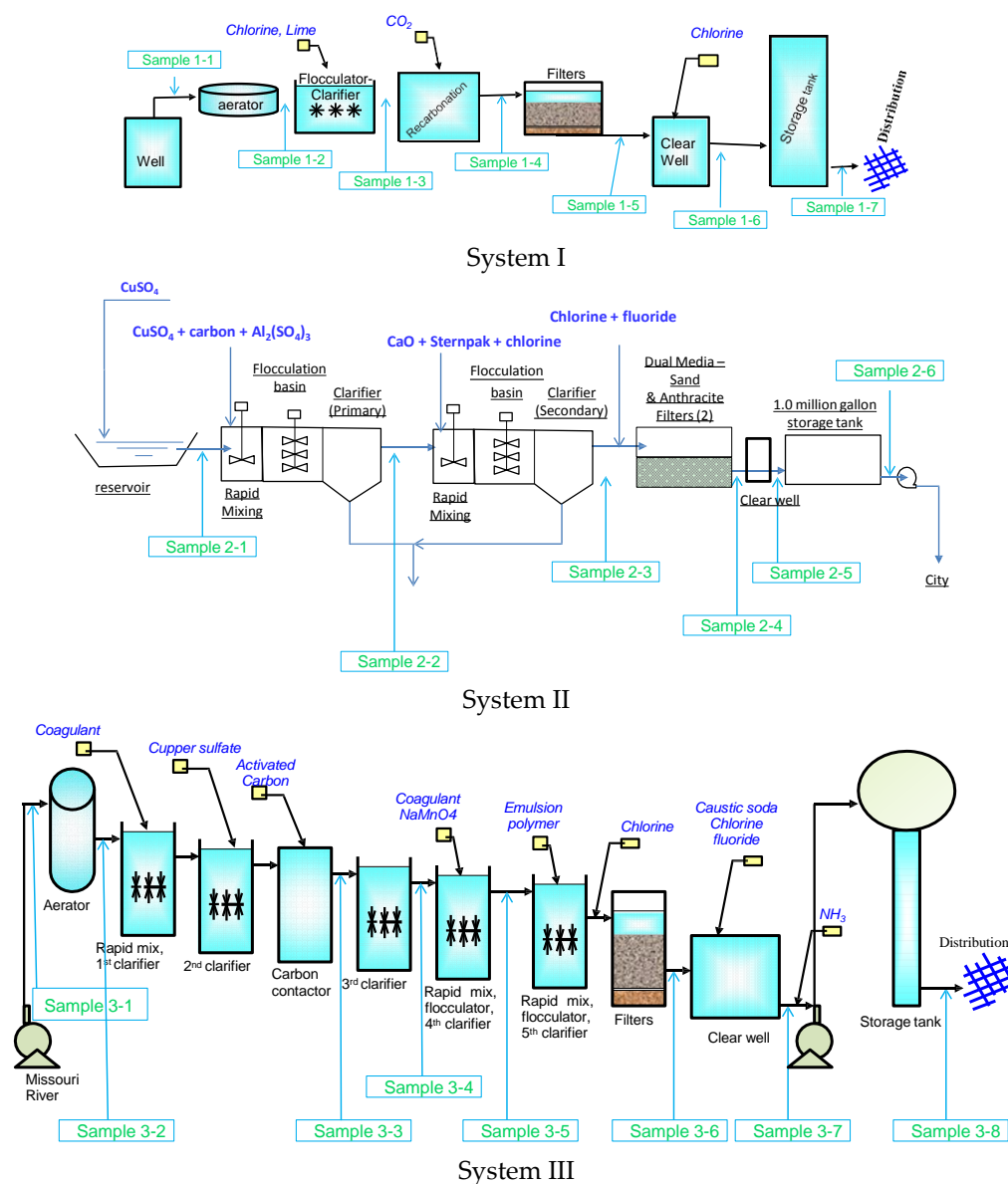
Figure 1. The schematics of treatment operation trains and sampling sites at each of the selected small systems.

