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Full Length Research Paper

Undesirable effects of drinking water chlorination by-products

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The fundamental objective of water treatment is the protection of consumers from pathogenic microorganisms. Chlorination of drinking water is essential to prevent waterborne disease. However, chlorine reacts with organic matter present in surface waters to form various by-products suspected of being carcinogenic. In the last decade, several epidemiological studies have been conducted to determine the connection between exposure to these chlorination by-products and human health defects. The purpose of this paper is to evaluate the genotoxicity of drinking water of Annaba city. The study have been carried out in different points of water distribution and in the station of treatment, using two tests of determination of genotoxic risk by means of SOS chromotest (using the strain *Escherichia coli PQ37*). SOS chromotest showed genotoxic effect of the sample collected from the exit of treatment station.

Key words: Drinking water, genotoxicity, SOS chromotest, *Escherichia coli PQ37.*

INTRODUCTION

Water is the most essential element to life on earth that is why it is a subject of attentive surveillance to prevent waterborne disease. The objectives of the surveillance of the quality of water destined for consumption are numerous and vary depending on means and process possibilities (Bouziani, 2000). Disinfection of drinking water has been widely practiced in drinking water treatment. It is essential to protect the public health and ensure water quality from the water treatment plant outlet to the consumer's tap (that is, during water distribution). Chlorine (Cl_2) is used as the most common disinfectant due to its high efficiency to eliminate pathogens and protect human health against waterborne diseases (United States Environmental Protection Agency (US EPA), 2000; Liu et al., 2011). However, chlorine and other disinfectants react with natural organic matter and/or inorganic substances occurring in water to form various disinfection by-products such as trihalomethanes (THMs), haloacetic acids (HAAs) and other compounds (Legay et al., 2010). The presence of these compounds depends certainly on added quantities of chlorine but also on some organic matter and present organohalogenated by-products (AOX) in water, which can be of natural origin (humic and fulvic acids) or artificial one (residues of pesticides, phenols) (Zekkour and Beron, 2001; Potelon and Zysman, 1998).

The fundamental objective of the treatment of water is to protect the consumers of the pathogenic microorganisms and unpleasant or dangerous impurity for health (OMS, 1994; Jouany, 2000). Nevertheless, epidemiological studies suggested a possible link between the chloration, chlorinated by products and increase risk of several types of cancer. Since the first research works about disinfection by-products (Rook, 1974; Bellar et al., 1974), trihalomethanes accepted a lot of attention because chloroforms have been shown as carcinogenic, further to work on laboratory animals. The United Sates Environmental Protection Agency (US EPA) (2000) reported that these THMs are human carcinogens, of which $CHCl_3$, $CHCl_2Br$ and $CHBr_3$ are carcinogen class B2 (human carcinogen) and $CHClBr_2$ is carcinogen class C (probable human carcinogen). The cancer of the genital tract and the gastro-intestinal cancer would be more frequent after consumption of chlorinated water (Rook, 1974; Urien, 1986; Monod, 1989; Lafferriere et al., 1999; Zekkour and Beron, 2001).

The objective of this paper was to investigate the effects of seasonal variation on physicochemical and genotoxic parameters of water quality and on the formation and species distribution of organohalogenated by-products of the water plant of Annaba city.

MATERIALS AND METHODS

Treatment of water

The treatment plant treats surface water coming from the dam on the Bou-Namoussa raw and water of the Bouchet Bridge and Hnichet, and water of the saline. Treatments performed on surface water are: prechlorination, coagulation floculation, decantation, filtration and sterilization.

