

## Practical Paper

# Presence of trihalomethanes in drinking water plants in Nicaragua

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### ABSTRACT

The impact of enhanced coagulation on the formation of trihalomethanes (THMs) from drinking water was studied in four treatment plants in Nicaragua. Enhanced and conventional coagulation techniques were compared with regard to the removal of natural organic matter (NOM), which was measured by surrogate parameters. The enhanced coagulation process showed a better removal of NOM, and as a consequence the THM formation was up to 50% lower than with conventional coagulation. The influences of chlorine dosage, temperature, pH and contact time on the THM formation in water treated by enhanced and conventional coagulation were also studied.

**Key words** | conventional coagulation, drinking water, enhanced coagulation, natural organic matter, surrogate parameters, trihalomethanes

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### INTRODUCTION

The impact of enhanced coagulation on the formation of trihalomethanes (THMs) from drinking water was studied in four treatment plants in Nicaragua. This country is located in the middle of Central America, and it has a land area of 130,000 square kilometres and 5 million inhabitants. During the last decades, the demand for drinking water in Nicaragua has strongly increased due to the rapid growth of the population and to the rise in living standards for some sectors of the population. There are seven drinking water plants using conventional treatment and two plants with slow sand filtration as the main treatment step. Groundwater, surface water or a combination of the two supplies are used as sources of raw water to the plants.

Chlorination is widely used in developing countries to ensure a safe drinking water in terms of water diseases. Chlorination is sometimes the only step, and commonly it is added after the conventional treatment. The chlorine reacts

with natural organic matter (NOM) that has not been completely removed in the treatment and it forms trihalomethanes such as (CHCl<sub>3</sub>, CHCl<sub>2</sub>Br, CHClBr<sub>2</sub>, and CHBr<sub>3</sub>). These compounds have been related to the occurrence of cancer, growth retardation, spontaneous abortion, and congenital cardiac defects (Ivancev *et al.* 1999; Mougdalet *et al.* 2000; Graves *et al.* 2001; Cedergren *et al.* 2002).

The total concentration of trihalomethanes and the distribution of the individual species in the chlorinated water depend on the raw water characteristics, on the operational parameters during the treatment and on the residual chlorine in the distribution system. Other parameters that should be taken into consideration are the pH, temperature, contact time with chlorine, bromide and chlorine concentration, total and dissolved organic carbon, and organic matter structure.

The natural organic matter is difficult to measure because there is no single parameter that can provide a

complete characterisation of NOM. Therefore, several surrogate parameters are used to describe the NOM characteristic. Turbidity, Colour, Total and Dissolved Carbon, Ultraviolet Absorbance (UV<sub>254</sub>), Specific Ultraviolet Absorption (SUVA) and Trihalomethane Formation Potential (THMFP) are commonly used as surrogate parameters of DBP precursors.

USEPA (USEPA 1999 & 2002) has published two regulations for the treatment of drinking water to diminish the content of disinfection by-products (DBPs). They established maximum contaminant levels (MCLs) of 0.080 mg/l for total trihalomethanes (THMs) and 0.060 mg/l for haloacetic acids (HAAs). According to the Nicaraguan guidelines (CAPRE 2000), the residual chlorine concentration at the exit of the drinking water plant and at the end of the distribution system should be 2 and 0.5 mg/l respectively. The presence of THMs is not measured in any of the drinking water systems.

Due to erosion and the deforestation of the watershed surrounding the water sources used for the drinking water treatment plants in Nicaragua, high values of colour and turbidity can be expected in the rainy season. Colour and turbidity are also surrogate parameters of NOM, which has been identified as a precursor of harmful DBPs such as THM and haloacetic acids (HAAs) (Marhaba & Pipada 2000; Kitis *et al.* 2001).

In some of the drinking water plants, a high chlorine concentration up to 5 mg/l is used to overcome treatment deficiencies such as broken tilted plates, and inappropriate depth of the filtration medium. As a consequence of the use of these high chlorine doses, the presence of DBPs can be expected.

Four major drinking water plants in Nicaragua (Figure 1) were sampled, at Boaco (P1), Camoapa (P2), Juigalpa (P3) and Santo Tomas (P4). These four plants were chosen because they are located in the same geographical area with the same watershed problems, and also due to logistical reasons.

