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**Towards the revision of the drinking water directive 98/83/EC. Development of a direct injection ion chromatographic-tandem mass spectrometric method for the monitoring of fifteen common and emerging disinfection by-products along the drinking water supply chain**

**This is the author's manuscript**

*Original Citation:*

*Availability:*

This version is available <http://hdl.handle.net/2318/1729241> since 2020-02-23T17:27:17Z

*Published version:*

DOI:10.1016/j.chroma.2019.07.004

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## Abstract

According to the recent proposal released by the European Commission for the revision of the 98/83/EC Directive, water suppliers will be requested to monitor the nine bromine- and chlorine congeners of haloacetic acids, HAAs, as well as the oxyhalides chlorite and chlorate, as disinfection by-products (DBPs) originated during the potabilization process.

In this work, we propose a direct-injection method based on ion chromatography and mass spectrometric detection for the determination of the mentioned DBPs as well as bromate (already included in the 98/83/EC), implemented also for the following emerging HAAs monoiodo-, chloriodo- and diiodo-acetic acids. The method was optimized to include the fifteen compounds in the same analytical run, tuning the chromatographic (column and gradient) and detection conditions (suppression current, transitions, RF lens settings and collision energies). To avoid matrix effect and to manage the instrumental conditions, optimization was performed directly in drinking water matrix. The method quantitation limits satisfy the new limits imposed by the future directive and range from 0.08  $\mu\text{g/L}$  (monobromoacetic acid) to 0.34  $\mu\text{g/L}$  (trichloroacetic acid). The performance of the method was checked along different strategic sampling points of three potabilization plants serving the city of Turin (Italy), including intermediate treatments and finished waters. Recovery was checked according to the  $\pm 30\%$  limit of acceptability set by EPA regulations. The effect of disproportionate concentrations of chlorite and chlorate in respect to HAAs on HAA signals was studied; this aspect is underestimated in literature. The method is routinely applied by the potabilization plant of the city of Turin to confirm the effectiveness of all control measures in abstraction, treatment, distribution and storage. This study represents the first example in Italy of development and use of a cutting-edge technique for HAAs analysis along the potabilization processes.

**Keywords:** drinking water directive, haloacetic acids, ion-chromatography, mass spectrometry, plant monitoring

46 **1. Introduction**

47 Within the European Community, the quality and safety of water intended for human  
48 consumption is currently disciplined by the so-called 98/83/EC Drinking Water Directive [1].

49 As a result of the Regulatory Fitness and Performance programme (REFIT) evaluation and of the  
50 follow up actions to the European Citizens' Initiative (ECI) Right2Water, the European Commission  
51 adopted on 1 February 2018 a proposal for the revision of the Drinking Water Directive [2]. In the  
52 upcoming proposal for the revision of the 98/83/EC Directive, attention is devoted to the disinfection by-  
53 products (DBPs) originated during potabilization process. More in detail, the directive requires the  
54 monitoring of the nine bromine- and chlorine congeners of haloacetic acids, HAAs, (monochloro-,  
55 dichloro-, and trichloro-acetic acid, mono- and dibromo-acetic acid, bromochloroacetic acid,  
56 bromodichloroacetic acid, dibromochloroacetic acid and tribromoacetic acid), which must not be present  
57 at concentrations higher than 80 µg/L as a sum. After trihalomethanes, HAAs are the second most  
58 prevalent DBP class generated in disinfected waters, and their toxicological effects are well ascertained  
59 [3].

60 The upcoming revision of the 98/83/EC Directive is also going to regulate the presence of chlorate  
61 and chlorite, which are predominantly formed when the disinfectants used are hypochlorite and/or  
62 chlorine dioxide solutions. According to WHO recommendations, the guideline value allowed for  
63 chlorite and chlorate in drinking water is 0.7 mg/L. According to indications provided by the European  
64 Food Safety Authority (EFSA) on toxicological reference value for chronic risk assessment provided for  
65 chlorate, the EU Commission is going to regulate the presence of both chlorate and chlorite at the stricter  
66 level of 0.25 mg/L, overcoming the fact that current EU drinking water directive does not set any specific  
67 limits in drinking water.

68 For those regions whose drinking water sources are impacted by sea water intrusion and thus  
69 contain relatively high concentrations of Br<sup>-</sup> and I<sup>-</sup> ions, besides brominated compounds, the presence of  
70 iodinated (emerging) DBPs in finished drinking waters could also be observed [4]. Monoiodoacetic acid

71 inhibits glyceraldehyde-3phosphate dehydrogenase (GAPDH) activity in a greater extent than bromo-  
72 and chloro-analogous [5].

73 Bromate occurrence in drinking water is ascribed to the oxidation of Br<sup>-</sup> naturally occurring in  
74 water during ozonation process, even if bromate could be present, as a contaminant, in commercial  
75 solutions of sodium hypochlorite used for disinfection of drinking water [6]. Bromate is considered a  
76 probable human carcinogen, it was listed in B2 Group by IARC and its presence is regulated in drinking  
77 waters by US EPA and 98/83/EC Directive which both set a limit of 10 µg/L.

78 Regarding the analytical determination of DBPs, the methods most used for this purpose are based  
79 on gas (GC) and liquid chromatographic (LC) techniques. GC is employed for HAA analysis after a  
80 preliminary derivatization step [7], as recommended by EPA 552.2 method [8]. Detection can be  
81 accomplished with ECD or MS [9] detectors at µg/L levels.

82 LC methods are mainly based on the anion-exchange methods, exploiting, if possible, the ionic  
83 nature of the DBPs. Ion chromatography coupled to MS-MS detection allows to achieve detection limits  
84 for selected HAAs at fractions of µg/L without sample pretreatment [10, 11]. Hundreds ng/L detection  
85 limits levels can be achieved for HAAs enriching acidified sample onto functionalized graphene/alumina  
86 nanocomposites [12]. So far, only few emerging iodinated HAAs have been monitored in waters, using  
87 GC-MS [13] and LC-MS [4] methods after sample pretreatment or direct large volume injection [14].  
88 Oxyhalide DBPs (chlorite, chlorate, perchlorate and bromate) are easily determined in drinking water  
89 using ion chromatography with suppressed conductivity as recommended by EPA methods 300.1 [15]  
90 and 314.0 [16], colorimetry [17] and in few cases by mass or mass tandem spectrometry [18].

91 In view of the upcoming revision of the Drinking Water Directive 98/83/EC, water suppliers that  
92 treat and supply drinking water as well as institutions in charge to control safety of the distributed water  
93 must be ready to measure all the above-mentioned compounds in a routine basis, to meet future legislative  
94 requirements.

95 The aim of this work is to develop a sensitive, accurate method without sample pretreatment for  
96 the determination of DBPs, including emerging iodinated HAAs, in one chromatographic run, to be used

97 by the water supplier laboratories for the routine controls required for the upcoming Drinking Water  
98 Directive.