Sampling and sampling frequency

Four samplings (one sampling by season) have been performed from 2003 to 2004. The directed months were: April, June, September and January. Sampling was accomplished to study the variation of physicochemical parameters of raw water that may influence water quality during seasons; and those which are in direct contact with the production of organohalogenated compounds, proven harmful to human health. The studied raw water parameters were: pH, temperature, turbidity, colour, alcalinity, hardness *ISO 6059-1984 (F)*, organic matter *ISO 8467:1993 (F)*, ammonium *ISO 7150/1-1984 (F)* and chlorine request *ISO 7393-3:1990 (F).*

The research of the complete organohalogenated products (AOX)

The AOX is a parameter used for regulatory purposes for water quality. It represents the totality of chlorides and organically linked bromides, adsorbed on active charcoal. Volatile halogenated compounds in suspension are also assayed. The proportion of AOX of raw and treated water in the different sampling points is determined according to international norm *ISO 9562: 1989 (F)*, using the apparatus *coulomat 702cl.*

Determination of genotoxic activity (the SOS chromotest)

SOS chromotest is a quantitative procedure, based on the measurement of two enzymatic activities (β-galactosidase and alkaline phosphatase) in liquid medium. It uses the SOS repair system of *Escherichia coli PQ37* strain, after 2 h of exposure. This assay is a simple, efficient and rapid test of genotoxicity that can beeasily adapted to the study of environmental water samples. The genotoxic activity of the concentration C is expressed by the

ratio $C = \beta/p$,

where β represents the β-galactosidase activity and p the alkaline phosphatase activity. The induction factor for a compound at concentration C is defined as:

$I(C) = R(C)/Ro$

where *Ro* is the genotoxic activity measured in the absence of this compound. A compound is considered genotoxic if the induction factor is higher than 1.5 according to Olivier and Marzin (1987).

RESULTS AND DISCUSSION

For the system of water samples collected from the studied water plant, the effects of seasonal variation concentrations on water quality and on the formation and distribution of chlorinated by product have been investigated. Table 1 displays the results of the analysis of variance of two classification criteria (water and seasons). The results of the analysis of variance show the influence of seasons on the change of water quality. The content of organic matter, turbidity and the pH of drinking water vary from season to season.

The interpretation of these results points out that the seasonal variation significantly influences the temperature changing between hot season and cold season. This variation is highly significant and induces variation of turbidity that changes depending on the rate of pluviometry and the organic matter content of raw water. The change in the colour parameter which is in direct relation with the presence of humic and fulvic acids is also significant with seasons.

Turbidity, organic matter and colour introduce parameters linked to the presence of the potential forerunners of the chlorinated by-products and the temperature being key parameter in reaction chlorinates - organic forerunners. The same result was reported by Lafferriere et al. (1999). They demonstrated, by analyses of correlation, the effect of colour and temperature of raw water; as well as the effect of residual chlorine concentrations of treated water in the formation of trihalomethanes (a class of volatile chlorinated by-products).

The results reported in Figure 1 represent concentration of organohalogenated by-products (AOX) at different sampling sites. The analysis of bar charts representing the rates of organohalogenated by-products adsorbed on active charcoal apparently revealed that the autumn is the critical season of the apparition of organohalogenated by-products.

Table 1. ANOVA test of 2 controlled factors (values from P to IC = 95%).

Parameter	Season	Water	Interaction (water × season)
pH	0.836^{NS}	0.000***	0.009**
Temperature	0.000***	0.858^{NS}	0.621^{NS}
Turbidity	0.004**	0.001***	0.003**
Organic matter	0.728^{NS}	0.001***	0.716^{NS}
Colour	0.086^{NS}	0.013*	0.104^{NS}
Alkalinity	0.431^{NS}	0.579^{NS}	0.524^{NS}
Hardness	0.409^{NS}	0.646^{NS}	0.761^{NS}
Conductivity	0.192^{NS}	0.474^{NS}	0.330^{NS}
Ammonium	-	-	-
chlorine request	/	/	/

NS: no significant differences. - :The most part of data are less than the range (< 0.06), there is no statistical differences. / : insufficient data for statistical study.
P > 0.05, no statistical differences. P ≤ 0.05 *, significant differences. P ≤ 0.01**, significant increase. P ≤ 0.001***, very significant increase.

