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Quantitative method to determine the regional drinking water odorant regulation goals based on odor sensitivity distribution: Illustrated using 2-MIB

Jianwei Yu[1], *Wei An*[1,*], *Nan Cao*[2], *Min Yang*[1,*], *Junong Gu*[2], *Dong Zhang*[3], *Ning Lu*[3]

1. *State Key Laboratory of Environmental Aquatic Chemistry, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: jwyu@rcees.ac.cn*
2. *Beijing Waterworks (Group) Co. Ltd., Beijing 100085, China*
3. *Shanghai National Engineering Research Center of Urban Water Resources Co., Ltd., Shanghai 200082, China*

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ABSTRACT

Taste and odor (T/O) in drinking water often cause consumer complaints and are thus regulated in many countries. However, people in different regions may exhibit different sensitivities toward T/O. This study proposed a method to determine the regional drinking water odorant regulation goals (ORGs) based on the odor sensitivity distribution of the local population. The distribution of odor sensitivity to 2-methylisoborneol (2-MIB) by the local population in Beijing, China was revealed by using a normal distribution function/model to describe the odor complaint response to a 2-MIB episode in 2005, and a 2-MIB concentration of 12.9 ng/L and FPA (flavor profile analysis) intensity of 2.5 was found to be the critical point to cause odor complaints. Thus the Beijing ORG for 2-MIB was determined to be 12.9 ng/L. Based on the assumption that the local FPA panel can represent the local population in terms of sensitivity to odor, and that the critical FPA intensity causing odor complaints was 2.5, this study tried to determine the ORGs for seven other cities of China by performing FPA tests using an FPA panel from the corresponding city. ORG values between 12.9 and 31.6 ng/L were determined, showing that a unified ORG may not be suitable for drinking water odor regulations. This study presents a novel approach for setting drinking water odor regulations.

Introduction

Odor in drinking water has long been a major cause of consumer complaints worldwide and is thus regulated in many countries (Yagi, 1988; Suffet et al., 1996; Bruchet, 1999; Yang et al., 2008; Yu et al., 2009; Proulx et al., 2012). In the USA, it is required that the threshold odor number be below 3 (US EPA, 2012; Wakayama, 2006), while in China, it is required that drinking water should be free from abnormal taste and odor (GB5749-2006). Japan shows a special concern for the two universally occurring cyanobacterial metabolites, *trans*-1,10-dimethyl-*trans*-9-decalol (geosmin) and 2-methylisoborneol (2-MIB) (Watson, 2004; Westerhoff et al., 2005; Li et al., 2012), requiring that the maximum contaminant levels (MCLs) for both should be below 10 ng/L (Wakayama, 2006). The same level was also used as the reference standard for the two odorants in China (GB5749-2006).

However, human responses to odorants are very complex. Individuals' sensitivity toward odorants has been found to be quite different. For example, the odor threshold concentration

* *Corresponding authors*. E-mail: anwei@rcees.ac.cn (Wei An); yangmin@rcees.ac.cn (Min Yang).

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(OTC) levels of geosmin and 2-MIB have been reported to range from 4 to 10 ng/L and 9 to 42 ng/L, respectively (Pirbazari et al., 1993; Lloyd et al., 1998; Watson et al., 2000; Worley et al., 2003). At the same time, adaptation due to long-term exposure to a background odor in drinking water could lead to the loss of sensitivity to some odors (Dalton and Wysocki, 1996; Whelton and Dietrich, 2004). In addition, the masking effects of commonly used disinfectants on the odors of geosmin and 2-MIB have been extensively reported (Oestman et al., 2004; Curren et al., 2009), and increasing water temperature was found to increase the responses for these odorants (Whelton and Dietrich, 2004). Consuming cool water is very common in Japan, while drinking tea with hot water is normal in China. Thus the differences in water consumption habits could also impact the human sensitivity to the odorants. Furthermore, the presence of other odor-causing compounds through wastewater discharge or leakage from synthetic premise plumbing materials (Heim and Dietrich, 2007) may also interfere with the responses to these odorants. Thus, differences in odor sensitivity should exist among different regions with different social and environmental backgrounds (WHO, 2011), and Japan's MCLs for 2-MIB and geosmin may be too strict for some populations, while not sufficient for others. Therefore, it is desirable that each region should regulate drinking water odorants according to the sensitivity distribution of the local population.

