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Assessment of the water chemical quality improvement based on human health risk indexes: Application to a drinking water treatment plant incorporating membrane technologies

Ramón López-Roldán [a,*], Alicia Rubalcaba [b], Jordi Martin-Alonso [c], Susana González [a], Vicenç Martí [b,c], Jose Luis Cortina [a,d]

[a] CETaqua, Carretera d'Esplugues, 75 08940 Cornellà de Llobregat, Barcelona, Spain
[b] CTM Technological Centre Foundation, Plaça de la Ciència, No. 2, 08243 Manresa, Spain
[c] Aigües de Barcelona, C/Gral. Batet 5-7, E-08028 Barcelona, Spain
[d] Department of Chemical Engineering, Universitat Politècnica de Catalunya (UPC), Diagonal 647, 08028 Barcelona, Spain

HIGHLIGHTS

- Indexes for health risk assessment of surface and drinking water are designed
- Annual evolution shows a decrease on the global indexes for all situations
- An improvement of the risk is related to the upgrade of the water treatment

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ABSTRACT

A methodology has been developed in order to evaluate the potential risk of drinking water for the health of the consumers. The methodology used for the assessment considered systemic and carcinogenic effects caused by oral ingestion of water based on the reference data developed by the World Health Organisation (WHO) and the Risk Assessment Information System (RAIS) for chemical contaminants. The exposure includes a hypothetical dose received by drinking this water according to the analysed contaminants. An assessment of the chemical quality improvement of produced water in the Drinking Water Treatment Plant (DWTP) after integration of membrane technologies was performed.

Series of concentration values covering up to 261 chemical parameters over 5 years (2008–2012) of raw and treated water in the Sant Joan Despí DWTP, at the lower part of the Llobregat River basin (NE Spain), were used. After the application of the methodology, the resulting global indexes were located below the thresholds except for carcinogenic risk in the output of DWTP, where the index was slightly above the threshold during 2008 and 2009 before the upgrade of the treatment works including membrane technologies was executed. The annual evolution of global indexes showed a reduction in the global values for all situations: H_Q systemic index based on RAIS dropped from 0.64 to 0.42 for surface water and from 0.61 to 0.31 for drinking water; the R carcinogenic index based on RAIS was negligible for input water and varied between 4.2×10^{-05} and 7.4×10^{-06} for drinking water; the W systemic index based on the WHO data varied between 0.41 and 0.16 for surface water and between 0.61 and 0.31 for drinking water. A specific analysis for the indexes associated with trihalomethanes (THMs) showed the same pattern.

1. Introduction

In developed countries, a wide implementation of water treating technologies and good management has led to a significant reduction in the risks associated with water ingestion. Good practices have led to a reduction of the pollution at source and to a better removal of the contaminants. In the European Union (EU) the Drinking Water Directive (reference to the uncited reference 98/83/EC) concerns the quality of water intended for human consumption. According to this legislation, a total of 48 microbiological, chemical and indicator parameters must be monitored and tested regularly. Nevertheless, the list of contaminants that need to be taken into account is continuously growing as the studies to define the effects on health progress.

* Corresponding author.
E-mail address: rlopez@aqualogy.net (R. López-Roldán).

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Water safety plans are considered by the World Health Organisation (WHO) as the most effective means of maintaining a safe supply of drinking water to the public. Hazards and risks need to be identified, and appropriate steps towards minimising these risks are then investigated (WHO, 2005). Additionally, the incidence of global driving forces, including climate change, increasing water scarcity, population growth, demographic changes and urbanisation are expected to affect the resilience of water supply and sanitation systems and services, also forcing managers to adapt their infrastructures to these driving forces (Guha-Sapir et al., 2011).

Membrane technologies have been identified as the most robust and flexible technologies used to improve water quality and taste by removing undesirable compounds and pathogens (Rahardianto et al., 2007; Reverberi and Gorenflo, 2007). Reverse osmosis (RO), nanofiltration (NF) and reverse electrodialysis (RED) are being applied worldwide to meet these needs (Birnhack and Lahav, 2007; Greenlee et al., 2009; Wang et al., 2006). The selection of a suitable membrane technology is based on technical criteria (removal of contaminants) and economic aspects (capital operation and maintenance). The implementation of new technologies in drinking water treatment plants (DWTP), such as membrane technologies, improves the quality of drinking water as they remove toxic contaminants (Metsämuuronen et al., 2014; Radjenović et al., 2008) and reduce human health risks associated with its consumption.

However, it should be stressed that in order to ensure the minimisation of pathogens, the required treatment generates disinfection by-products (DBPs), which is one of the main drawbacks of the drinking water production. These compounds are produced by the reaction between chemical disinfectants and naturally occurring organic material (NOM), bromide, iodide, and anthropogenic pollutants present in the source water (Boorman et al., 1999; Krasner, 2009). The trihalomethanes (THMs), the most abundant DBPs, are probable human carcinogens according to the WHO (2005) based on sufficient animal evidence and inadequate human evidence of carcinogenicity. From January 1st 2009, a maximum limit of THMs of 100 μg L^{-1} was established in the EU (98/83/EC). Although values have been established for a number of DBPs, the risks associated with an inadequate disinfection are far greater than the potential risks from long-term exposure to DBPs (WHO, 2014).