99 With the aim of satisfying currently accepted EPA standards [10] in an analytical method of wider  
100 applicability, an ion chromatographic method with tandem mass spectrometry was here optimized for  
101 the simultaneous determination of the DBPs subjected to the attention of the future legislation, i.e.  
102 monochloro-, dichloro-, and trichloro-acetic acid, mono- and dibromo-acetic acid, bromochloroacetic  
103 acid, bromodichloroacetic acid, dibromochloroacetic acid and tribromoacetic acid, chlorite, chlorate, as  
104 well as bromate (already included in the 98/83/EC), and monoiodo-, chloriodo- and diiodo-acetic acids  
105 as emerging HAAs.

106 Before applying the developed method to real samples of different provenience, the robustness of  
107 the method was checked evaluating the recovery of analytes in samples withdrawn from different points  
108 of three potabilization plants, characterized by matrix composition at different complexity. Quantitation  
109 limits and acceptance criteria of the method fully comply future regulatory requirements. The method is  
110 currently routinely applied for the analysis of fifteen DBPs by the laboratory in charge of supplying and  
111 monitoring drinking water in the Italian city of Torino.

112 This study represents the first example of simultaneous analysis of the DBPs included in the  
113 forthcoming Drinking Water Directive revision and a rare example in Italy of development and  
114 application of direct injection IC/MS-MS technique for the analysis of organic and inorganic disinfection  
115 by-products along the drinking water supply chain (raw, treated and distributed waters).

116

## 117 **2. Materials and methods**

### 118 *2.1 Chemical standards and reagents*

119 Acetonitrile, ammonium chloride, monoiodoacetic acid (MIAA), as well as the following  
120 isotopically enriched internal standards monobromoacetic acid-1-<sup>13</sup>C (MBAA-<sup>13</sup>C), dichloroacetic acid-  
121 2-<sup>13</sup>C (DCAA-<sup>13</sup>C), trichloroacetic acid-2-<sup>13</sup>C (TCAA-<sup>13</sup>C), were from Sigma Aldrich (St. Louis, MO,  
122 USA). Iodoacetic acid-D3 (MIAA-D3), diiodoacetic acid (DIAA) and chloriodoacetic acid (CIAA),

123 were from Chemical Research (Rome, Italy). Inorganic anions were purchased in a standard mixture of  
124 1000 mg/L from Ultra Scientific (Bologna, Italy). The nine bromo- chloro- HAA congeners  
125 (monochloro- MCAA, dichloro-DCAA, and trichloro-acetic acid TCAA, mono- MBAA and dibromo-  
126 acetic acid DBAA, bromochloroacetic acid BCAA, bromodichloroacetic acid BDCAA,  
127 dibromochloroacetic acid DBCAA and tribromoacetic acid TBAA) were purchased from Restek  
128 (Bellefonte, PA, USA) in a mixture containing 1000 mg/L of each HAA in MTBE. Deionized water (18.2  
129 MΩcm resistivity) for eluent preparation and for dilution of stock standard solutions was obtained by an  
130 EMD Millipore Milli-Q Direct Water Purification System (Millipore, Bedford, MA, USA).

## 131 *2.2 Instrumental equipment and operating conditions*

132 A Thermo Fisher Scientific (Waltham, MA USA) ICS-5000 IC system was used throughout this  
133 work. The system includes a DP dual pump module for analytical and capillary applications, a CD  
134 conductivity detector, an AS autosampler, and a Reagent-Free (RFIC) eluent generator EG-5000 with  
135 ECG III cartridges KOH to provide the gradient of KOH (mobile phase) using deionized water from an  
136 AXP-MS pump (Thermo Fisher Scientific). For sample injections (120 μL), two autosamplers without  
137 (AS-DV) and with sample tray temperature control (AS-AP) set at  $9\pm 1$  °C were used; both were from  
138 Thermo Fisher Scientific. Separations were performed on an IonPac AS24 (250x2 mm i.d.) coupled with  
139 a guard column IonPac AG24 (50x2 mm i.d.) both from Thermo Fisher Scientific, thermostatted at 15  
140 °C in order to minimize the degradation at high pH values for MBAA, CDBAA and TBAA. Eluent  
141 gradient (0.3 mL/min) was set as follows, 7 mM KOH: t=0-15.1 min; 7-15.5 mM KOH: t=15.1-25.8 min;  
142 60 mM KOH: t=25.9 min, keep until 46 min; 7 mM KOH; t=47-58 min.

143 To remove trace anion contaminants from hydroxide eluent and to minimize base line shifts  
144 during gradient operation, an electrolytically continuously regenerated trap column (CR-ATC, 8% DVB  
145 crosslinking, 55 μm particle size) was installed in the eluent line after the pump prior to the sample  
146 injection. After eluent generation and before the separation column, Electrolytic suppression was  
147 accomplished using an ASRS 500 (2-mm) from Thermo Fisher Scientific.

149 A TSQ Endura triple-stage quadrupole mass spectrometer with ESI interface (HESI-II) was  
150 employed for detection. A diverter valve was used to waste the anion interfering species from matrix,  
151 thus preventing inorganic anions to enter the MS equipment. After the IC suppressor and before the ESI  
152 inlet, acetonitrile (CH<sub>3</sub>CN) was added to the eluate at 0.3 mL/min through an additional AXP-MS pump.  
153 The addition of CH<sub>3</sub>CN leads to higher efficiency in gas phase ion generation during the ESI process  
154 [19], enhancing analyte sensitivity [20]. The MS spectrometer was tuned and calibrated through the  
155 software TSQ Endurance Tune Application 2.1 (Thermo Fisher Scientific) by direct infusion of  
156 polytyrosine-1,3,6 (Thermo Fisher Scientific). Performance was checked every two weeks using the  
157 same polytyrosine-1,3,6 solution.

158

### 159 *2.3 Preparation of standard solutions and water samples*

160 Standard solutions were prepared in 5-mL vials directly in the autosampler. Ten levels of standard  
161 solutions were used for the construction of the calibration curve which was comprised between 0.25 and  
162 20 µg/L starting from a 1 mg/L standard mixture of DBPs in water. To each standard solution, 500 µL  
163 of 1000 mg/L NH<sub>4</sub>Cl were added to reach a final concentration of 100 mg/L NH<sub>4</sub>Cl as well as and 50 µL  
164 of internal standard solution (0.4 mg/L) to reach a final concentration of 4 µg/L.

165 Water samples were withdrawn from the treatment train of the water plant and filtered in Millex  
166 Gv filters (0.22-µm, Millipore). Water was sampled into 100 mL glass flasks containing 10 mg NH<sub>4</sub>Cl  
167 and immediately analysed.

168

169

## 170 **3. Results and Discussion**

### 171 *3.1 Optimization of MS/MS conditions*

172 Starting key MS/MS conditions were set as follows. Ion source polarity was in the negative ion  
173 mode, spray voltage: 3200 V, vaporizer gas pressure (N<sub>2</sub>): 45 units, auxiliary gas pressure (N<sub>2</sub>): 10 units,  
174 capillary temperature: 200 °C, vaporizer temperature: 200 °C, collision gas (Ar) pressure: 1.5 mTorr, ion



175 cycle time: 0.5 s. To maximise the peak response for the analytes, capillary and vaporizer temperatures  
176 were further optimized in the range 200-230 °C (capillary T) and 200-260 °C (vaporizer T) by the  
177 injection of analyte mixtures at 5 µg/L. Best conditions were achieved with capillary temperature of 220  
178 °C and vaporizer temperature of 250 °C. Further increase of these values lead to decreased peak signals  
179 especially for HAAs due to analyte degradation [21].

