



## Factors influencing disinfection by-products formation in drinking water of six cities in China

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### ABSTRACT

Based on the measured chemical and physical data in drinking water from six cities in China, the factors including total organic carbon (TOC), ultraviolet absorbance at 254 nm ( $UV_{254}$ ), pH, applied chlorine dosage, temperature, concentrations of bromide ion and several chemical elements which possibly affect the formation of trihalomethane (THM) and haloacetic acid (HAA) have been studied. The results showed that: in all factors, TOC and  $UV_{254}$  have definite correlations with total THM, but have nonsignificant relationships with total HAA. In the studied pH range of 6.5–8.5 for drinking water, the total THM concentration increased with the increasing of pH value, but the total HAA concentration slightly decreased. A low but significant relationship ( $r=0.26$ ,  $p<0.01$ ) occurred between total THM and applied chlorine dosage. Similar relationship ( $r=0.21$ ,  $p<0.01$ ) was found between total HAA and applied chlorine dosage. When the water temperature was low, the variation of THMs and HAAs was little, but in warmer water, the concentration of THMs and HAAs varied quickly. The extent of bromine incorporation into the DBPs increases with increasing bromide ion concentration. Based on the effect of chemical elements for the DBPs remove effect, the polyferric chloride could be a preferred flocculant agent in waterworks.

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### 1. Introduction

Chlorine, the most widely used disinfectant for drinking water in China, will give rise to trihalomethanes (THMs) and haloacetic acids (HAAs), two most prevalent disinfection by-products (DBPs), when it is added to the drinking water as a disinfectant. THMs include chloroform (TCM), bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform (TBM). Total trihalomethanes (TTHM) refer to the sum of these four chemical substances. HAAs include nine substances, only five of them are regulated by the current Disinfectants/Disinfection By-Products (D/DBP) Rule due to limited formation and occurrence data for some of the species [1]. The five HAAs are monochloro- and monobromo-acetic acid, dichloro- and trichloroacetic acid, and dibromoacetic acid (MCAA, MBAA, DCAA, TCAA, and DBAA, respectively). The main species of HAAs in drinking water are DCAA and TCAA and others are generally found at lower levels. The sum of DCAA, TCAA, DBAA, MCAA and MBAA is commonly denoted as total haloacetic acids (THAA). Some epidemiologic studies [2–4] have shown an association between long-term exposure to disinfection by-products and increased risk of cancer and potential

adverse reproductive effect. Many researches indicated that DBPs in the drinking water were affected by natural organic matter (NOM), which is generally measured as total organic carbon (TOC) and ultraviolet absorption at 254 nm ( $UV_{254}$ ), pH, water temperature ( $T$ ), bromide concentration ( $Br^-$ ), chlorine dosage ( $Cl_2$ ) and residence time ( $t$ ) [5–10]. In the past, most of researches on disinfection by-products were from laboratory-scaled studies [11–15]. But the conditions of the laboratory-scaled studies were great different from that of the water on local waterworks. The results of studies could not fit in with the sample that was obtained from the local waterworks.

The primary objective of this study was to determine water quality parameters of drinking water of local waterworks from six selected cities of China and assess the effects of some water quality and operational parameters on HAA and THM formation.

### 2. Materials and methods

#### 2.1. Experimental design

Water samples used in this study were collected from the water treatment plants in Daqing, Beijing, Tianjin, Zhengzhou, Changsha and Shenzhen cities. These waterworks were selected to provide waters with different TOC and  $UV_{254}$  values as well as geographical differentiation. A total of 41 treatment plants were sampled

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both in summer and winter. For all waterworks, six samples (raw water, treated water before chlorination, treated water following chlorination, finished water, water between the treatment plant and the system extremities and water at the end point of the distribution system) which represent variable residence times of water were selected for the purposes of water quality parameters and DBPs measurements. The sampling points were selected from the monitor points of water quality that provided by the centers for disease control and prevention (CDC) of local city. The water quality parameters including TOC, UV<sub>254</sub>, pH, chlorine dose, bromide ion concentration, residence time, water temperature and chemical elements in these six cities were analyzed. The four THM species and the five regulated HAA were also determined.

