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Seasonally related effects on natural organic matter characteristics from source to tap in Korea

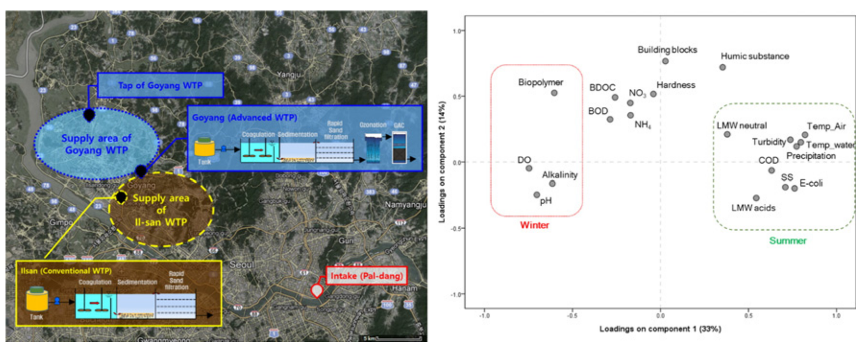
S.H. So [a], I.H. Choi [b], H.C. Kim [c], S.K. Maeng [a,*]

[a] Department of Civil and Environmental Engineering, Sejong University, 98 Gunja-Dong, Gwangjin-Gu, Seoul 143-747, Republic of Korea
[b] Water Analysis and Research Center, K-water, 560 Sintanjin-ro, Daedeok-gu, Daejeon, Republic of Korea
[c] Water Resources Research Institute, Sejong University, 98 Gunja-Dong, Gwangjin-Gu, Seoul 143-747, Republic of Korea

HIGHLIGHTS

- NOM were investigated over three years to determine seasonal variations in Korea.
- LC-OCD was used in the determination of NOM and BDOC from source to tap.
- The distribution of NOM components varied seasonally.
- CSR and BAC showed higher removal rates of BDOC in winter and summer, respectively.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, natural organic matter (NOM) characteristics were investigated over three years of monthly monitoring to determine the effect of seasonal variations on NOM levels from source to tap. Liquid chromatography with organic carbon detection (LC-OCD) was used to determine NOM characteristics and the level of reduction of biodegradable dissolved organic carbon (BDOC). The average dissolved organic matter concentration in the source water (Lake Paldang, Korea) was not significantly different between summer and winter. However, the distribution of NOM components, such as biopolymers, building blocks, low molecular weight (MW) neutrals and acids, identified by LC-OCD, varied seasonally. While high MW NOM was preferentially removed by coagulation/sedimentation/rapid sand filtration (CSR), no seasonal effects were observed on the removal of high MW NOM. CSR and biological activated carbon (BAC) filtration showed a better efficiency of BDOC removal in winter and summer, respectively. High concentrations of chlorine used in the treatment plants in summer resulted in 10% higher DOC concentrations during disinfection. Overall NOM removal efficiencies from source to tap were 45% and 35% for summer and winter, respectively. Principal component analysis also indicated that seasonal variations (principal component 1) showed the strongest positive correlation with the overall performance of water treatment. The long-term monitoring of drinking water treatment processes showed that seasonal variations were important factors affecting NOM characteristics during water treatment.

* Corresponding author.
E-mail address: smaeng@sejong.ac.kr (S.K. Maeng).

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1. Introduction

Natural organic matter (NOM) causes adverse effects on drinking water treatment and distribution systems. NOM is a precursor of disinfection byproducts (Hu et al., 1999) during chlorination, a substrate for microbial growth in distribution networks, and a complex mixture of organic compounds that originate from different sources (Chow et al., 1999; Lehtola et al., 2002). It is critical to monitor the behavior, removal, and characteristics of NOM, which play an important role in disinfection and biostability of drinking water (Park et al., 2016). Jiao et al. (2014) reported that the performance of drinking water treatment systems varied with the characteristics of dissolved organic matter. Therefore, it is important to understand and predict the changes in the characteristics and reactivity of NOM at different steps of water treatment (Matilainen et al., 2011).

Seasonal and temporal variations are important factors affecting the NOM characteristics (Fabris et al., 2008), which depend on climate, geology, and topography. For instance, heavy rainfall can elevate NOM loadings in water resources (Fearing, 2004). An increase in daily sunshine duration could change the NOM characteristics in freshwaters by producing UV transformation products (Soh et al., 2008). The effects of seasonal variations on NOM removal in a drinking water treatment plant have previously been reported (Pharand et al., 2015; Scheili et al., 2015). Sharp et al. (2006) reported that understanding the seasonal variations in NOM characteristics provided a better insight into the robust coagulation for consistent water quality. They also observed that changes in NOM characteristics and concentrations increased the demand for coagulants during the ten-month monitoring period. Therefore, it is important to monitor NOM characteristics and concentrations with respect to seasons. However, there are no long-term monitoring studies that have investigated seasonal variations in NOM characteristics from source to tap using advanced dissolved organic matter characterization tools, such as liquid chromatography coupled with organic carbon detection (LC-OCD), which determine not only the NOM concentrations but also different molecular weight (MW) fractions of NOM.