2.2. Water Sample Collection

In an effort to assess water quality changes after each treatment operation and evaluate treatment efficacy relevant to the potential cause for high TTHM in the finished water, water samples were collected quarterly (3-monthly) at each major treatment process, from source water to finished water, in the three selected systems during the period of May 2012 to March 2013. Total 164 samples

were collected and the sampling locations illustrated in Figure 1. The water samples for metal analysis were collected in 125-mL pre-acid cleaned high density polyethylene bottles and acidified using concentrated nitric acid (HNO_3) to make a final concentration of 1% HNO_3. The samples for dissolved organic carbon (DOC), ultraviolet light absorbance at the wavelength of 254 nm (UV_{254}), and trihalomethane formation potential (THMFP) analysis were collected in pre-cleaned and baked 500-mL amber glass bottles with Teflon liner caps. For the finished tap water, the waters were collected to completely fill up the bottle with no headspace and no overflow, after allowing to flow for about 5 min. All water-sampling procedures followed the USEPA guidelines. After collection, the samples were transported to laboratory in ice-packed coolers and refrigerated at 4 °C until analyses. All water analyses were completed within one month of storage time limits.

2.3. Chemical Analysis

The collected water samples were filtered through a 0.45 μm nylon membrane filter to remove particles and microbes and analyzed for major water quality parameters including pH, UV_{254}, DOC, bromide, major and trace metal elements (Fe, Mg, Cu, *etc.*), inorganic ions (F^-, NO_3^-, NO_2^-, Cl^-, and SO_4^{2-}), chlorine species, and ammonia following the standard methods [14]. Trihalomethane formation potential (THMFP) were measured to evaluate the removal efficacy of THM precursors. In this manuscript, only the most relevant data of UV_{254}, DOC, and THMFP were presented and discussed. DOC was measured following the USEPA standard method 415.3 using a Shimadzu Model TOC-L total organic carbon (TOC) analyzer. THMFP was analyzed following the EPA standard method [15] and a solid-phase microextraction gas chromatography-mass spectrometry (SPME-GC-MS) [16] with modification using micro-electron capture detection (μECD) and SPME auto-sampler. The method was validated for a consistent and reproducible performance before the water sample analysis. The modified method further improved detection limits and reproducibility.

3. Results and Discussion

3.1. System I

System I used ground water near Missouri river as the source water. The treatment processes included aeration, chlorine addition and coagulation-flocculation-sedimentation, re-carbonation, filtration, and chlorine disinfection as shown in Figure 1. Analysis of the source water from sampling location 1-1 (Figure 1) showed high concentrations of Fe (II) (15.3 ± 1.7 ppm), Mn (II) (1.63 ± 0.13 ppm), and NH_3 (1.01 ± 0.12 ppm). Air aeration was introduced to oxidize and precipitate Fe and Mn ions. Chlorine was added to react with NH_3 to form trichloramine (breakpoint chlorination) for the NH_3 removal, while lime added to soften the water for the hardness reduction. The results indicated that Fe (II), Mn (II), and NH_3 were effectively removed from source water by the treatments and reduced to low concentrations or below detection limits (data not shown). Carbon dioxide was used to lower water pH and gravel filter to reduce suspended solids in water. Chlorine was added in clear well for disinfection as well as maintaining the chlorine residue in the water distribution system. There was no activated carbon or polymer coagulant used in System I.

Measurements of UV_{254}, DOC and specific UV absorbance (SUVA = UV_{254}/DOC) in the water samples collected from System I are summarized in Table 2. Data showed that DOC concentrations in the source groundwater were low as compared with those in System II and III (Tables 4 and 6). The treatments significantly reduced UV_{254} or SUVA values in the finished water (1-7), especially from 1-1 to 1-2, however, DOC remained relatively constant across treatments. Measurement indicated that the treatment processes substantially altered the chemical properties for dissolved organic materials without a significant degradation of dissolved organic matter (DOM). As UV_{254} is often related to aromatic moieties in DOM [17–21], this observation implied that the aeration (oxidation) process has significantly reduced the aromatic functional groups without complete oxidation of DOM. The oxidation of Fe (II) or Mn (II) inside cells by aeration process could induce the generation of free

radicals, and those radicals have demonstrated the strong ability to alter the chemical structures of organic molecules [22–24]. The substantial decreases in SUVA from 1-1 to 1-2 without significant variations in DOC might be attributed to a similar mechanism.