The purpose of this work is to determine whether trihalomethanes are actually present at the exit of the four drinking water treatment plants and to what extent the use of enhanced coagulation can decrease their concentrations. The influence of parameters such as pH, contact time and temperature on the formation of THMs has also been studied.



Figure 1 | Location of the four drinking water systems.

Only the concentration of THMs was determined because they are one of the main representatives of the DBPs compounds and also because of some laboratory limitations.

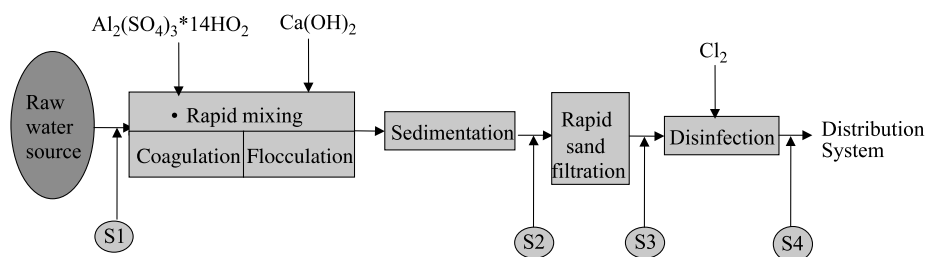
Measurements were made to characterise the physical, chemical and microbiological water parameters at different sample points at the four facilities. Enhanced coagulation using Jar Tests was performed using the raw waters from the four facilities in order to see whether this technique removes more natural organic matter. Chlorination experiments after enhanced coagulation were carried out in order to evaluate the THM formation. Comparisons were made between conventional (CC) and enhanced (EC) coagulation with regard to the formation of THMs when chlorination is applied after the filtration step. These results can be useful to improve the operation of the existing plants or in the design of future plants.

## METHODS

### Sampling sites

The conventional treatment used in these facilities consists of mixing with aluminium sulphate as coagulant and calcium hydroxide to adjust the pH, followed by flocculation, sedimentation, rapid sand filtration and disinfection with chlorine (Figure 2).

A total of 32 samples were collected over a period of six months (rainy season of 2003) at each facility. Four



**Figure 2** | A diagram of the conventional treatment at the drinking water plants and the location of the sampling points.

sampling points were chosen in each facility (Figure 2). Sample 1 (S1) was used to determine the physical, chemical and microbiological characteristics of the raw water used in the treatment plants. This sample was also used to analyse the NOM surrogate parameters (TOC, DOC,  $UV_{254}$  and SUVA) and for enhanced coagulation tests at the laboratory using the procedures described by USEPA (1999). Samples 2 (S2) and 3 (S3) were taken to determine the removal of NOM and the chemical, organic, and physical characteristics of the water after conventional coagulation and after rapid sand filtration respectively. Sample 4 (S4) was taken for analysis to determine the presence of THMs in the facilities after disinfection with chlorine. Samples were taken on eight occasions in each facility.

All the samples were preserved with ice at a temperature of 4°C and kept away from light until extraction. Some were preserved with HCl. Immediately after arrival at the laboratory, the sample temperature was adjusted to room temperature and the sample was analysed immediately. All the measurements were made in triplicate. The chemicals used for the analytical determinations were of reagent grade from Merck (Darmstadt, Germany).

### Analytical procedures

Turbidity, colour, water temperature, conductivity, pH, and residual chlorine were measured at the sample collection sites. Some samples for TOC, DOC and THM determinations were sent abroad for comparison with the HACH methods (10129, 10132) used in Nicaragua and the methodology used in Sweden. The other parameters were measured in the laboratory using the procedures of the Standard Method (SM) (1998). UV absorbance was measured using a UV/Vis spectrophotometer (Genesis II)

at 254 nm in 1 cm quartz cells. Faecal Coliforms in water were determined by the membrane filtration method.