180 RF lens settings and collision energies (CE) for each transition were specifically optimised for each  
181 analyte, by infusion of 500 µg/L of each HAA and isotopically enriched internal standard (Table 1).  
182 According to literature data [22, 23],  $[M-H]^-$ , resulting from deprotonation of molecular ion, is the  
183 predominant precursor ion for haloacetic acids containing one or two halogen atoms, whereas  $[M-$   
184  $COOH]^-$  precursor is preferred for haloacetic acids containing three halogen atoms. Dimer ions can even  
185 be formed increasing infusion concentration ( $>1$  µg/L) [24]. In this work, each precursor ion was selected  
186 based on literature information on the most abundant species formed in ESI detection [10, 24]. In detail,  
187 for HAAs, the selected precursor ion is the one deriving from deprotonation ( $[M-H]^-$ ) of molecular ion  
188 for MCAA, MIAA, DCAA, MBAA, BCAA, DBAA, CIAA, DIAA and TCAA of the acid, whereas for  
189 BDCAA, CDBAA and TBAA, the precursor ion selected is the one resulting from decarboxylation ( $[M-$   
190  $COOH]^-$ ) of the acid. For TCAA, even if many authors suggest the selection of  $[M-COOH]^-$  as the  
191 precursor ion [22, 23], it is not infrequent the selection of the  $[M-H]^-$  species [10, 20]. In this work, the  
192  $[M-H]^-$  was preferred over the  $[M-COOH]^-$  species due to the difference in signal response which was as  
193 high as  $10^4$  ( $[M-H]^- / [M-COOH]^-$ ).

194 For each precursor ion, the three most abundant product ions were monitored. Transitions to halide  
195 substituent were found to be the most abundant for HAAs containing one and three halogen atoms, i.e.  
196 MCAA, MBAA, MIAA, BDCAA, CDBAA, TBAA, except for TCA, for which transition to the  $[M-$   
197  $COOH]^-$  ion is preferred. For HAAs containing two halogen atoms, except for CIAA, the  $[M-COOH]^-$   
198 ion is also preferred. These findings are coherent with literature reports [23]. CIAA exhibits the most  
199 abundant transition to the  $I^-$  ion in agreement with detection studies conducted in reversed phase liquid  
200 chromatography and tandem mass spectrometry [14].

201 Precursor ion was used as quantifier ion, whereas product ion was used as qualifier ion.

202

### 203 *3.2 Optimization of ion chromatographic conditions*

204 *Separation column.* The fifteen DBPs and the main common anions in drinking water are  
205 characterized by different chemical properties, hence their simultaneous separation in matrix is a  
206 challenging task. Gradient conditions are often required to provide elution in reasonable analysis time  
207 and baseline resolution for analytes belonging to different classes. The elution of chlorite, chlorate and  
208 bromate is usually accomplished with isocratic runs on high capacity carbonate selective columns, such  
209 as IonPac AS9-HC, and more recently IonPac AS23 [25] which ensure baseline resolution of oxyhalides  
210 even at high matrix ion content. However, carbonate selective columns are not recommended for gradient  
211 elution, since baseline drift is too severe, hence hydroxide selective columns are the election choice.  
212 Hydroxide selective column such as IonPac AS19 have shown improved sensitivity and allows the  
213 detection of chlorite, chlorate and bromate at lower concentrations in respect to the carbonate selective  
214 IonPac AS23 column [26].

215 On the other hand, hydroxide selective columns of even high capacity are best suited for HAAs  
216 monitoring in drinking waters where common ions can be present in concentrations as high as 250 mg/L  
217  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  [20].

218 At the light of the above considerations, for the simultaneous elution of the fifteen DBPs, the  
219 column chosen was the IonPac AS24, which is as yet the best hydroxide selective high-capacity column  
220 available in the market for the elution of nine Cl-, Br- HAA congeners. The separation for all the fifteen  
221 DBPs in the presence of  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{CO}_3^{2-}$  ions must be preliminarily checked with conductivity  
222 detection (see below). A good separation of matrix ions from analytes of interest is important to reduce  
223 matrix effects and to preserve the ESI source, through eluate diversion to the waste. In fact, it has been  
224 shown that in the absence of matrix diversion, recoveries for species eluting close to  $\text{Cl}^-$  ion can be  
225 reduced to  $77\pm 10\%$  in finished drinking waters [23].

226 *Elution conditions.* Gradient profile proposed by column manufacturer (Eluent #1, Table 2) was  
227 initially tested in drinking water distributed in Turin, Italy (15 mg/L Cl<sup>-</sup>, 20 mg/L NO<sub>3</sub><sup>-</sup>, 35 mg/L SO<sub>4</sub><sup>2-</sup>,  
228 250 mg/L HCO<sub>3</sub><sup>-</sup>), spiking 5 µg/L of each analyte. Although the fifteen analytes could be separated from  
229 matrix interferent, diversion to waste could not avoid the enhancement of chlorate signal by carbonate  
230 ion and the suppression of DIAA signal by sulfate ion. This suppression can be avoided changing the  
231 selectivity coefficient DIAA/sulfate ion. Taking advantages of the fact that changes in counter-ion eluent  
232 concentration (OH<sup>-</sup>) have greater effects on divalent ions rather than on monovalent ions, as predicted by  
233 the ion-exchange mechanisms [27], the instantaneous eluent change to 60 mM KOH was anticipated just  
234 after the elution of DCAA (Eluent #2, Table 2), keeping constant the slope of gradient after the first 15  
235 minutes of elution. As expected, the increase of eluent strength shifted the divalent SO<sub>4</sub><sup>2-</sup> ion more than  
236 the monovalent DIAA, moving SO<sub>4</sub><sup>2-</sup> ion close to carbonate ion which could be both diverted to waste  
237 (Table 2). Therefore, the following time intervals for eluate diversion to waste were set: 18-23 min (Cl<sup>-</sup>  
238 ), 28.3-28.8 min (CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>), 30.5-32.3 min (NO<sub>3</sub><sup>-</sup>) which allow us to detect all the fifteen DBPs. The  
239 optimized diverter times eliminate the suppression effect on chlorate due to carbonate ion, which in  
240 drinking water samples was about 35%.

241 The optimized separation of the fifteen DBPs is shown in Fig. 1. Total analysis time is 60 minutes  
242 and includes the re-equilibration of the column to the starting gradient conditions.