Table 2. Measurements of UV_{254}, dissolved organic matter (DOC), and specific UV absorbance (SUVA) in the waters collected in System I.

Sample ID	UV_{254}			DOC (mg/L)			SUVA (UV_{254}/DOC)		
	2nd	**3rd**	**4th**	**2nd**	**3rd**	**4th**	**2nd**	**3rd**	**4th**
1-1	0.105	0.207	0.308	2.8	3.3	2.6	0.038	0.063	0.118
1-2	0.076	0.082	0.074	3.4	3.5	3.9	0.022	0.023	0.019
1-3	0.081	0.058	0.049	2. 7	2.9	2.8	0.030	0.020	0.018
1-4	0.060	0.053	0.038	2.6	3.0	3.1	0.023	0.018	0.012
1-5	0.054	0.052	0.046	2.8	3.0	2.8	0.020	0.017	0.016
1-6	0.051	0.054	0.045	2.7	3.0	2.8	0.019	0.018	0.016
1-7	0.052	0.059	0.046	3.1	3.1	3.2	0.017	0.019	0.014

The listed sample IDs were the same as shown in Figure 1. The 2nd, 3rd, and 4th represented the sampling time from each quarter.

Table 3 showed the 7-day THMFP and three individual trihaolmethanes measured in the selected samples collected from System I. The dominant THM species was $CHCl_3$ followed by $CHBrCl_2$ and $CHBr_2Cl$. Both source groundwater and finished water displayed THMFP higher than the EPA regulation (80 µg/L). Similar values of THMFP in the source and finished water implied that the treatment process was not effective for THM precursor or DOM removals.

Table 3. Trihalomethane (THM) formation potential and major THM species in the selected samples from System I.

Sample ID	THM Concentrations (µg/L)											
	$CHCl_3$			$CHBrCl_2$			$CHBr_2Cl$			THMFP		
	2nd	**3rd**	**4th**	**2nd**	**3rd**	**4th**	**2nd**	**3rd**	**4th**	**2nd**	**3rd**	**4th**
1-1	66.7	111.7	54.0	33.4	79.3	36.5	16.2	50.5	20.6	117.5	247.0	112.4
1-2	77.0	-	-	35.2	-	-	18.5	-	-	132.0	-	-
1-7	74.6	161.8	54.6	22.8	83.9	36.8	17.3	58.3	28.5	122.2	314.4	127.9

Blanks mean data were not available due to insufficient sample volume. The listed sample IDs were the same as shown in Figure 1. The 2nd, 3rd, and 4th represented the sampling time from each quarter.

It was suggested that SUVA could be used as a surrogate for predicting THMFP [21,25,26]. However, it was clearly not the case in this study. The data in Table 2 showed that SUVA value in the finished water were reduced by 55% to 88%, while DOC value remained similar, implying that DOC rather than SUVA could be a better indicator of the THM precursors for System I. Therefore, the strategy to mitigate THMFP in compliance with the EPA regulation in System I should aim at the removal of DOC from the source water. It was recommended that addition of powdered activated carbon (PAC) as an additional treatment step should be included in the operation train to lower DOC and thus reduce THMFP in the finished water. Another recommendation was to use chloramines instead of free chlorine as residual disinfectant in finished drinking water for the distribution system. This treatment modification was implemented by the system in 2013. The water quality monitored after the modification indicated that TTHM concentration was lowered to ~40 µg/L, making the system in compliance with the EPA regulation limit (80 µg/L). In addition, eight *N*-nitrosamines formation potentials were also measured to ensure no high levels of any *N*-nitrosamine formed due to monochloramine used as residual disinfectant. Recent results (data not shown) indicated that the *N*-nitrosamines, if formed, all were below the method detection limits.