## 2.2. Analytical method

THM content of water samples was performed according to Standard Method 6232D [16]. The instrument was a gas chromatograph (Shimadzu, Japan, model GC-17A), Tekmar 3000 purge trap and concentrator and Tekmar 2016 Purge Trap autosampler. The HAAs were analyzed following derivatization with diazomethane using a micro liquid–liquid extraction gas chromatographic method which was developed by USEPA Method 552 [17]. UV<sub>254</sub> determination adopted Standard Method 5910A [16]. TOC analyzer (Shimadzu, model TOC-ASI-5000A) was used to analyze the value of total organic carbon (TOC). The pH of water sample was analyzed by pH meter. Bromide ion concentration was determined using a Dionex ion chromatographic (IC) system (Sunnyvale, CA). The water temperature was counted and determined directly with the water thermometer. The residual chlorine was determined using appro-

priate powder pillows (DPD for free chlorine) and a HACH LANGE NEW Pocket Colorimeter II. Chemical elements in drinking water were determined through EPA method 200.8 [18] and the Agilent 7500a ICP-MS was used.

## 3. Results and discussion

The water quality parameters and disinfection by-products of drinking water for six selected cities in China are presented in Tables 1 and 2. The average values of TTHM and THAA in six cities of China are similar to that of drinking water in Korea [19] but are lower than that of drinking water in Pennsylvania (USA) [20], Istanbul (Turkey) and Salerno (Italy) [21]. Table 2 shows that pH and Br<sup>-</sup> values are higher in north of China (Daqing, Beijing, Tianjin and Zhengzhou) than that in south (Changsha and Shenzhen). And TOC and UV<sub>254</sub> values in raw water are significantly higher in three cities of north China (Daqing, Tianjin and Zhengzhou). Although Beijing is also in the north of China, TOC and UV<sub>254</sub> values are the lowest in six cities due to use groundwater as main source of drinking water. The free chlorine in finish water is variable in different cities and is highest in Tianjin city. The regional difference of TTHM concentration of six cities is in an order of Zhengzhou > Tianjin > Daqing > Shenzhen > Changsha > Beijing. The regional difference of TTHM is mainly related to the difference of TOC, UV<sub>254</sub> and chlorine dose levels. The concentration of THAA in Changsha is most abundant, followed by Tianjin and Shenzhen. THAA of Daqing and Zhengzhou is relatively lower. And THAA of Beijing is the lowest in six cities. The possible explanations may be the greater occurrence of precursors favoring the formation of HAAs instead of THMs in Changsha and Shenzhen cities.

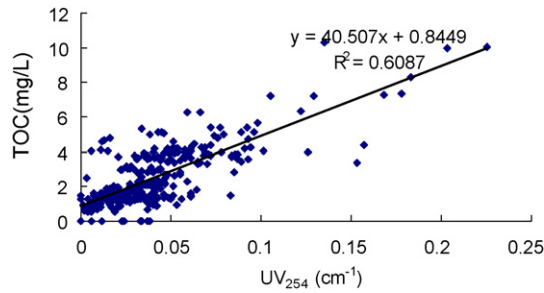
**Table 1**  
Drinking water quality parameters and DBPs for six selected cities in China.