243

### 244 *3.3 Optimization of suppressor current*

245 Factors known to favour ionization process at atmospheric pressure, besides organic solvents such  
246 as methanol or acetonitrile, are: (i) low ionic strength, (ii) the absence of inorganic non-volatile salts and  
247 (iii) the presence of the analyte as an ion in solution [28]. Chemical suppression is a necessary step to  
248 meet these conditions; the efficiency of eluent suppression affects the sensitivity of the MS detection,  
249 since excessive background conductivity causes MS signal suppression. The suppressor current value  
250 was optimized through the injection of HAA mixture and the evaluation of limits of detection (LODs)  
251 and quantitation (LOQs) according to Shrivastava and Gupta [29]. The current range explored was

252 varied between 45 mA and 70 mA, which corresponds to the recommended range for current setting at  
253 the higher KOH concentration reached in the gradient. Data obtained show that the lowest quantitation  
254 limits can be achieved setting the suppressor current at 50 mA; higher current values enhance the  
255 background noise. The best improvements of quantitation limits were observed for DBAA, DCBAA e  
256 DBCAA and in a less extent for TBAA. At this current value, total conductivity within the imposed  
257 gradient conditions varies from 0.8 to 3.0  $\mu\text{S}$ .

### 258

#### 259 *3.4 Figures of merit of the method*

260 *Linearity, limits of detection and quantitation.* Linearity was evaluated over two orders of  
261 magnitude, correcting peak response of each analyte with the relative response factor of the internal  
262 standard, as assigned in Table 1. Table 3 collects the results obtained, as well as the LOD and LOQ values  
263 [29].

264 A comparison of LOD values with EPA 557 method is not possible for all the analytes, since this  
265 study also includes oxyhalide DBPs (chlorite, chlorate) and emerging iodoacetic (monoiodo-,  
266 chloroiodo- and diiodo-acetic) acids not included in the above-mentioned standard. However, the  
267 optimization carried out allowed to get improved (from 2 to 3 times) detection limits for MCAA, MBAA,  
268 BCAA and TBAA, but higher (from 2 to 3.5 times) for DBAA, BDCAA, DBCAA and bromate.  
269 Comparable LODs were obtained for DCAA and TCAA.

270 As regards iodoacetic acids, when comparisons are possible, detection limits are improved in  
271 respect to the IC-ICP/MS approach [30], and comparable or even better than IC-tandem mass  
272 spectrometry methods [14].

273 As regards oxyhalides (chlorite, chlorate and bromate) our LODs are more than 20 times better  
274 than conductivity detection in hydroxide selective columns [26] and comparable for chlorite and bromate  
275 to those shown by the few studies based on IC-MS for oxyhalides [18]. The slightly better LOD obtained  
276 for chlorate in respect to this work (0.045 vs 0.188  $\mu\text{g/L}$ ) is explained with the pretreatment of drinking  
277 water samples with OnGuard cartridges for matrix removal, which is effective also for carbonate ions.

278 *Effect of refrigeration.* Current literature dealing with HAAs determination underline the  
279 possibility of degradation of MBAA, DBCAA and TBAA with temperature at high pH value, thus  
280 recommending the injection of samples at refrigerated conditions and elution at sub-ambient temperature.  
281 Differently from what expected, refrigeration was found also beneficial for the enhancement of signal  
282 intensity for TCAA (+73%) > DCAA (+62%) > BCAA (+58%) > DBAA (+41%) > bromate (40%). The  
283 easier degradation of tri-substituted haloacids agrees with the degradation studies presented by Lifongo  
284 et al. [31]. The limits of detections obtained within this work at controlled autosampler and elution  
285 temperature conditions (Table 3) were compared with those obtained by Wu et al. [23], who eluted HAAs  
286 at alkaline conditions, thermostating the column at 45 °C, without any control of injection temperature.  
287 In this regard, the limits presented [23] for some analytes seem surprisingly low (MCAA: 0.041 µg/L,  
288 bromate: 0.0051 µg/L, TCAA: 0.03 µg/L) in consideration of the above-mentioned discussion on  
289 compound stabilities and of the limits obtained in this work and current literature [10].

290 *Accuracy and precision.* Recovery (R) for all analytes were determined at five concentration  
291 levels spiking known concentrations from 0.25 to 20 µg/L for each analyte in ultrapure water in the  
292 presence of 100 mg/L NH<sub>4</sub>Cl. Each concentration level was analysed with 24 repetitions for each DBP  
293 and 57 repetitions for internal standards. The following equation was used [10]:

$$294 \quad R = 100 \cdot \frac{(A - B)}{C}$$

295 where A= measured concentration in the fortified sample; B= measured concentration in the  
296 unfortified sample; C= fortification concentration.

297  
298 According to the data obtained (Table 4), recovery is within ±50% of the true value for 0.25 µg/L  
299 (which corresponds to the lowest calibration level of the calibration curve) and within ±30% of the true  
300 value for the other levels, thus fulfilling the requirement set by EPA [10].

301 Precision ranged from 1.3% (MIAA) to 12% (MCAA) for the lowest calibration level and from  
302 1% (MIAA) to 5.4% (chlorate) for the highest calibration level. These data fully satisfy precision

303 requirements set by EPA according to which seven replicates in the midrange of calibration curve should  
304 be  $\leq 20\%$  [10]. Since a unique method for the determination of the disinfection by-products considered  
305 in this work is not available in literature, comparisons are possible only for classes of analytes determined  
306 with different analytical approach. For the nine Cl- and Br- congeners, mean recoveries for the same  
307 fortification levels are comparable or even improved (DCAA, DCBAA) in respect to other IC-MS/MS  
308 methods [10]. For iodinated DBPs, better mean recoveries were obtained within this work for MCAA in  
309 respect to the ones obtained by reversed-phase LC-MS/MS with large volume injection [14]. It should  
310 be remarked that the above-mentioned methods were tested for limited numbers of replicates (n=4-15)  
311 in respect to our study.

312 Inter-day, evaluated in 4 different days by 57 replicates, and intra-day precision, evaluated within  
313 the same day by 15 replicates, was studied using internal standards at 4  $\mu\text{g/L}$  concentration. The  
314 satisfactory data obtained (Table 4) indicate the robustness of the method developed.

315  
316  
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318  
319 *3.5 Application to drinking water supply chain*

320 Before applying the developed method to the analysis of drinking water samples, the robustness  
321 of the method was checked evaluating the recovery of analytes in samples withdrawn from different  
322 points of the treatment train, characterized by matrix composition at different complexity.

323 Three drinking water plants (DW1, DW2, DW3) were considered and analysed. The first two,  
324 DW1 and DW2, are conventional treatment plants, including dynamic separation basins (DSB) for the  
325 removal of slurry from clarified waters, in which coagulant, hypochlorite and chlorine dioxide solutions  
326 are dosed. The third, DW3, is an advanced treatment plant, dosing ozone as oxidant and performing  
327 biological treatment and extended activated carbon filtration; samples were taken at the outlet of a

328 clarification basin (CB3) in which coagulant and hypochlorite solutions are added. Effluents from DW  
329 plants (E1, E2, E3), which represent distributed waters, were also analysed.