3.2. System II

System II used reservoir water in an agricultural watershed as the source water. As shown in Figure 1, copper sulfate was added in the source water reservoir for algae control. Up to 30 mg/L PAC (Sabre Series) was then dosed in the first flocculation basin for DOC removal, resulting in 44%, 51%, 43%, and 26% of DOC reduction (from 2-1 to 2-2), respectively, in each quarterly sample Table 4. There was no significant change of DOC in the later treatments.

Table 4. Measurements of UV_{254}, DOC, and SUVA in the waters collected in System II.

Sample ID	UV_{254}				DOC (mg/L)				SUVA (UV_{254}:DOC)			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
2-1	0.297	0.154	0.142	0.092	8.9	7.6	7.9	6.8	0.033	0.020	0.018	0.013
2-2	0.055	0.055	0.052	0.040	5.0	3.7	4.5	5.0	0.011	0.015	0.012	0.008
2-3	0.055	0.041	0.035	0.037	3.4	4.0	4.5	5.2	0.016	0.010	0.008	0.007
2-4	0.038	0.038	0.035	0.035	2.7	3.9	4.7	5.0	0.014	0.010	0.007	0.007
2-5	0.037	0.038	0.034	0.036	3.2	4.0	4.3	5.0	0.012	0.010	0.008	0.007
2-6	0.030	0.033	0.035	0.034	-	3.8	4.6	5.0	-	0.009	0.008	0.007

Blanks mean data were not available due to insufficient sample volume. The listed sample IDs were the same as shown in Figure 1. The 1st, 2nd, 3rd, and 4th represented the sampling time for each quarter.

The values of THMFP from the source water to finished water were all higher than the EPA regulation (80 μg/L) as indicated in Table 5. The dominant THM species were similar to those in System I (Table 3), however, the ratio of $CHCl_3$ and $CHBrCl_2$ were much higher in System II. The discrepancy could be attributed to the higher total Br in the source water in System I. There were significant THMFP reductions from the source water to finished water, 53%, 55%, 56%, and 34%, respectively, for each quarterly collected sample. THMFP was found being highly correlated to the removal efficiencies of DOC with a correlation coefficient (R^2) of 0.85, indicating that DOC is the primary precursors contributing to the THM formation.

Table 5. THM formation potential and major THM species in the selected samples of System II.

Sample ID	THM Concentrations (μ/L)															
	$CHCl_3$				$CHBrCl_2$				$CHBr_2Cl$				THMFP			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
2-1	191.3	233.9	230.7	133.1	10.4	21.1	39.2	42.8	0.1	3.9	5.6	9.3	201.9	252.0	275.5	186.2
2-2	103.7	89.3	-		9.4	17.9	-		0.8	5.2	-		113.9	105.3	-	
2-3	125.8	-	-		10.4	-	-		0.8		-		136.9	-	-	
2-4	129.4	-	-		9.4	-	-		0.8		-		139.6	-	-	
2-5	129.7	-	77.9		9.6	-	19.7		0.8		7.9		140.1	-	105.9	
2-6	90.1	99.4	-	71.6	5.4	12.6	-	24.1	0.6	5.2	-	12.0	96.1	111.6	-	109.0

Blank means data were not available due to insufficient sample. The listed sample IDs were the same as shown in Figure 1. The 1st, 2nd, 3rd, and 4th represented the sampling time for each quarter.

The application of PAC in System II led to about 50% reduction of both DOC and THMFP in finished water. The value of SUVA was also not a good indicator for the prediction of THMFP in this system. As substantial amount of PAC had already been used for DOC removal, the strategy to mitigate THMFP in compliance with the EPA regulation in System II should consider the application of high efficient PAC for the removal of THM precursors, especially $CHCl_3$-related precursor, as it was the dominant species responsible for THMFP in System II. Another recommendation for System II was to reduce the retention time for the finished water. Recent pilot-scale tests indicated that the operational change could lower TTHM for the regulation compliance. A recommendation for investing a mixing system to reduce the water detention time has been submitted to the local administrators.