Parameter	N	Mean value	Maximum	Middle value	Minimum	Standard deviation
TOC (mg/L)	339	2.52	10.29	1.89	0.54	1.71
UV <sub>254</sub> (abs)	344	0.040	0.324	0.034	0.001	0.036
pH	329	7.46	8.44	7.49	6.31	0.37
Br <sup>-</sup> (mg/L)	289	0.040	0.318	0.033	0.004	0.036
Chlorine (mg/L)	290	0.41	1.92	0.30	ND	0.45
t (h)	414	7.38	30	5	ND	8.20
Water temperature (°C)	304	19.85	29	24	ND	8.69
TCM (μg/L)	353	5.96	44.91	3.86	ND	7.72
DCBM (μg/L)	353	4.01	32.61	1.61	ND	6.24
DBCm (μg/L)	353	2.14	18.48	0.50	ND	3.58
TBM (μg/L)	353	0.29	4.54	ND	ND	0.65
TTHM (μg/L)	353	12.4	92.77	6.78	ND	17.06
MCAA (μg/L)	207	0.99	2.29	ND	ND	2.94
MBAA (μg/L)	360	0.16	1.6	ND	ND	0.44
DCAA (μg/L)	359	2.49	15.6	1.55	ND	2.75
DBAA (μg/L)	358	0.38	2.54	ND	ND	0.57
TCAA (μg/L)	360	3.79	21.07	1.05	ND	5.32
THAA (μg/L)	358	7.44	40.03	3.80	ND	8.32

Note: ND, not detected.

**Table 2**  
Characteristics of water quality and DBPs of six cities in China.

	City	Daqing	Beijing	Tianjin	Zhengzhou	Changsha	Shenzhen
Raw water	PH	7.641	7.424	7.817	8.240	6.984	7.340
	TOC (mg/L)	6.282	1.508	3.911	3.029	2.582	1.925
	UV <sub>254</sub> (cm <sup>-1</sup> )	0.104	0.018	0.052	0.060	0.052	0.051
	Br <sup>-</sup>	0.062	0.078	0.063	0.073	0.015	0.028
Finished water	PH	7.501	7.405	7.642	8.241	7.199	7.396
	TOC(mg/L)	4.398	1.102	3.644	2.507	1.797	1.265
	UV <sub>254</sub> (cm <sup>-1</sup> )	0.041	0.011	0.044	0.041	0.031	0.025
	Br <sup>-</sup> (mg/L)	0.043	0.052	0.040	0.042	0.012	0.032
	Free chlorine (mg/L)	0.329	0.309	0.787	0.331	0.314	0.466
	THMs (μg/L)	13.79	10.66	42.27	35.29	10.76	11.51
	HAAs (μg/L)	8.56	4.74	12.90	7.23	13.77	11.43



**Fig. 1.** Correlation between TOC and UV<sub>254</sub> absorbance of various drinking waters in six cities of China.

**Table 3**

The correlation between water quality parameters and DBPs.

		<i>t</i>	<i>T</i>	pH	TOC	UV <sub>254</sub>	Br <sup>-</sup>	Cl <sub>2</sub>
TCM	<i>r</i>	0.14	0.43**	0.43**	0.02	0.04	-0.11	0.33**
	<i>p</i>	0.10	0.00	0.00	0.84	0.68	0.20	0.00
DCBM	<i>r</i>	0.07	0.06	0.49**	0.35**	0.29**	0.07	0.20*
	<i>p</i>	0.40	0.53	0.00	0.00	0.00	0.42	0.02
DBCM	<i>r</i>	0.01	-0.15	0.48**	0.46**	0.32**	0.15	0.13
	<i>p</i>	0.91	0.09	0.00	0.00	0.00	0.09	0.14
TBM	<i>r</i>	0.00	-0.12	0.38**	0.20	0.11	0.28**	0.03
	<i>p</i>	0.99	0.17	0.00	0.02	0.23	0.00	0.71
TTHM	<i>r</i>	0.10	0.18*	0.51**	0.25**	0.20*	0.02	0.26**
	<i>p</i>	0.27	0.04	0.00	0.00	0.02	0.83	0.00
MCAA	<i>r</i>	-0.02	-0.12	-0.06	0.35**	0.32**	0.00	0.10
	<i>p</i>	0.85	0.34	0.64	0.00	0.01	0.99	0.41
MBAA	<i>r</i>	0.00	0.30**	0.47**	0.14	0.09	0.09	0.13
	<i>p</i>	0.99	0.00	0.00	0.12	0.30	0.32	0.13
DCAA	<i>r</i>	0.07	0.20	-0.05	0.17*	0.21*	-0.29**	0.09
	<i>p</i>	0.40	0.02	0.60	0.05	0.02	0.00	0.31
TCAA	<i>r</i>	0.23**	0.54**	0.14	-0.27**	-0.20*	-0.26**	0.17*
	<i>p</i>	0.01	0.00	0.12	0.00	0.02	0.00	0.05
DBAA	<i>r</i>	-0.38**	-0.25**	0.06	0.28**	0.12	0.29**	0.03
	<i>p</i>	0.00	0.00	0.47	0.00	0.19	0.00	0.77
THAA	<i>r</i>	0.13	0.49**	0.13	-0.06	-0.02	-0.22**	0.21**
	<i>p</i>	0.13	0.00	0.15	0.50	0.86	0.01	0.01