The samples for TOC and DOC were taken using amber glass containers of 120 ml having a screw cap with a Teflon septum. They were preserved with HCl to a pH lower than 2. The samples for DOC were filtered using a 0.45 µm fibre filter (Whatman). For THM preservation, sodium thiosulfate was used as quenching agent and acidification was carried out with HCl. The Method SM 5310C was used for TOC and DOC analyses. THM was analysed by the EPA 502.2 method.

### Jar Test enhanced coagulation experiments

Samples S1 from the different sources were used for enhanced coagulation experiments at the laboratory, using the procedure described by USEPA (1999). The same coagulant type ( $Al_2(SO_4)_3 \cdot 14H_2O$ ) as that used at the drinking water plants was applied in these experiments. The common dosage of coagulants at those facilities was 20–30 mg/l of  $Al_2(SO_4)_3 \cdot 14H_2O$  depending on the turbidity of the raw water source.

Enhanced coagulation experiments were performed using two Jar Test apparatuses (Phipps and Bird). The coagulant dose used in the enhanced coagulation tests depends on the TOC removal requirement according to the USEPA procedure (1999). The ranges of doses used for the different raw waters are shown in Table 1. Each Jar Test was surrounded with a plexy-glass box to keep the temperature at  $25^\circ C \pm 0.1$ .

The effectiveness of the enhanced coagulation was evaluated in terms of the removal of precursors of THMs, and the decrease in THM level. A comparison was also made between the removal of other physical, chemical and

**Table 1** | Ranges of coagulant doses applied in the enhanced coagulation procedure

	P1 Boaco	P2 Camoapa	P3 Juigalpa	P4 Santo Tomas
Ranges of coagulant doses (mg/l)	20–50	10–50	10–50	10–60

microbiological contaminants in the facilities and that achieved in the laboratory by enhanced coagulation.

The THMs were measured to the disinfected water at the facility, to the daily conditions at the plant and to the disinfected water jar that complies with the requirement of (USEPA 1999) previous enhanced coagulation treatment and filtration.

### THMs and the influences of chlorine dosage, pH, contact time and temperature

The influences of chlorine dosage, pH, contact time and temperature on the formation of trihalomethane were investigated for waters treated with conventional and enhanced coagulation. In the facilities, the water sample taken after conventional coagulation and rapid sand filtration, S3, was used. In the laboratory, the water previously treated by enhanced coagulation, which should fulfil the TOC requirements, was used after filtration with paper filter (Whatman No. 1). Both waters were treated in the laboratory using different chlorine dosages, pH, contact times and temperatures. The ranges were chosen so that they included the values used at the facilities.

Reagent grade sodium hypochlorite was used as chlorine source. A constant temperature was maintained using three thermostats (LAUDA, M40). 300 ml of water was used for each test.

## RESULTS AND DISCUSSIONS

### Characterisation of the raw water at the four facilities

The results presented for each parameter in this section are the average values for eight samples taken in each facility. Table 2 shows the characteristics of the raw, settled and disinfected water at the facilities studied. The pH ranged from 7.2 to 8.1. The TOC levels as surrogate parameter of the DBP precursor were high, ranging from 4.0 to 29.2 mg/l. TOC

values higher than 1 mg/l indicate high organic matter content. The DOC of the samples ranged from 3.6 to 23.9 mg/l. A value of 3.6 mg/l of DOC is within the typical range for surface water samples (Croué *et al.* 1999), but a DOC of 23.9 mg/l is considered to be very high. However, the  $UV_{254}$  absorbance was low in the four facilities in comparison with the high DOC values; it ranged from 0.07 to  $0.4 \text{ cm}^{-1}$ . A low  $UV_{254}$  value implies less formation of CBPs due to low aromaticity.  $UV_{254}$  and CBPs concentration are highly correlated parameters. Turbidity which is also surrogate parameters of NOM was present in the raw water of the four plants between 29.1–66.0 NTU. SUVA values (1.4–2.0) which are less than 2 indicate that most of the organic matter in the raw water is hydrophilic, of low molecular weight and contains non humic compounds (protein, amino acid, carbohydrates, hydrophilic acids) which are less reactive with chlorine. Several authors have reported that SUVA values over 2 l/mg-m favour THM formation. However, Owen *et al.* (1995), Krasner *et al.* (1996), Lin *et al.* (2000), and Imai *et al.* (2003) reported that the non humic fraction reacts with chlorine and produces THM per unit DOC at an extent comparable to the hydrophobic fraction. For waters with low SUVA (2 or less), TOC will not control the coagulant dose, but the amount of particles (turbidity) determines the coagulant demand (Pernitsky 2003).