330 Due to the unbalanced amounts of HAAs and bromate in respect to chlorite and chlorate ions  
331 (which derive from reagent conversion), recoveries of analytes were determined in DSB1, DSB2, E1, E2  
332 (for DW1 and DW2 plants), and in CB3 and E3 (for DW3 plant) for HAAs and bromate. The five  
333 samples withdrawn from each treatment stage (DSB1, DSB2, E1, E2, CB3 and E3), added with 100 mg/L  
334  $\text{NH}_4\text{Cl}$ , were fortified with 5  $\mu\text{g/L}$  HAAs and bromate and analysed. The data obtained (Table 5) clearly  
335 show that all HAAs (except MCAA) satisfy the  $\pm 30\%$  requisite of the EPA regulation. MCAA is at the  
336 lower limit of acceptability of the above-mentioned requisite in DSB1-2 and in E1.

337 This behaviour is explained by the suppression effect of chlorite ion, which in DSB1-2 and in E1  
338 samples is present in disproportionate concentrations (about 350  $\mu\text{g/L}$ , respectively) in respect to MCAA  
339 (5  $\mu\text{g/L}$ ).

340 To this purpose, the effect of chlorite on MCAA signal suppression in drinking water samples is  
341 reported in Figure 2, where the continuous line represents the spiked MCAA concentration (5  $\mu\text{g/L}$ ) and  
342 the two dotted lines represent the  $\pm 30\%$  requisite (3.5 and 6.5  $\mu\text{g/L}$ ).

343 Data show that the limit set for chlorite (250  $\mu\text{g/L}$ ) by the revision of the Drinking Water Directive  
344 98/83/EC allows the determination of MCAA with the required accuracy. Concentrations of chlorite as  
345 high as 1 mg/L still allow the quantitation of MCAA with standard addition method (20% recovery for  
346 MCAA). It is worth mentioning that the effect of chlorite on MCAA detection is not investigated in  
347 current literature [14, 23], since only  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$  are considered in the matrix. Moreover,  
348 current EPA method [10] does not allow the determination of MCAA in waters containing chlorite.

349 The method developed was hence used to check the drinking water supply chain in the main  
350 stages of treatment for each DW plant on a daily basis (Table 6), as well as in domestic tap water samples  
351 of different provenience (Table 7).

352 As far as the plant is concerned, the presence of DBPs in DSB1-2 and CB3 is coherent with the  
353 addition of the hypochlorite solution. This intermediate disinfection stage is of low impact in HAAs

354 formation, since the sum of the compounds subjected to regulation is well below the limit established for  
355 finished waters (80 µg/L). The subsequent filtration stages are efficient in the reduction of HAA9 since  
356 these compounds are present in the distributed waters at concentrations below 6 µg/L. The frequency of  
357 occurrence of haloacetic DBPs roughly followed the order  
358 DCAA>TBAA>BCAA>TCAA>>DBAA>>DCBAA>>MBAA. Emerging iodinated compounds were  
359 not detected.

360 Regarding the domestic tap water samples, two of them were withdrawn from houses served by  
361 the plant here studied (samples A,B, Turin, Italy), one from a house located in Monte Carlo (sample C,  
362 Principality of Monaco) and one from a drinking fountain of the province of Imperia (sample D, Italy).  
363 Samples C and D were chosen since their sampling areas correspond to municipalities located in coastal  
364 zones and hence vulnerable to the presence of brominated and iodinated compounds.

365 The results on tap waters sampled in houses located in the plant area considered confirms the  
366 absence of any criticality. Waters sampled from the coastal area are not affected by the presence of  
367 iodinated HAAs, even if a signal below the quantitation limit could be ascribed to MIAA. In one case,  
368 the presence of brominated species (BCAA, DBAA) at very low concentration levels (sum 1 µg/L) was  
369 revealed.

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#### 371 **4. Conclusions**

372 This paper reports the first chromatographic method to fulfil the upcoming revision of the  
373 Drinking Water 98/83/EC Directive, allowing the simultaneous determination of the nine HAAs and the  
374 three oxyhalides ions listed in the regulation. The method already includes three additional emerging  
375 iodinated acids (not yet considered by the revision). The method, validated directly in waters withdrawn  
376 from strategic points of the potabilization plant, is a powerful tool for water suppliers which are asked to  
377 put in place operational, supply-specific monitoring programmes intended to confirm the effectiveness  
378 of all control measures in abstraction, treatment, distribution and storage.

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380

381 **Acknowledgements**

382 Financial support from Ministero dell'Istruzione, dell'Università e della Ricerca is gratefully  
383 acknowledged. M. Castiglioni is grateful to SMAT for the scholarship granted. The authors are grateful  
384 to Mr. Maurizio Politi (SMAT, Turin) for his assistance in laboratory activities.

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466 **Table 1.** Optimised MS transitions for each compound of this study.

Analyte	Assigned internal standard	Precursor ion ( <i>m/z</i> )	Product ion ( <i>m/z</i> )	RF lens (V)	CE (V)
MCAA	MBAA- <sup>13</sup> C	93.113	35.444	55.18	10.253
Chlorite	MBAA- <sup>13</sup> C	67.262	51.286	65.49	13.64
MBAA- <sup>13</sup> C	-	137.848	79.058	50.629	10.253
MBAA	MBAA- <sup>13</sup> C	136.991	79.04	53.663	10.253
MIAA-D3		186.862	126.946	53.36	13.89
MIAA	MIAA-D3	184.878	126.889	51.236	10.253
Bromate	MBAA- <sup>13</sup> C	126.9	110.929	131.933	22.792
DCAA- <sup>13</sup> C	-	128	84.04	66.101	10.253
DCAA	DCAA- <sup>13</sup> C	127.052	83.04	73.382	10.253
BCAA	DCAA- <sup>13</sup> C	172.87	128.889	61.551	10.253
CIAA	MIAA-D3	218.862	126.911	64.28	21.78
DBAA	DCAA- <sup>13</sup> C	216.83	172.778	64.888	10.253
Chlorate	DCAA- <sup>13</sup> C	83.162	67.125	95.83	20.01
DIAA	MIAA-D3	310.725	266.679	70.65	10.25
TCAA	TCAA- <sup>13</sup> C	160.839	116.946	43.652	10.253
TCAA- <sup>13</sup> C	-	161.909	117.946	40.92	10.25
DCBAA	TCAA- <sup>13</sup> C	162.839	81.071	57	10.253
DBCBA	TCAA- <sup>13</sup> C	207.052	79.04	70.652	11.77
TBAA	TCAA- <sup>13</sup> C	252.726	81.071	83.393	19.809

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470 **Table 2.** Eluent gradient optimization for the separation and detection of DBPs in drinking water  
471 matrix.