\* Correlation is significant at the 0.05 level (2-tailed)

\*\* Correlation is significant at the 0.01 level (2-tailed).

### 3.1. Effect of TOC and UV<sub>254</sub>

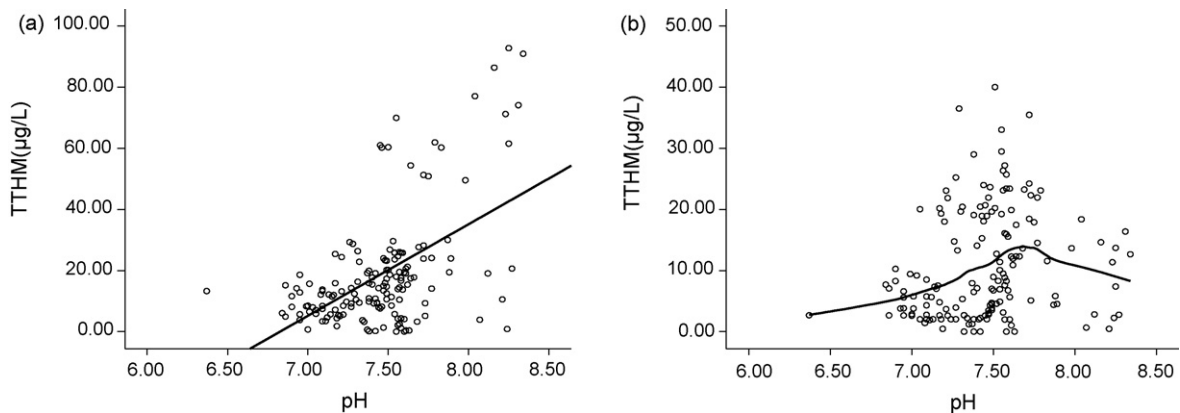
Many types of organic compounds are found in natural waters. They are of natural origin, referred to as natural organic matter

(NOM). The DBPs are formed when the disinfectant reacts with NOM. TOC is one of the most widely used measures for quantifying the amount of NOM in water [22]. UV<sub>254</sub> has been widely used to predict natural dissolved organic carbon (DOC) in water or its reactivity in forming disinfection by-products during chlorination process [22]. Because of easy measurement, UV<sub>254</sub> offers potentially simple and reliable methods to quantify the contribution of organic carbon in water to formation of DBPs during chlorination [5,22]. The TOC and UV<sub>254</sub> can provide insight into the nature of the organics present and the potential for DBP formation. Fig. 1 illustrates the relation between TOC and UV<sub>254</sub> in all samples of drinking water in selected six cities. Better relationship ( $R^2 = 0.6087$ ) was obtained in these samples.

Using Pearson correlation method, a low but significant relationship ( $r = 0.25$ ) is obtained between TTHM formation and TOC for the selected six cities as shown in Table 3. So do the relationship ( $r = 0.20$ ) between TTHM and UV<sub>254</sub>. Most investigators found that THMs formation rises with increasing soluble humic material content in natural occurring water [23]. The rate of THMs formation is equal to that of the TOC consumption [23]. These results also show that a higher available TOC or UV<sub>254</sub> will provide more TTHM. However, Table 3 shows that there is not significant relationship between TOC and THAA or UV<sub>254</sub> and THAA. In case of 41 treatment plants of six cities of China, DCAA and TCAA are dominant species of total HAA and account for 84% total HAA. DCAA value is higher than TCAA in Daqing, Beijing and Tianjin cities, but TCAA is dominant in other cities. TCAA and DCAA might have different precursors [24]. TOC and UV<sub>254</sub> are indicators of mass organic substance and do not differentiate between the various chemical compounds that make up the precursor compounds [5,25]. Table 3 also shows TOC and UV<sub>254</sub> have a tendency to produce DCAA rather than TCAA. Thus, there is no universal relationship that can be used to predict THAA in the distribution system based on TOC values and UV<sub>254</sub>. This is the cause for not significant relationship between TOC and THAA or UV<sub>254</sub> and THAA for selected six cities.