Despite most of the raw waters being visibly coloured, which indicates that possibly the organic matter present is rich in humic content and tannin, the colour is due to the high concentration of iron (1–2.3 mg/l) found in the four water sources.

The ammonia concentration in the raw water of the facilities P1 and P4 was 0.5 mg/l, values which are associated with decaying organic matter (especially protein), it also confirms that the type of NOM present in the raw water is mainly non humic instead of humic. Schaefer (1992) reported that ammonia is a pollution indicator of organic matter in the water. For P2 and P3 the average ammonia concentrations were 0.04 and 0.09 mg/l

**Table 2** | Results of the characterisation of the raw, settled and disinfected water of the four plants evaluated

Parameters	P1 Boaco			P2 Camoapa			P3 Juigalpa			P4 Santo Tomas		
	Raw Water	Settled Water	Disinfected Water	Raw Water	Settled Water	Disinfected Water	Raw Water	Settled Water	Disinfected Water	Raw Water	Settled Water	Disinfected Water
Temperature (°C)	23.6	23.3	23.4	23.2	23.1	24.1	26.5	26.1	28.0	26.0	25.0	25.0
Colour (PtCo)	101.5	10.1	7.2	101.2	15.9	12.8	60.8	4.0	1.0	114.0	9.1	2.1
Conductivity ( $\mu\text{s}/\text{cm}$ )	222.6	197.4	199.1	121.5	148.5	136.7	202.0	204.0	225.0	187.4	206.8	313.2
Turbidity (NTU)	35.9	5.4	3.6	52.2	4.4	3.1	29.1	1.5	0.7	66.0	2.4	0.6
pH	8.0	7.4	7.2	8.1	7.6	7.3	7.8	7.3	7.2	7.2	6.8	6.9
Alkalinity (mg/l)	101.0	72.5	77.9	70.0	33.1	29.5	101.1	74.1	66.5	109.6	77.5	63.3
Ammonia (mg/l)	0.5	0.2	0.2	0.04	0.03	0.04	0.09	0.02	0.01	0.5	0.4	0.2
Total Iron (mg/l)	1.03	0.2	0.2	2.2	0.6	0.4	2.3	1.4	1.1	1.0	0.1	0.09
Bromide (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TOC (mg/l)	15.5	5.2	1.7	29.2	10.0	5.8	4.0	2.8	2.0	26.9	5.5	3.1
DOC (mg/l)	9.6	4.5	1.7	21.0	9.4	5.2	3.6	2.6	1.6	23.9	4.4	2.1
UV <sub>254</sub> ( $\text{cm}^{-1}$ )	0.14	0.04	0.03	0.3	0.15	0.09	0.07	0.05	0.04	0.4	0.07	0.04
SUVA (l/mg-m)	1.5	1.2	2.2	1.4	1.2	2.8	2.0	1.9	2.5	1.7	1.6	2.1
Residual Chlorine (mg/l)	-	-	4.4	-	-	0.5	-	-	2.0	-	-	3.0
Faecal Coliforms (UFC/100 ml)	350	-	0.0	480	-	0.0	320	-	0.0	520	-	0.0



respectively. Ammonia can react with free chlorine and form chloramines which originate little or not trihalomethanes at all, for that reason in many drinking water plants chloramines is used in substitution of chlorine.

Bromide concentration was lower than 0.1 mg/l for the four plants. Trussell and Umphres (1978) demonstrated that the presence of bromide in the water source can influence the rate of THM reaction and yield of THMs. Due to the HACH method used for the determination of THMs can give the total THMs and not the speciation, is impossible to determine the amount of brominated THMs and chlorinated THMs on the disinfected water. However, because of the high amount of organic matter presents a higher chlorine dosage in the disinfection step is necessary, which results in less probability that brominated THMs are formed. Xie (2004) has reported that a low level of NOM results in a higher percentage of the brominated CBPs than that for a high level of NOM. This is due to the fact that a higher NOM level requires a higher chlorine dosage, which results in a lower ratio between bromide and chlorine.