3.3. System III

System III used Missouri River water as source water. Similar to System I, there were substantial decreases in UV_{254} or SUVA by treatments between the source water and finished water, but no significant variations in DOC were detected (Table 6) although PAC (CR325AA-10) was applied prior to the sampling location 3-3. The addition of PAC was intended to remove odor and color. To deal with potential high THMFP issue in the finished water, NH_3 was added in the water prior to the storage tank for maintaining chloramine level as disinfectant residue in the distribution system, as shown in Figure 1.

Table 6. Measurements of UV_{254}, DOC, and SUVA in the waters collected in System III.

Sample ID	UV_{254}			DOC(ppm)			SUVA (UV_{254}:DOC)		
	2nd	3rd	4th	2nd	3rd	4th	2nd	3rd	4th
3-1	0.091	0.082	0.072	4.0	4.1	4.9	0.022	0.020	0.015
3-2	0.073	0.082	N/A	3.5	4.2	N/A	0.021	0.020	N/A
3-3	0.007	0.066	0.060	3.6	4.2	4.1	0.002	0.016	0.015
3-4	0.061	0.056	0.053	3.4	3.7	3.6	0.018	0.015	0.015
3-5	0.060	0.056	0.052	3.6	4.2	4.4	0.017	0.013	0.012
3-6	0.045	0.045	0.042	3.6	3.6	3.5	0.012	0.012	0.012
3-7	0.042	0.059	0.057	3.5	3.7	3.4	0.012	0.016	0.017
3-8	0.041	0.039	0.050	3.6	3.5	3.2	0.011	0.011	0.016

The listed sample IDs were the same as shown in Figure 1. The 2nd, 3rd, and 4th represented the sampling time at each quarter.

Table 7 showed that the dominant THM species were $CHCl_3$ and $CHBrCl_2$, similar to those in System II. In comparison of THMFP between the 1st and 2nd quarter, the addition of a few mg/L of PAC showed no more than 18% reduction, however, the addition of NH_3 in the water leaving the clear well led to 27%–55% reduction in THMFP in the finished water. Although a significant reduction in THMFP was caused by the application of NH_3, only one of the four finished water samples (3–8) had TTHM below 80 μg/L. Meanwhile, a potential problem related to the NH_3 application for THM control was the formation of toxic N-DBPs (e.g., *N*-nitrosodimethylamine), which resulted from the reactions between the nitrogen-containing compounds and the disinfectants during water disinfection process [27–30]. Our recommendations for System III would include (1) increasing the dosage of PAC for more effective DOC removal; (2) changing the type of PAC that is highly efficient in the removal of the precursors of both $CHCl_3$ and $CHBrCl_2$. The performance of various activated carbons was investigated for the DOC removal. Recent data showed that a coconut-based activated carbon performed better than the currently used coal-based activated carbon. Based on the findings, the coconut-based activated carbon was recommended; and (3) optimizing the NH_3 dosage to reduce potential formation of N-DBPs in the finished water.

Table 7. THM formation potential and major THM species in the selected samples of System III.

Sample ID	THM Concentrations (ppb)															
	$CHCl_3$				$CHBrCl_2$				$CHBr_2Cl$				THMFP			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
3-1	166.8	74.49	136.9	103.3	25.1	48.47	22.4	30.5	2.7	29.30	4.7	6.9	194.6	156.9	163.6	141.3
3-2	118.4	-	-	-	22.9	-	-	-	4.0	-			145.3	-	-	-
3-3	134.6	73.51	-	-	22.4	51.12	-	-	2.9	29.91			159.9	160.0	-	-
3-4	120.5	-	-	-	20.7	-	-	-	2.9	-			144.1	-	-	-
3-5	120.1	60.49	-	-	20.5	47.36	-	-	2.7	33.38			143.3	148.3	-	-
3-6	116.1	-	-	-	14.7	-	-	-	2.7	-			133.5	-	-	-
3-7	135.1	-	-	-	13.7	-	-	-	2.6	-			151.4	-	-	-
3-8	79.5	33.34	76.9	82.2	14.5	14.91	17.5	22.0	3.5	15.60	5.1	7.5	97.5	71.1	99.6	102.8

Blank means data were not available due to insufficient sample. The listed sample IDs were the same as shown in Figure 1. The 1st, 2nd, 3rd, and 4th represented the sampling time for each quarter.