### 3.2. Effect of pH

As shown in Fig. 2a, increasing pH from 6 to 8.5 has significant effect on the formation of TTHM, and TTHM content increases with rising of pH. By Pearson correlation method, a moderate and definite relationship ( $r = 0.43, 0.49, 0.48, 0.38, 0.51$  respectively) was obtained between TCM, DCBM, DBCM, TBM, TTHM formation and pH. This is similar to the results of other researches [26]. Fig. 2b shows, increasing pH from 6 to 8.5, the content of THAA does not change quickly with the increasing pH. In the pH range of 6.5–7.7, THAA content increases slowly with pH, but in the pH range of 7.7–8.5, the concentration of THAA decreases instead.



**Fig. 2.** Effect of pH in water on the formation of DBPs ((a) TTHM; (b) THAA).

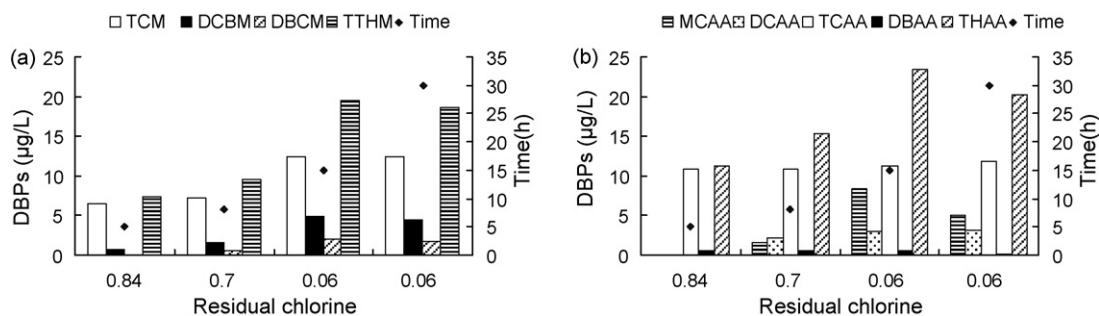


Fig. 3. Effect of residue chlorine and residence time on the formation of DBPs ((a) THMs; (b) HAAs).

There is not significant relationship ( $r=0.13$ ,  $p=0.15$ ) between pH and THAA.

### 3.3. Effect of the chlorine dosage and residue chlorine

Attempts were made to determine the effect of chlorination dosage on the concentration of THMs and HAAs in the water distribution system of six selected cities in China. As shown in Table 3, using Pearson correlation method, a low but significant relationship ( $r=0.26$ ) was obtained between TTHM formation and chlorine dosage. Similar relationship ( $r=0.21$ ) was obtained between THAA formation and chlorine dosage. Fig. 3 shows the residue chlorine content versus the THMs and HAAs formation. As the residue free chlorine content decreases, the concentration of THMs and HAAs production increases. However, at last, if the residue chlorine were unable to satisfy the further reaction of DBPs formation, the quantity of DBPs produced would be changed little. Furthermore, because of DBPs decomposition, with the residue free chlorine decreasing, DBPs concentration would decrease.

