N-nitrosodimethylamine (NDMA) in Drinking Water: A Probabilistic Health Risk Assessment in Asia

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Abstract N-nitrosodimethylamine (NDMA) has been detected in many daily usable items including drinking water, foods, and cosmetics. It can be formed in drinking water during the disinfection process, which has been detected in numerous drinking water systems worldwide, posing significant public health issues. NDMA in drinking water is often linked to disinfection processes such as chloramination, chlorination and ozonation. In this study, multi-pathway human exposure and risk of NDMA in drinking water was analyzed for Asia continent using the probabilistic concept. The major pathways of NDMA exposure include ingestion with drinking water, and inhalation and dermal contact during bathing, showering, swimming in chlorinated swimming pools and house-cleaning. The estimated average lifetime cancer risk for NDMA was 3.42×10^{-5}, exceeding the USEPA's acceptable threshold of 1.0×10^{-6} by 34.2 times, highlighting public health concerns. Several possible strategies were highlighted to control NDMA in drinking water. The findings underscore the need for establishing stricter regulations, improved finished water, NDMA exposure reduction and risk mitigation measures for drinking water.

Keywords: Drinking water; N-nitrosodimethylamine (NDMA); human exposure; cancer risk; loss of disability adjusted life year (DALY)

1. Introduction

NDMA is primarily formed through chlorination and chloramination of drinking water and recognized as a potent human carcinogen (Sang et al., 2019). The U.S. Environmental Protection Agency (USEPA) classifies NDMA as a B2 category carcinogen and has set a recommended level of 0.70 ng/L in drinking water, correlating to a lifetime cancer risk threshold of 1.0×10^{-6} (Farré et al., 2012; USEPA, 2017). NDMA was reported in 1,861 of 18,098 drinking water samples across 324 U.S. public water systems, with concentrations ranging from 2.0 to 630 ng/L (mean: 8.8 ng/L, median: 4.0 ng/L) (Chowdhury, 2014). NDMA was frequently detected in drinking water in the Asian countries, particularly in China, Japan and Korea (Bei et al., 2016). Despite public health concerns, many other Asian countries do not have necessary protocols and/or requirements for monitoring DBPs in drinking water, particularly NDMA monitoring systems are seldom reported. To date, several studies have been conducted on the exposure and risk analysis of NDMA in various countries worldwide (Sang et al., 2019). However, no study was conducted to assess the risk of NDMA in drinking water considering the entire Asia Continent. In this study, occurrences of NDMA in the drinking water systems in the Asian countries were obtained from literature. Using these data, a probabilistic health risk assessment of NDMA was conducted considering different exposure routes: inhalation, ingestion and dermal contact. The strategy to reduce exposure to NDMA in drinking water and risk control was highlighted.

2. Methodology

2.1. Data Collection

In this study, NDMA levels in drinking water from various countries in Asia were obtained from past articles and other published literature from 2009 to 2024 (Table 1). The data were characterized through standard statistical distributions and other statistical parameters. Using the statistical distributions, 5000 random scenarios were generated for exposure and risk assessments.

2.3. Exposure and Risk Assessment

The assessment of human exposure to NDMA in drinking water and its associated health risks were conducted in accordance with the Risk Assessment Guidance for Superfund, Parts A, E, and F (USEPA, 2009). The chronic daily intake (CDI) of NDMA was calculated based on NDMA's concentrations in supply water and other necessary parameters. Human exposure through multiple routes including ingestion with drinking water, and inhalation and dermal absorption during bathing and showering were incorporated. The lifetime risk of cancer was determined by multiplying the CDI with the chemical-specific the inhalation unit risk (IUR) or cancer slope factor (SF). The age-dependent adjustment factors (ADAF) were used to improve risk estimation accuracy following USPEA recommendation to incorporate the sensitivity of early life exposure. Further details on exposure and risk assessment can be found in literature (USEPA, 2009, 2017).