It is widely accepted that all stakeholders responsible for water safety should make efforts to improve risk management and risk communication to the consumers, that is, the provision of information and health-based assessments on the various microbial, chemical, radiological and physical human health hazards that may be present in the water cycle. The evaluation of existing and emerging hazards in water should include a proper monitoring at the source, after treatment and throughout the distribution network in order to reduce risks and an adequate approach to manage these associated risks.

Assessing exposure and health consequences of chemicals in drinking water is a challenge: exposures are typically at low concentrations, measurements in water are frequently insufficient, chemicals are present in mixtures, exposure periods are usually long, multiple exposure routes may be involved, and valid biomarkers reflecting the relevant exposure period are scarce. In addition, the magnitude of the relative risks tends to be small (Villanueva et al., 2013). Studies to assess the exposure of contaminants due to drinking water ingestion detected values of arsenic and THMs above the threshold in Turkey (Caylak, 2012) and perfluorooctane sulphonate (PFOS) in Taiwan (Chimeddulam and Wu, 2013). Industrial contamination led to high risk indexes due to metals in India (Krishna and Mohan, 2014) and Pakistan (Muhammad et al., 2011). Studies in developed countries are more focused on emerging compounds but they are limited by the availability of reference data. The risk of adverse health effects from pharmaceuticals appeared to be negligibly low in the Netherlands (Houtman et al., 2014). Schriks et al. (2010) concluded that the majority of the compounds evaluated pose no appreciable concern individually to human health in the Rhine and Meuse Rivers. Ribera et al. (2014) used a combination of Life Cycle Assessment (LCA) and human health risk assessment in order to select the percentage of water in DWTPs that should be nanofiltered. Results show a reduction of one order of magnitude for the carcinogenic risk index when NF produces 100% of drinking water when it is compared to the direct consumption without treatment.

In this work, we have developed a methodology to determine the evolution of the chemical hazard of water. Additionally, an assessment is included on how this risk has been affected after the implementation of the new treatment processes. The methodology is based on toxic effects assessment, exposure assessment and risk index characterisation (Durham and Swenberg, 2013). The exposure assessment in this work only considers the ingestion of drinking water containing pollutants through the oral route as the unique pathway and two typologies of effects on the human health were considered: a) systemic toxicity that refers to adverse effects on any organ system following the absorption and distribution of a chemical throughout the body; and b) carcinogenic effects.

A set of water quality data recorded over five years from the DWTP monitoring programme has been used to implement the risk assessment methodology. The results obtained will be used to quantify numerically the improvement of the water quality through the use of risk indexes. This study should help to develop new managing practices based, not only on the occurrence, but also on the potential hazard of the chemical contaminants.

2. Materials and methods

2.1. Case study description: Llobregat River and Sant Joan Despí DWTP

In recent decades, the drinking water supply network of the Barcelona Metropolitan Area (BMA), which is 635 km^2 in size and has a population of 4.5 million inhabitants, has been primarily based on surface water resources from the Llobregat and Ter Rivers. These resources are suffering the effects of mining and industrial discharges, as well as a reduction in quantity, thereby reducing the quality of the raw water. Additionally, due to the Mediterranean climate, the natural water resource availability is periodically lower than the water demand in the area (López-Roldán et al., 2013).

To improve the water quality of the Llobregat River and its tributaries, more than 30 wastewater treatment plants (WWTPs) treating a mixture of urban and industrial wastewaters have been set up along the river. The main industries sited along the Llobregat River are tannery, food products, textile, pulp and paper, discharging a broad spectrum of organic chemicals into the river. Therefore the river receives effluents from these WWTPs and surface runoff from agricultural areas. The removal of contaminants by WWTPs is not comprehensive; consequently they can enter into the environment via sewage effluents and thus become a potential risk to the receiving bodies and in addition, to the production of drinking water (González et al., 2012; Köck-Schulmeyer et al., 2011; Valero and Arbós, 2010).

Sant Joan Despí DWTP treats water from the Llobregat River following the process flow sheet described in Fig. 1. The plant has a maximum treatment capacity of 5.5 $m^3 s^{-1}$, and provides almost 50% of the annual drinking water in the BMA. In 2009, an improved treatment line began its operation. The new process uses membrane technology and treats 50% of the water flow with a pre-treatment via micro-coagulation and ultrafiltration (UF) as protection for the RO step. Water is remineralised before being blended with water from the conventional treatment and sent to the post-chlorination stages. This process, the membrane treatment line according to Fig. 1, is placed after the sand bed filtration where the flow is split and 50% is treated with the new process; the remaining 50% will undergo ozonisation and granular activated carbon (GAC) filtration as before.