At the present time, revealing the odor sensitivity distribution in a region is still a challenge, since normal people's responses to odorants are difficult to quantify, and there is no available approach to conduct such an investigation. In general, each person has a specific odor threshold (Doty et al., 1985; Schweitzer and Suffet, 1999; Devesa and Fabrellas, 2003; Mackey et al., 2004). In an odor episode, people may try to report a complaint when the odor level exceeds their odor threshold. Thus, it may be possible to reveal the odor sensitivity distribution of the local population in a region based on the daily odor complaint records. Based on this assumption, the 2-MIB sensitivity distribution of Beijing's population was acquired by using the complaint data in a 2-MIB odor episode in 2005. The 2-MIB odor regulation goal (ORG) was then derived for Beijing. The question is, how can one reveal the sensitivity distributions for other cities where the complaint data are not available?

Flavor profile analysis (FPA), which uses a minimum of four trained panelists to identify the types and intensities of the odors present in samples (APHA et al., 2005; Rashash et al., 1997), is one of the most popular drinking water odor sensory methods. FPA data can be described using the Weber–Fechner model to relate odor intensity to the logarithm of odorant concentration. In this study, eight groups of panelists from eight cities were formed, and each group on behalf of the local population of its own city was assigned to obtain a Weber–Fechner plot for 2-MIB. By matching the sensitivity distribution result derived from the complaint data with the Weber–Fechner plot acquired, it is possible to determine the critical FPA intensity causing odor complaints in Beijing's odor episode. By assuming that the critical FPA intensity causing odor complaint was the same for each city, the 2-MIB ORGs for the other cities could be obtained from their respective Weber–Fechner plots. This study can provide a valuable approach for odor regulation setting in the management of drinking water quality.

1. Materials and methods

1.1. Diagram for determination of odorant regulation goals

Fig. 1 shows the procedure for the determination of the ORG of a city, which mainly consists of two parts: acquiring the Weber–Fechner plot of 2-MIB for each city, and deriving the odor sensitivity distribution of a city using the odor complaint data during an odor episode. This study tried to use the 2-MIB episode in Beijing in 2005 (Yu et al., 2009) as an example to illustrate the approach to reveal the odor sensitivity distribution of Beijing. By matching the sensitivity distribution result with the Weber–Fechner plot acquired for Beijing, the critical FPA intensity causing odor complaints was acquired. The 2-MIB concentration corresponding to this critical FPA value could be set as the ORG. By assuming that the critical FPA value is the same for the other cities, the ORGs for the other cities could be obtained from their respective Weber–Fechner plots.

1.2. Odor evaluation

FPA training and its applications are described in detail in the Standard Methods for the Examination of Water and Wastewater (APHA et al., 2005). In this study, eight panels from the drinking water quality monitoring centers of eight cities (Beijing, Wuxi, Hangzhou, Shijiazhuang, Haerbin, Zhengzhou, Shanghai and Kunming) were selected to perform the odor evaluation. Before performing odor evaluation, the panelists were initially given a centralized training for 4 days according to the FPA method. The training and odor evaluation were performed over a period of 5–25 Sep 2011. On the test days, the panelists were requested not to wear perfume, aftershave, hand lotion, or other substances. The samples were maintained at 45°C in a water bath, with at least one of them acting as a control consisting only of reagent water labeled "odor-free." Six concentrations of 2-MIB, including 15, 40, 80, 200, 400 and 600 ng/L, were selected for FPA evaluations. Every panelist recorded the descriptor and the intensity of each sample, and each panel had its own average result. Then the Weber–Fechner plots of 2-MIB for each city were fitted using a linear function with *R*.

1.3. 2-MIB analysis

2-MIB was analyzed using headspace solid-phase microextraction combined with gas chromatography/mass spectrometry (GC/MS) (Watson et al., 2000; Lin et al., 2002). Briefly, 50 mL water samples were placed into a 75 mL vial containing 12.5 g of desiccated NaCl, with 10 ng/L 2-isopropyl-3-methoxy pyrazine added as the internal standard. Solid-phase microextraction fiber (No. 57348-U, Supelco, USA) was inserted into the headspace of the vial and maintained at 65°C for 30 min. The GC/MS system included an HP 6890 GC with a 30 m × 0.25 μm × 0.25 mm HP-5 MS capillary column and an HP 5973 mass spectrometer detector (Agilent, USA) and was operated in selective ion monitoring mode for quantification. The method detection limit for 2-MIB was 1 ng/L.

1.4. Odor complaint data source and analysis

Data from a 2-MIB odor episode in Beijing in 2005, including the complaint telephone records for unpleasant odor and the 2-MIB concentrations in finished water, were used for this study (Yu et al., 2009, 2013). The daily complaint number is the cumulative number of sensitive population beyond a specific