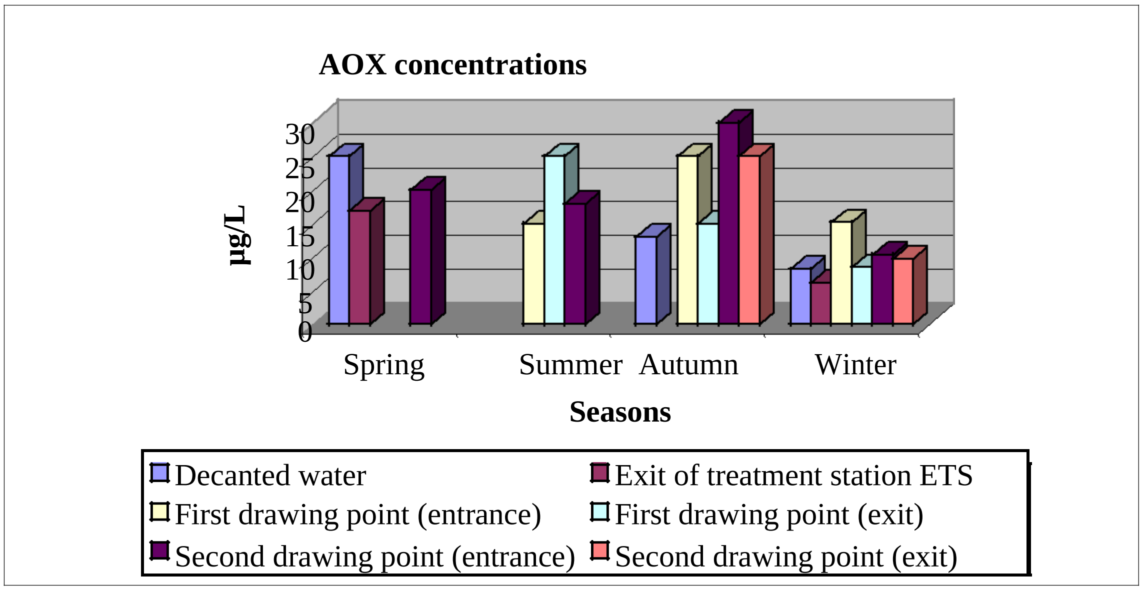

Figure 1. Spatiotemporal variation of AOX.

These results agree with those reported by Le et al. (1996). They found that contents of AOX in autumn, caused by the decomposition of organic matters notably after the fall of leaves, are 75 to 110% higher from those reported in spring.

Standard SOS chromotest

Results of the present test are cited in Figure 2. The analysis of the interpretative bar charts of the mailman of induction I (C) showed that the sample Exit of Treatment Station (ETS) have a genotoxic activity superior to the other two. This proves that chlorinated by-products present in ETS are more genotoxic than those present in water and last point of sampling. Therefore, chlorinated by-products changes in the course of distribution are depending on the added doses of chlorine, to the stocking and to seasonal variation; as it leads to changes in physicochemical characteristics of water (pH, temperature, colour, turbidity and organic matter), which is consistent with the results of this work and previous works elaborated across the world to identify the adverse effect, especially genotoxic issues induced by compounds produced from the disinfection of waters intended for human consumption (Urien, 1986; Lebel et al., 1995; Williams et al., 1995, 1998; Chen and Weisel, 1998).