The concentrations of faecal Coliforms were higher in the plant but in the disinfection step were removed totally.

DOC,  $UV_{254}$ , and Colour values for the raw water in the eight sampling occasions for each facility were studied to find out whether these values are correlated. Figure 3 shows DOC concentration for the four facilities versus  $UV_{254}$ . A very good correlation was observed between DOC and  $UV_{254}$ . ( $r^2 = 0.99$ ) The same coefficient of determination was found by Bartels (1990). The UV can be used to estimate DOC concentration since naturally occurring DOC

contains benzenoid type components and unsaturated aliphatic bonds that absorb UV radiation (Pernitsky 2003).

A relatively poor correlation is found between Colour and DOC (Figure 4) and between Colour and  $UV_{254}$  (not shown).

### NOM and conventional coagulation

Table 3 presents the average values of TOC, DOC and  $UV_{254}$  in the settled water at these four plants after conventional coagulation, S2. The coagulant dose used at these facilities varied between 20 and 30 mg/l.

The optimal pH for NOM removal by coagulation with alum salts is in the range of 5 to 6. Below a pH of 5 alkalinity on the water is insufficient to allow that aluminium ions become insoluble and do not participate in the hydration to make the alum effective as coagulant. When the pH level of the water is above 6, the aluminium ions are soluble and the efficiency of the coagulation decreases. That is the explanation why the removal of surrogates NOM was low for P1, P2, P3 and P4 due the pH before the addition of alum were 8.0, 8.1, 7.8 and 7.2 respectively and after the application of alum the pH drops to 7.4, 7.6, 7.3 and 6.8 values exceeding the optimum range causing the low coagulation efficiency and low water quality. The higher alkalinity in the plants make high coagulant doses necessary to depress the pH to values favourable for coagulation, as the coagulant dose used at those plants is 20 to 30 mg/l; with enhanced coagulation that use higher coagulant doses it is expected that the removal of NOM increases For these plants it is necessary to adjust the

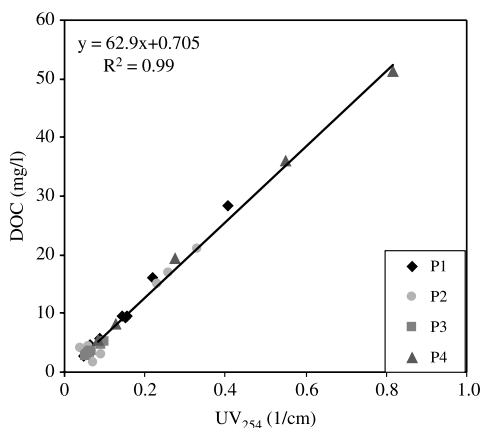


Figure 3 | DOC vs  $UV_{254}$ .

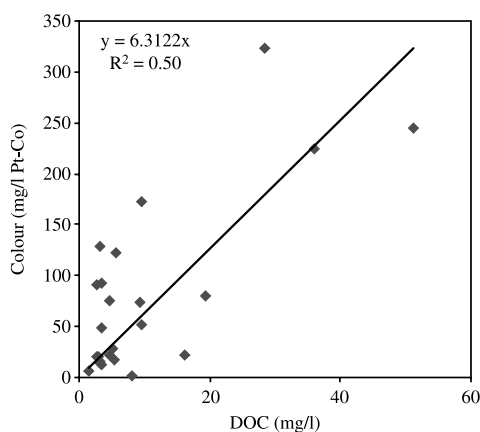


Figure 4 | Colour vs DOC.

**Table 3** | NOM surrogate parameters and percentage of removal after conventional coagulation

Parameters	P1	P2	P3	P4
TOC (mg/l)	5.2 (67%)	10.0 (66%)	2.8 (30%)	5.5 (80%)
DOC (mg/l)	4.5 (53%)	9.4 (55%)	2.6 (28%)	4.4 (82%)
UV <sub>254</sub> (cm <sup>-1</sup> )	0.04 (71%)	0.15 (50%)	0.05 (29%)	0.07 (83%)
SUVA (l/mg-m)	1.2	1.2	1.9	1.6

pH in the coagulation process. Therefore, an adequate control of the pH could increase the removal of TOC, DOC, and UV<sub>254</sub> in these facilities. If the organic matter is not properly removed, there is a higher probability that THMs will form because more organic matter is still present when the disinfection is applied.