	MCAA	ClO <sub>2</sub> <sup>-</sup>	MBAA	MIAA	BrO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	DCAA	BCAA	CIAA	DBAA	CO <sub>3</sub> <sup>2-</sup>	ClO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	DIAA	NO <sub>3</sub> <sup>-</sup>	TCAA	DCBAA	DBCBA	TBAA
Eluent										t <sub>r</sub> (min)									
#1 <sup>a)</sup>	12.9	13.1	14.7	15.4	15.7	20.3	24.9	26.6	28.6	28.9	32.7	33.0	35.3	35.9	37.1	39.5	41.6	44.6	48.8
#2 <sup>b)</sup>	12.7	13.0	14.3	15.0	15.1	20.2	24.0	25.5	27.3	27.5	28.5	29.1	28.5	29.8	31.9	32.8	37.8	40.7	43.5

472 <sup>a)</sup> Eluent #1: 7 mM KOH: t=0-15 min; 7-18 mM KOH: t=15.1-30.8 min; 60 mM KOH: t=31 min, keep  
473 until 46 min; 70 mM KOH: t=47-58 min. Diversion valve to the waste: 19-24 min, 35.1-35.6 min, 37.4-38.2 min.

474 <sup>b)</sup> Eluent #2: 7 mM KOH: t=0-15 min; 7-15 mM KOH: t=15.1-23.8 min; 60 mM KOH: t=23.9 min, keep  
475 until 46 min; 7 mM KOH: t=47-58 min. Diversion valve to the waste: 18-23 min, 28.3-28.8 min, 30.5-32.3 min

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**Table 3.** Limits of detection (LOD) and quantitation (LOQ) for the fifteen DBPs.

Analyte	Regression equation	R <sup>2</sup>	LOD (µg/L)	LOQ (µg/L)
Chlorite	0.0646x+0.0073	0.9999	0.036	0.110
MCAA	0.0461x+0.011	0.9999	0.134	0.405
MBAA	0.3863x+0.0038	0.9999	0.026	0.078
MIAA	0.5391x+0.0059	0.9999	0.045	0.136
Bromate	0.3860x+0.0628	0.9998	0.042	0.127
DCAA	0.3451x+0.0109	0.9999	0.059	0.177
BCAA	0.2764x+0.0008	0.9999	0.037	0.111
DBAA	0.5612x+0.0005	0.9999	0.055	0.166
CIAA	0.0745x+0.0047	0.9999	0.085	0.256
Chlorate	0.0334x+0.0095	0.9999	0.188	0.569
DIAA	1.1879x+0.0861	0.9999	0.036	0.109
TCAA	0.3032x+0.1699	0.9999	0.113	0.342
DCBAA	0.0136x+0.0052	0.9999	0.099	0.301
DBCBA	0.0108x+0.0048	0.9998	0.108	0.326
TBAA	0.0167x+0.0051	0.9995	0.037	0.111

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**Table 4.** Mean percentage recovery and relative standard deviation (n=24) at different concentration levels for the fifteen DBPs. Inter-day (4 days, 57 replicates) and intra-day precision (15 replicates in one day) for 4 µg/L internal standards is also shown.

Analyte	Recovery % (RSD%, n=24)					Inter-day precision	Intra-day precision
	0.25	0.5	1	10	20		
	µg/L						
Chlorite	71.3±8.0 (11)	74.5±8.4 (11)	105±4.3 (4.1)	103±2.4 (2.4)	94.5±1.4 (1.5)		
MCAA	88.1±10.6 (12)	99.7±4.6 (4.6)	107±3.2 (3.0)	106±1.7 (1.6)	95.0±2.0 (2.0)		
MBAA- <sup>13</sup> C						4.2	2.0-3.7
MBAA	88.7±5.6 (6.3)	96.8±3.6 (3.7)	104±3 (2.9)	101±1.2 (1.2)	95.5±1.4 (1.5)		
MIAA-D3						4.1	1.6-6.1
MIAA	105±1.4 (1.3)	99.7±1.7 (1.7)	101±1.2 (1.2)	104±0.7 (0.7)	104±1.0 (1.0)		
Bromate	85.6±5.2 (6.1)	95.6±3.6 (3.7)	102±2.1 (2.1)	99.1±1.4 (1.4)	92.3±1.3 (1.4)		
DCAA- <sup>13</sup> C						1.9	0.9-2.1
DCAA	105±2.0 (1.9)	97.7±4.7 (4.8)	96.1±1.2 (1.3)	99.2±1.1 (1.1)	98.8±1.1 (1.1)		
BCAA	102±4.7 (4.6)	96.3±2.2 (2.3)	96.1±1.4 (1.4)	99.3±1.1 (1.1)	99.8±1.2 (1.2)		
DBAA	109±2.9 (2.7)	99.4±1.5 (1.5)	95.9±1.2 (1.2)	99.6±0.9 (1.1)	99.5±1.2 (1.2)		
CIAA	134±4.5 (3.4)	112±34 (30)	103±1.5 (1.5)	102±1.4 (1.4)	103±1.3 (1.2)		
Chlorate	88.41±5 (5.7)	85.4±3.0 (3.5)	104±3.0 (2.9)	99.6±2.6 (2.6)	94.6±2.3 (2.4)		
DIAA	105±1.7 (1.6)	111±5.0 (4.6)	97.6±1.0 (1.0)	100±2.2 (2.2)	99.0±1.6 (1.6)		
DCAA- <sup>13</sup> C						2.2	1.4-29
TCAA	120±6.7 (5.6)	106±6.2 (5.9)	108±14 (13)	103±1.9 (1.9)	100±2.1 (2.1)		
DCBAA	105±37 (36)	102±8.2 (8.0)	99.0±8.1 (8.1)	108±2.7 (2.5)	102±3.4 (3.3)		
DBCBA	106±25 (24)	90.7±17 (19)	111±13 (12)	106±9.1 (8.6)	99.9±4.9 (4.9)		
TBAA	106±10 (9.4)	103±8.8 (8.5)	105±8.2 (7.8)	99.6±19 (19)	96.8±3.2 (3.3)		

497 **Table 5.** Recovery of 5 µg/L HAAs (including emergent compounds) and 5 µg/L bromate  
 498 spiked on five water samples withdrawn from intermediate and final purification stages of three  
 499 potabilization plants.