3. Results and Discussions

The overall average of NDMA was 32.8 ng/L with the range of ND (not detected) to 189 ng/L. The highest average was 55.2 ng/L in natural and drinking water sample from Guangdong province, China. The lowest average was reported to be 0.9 ng/L in treated water from Korea. The predicted cancer risks are summarized in Table 2. The averages of cancer risks through inhalation, ingestion and dermal routes were 1.73×10^{-7}, 3.40×10^{-5} and 5.55×10^{-8} respectively. The overall average of total risks was 3.42×10^{-5} and the range of risks was 2.14×10^{-6} - 1.07×10^{-4} (Table 2). The ingestion route accounted for the highest risk contribution (99.3%) followed by inhalation (0.5%) and dermal absorption (0.2%) pathways. The average cancer risk exceeded the USEPA's recommended threshold of 1.0×10^{-6} by 34.2 times, indicating that NDMA in supply water might pose significant risks to humans (USEPA, 2017). A study from Taiwan reported an average cancer risk of 6.4×10−6 for NDMA in drinking water, which was lower than the value estimated in this study (Fan & Lin, 2018). Sang et al., (2019) reported higher value of cancer risk with the average of 4.01×10−5 (Sang et al., 2019). The relatively higher risks of NDMA in Asia might be due to the higher concentrations of NDMA in drinking water, which may need attention of the water supply systems.

Table 1. NDMA (ng/L) in drinking water in Asia.

Mean (ng/L)	Range (ng/L)	Source
	ND-53.6	Finished water
32.0	ND-189.0	Finished & tap water
25.1	4.4-67.1	Treated water
21.7	0.3-118.7	Tap water
55.2	40.6-64.7	Natural & drinking water
13.1 ± 9.0	1.1-45.4	Finished water
6.6 ± 7.9		Tap water
35.8 ± 19.6	14.2-46.7	WTP-A
5.1 ± 2.0	2.9-7.3	WTP-B
	72.1-143.0	Tap water
	ND-8.8	Finished water
	ND-13.3	Tap water
32.9 ± 19.0	12.3-49.9	Finished water
	4.6-20.5	Finished water
	ND-46.2	Treated & tap water
54.2 ± 26.7	26.1-112.0	Treated & tap water
0.9		Finished water
46.6 ± 22.7	0.1-80.7	Tap water
	ND-4.9	Tap water
	ND-4.6	Tap water
	ND-2.2	Finished water (summer)
	ND-10.0	Finished water (winter)
	0.5-5.2	Groundwater
	ND-16.3	Finished water
	ND-2.5	Finished water
	1.1-6.4	Tap water

Table 2. Cancer risks from NDMA in drinking water.

Risk route	Average	SD (±)	Minimum	Maximum
Ingestion	3.40×10^{-5}	1.57×10^{-5}	2.12×10^{-6}	1.06×10^{-4}
Inhalation	1.73×10^{-7}	8.46×10^{-8}	7.43×10^{-9}	5.35×10^{-7}
Dermal contact	5.55×10^{-8}	2.40×10^{-8}	3.59×10^{-9}	1.39×10^{-7}
Total	3.42×10^{-5}	1.57×10^{-5}	2.14×10^{-6}	1.07×10^{-4}

The cancer risk distributions are shown in Figure 1. The shape parameters range from 2.1 to 2.5 indicating the right-skewed distributions meaning that a fraction of populations has higher risks. Past studies have reported higher concentrations and risks of NDMA from several exogenous sources including meat, milk and tobacco smoke (Chowdhury, 2014; Sang et al., 2019).

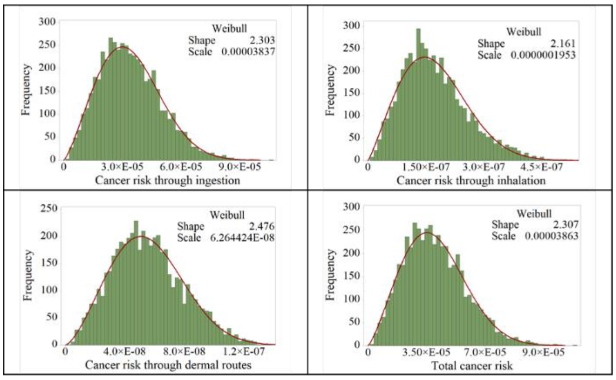

Figure 1. Distributions of Cancer risks

4. Conclusions

The estimated cancer risk due to NDMA exposure was 3.42×10^{-5}, which was much higher than the USEPA's acceptable threshold. The results of this study are not free from uncertainty, due mainly to the limited data and uncertainties in the parameter values. The 5000 random scenarios were likely to incorporate uncertainty. However, more data from the exposure points (e.g., tap in house) and from other countries will assist for better prediction of human exposure and risks. Future study should focus on more data collection from large number of water systems across the Asian countries. Apart from the limitations, the findings highlighted the need for stricter regulatory guidelines, enhanced water treatment technologies, and effective risk mitigation strategies to minimize NDMA exposure in drinking water.

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