### 3.4. Effect of water temperature

As shown in Table 3, by Pearson correlation method, a low but definite with small relationship ( $r=0.18$ ) was obtained between TTHM formation and water temperature. And moderate correlation with substantial relationship ( $r=0.49$ ) was obtained for THAA formation. Some researches indicated that THMs and HAAs formations have a key temperature [26,27]. For example, the key temperature ( $T_c$ ) for THMs formation is  $18.97^\circ\text{C}$  [26]. THMs level is reduced drastically when the temperature is increased above  $T_c$  value. The reason is that temperature increases the rate of formation up to  $T_c$ ; at which the rate of removal of THMs, most likely owing to their volatility, becomes higher than their formation rate [27]. The variation of HAAs formation is similar to THMs, but HAAs is not volatile material, so HAAs level will not decrease rapidly with temperature rising after the temperature exceeding the key temperature

[28]. As shown in Fig. 4, in range of study water temperature, in cold water (water temperature  $<15^\circ\text{C}$ ), the variation of TTHM and THAA are little, but in warmer water (water temperature  $>15^\circ\text{C}$ ), the concentrations of TTHM and THAA are varied quickly. This could be accounted for these reasons: the samples in this research were mainly gathered in summer and winter, and the water temperature varied obviously, thus the changes of THMs and HAAs formation indicate obvious seasonality. DBPs content varied quicker in summer compared with that in winter.

### 3.5. Effect of residence time

Fig. 3 also indicates that levels of TTHM and THAA increase with the residence time in a treatment plant at which the natural organic matter and the applied chlorine dose are in abundance. But Table 3 also shows, using Pearson method of correlation, a low and indefinite relationship was obtained between TTHM, THAA formation and residence time for selected six cities. Generally, DBPs continue to form in drinking water as long as a disinfectant residual and precursors are present [29]. However, THMs and HAAs cannot be consistently related to water age because THMs are known to volatilize and HAAs are known to biodegrade over time when the disinfectant residual is low. This might result in relatively low THMs and HAAs concentrations in areas of the distribution system where disinfectant residuals are depleted [30]. Baribeau et al. [31] reported there was greater concentration of THMs and HAAs in the treatment plant than in the distribution system. Biodegradation is suggested to be responsible for the decrease in THMs and HAAs along the distribution system. Speight and Singer [32] reported that the increase in residence time leads to a decrease in chlorine residual in the water distribution system and this accounts for the low concentrations of HAAs observed. The water quality parameters including TOC,  $\text{UV}_{254}$  and residual chlorine are varied greatly in the selected six cities. These are the causes for the low and indefinite relationship between TTHM, THAA formation and residence time for selected six cities.

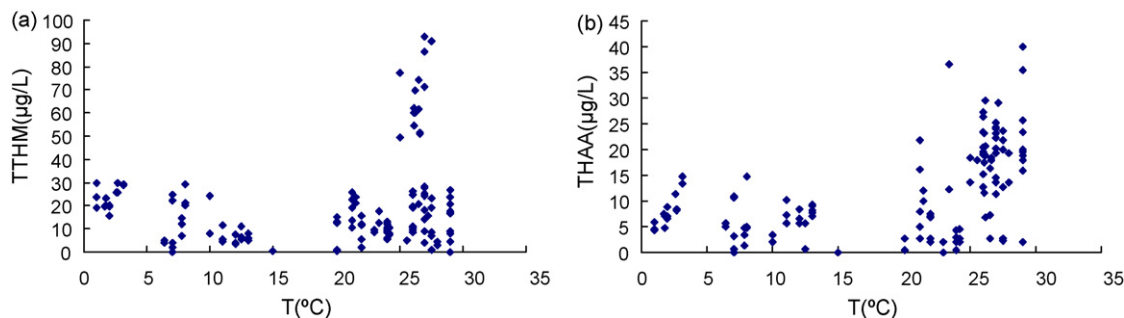


Fig. 4. Effect of water temperature on the formation of DBPs ((a) TTHM; (b) THAA).

**Table 4**

The correlation between some elements and THM.