	Intermediate treatments			Finished waters		
	DSB1	DSB2	CB3	E1	E2	E3
MCAA	69±5.9 (8.5)	69.1±5.9 (8.5)	113±3.6 (2.3)	62.2±5.7 (9.2)	79.6±4.7 (6.0)	94.8±6.1 (6.5)
MBAA	101±2.1 (2.1)	100±3.7 (3.7)	104±2.9 (2.8)	103±2.6 (2.5)	103±2.6 (2.5)	100±1.3 (1.3)
MIAA	100±1.0 (1.0)	99.7±1.1 (1.2)	98.9±0.9 (1.0)	100±0.9 (0.9)	99.3±1.2 (1.2)	99.2±1.3 (1.3)
Bromate	111±3.7 (3.3)	113±3.4 (3.0)	115±2.9 (2.5)	116±2.4 (2.1)	116±5.1 (4.4)	115±3.8 (3.3)
DCAA	96.2±8.1 (8.4)	99.5±5.0 (5.0)	101±2.4 (2.4)	102±1.0 (1.0)	101±1.9 (1.9)	102±1.0 (1.0)
BCAA	96.0±6.0 (6.2)	98.6±6.4 (6.5)	100±2.5 (2.5)	100±3.8 (3.8)	101±2.6 (2.6)	101±1.2 (1.1)
DBAA	97.7±3.9 (3.9)	97.7±2.6 (2.7)	99.3±2.7 (2.7)	97.8±1.6 (1.6)	98.9±2.0 (2.1)	99.7±1.0 (1.0)
CIAA	98.7±1.9 (2.0)	99.5±2.9 (3.0)	99.6±0.9 (0.9)	98.9±2.2 (2.2)	98.0±2.2 (2.3)	98.4±2.7 (2.7)
DIAA	97.9±1.6 (1.6)	97.4±3.7 (3.8)	97.1±1.0 (1.1)	97.9±2.4 (2.5)	96.4±2.6 (2.7)	95.5±2.4 (2.5)
TCAA	91.4±9.1 (9.9)	93.2±9.5 (10.2)	94.2±1.5 (1.6)	91.8±2.2 (2.4)	93.5±3.5 (3.7)	95.9±1.3 (1.3)
DCBAA	107±12 (11)	92.4±12 (13)	103±6.9 (6.7)	105±1.3 (1.3)	104±4.1 (3.9)	105±4.7 (4.4)
DBCBA	93.5±8.9 (9.6)	91.5±17 (18)	89.2±25 (29)	108±23 (21)	111±21(19)	110±25 (23)
TBAA	81.6±18 (22)	85.2±15 (17)	95.9±9.5 (9.9)	87.2±9.8 (11)	93.7±14 (15)	104±4.3 (4.1)

500 Mean chlorite concentration, mg/L (n=5): DSB1: 395; DSB2: 340; E1: 350; E2: 230, E3: 85.

501 Mean chlorate concentration, mg/L (n=5): DSB1: 420; DSB2: 440; CB3: 80; E1: 470; E2: 450, E3: 165.

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504           **Table 6.** Concentrations (expressed in  $\mu\text{g/L}$ ) of the fifteen DBPs along the treatment train of three  
505 potabilization plants evaluated by the method developed.

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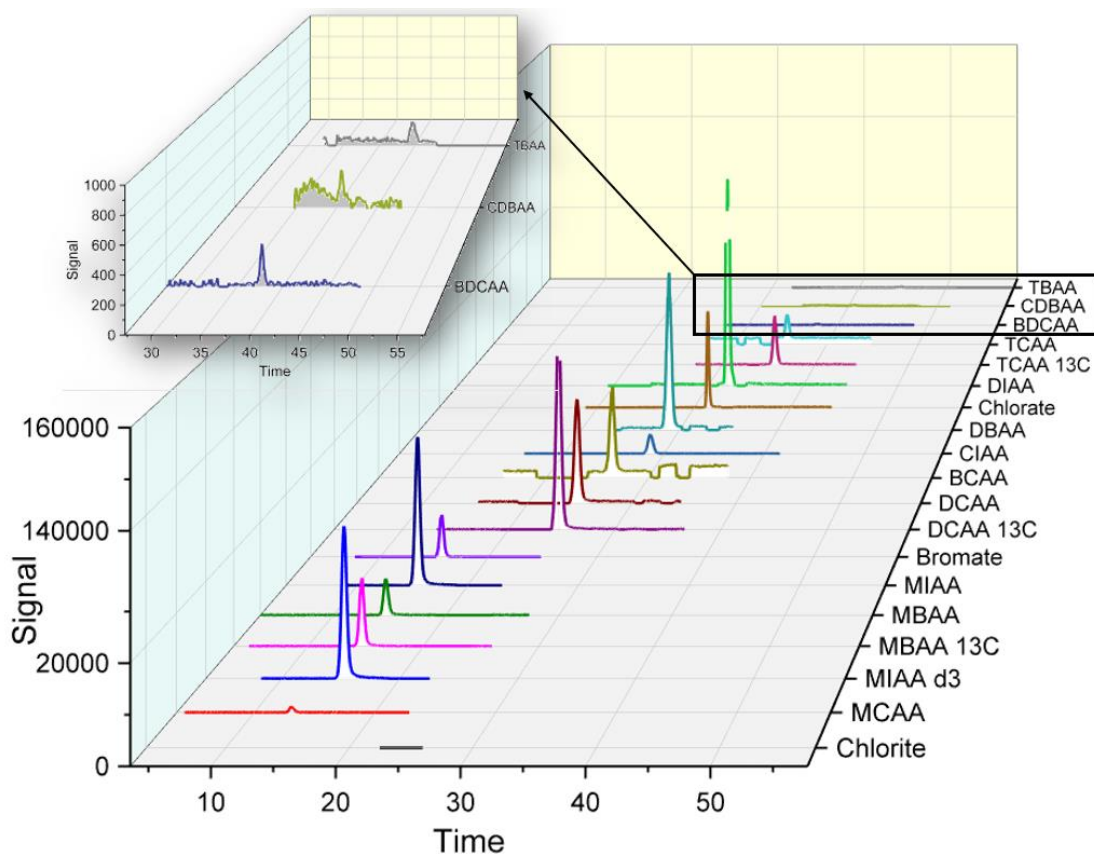
Day	Treatment stage	Analyte (µg/l)															Sum <sup>a)</sup>
		ClO <sub>2</sub> <sup>-</sup>	MCAA	MBAA	MIAA	BrO <sub>3</sub> <sup>-</sup>	DCAA	BCAA	CIAA	ClO <sub>3</sub> <sup>-</sup>	DBAA	DIAA	TCAA	DCBAA	DBCBA	TBAA	
	Raw river water	0.49	nd	nd	<LOQ	nd	nd	<LOQ	nd	<LOQ	nd	<LOQ	nd	nd	nd	-	
1	DSB1	550	nd	0.24	<LOQ	0.91	2.56	1.79	nd	350	0.87	nd	1.53	0.86	nd	2.25	10.1
1	E1	297	nd	nd	<LOQ	0.52	0.26	0.33	nd	580	<LOQ	nd	0.72	0.41	nd	0.88	1.3
1	CB3	-	nd	<LOQ	<LOQ	1.04	0.97	0.78	nd	89	0.37	nd	0.38	nd	2.69	0.89	6.1
1	E3	100	nd	nd	<LOQ	0.45	<LOQ	0.11	nd	211	<LOQ	nd	Nd	nd	nd	nd	0.1
2	DSB1	408	nd	0.16	<LOQ	0.55	1.64	1.20	nd	380	0.55	nd	0.85	0.44	nd	1.42	6.3
2	E1	313	nd	nd	<LOQ	0.49	0.34	0.33	nd	446	<LOQ	nd	0.56	nd	nd	1.28	2.5
3	DSB1	330	nd	<LOQ	<LOQ	0.41	1.47	1.16	nd	451	0.62	nd	0.41	0.19	nd	1.69	5.5
3	E1	418	nd	nd	<LOQ	0.49	0.23	0.29	nd	431	<LOQ	nd	0.89	nd	nd	1.12	2.5
3	DSB2	340	nd	<LOQ	<LOQ	0.65	1.84	1.34	nd	395	0.47	nd	1.29	0.83	nd	2.08	7.8
3	E2	267	nd	nd	<LOQ	0.59	0.42	0.35	nd	367	<LOQ	nd	0.66	nd	nd	1.48	2.9
3	CB3	-	<LOQ	<LOQ	<LOQ	0.84	0.94	0.67	nd	57	0.40	nd	0.5	nd	nd	nd	2.5
3	E3	113	nd	nd	<LOQ	0.43	<LOQ	0.12	nd	136	Nd	nd	Nd	nd	1.07	nd	1.2
4	DSB1	248	nd	<LOQ	<LOQ	0.19	1.73	1.25	nd	459	0.53	nd	0.75	0.38	nd	1.88	6.5
4	E1	369	nd	nd	<LOQ	0.52	0.30	0.30	nd	762	<LOQ	nd	0.62	0.64	nd	1.53	6.1
4	DSB2	279	nd	<LOQ	<LOQ	0.59	1.78	1.30	nd	508	0.56	nd	0.84	0.75	nd	2.29	7.5
4	E2	231	nd	<LOQ	<LOQ	0.63	0.50	0.11	nd	645	<LOQ	nd	0.42	<LOQ	nd	1.15	2.2
4	CB3	-	<LOQ	<LOQ	<LOQ	1.27	1.02	0.81	nd	133	0.44	nd	0.35	nd	nd	0.53	3.1
4	E3	90	nd	nd	<LOQ	0.51	<LOQ	nd	nd	147	Nd	nd	Nd	nd	nd	0.26	0.3
4	DSB1	344	nd	<LOQ	<LOQ	0.16	1.59	1.11	nd	488	0.52	nd	0.58	0.39	nd	0.96	5.2
4	E1	336	nd	nd	<LOQ	0.14	0.36	<LOQ	nd	560	<LOQ	nd	0.52	0.29	nd	<LOQ	1.2
4	DSB2	328	nd	<LOQ	<LOQ	0.14	1.62	1.17	nd	408	0.52	nd	0.68	<LOQ	nd	1.36	5.3
4	E2	215	nd	<LOQ	<LOQ	0.17	0.53	0.40	nd	408	<LOQ	nd	0.33	<LOQ	nd	0.94	2.2
4	CB3	-	<LOQ	<LOQ	<LOQ	1.03	0.81	0.78	nd	88	0.40	nd	<LOQ	nd	nd	nd	2.0
4	E3	30	nd	nd	<LOQ	0.46	<LOQ	nd	nd	132	<LOQ	nd	Nd	nd	nd	nd	-