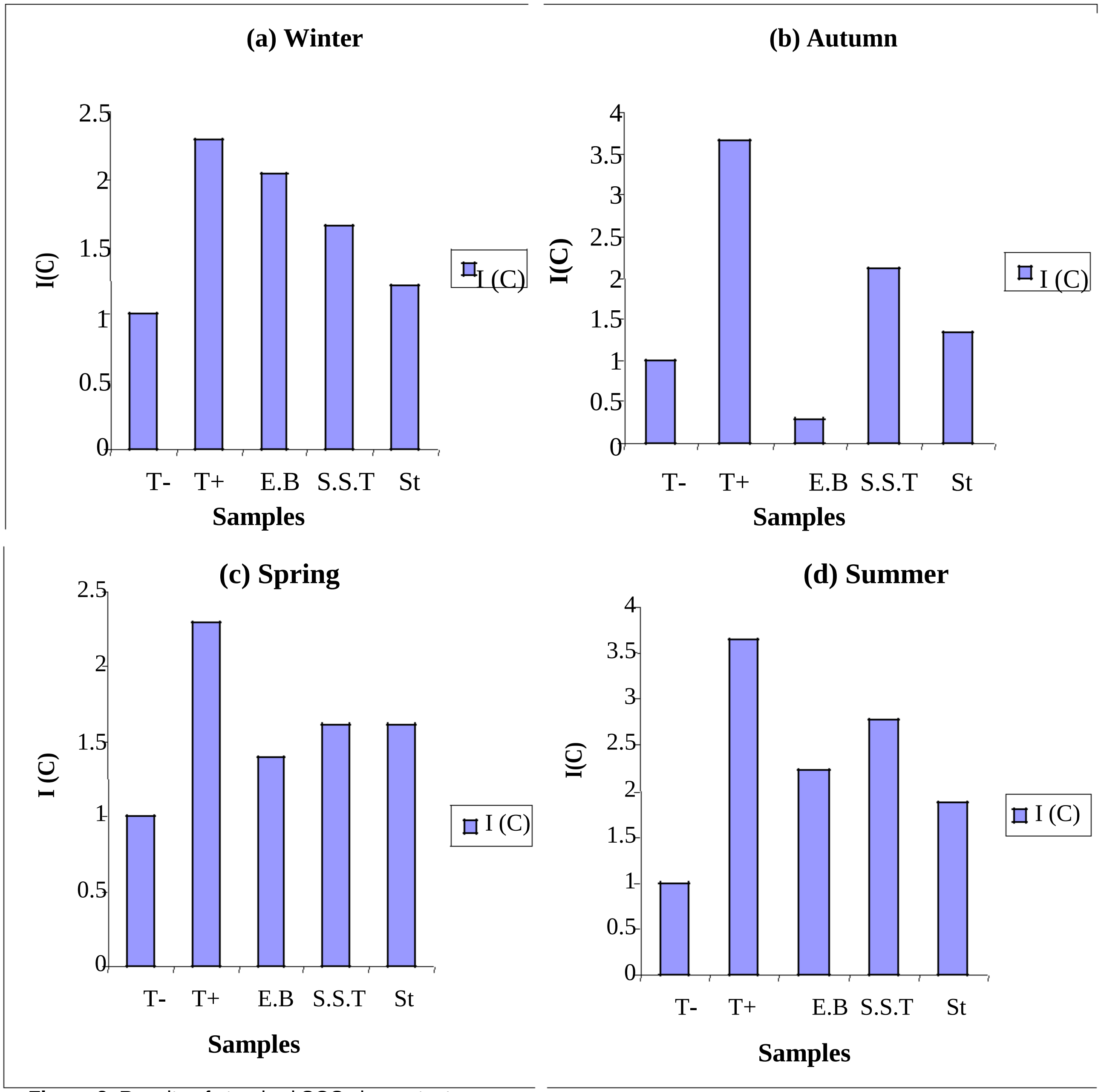

Figure 2. Results of standard SOS chromotest.

Conclusion

The study of the genotoxic effects of drinking water, treated with chlorine, constitutes a new approach to assess the pollution of drinking water. The introduction of the genotoxic tests of water as a new quality criterion for drinking water, in addition to the already existent physicochemical and microbiological parameters, could be beneficial. Physicochemical identification, microbiological quantification and study of the genotoxicity of the potentially hazardous agents are important approaches to fix norms in order to minimize health risks. In other words, the group efforts aiming to restrict the production of the genotxic agents, notably by using less chlorine, must never put in danger the perfect disinfection of water intended for consumption.

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