		Al	Fe	Zn	Mn	As	Mo	Ba	K	Na	Ca	Mg
TCM	<i>r</i>	0.09	-0.41*	-0.25	-0.30	-0.08	0.68**	-0.15	0.40**	0.46**	-0.19*	-0.04
	<i>p</i>	0.41	0.05	0.20	0.08	0.47	0.00	0.12	0.00	0.00	0.05	0.71
DCBM	<i>r</i>	0.05	-0.42*	-0.20	-0.25	-0.31**	0.87**	0.00	0.29**	0.62**	-0.16	0.22*
	<i>p</i>	0.63	0.05	0.32	0.15	0.00	0.00	0.98	0.00	0.00	0.10	0.02
DBCM	<i>r</i>	0.06	-0.38	-0.04	-0.31	-0.36**	0.85**	0.08	0.21*	0.63**	-0.12	0.31**
	<i>p</i>	0.62	0.08	0.86	0.07	0.00	0.00	0.40	0.03	0.00	0.23	0.00
TBM	<i>r</i>	0.03	0.07	0.12	-0.23	-0.33**	0.60**	0.20†	0.11	0.55**	0.06	0.42**
	<i>p</i>	0.79	0.74	0.57	0.17	0.00	0.00	0.04	0.26	0.00	0.54	0.00
TTHM	<i>r</i>	0.08	-0.39	-0.18	-0.30	-0.24*	0.83**	-0.04	0.33**	0.59**	-0.16	0.15
	<i>p</i>	0.50	0.06	0.36	0.08	0.02	0.00	0.70	0.00	0.00	0.09	0.12

† Correlation is significant at the 0.05 level (2-tailed).

\* Correlation is significant at the 0.01 level (2-tailed).

### 3.6. Effect of bromide ion

In general, TTHM concentration increases slightly with increasing bromide ion concentration. But, a slight decrease in TTHM with higher  $\text{Br}^-$  concentration is noted at lower chlorine dosage. Using Pearson method of correlation, an indefinite relationship between  $\text{Br}^-$  and TTHM was obtained ( $p = 0.83$ ). However, there was a low but definite with small relationship ( $r = 0.28$ ) between TBM formation and  $\text{Br}^-$  concentration. A low and moderate definite relationship between DBCM formation and  $\text{Br}^-$  concentration ( $r = 0.15$ ,  $p = 0.09$ ) was also obtained. The component of bromide increases following TCM, DCBM, DBCM and TBM. In the formation of THMs, with the  $\text{Br}^-$  content increasing, the content of DCBM, DBCM and TBM increase too. As indicated in some research, the content of HAAs will be reduced with the increase in  $\text{Br}^-$  concentration, but when the  $\text{Br}^-$  concentration reached a confined range, the HAAs concentration increases with the  $\text{Br}^-$  concentration [33]. As shown in Table 3, there is a definite negative correlation between THAA, DCAA, TCAA formation and  $\text{Br}^-$  concentration. And a low but definite positive correlation between DBAA formation and  $\text{Br}^-$  concentration was obtained. The results show that in the compositions of DBPs, with the increasing  $\text{Br}^-$  concentration, the component of chlorine decreased gradually, and the component of bromine increased on the contrary.

### 3.7. Effect of chemical element

Polyaluminium chloride, polyferric chloride and polymeric aluminium ferric chloride were used as coagulant in most waterworks

in China. Several chemical element such as Mo, As, Mn, Ba, K, Na, Ca, Mg, Fe, etc. had been examined in water for the selected waterworks. On the one hand these chemical elements influenced the effect of water purification; on the other hand these chemical elements also influenced the formation of THMs and HAAs.

As shown in Table 4, using Pearson correlation method, significant positive relationships between THMs formation and the elements (Mo, Na and K) are found. However, there are negative correlations between THMs (TTHM, TCM, DCBM and DBCM) formation and elements (Fe, Mn and Ca). The result shows that Fe, Mn and Ca could be used to remove THMs. And the THMs remove effect is  $\text{Fe} > \text{Mn} > \text{Ca}$ .