3.4. Disscusion

From the data presented in Tables 2–7 it was clear that the three selected small systems had higher THMFP in finished water than the USEPA MCL in all but one case. From the analysis of the treatment efficiency for each operation in all three small systems, the major issue could be the low removal efficiency of DOC. Additionally, this study indicated that SUV should not be used as a THMFP indicator without considering the unique properties for source water. Our recommendations for the DBP control in the three systems included switching the types of PAC (e.g., from coal-based PAC to wood-based PAC) and optimizing the operation conditions to more effectively reduce the DBP precursors. Nevertheless, the selection of the PAC types often involves a compromise between operation costs and operation performance.

Common strategies in the DBP control include using alternative disinfectant, changing source water, using solar pasteurization and household filters, and optimizing operational conditions. There are many options for disinfectant selection, e.g., ozone, chloramines. All disinfectants have both advantages and disadvantages [31–33]. Using chloramines instead of free chlorine as residual disinfectant in finished drinking water for the distribution system is a practical approach for small systems if the formation of *N*-nitrosamines is low. The implementation of this practice was successful for System I, which could be applicable to the small systems with similar conditions. In the USA, the most popular disinfection method is chlorination due to the low cost and easy handling, while in some Europe countries ozone is used as a disinfectant. Ozonation was not recommended for the small systems because of the operational costs and high-technical maintenance. In addition, ozonation could result in the formation of bromate, a regulated toxic DBP in the USA with a MCL of 10 µg/L [31]. In the USA, about 50% drinking source water is from groundwater, and another 50% from surface water. Once the source is selected, it is often difficult to make a change due to infrastructure, costs and the availability of alternative water sources. Solar pasteurization and household filters are more appropriately used for isolated or remote houses, while the photo-disinfection by sunlight is good weather dependent [34]. Optimization of the operational conditions is often adapted for the DBP control in drinking water systems. For System II, pilot-scale tests have demonstrated that reducing the water retention time in storage could lower TTHM in the distribution system. Statistically modeling approaches for multivariate analysis that have been successfully applied in real-life environment quality management could be introduced in this approach [35–37]. A review on the predictive models that correlate water chemistry and operational conditions for the simulation of DBP formation potential could provide an excellent tool for the operators in the small systems and local administrators in decision-making on water quality improvement [38].

4. Conclusions

This study indicated that the elevated DOC in source water was the major water quality issue facing small, rural water systems, especial those species considered as the DBP precursors. Water treatments that lead to a high-efficient removal of DOC or reduction in THM formation would be the biggest challenge in compliance with the USEPA drinking water quality regulations. The dominant THM species was $CHCl_3$ for all three facilities; however, $CHBrCl_2$ was significant for the system using Br-elevated groundwater as the source water. Powdered activated carbon was effective for reducing both DOC and THMFP in System II but not in System III, which could be caused by the dosages used, the carbon types, and/or the differences in the source water chemistry. Addition of NH_3 for the DBP mitigation in the finished water is a common practice, however, the generation of N-DBPs could pose potential problem in drinking water quality, as the USEPA is currently considering regulating N-DBPs in the future. To solve the problem, high-efficient PAC should be tested, especially on pilot-scale for the removal of DBP precursors. To implement new treatment strategies for the small drinking water systems, more pilot-scale or industrial-scale tests and data are needed to validate the treatment performance. Data of the following-up research for this project will be reported in separate manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DBP	Disinfection Byproduct
DOC	Dissolved Organic Carbon
EPA	Environmental Protection Agency
N-DBP	Nitrogen Containing Disinfection Byproduct
NOM	Natural Organic Matter
PAC	Powdered Activated Carbon
SUVA	Specific UV Absorbance
THM	Trihalomethane
THMFP	Trihalomethane Formation Potential
TTHM	Total Trihalomethanes
US	the United States
UV_{254}	Absorbance of Ultraviolet Light at Wavelength 254 nm

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