A comparison of the SUVA values of the raw water (Table 2) and of the water settled after coagulation (Table 3) shows a poor diminution. This may be because the SUVA values reflecting the fact that the residual organic matter was primarily non-humic (hydrophilic) and therefore more difficult to remove by coagulation. However, Marhaba & Pipada (2000) found that hydrophilic substances could be removed adequately by coagulation, although conventional coagulation usually only removes larger molecules and hydrophobic DOC.

### NOM and enhanced coagulation

The first step in the DBPs regulations establishes the TOC removal requirements based on raw water TOC and alkalinity (USEPA, 1999). The higher the TOC concentration in the raw water, the greater is the percentage of TOC

removed by enhanced coagulation. Dosages varying from 10 and 60 mg/l of Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> \* 14H<sub>2</sub>O were applied to reach the required level of removal of TOC. Table 4 shows the TOC and DOC concentrations after enhanced coagulation and the removal percentage related to the raw water of each plant.

A comparison between Table 3 and Table 4 shows that enhanced coagulation was more effective than conventional coagulation in removing the surrogate parameters of NOM. This can be attributed to the higher concentration of alum salt used in these processes that depress the pH close to 6. The average pHs after enhanced coagulation were 6.3, 6.6, 6.3 and 6.2 for P1, P2, P3 and P4 respectively. According to Pernitsky (2003), when turbidity controls the coagulation, it is necessary to add sufficient coagulant to destabilise the suspended colloids and to create settling flocs. As a consequence, the NOM concentration is less in the subsequent treatment step. Conventional coagulation uses a low coagulant dose in comparison with enhanced coagulation. The SUVA indicates the presence of non humic matter.

One example of the effect of enhanced coagulation on the raw water TOC at the four facilities is shown in Figure 5. For alum doses of 20 to 60 mg/l, TOC removal of approximately 85-90% was obtained. UV<sub>254</sub> was also

**Table 4** | NOM surrogate parameters and percentage of removal after enhanced coagulation

Parameters	P1	P2	P3	P4
TOC (mg/l)	1.9 (88%)	5.6 (81%)	0.9 (78%)	3.5 (87%)
DOC (mg/l)	0.8 (92%)	5.1 (83%)	0.8 (79%)	2.3 (90)
UV <sub>254</sub> (cm <sup>-1</sup> )	0.012 (91%)	0.016 (95%)	0.016 (77%)	0.04 (90%)
SUVA (l/mg-m)	1.4	1.3	1.8	1.5

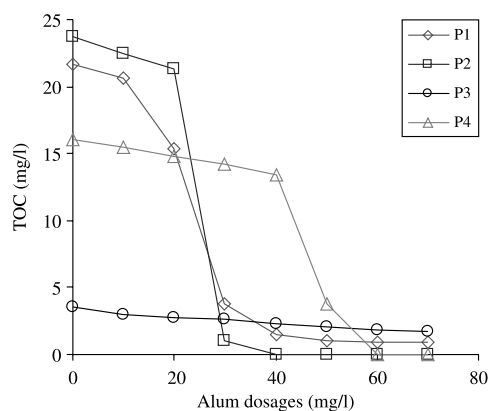


Figure 5 | Enhanced coagulation at the different drinking water plants.

removed almost completely when a dose of 60 mg/l of alum was used.

### Trihalomethanes formation after conventional and enhanced coagulation

Organic matter still present after conventional or enhanced coagulation can react with chlorine in the disinfection step to form trihalomethanes. The Total Trihalomethane (TTHM) concentrations after apply enhanced coagulation varied from 0.002 to 0.063 mg/l for the four plants.