a) Sum of the nine HAAs as foreseen by the proposal for the revision of the Drinking Water Directive

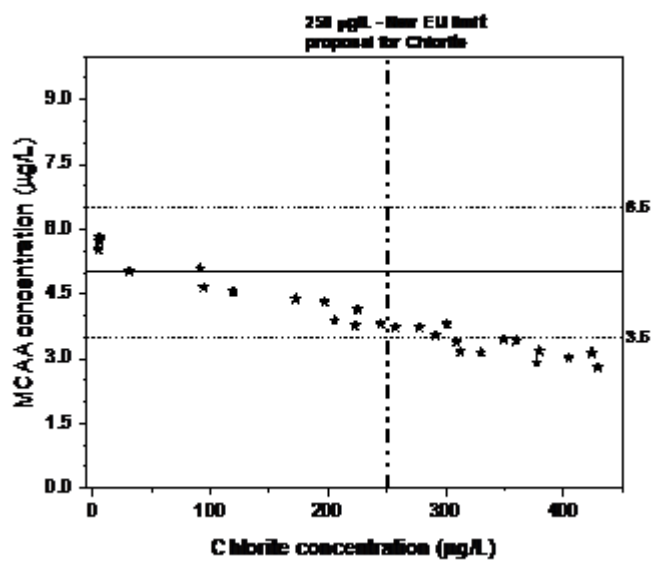
nd: not detected

**Table 7.** Analysis of drinking waters of different origins by the method developed. A,B: houses (Turin, Italy) ; C: house (Monte Carlo, Principality of Monaco); D: drinking fountain (Imperia, Italy). Concentrations are expressed in  $\mu\text{g/L}$ .

<b>Analyte</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
Chlorite	nd	nd	nd	173
MCAA	nd	nd	nd	nd
MBAA	<LOQ	<LOQ	<LOQ	nd
MIAA	nd	nd	<LOQ	<LOQ
Bromate	nd	nd	<LOQ	nd
DCAA	nd	<LOQ	nd	nd
BCAA	<LOQ	0.29	0.28	nd
CIAA	nd	nd	nd	nd
DBAA	<LOQ	<LOQ	0.72	nd
Chlorate	13.0	15.3	nd	7.00
DIAA	nd	nd	nd	nd
TCAA	<LOQ	<LOQ	nd	<LOQ
DCBAA	nd	nd	<LOQ	nd
DBCBA	nd	nd	nd	nd
TBAA	nd	nd	nd	nd



**Figure 1.** IC-MS/MS separation of fifteen DBPs and isotopically enriched internal standards (2 µg/L each).



**Figure 2.** Effect of chlorite concentration on the suppression of MCAA signal. Continuous line: spiked MCAA concentration (5 µg/L); dotted lines: ±30% requisite (3.5 and 6.5 µg/L).

	MCAA	ClO <sub>2</sub> <sup>-</sup>	MBAA	MIAA	BrO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	DCAA	BCAA	CIAA	DBAA	CO <sub>3</sub> <sup>2-</sup>	ClO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	DIAA	NO <sub>3</sub> <sup>-</sup>	TCAA	DCBAA	DBCAA	TBAA
Eluent										t <sub>r</sub> (min)									
#1 <sup>a)</sup>	12.9	13.1	14.7	15.4	15.7	20.3	24.9	26.6	28.6	28.9	32.7	33.0	35.3	35.9	37.1	39.5	41.6	44.6	48.8
#2 <sup>b)</sup>	12.7	13.0	14.3	15.0	15.1	20.2	24.0	25.5	27.3	27.5	28.5	29.1	28.5	29.8	31.9	32.8	37.8	40.7	43.5

Analyte	Eluent	
	#1 <sup>a)</sup>	#2 <sup>b)</sup>
tr (min)		
MCAA	12.9	12.7
ClO <sub>2</sub> <sup>-</sup>	13.1	13.0
MBAA	14.7	14.3
MIAA	15.4	15.0
BrO <sub>3</sub> <sup>-</sup>	15.7	15.1
Cl <sup>-</sup>	20.3	20.2
DCAA	24.9	24
BCAA	26.6	25.5
CIAA	28.6	27.3
DBAA	28.9	27.5
CO <sub>3</sub> <sup>2-</sup>	32.7	28.5
ClO <sub>3</sub> <sup>-</sup>	33.0	29.1
SO <sub>4</sub> <sup>2-</sup>	35.3	28.5
DIAA	35.9	29.8
NO <sub>3</sub> <sup>-</sup>	37.1	31.9
TCAA	39.5	32.8
DCBAA	41.6	37.8
DBCAA	44.6	40.7
TBAA	48.8	43.5