Table 5 shows the relationship between HAAs with several chemical elements. Significant negative correlations are present between DBAA formation and Al, As, K. The result could indicate that Al, As and K could be used to reduce the DBAA formation. However, there were significant positive correlations between DCAA, TCAA, THAA formation and these chemical elements. The concentration of DCAA, TCAA and THAA would increase with the increasing of the content of Al, As and K. For the relation with HAA formation, the elements of Ba and Na were contrary to Al, As and K. Significant negative correlations were obtained between DBAA formation and Ba, Na. But, significant positive correlations were obtained between DCAA, TCAA, THAA formation and Ba, Na. There are negative but not significant correlations between HAAs formation (except DBAA) and Fe element, and no relations between DBAA formation and Fe.

The use of polyaluminium chloride coagulant will result in an increased aluminium, but when the polyferric chloride was selected

**Table 5**

The correlation between some elements and HAA.

		Al	Fe	Zn	Mn	As	Mo	Ba	K	Na	Ca	Mg
MCAA	<i>r</i>	0.18	-0.15	-0.13	0.02	-0.16	-0.16	-0.28**	-0.06	-0.11	-0.31**	-0.22*
	<i>p</i>	0.11	0.48	0.51	0.89	0.14	0.09	0.00	0.57	0.27	0.00	0.02
MBAA	<i>r</i>	0.08	-0.32	0.06	-0.30	-0.29**	0.87	0.18	0.24**	0.62**	-0.04	0.32
	<i>p</i>	0.48	0.14	0.75	0.07	0.01	0.00	0.06	0.01	0.00	0.65	0.00
DCAA	<i>r</i>	0.34**	-0.30	-0.06	-0.23	0.19	0.16	-0.44**	0.47**	-0.14	-0.32**	-0.41**
	<i>p</i>	0.00	0.17	0.75	0.18	0.08	0.10	0.00	0.00	0.16	0.00	0.00
TCAA	<i>r</i>	0.32**	-0.33	-0.16	0.09	0.53**	-0.18	-0.47**	0.62**	-0.32**	-0.25**	-0.69**
	<i>p</i>	0.00	0.12	0.43	0.62	0.00	0.07	0.00	0.00	0.00	0.01	0.00
DBAA	<i>r</i>	-0.21	0.11	0.07	-0.24	-0.45**	0.03	0.11	-0.45**	0.13	0.11	0.45**
	<i>p</i>	0.07	0.60	0.72	0.17	0.00	0.74	0.24	0.00	0.17	0.27	0.00
THAA	<i>r</i>	0.42**	-0.33	-0.13	-0.08	0.31**	-0.07	-0.56**	0.54**	-0.26**	-0.39**	-0.65**
	<i>p</i>	0.00	0.12	0.50	0.66	0.00	0.46	0.00	0.00	0.01	0.00	0.00

\* Correlation is significant at the 0.05 level (2-tailed).

\*\* Correlation is significant at the 0.01 level (2-tailed).

as coagulant the ferrum increases quickly. Thus, the effect of removing THMs and HAAs is polyferric chloride > polyaluminium chloride. In order to control the THMs and HAAs formation, polyferric chloride could be a preferred flocculant agent in waterworks.

#### 4. Conclusions

This study elucidated that: The THMs and HAAs formation are influenced by many water quality parameters including TOC, UV<sub>254</sub>, pH, water temperature, residence time, residual chlorine, bromide ion concentration and chemical elements.

The correlations between THMs formation and natural organic matter (TOC and UV<sub>254</sub>) are significant positive correlation ( $p < 0.01$  and  $p < 0.05$ ). And there is poor significant positive relationship between HAAs formation and natural organic matter (TOC and UV<sub>254</sub>) ( $p = 0.25$  and  $p = 0.21$ ).

In range of pH (6.5–8.5) of drinking water in six selected cities, pH had a little effect on HAAs formation. The content of THAA is decreased with the increasing of pH. But pH has a great influence on THMs formation. The concentration of TTHM is increased with the increasing of pH.

The chlorine dose and residence time have a functional relationship with the formation of HAAs and THMs, and the concentration of HAAs and THMs displays a seasonal variation with the variation of water temperature. Bromide ion concentration and chemical element also affect the THMs and HAAs formation.

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