Table 5 shows the average THM concentration for both coagulations. In comparison with the other plants, P3 had the highest THM concentration for both coagulation procedures. This may be due to poor reduction of organic matter of the water source (Tables 3 and 4). The effluents from plants P3 and P4 treated by conventional coagulation exceeded the MCL of 0.080 mg/l for THMs (USEPA 1999), but no overpass the 0.460 mg/l of the Nicaragua guideline (CAPRE). P2 presents the lower THMs concentration after conventional coagulation and it is explained due to the low residual chlorine concentration (0.5 mg/l) found in comparison with the other plants. The TTHM values were reduced by almost

50% when enhanced coagulation was used. Therefore, the lower levels of THMs after enhanced coagulation could be accounted for by the lower DOC levels found in the plants (See Tables 3 and 4).

Raw water with a higher DOC level is likely to produce more THMs. The THM concentrations found at these plants varied from 0.017 to 0.122 mg/l, most of them being low in comparison with results in the literature (Yoon *et al.* 2003). This low concentration may be partially accounted for by the DOC levels present to react with chlorine after coagulation processes. Most of these results exceed the MCL of 0.08 mg/l recommended by EPA.

### Trihalomethanes and the influences of chlorine, pH, contact time and temperature

The extent of CBP formation depends on the dosage of disinfectant, on the nature and concentration of precursors and on various parameters such as contact time, temperature, chlorine dosages and pH. The impact of varying these parameters on the formation of THMs was investigated and is described below for the four facilities. Since the raw waters into each plant are different, comparison between them is difficult. Therefore, trend results are presented for the four facilities.

### Trihalomethanes and the influence of chlorine and pH

The level of residual chlorine found at the plants varied in the range of 2–5 mg/l for P1 and P3, 0.5–2 mg/l for P2, and 2–4 mg/l for P4. For this reason, chlorine doses from 0.5–5 mg/l were applied to simulate the disinfection process in the laboratory after conventional and enhanced coagulation; the contact time used was 120 minutes. It can be seen in Figure 6 that the THM concentration tends to increase with increasing chlorine dose. In all cases, the THM concentration was higher when conventional coagulation was used and

Table 5 | Total THM formation after enhanced and conventional coagulation

Parameters	Conventional Coagulation				Enhanced Coagulation			
	P1	P2	P3	P4	P1	P2	P3	P4
TTHM (mg/l)	0.076	0.034	0.104	0.085	0.036	0.017	0.047	0.042



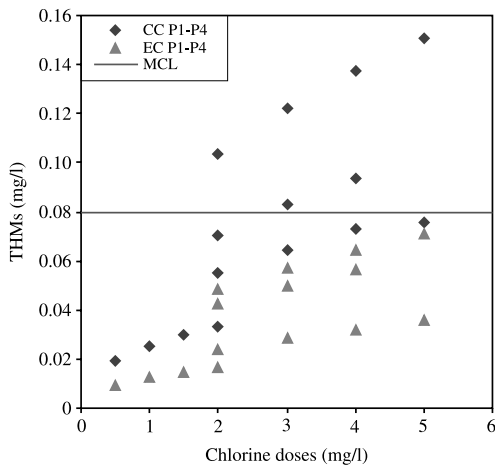


Figure 6 | Influence of chlorine dose on THM formation.

exceeded the MCL (horizontal line at 0.08 mg/l) on some occasions. On the other hand, enhanced coagulation led to values below this target value. The higher THM values obtained with conventional coagulation can be explained by the larger amount of soluble organic matter that is not properly removed and which reacts with chlorine to form THM. The THMs increase when high chlorine dosages and pH are used; the high pH creates an alkaline environment which causes a fast chlorination, and the high chlorination provokes more halogenation and opening of the aromatic structures of the still available NOM after conventional and enhanced coagulation. As a consequence of fast substitution and oxidation of the organic matter structures by chlorine, more THMs are originated. One disadvantage is that at high pH the dominant species is  $\text{ClO}^-$  which is less effective at killing bacteria and viruses. On the contrary, when pH value of 6 or lower is used, the environment is acid and the reaction is too slow to form end products such as THMs, only intermediate products as dichloroacetonitrile, trichloroacetic and dichloropropanone can be formed. At low pH the dominant chlorine species is  $\text{HOCl}$  ( $\text{pH} < 7$ ) which is a neutral molecule and it can penetrate the cell membrane of microorganisms more easily than  $\text{OCl}^-$  can and therefore have more bactericidal effectiveness. Consequently, it is better to disinfect with the pH around 7 to ensure less THMs and high bactericidal effects. Disinfection with chlorine with concentrations lower than 2 mg/l should be avoided as in P2, due to problems of leakages and microbial regrowth in the distribution system.