The assessment of NOM characteristics is often carried out by measuring dissolved organic carbon (DOC), UV absorbance at a wavelength of 254 nm (UVA_{254}), and specific ultraviolet absorbance (SUVA) (Weishaar et al., 2003). However, the use of these bulk parameters has its limitations in understanding NOM characteristics. The MW distribution of NOM can be useful in conjunction with DOC and SUVA because different MW fractions of NOM can behave differently at each step of the water treatment. LC-OCD that fractionates NOM into five defined molecular size fractions (biopolymers, humic substances, building blocks, low MW acids, and low MW neutrals) based on MW (Huber et al., 2011) has previously been used in the characterization of NOM in aquatic environments (Frimmel, 1998; Świetlik and Sikorska, 2006). He et al. (2016) determined dissolved organic matter in natural wetlands using LC-OCD and detected season-dependent variations in NOM characteristics, indicating that humic substances play an important role in the compositional distribution of NOM. A few short-term studies investigated NOM removal with LC-OCD during drinking water treatment (Baghoth et al., 2011; Vasyukova et al., 2013). The removal of different fractions of NOM varied during water treatment; high and medium MW dissolved organic compounds were mainly removed during the clarification step (Vasyukova et al., 2013).

The fate of biodegradable fractions in NOM is another important factor because it can prevent bacterial contamination by reducing the carbon sources in the distribution systems. The biodegradable NOM fraction can be determined by measuring biodegradable dissolved organic carbon (BDOC) or assimilable organic carbon (AOC). BDOC characterization by LC-OCD provided important insights for minimizing the risk of microbial contamination in distribution networks (Vasyukova et al., 2014). Most of the previous studies used a total organic carbon analyzer to determine BDOC concentrations; therefore, it was not possible to estimate the composition and characteristics of BDOC. Very few studies have used LC-OCD to determine the NOM fractions that influence biodegradability. Using LC-OCD in the determination of BDOC allows the observation of the reduction of fractions characterized by LC-OCD during BDOC incubation. The readily biodegradable carbon fractions in NOM are important factors in the determination of seasonal effects on the fate of NOM since high temperatures increase microbial biodegradation and the amount of disinfection byproducts (Shiah and Ducklow, 1994; Zhang et al., 2013).

Even though NOM characteristics have been comprehensively investigated using various methods, there is much that remains unknown. In this study, NOM characteristics and BDOC were investigated from source to tap over three years. To the best of our knowledge, no study has compared the NOM properties, characterized by LC-OCD, with the biodegradable organics from a full-scale water treatment plant or evaluated the correlations of water quality parameters. To date, little research has been carried out to determine the relationship between water quality parameters, including NOM characteristics and abiotic factors such as seasonal variations. We employed principal component analysis (PCA) as a multivariate statistical method to identify the important components that explain the total variance of water quality parameters in the source water. We also investigated the effects of different treatment schemes on the fate of NOM components in two treatment plants that use the same water source. The main objectives of this study were to: 1) investigate the seasonal changes in NOM characteristics to provide a better insight into NOM for water utilities, 2) compare the behavior of biodegradable organic matter, detected by LC-OCD during water treatment, and 3) determine factors that explain the total variance in the source water using PCA.

2. Materials and methods

2.1. Source to tap sampling

Water samples were collected on a monthly basis from two full-scale drinking water treatment plants (Goyang and Ilsan) located in Gyeonggi-do, Korea from 2012 to 2014 (Table 1). The Goyang drinking water treatment plant consists of prechlorination, coagulation/flocculation/sedimentation/rapid sand filtration (CSR), ozonation, biological activated carbon (BAC) filtration, and chlorine disinfection units with a residence time of 13.5 h. It was designed to supply 210,000 m^3/d of drinking water (Fig. 1). The Ilsan drinking water treatment plant consists of prechlorination, CSR, and chlorine disinfection units with a residence time of 16 h. It was designed to supply 250,000 m^3/d of drinking water. Note that the Goyang treatment plant has additional treatment steps, such as ozonation and BAC, different from Ilsan. These two treatment plants use water from the same source at the intake of Lake Paldang (Gyeonggi-do, Korea), which consists of one minor tributary (Gyung-an stream) and two major tributaries (South Han River and North Han River). The watershed area of the lake is 23,800 km^2, with a total storage capacity of 244 million m^3. Since 25 million citizens depend on Lake Paldang as their water source, any change in its quality and quantity is always of great concern for the water utilities. Samples of the tap water were collected from two households located 12 km from Goyang waterworks. Fig. 1 shows the location of Lake Paldang and the water supply districts of the Goyang and Ilsan treatment plants.

2.2. NOM characterization with LC-OCD

Size-exclusion chromatography (SEC) with organic carbon detection was carried out using an LC-OCD system (DOC-LABOR, Germany) to determine five molecular size fractions: biopolymers, humics, building blocks, low MW neutrals, and low MW organic acids (Huber et al., 2011). The system consisted of size exclusion columns with UV and online organic carbon detection (OCD) for separating organic molecules based on their molecular size. Substances with small molecular size can travel further through the internal pore volume than those with