### Trihalomethanes and the influence of contact time

One of the most important factors in the THM formation is the time during which a particular disinfectant remains in contact with the precursors. Koch *et al.* (1991) and Singer (1999) indicate that the formation of THMs rises quickly during the first hours. In Figure 7, there is a large increment in THM formation after 30 minutes contact time when conventional coagulation was used, exceeding the MCLs of 0.08 mg/l in some cases. The values for P2 are lower even than with conventional coagulation, due to the smaller chlorine dosage used.

The maximum time used in the experiments was only of two hours, which corresponds to the time that the water is maintained in the water distribution system. This short time is due to problems of shortage and drought that mean that the delivered water is immediately consumed by the population. Drinking water is delivered during only a few hours each day. The THMs increase with time because trihalomethanes are hydrolysis products and a chlorination end product. The high chlorine activity makes the formation rate of THMs faster at the beginning and then decreases because of loss of residual chlorine.

### Trihalomethanes and the influence of temperature

The results shown in Figure 8 indicate that increasing temperature significantly raises the THM formation which augment the reactivity between chlorine and NOM and, as a consequence, a higher rate of hydrolysis reaction of the

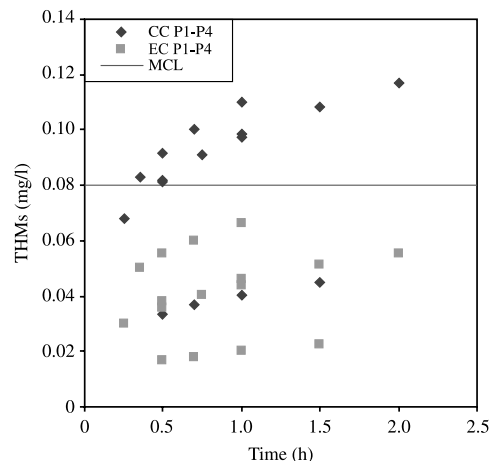


Figure 7 | Influence of time at THM formation.

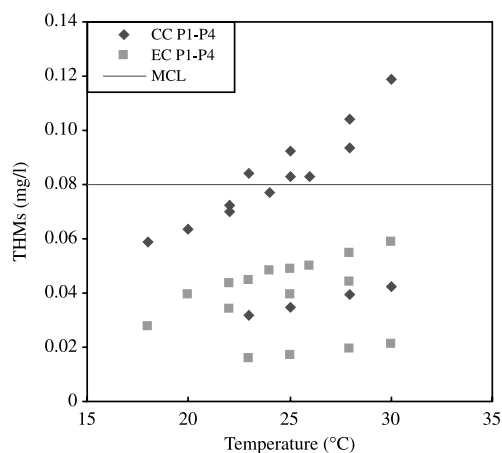


Figure 8 | Influence of temperature at THM formation.

final end product, such as THMs, is expected. The reaction causes a fast break up of the aromatic bonds allowing the halogenation and formation of THMs. These results are in agreement with the findings of Stevens *et al.* (1976) and Singer (1999). For the facilities using conventional coagulation, the TTHM exceeds the MCL of 0.08 mg/l when the temperature is higher than 25°C. Enhanced coagulation gives a lower THM concentration.

## CONCLUSIONS

The organic matter present in the water sources of these four plants is non humic according with the SUVA of less than 2 l/mg-m and form less THMs. According to the results of this study, enhanced coagulation reduces the THM precursors at these drinking water plants below the 0.08 mg/l recommended by USEPA (1999). When only conventional coagulation is applied, the THM concentration exceeded the MCL on several occasions in these four water plants. Chlorine dosage, pH, and contact time during the chlorination process have a significant influence on the formation of THM. A further study of DBPs including haloacetic acids and other parameters such THM formation potential will be carried out.

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