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RISK ASSESSMENT ON TRIHALOMETHANES IN THE URBAN WATER SUPPLY SYSTEM IN NATAL/RN/BRAZIL

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ABSTRACT

Water intended for human consumption must not pose health risks. Therefore, quantitative risk assessments are essential tools for analyzing contamination risks in public water supply systems. This study aims to evaluate the carcinogenic and non-carcinogenic risks associated with exposure to contaminants present in the treated water distributed by the Extremoz Lagoon Water Treatment Plant.
The results showed the formation of trihalomethanes (THMs)—carcinogenic compounds—in concentrations above regulatory limits during the water treatment process. Quantitative risk assessments indicated that the distributed water poses a potential health hazard, both for non-carcinogenic and carcinogenic risks, due to exposure to THMs. Accordingly, there is an urgent need to mitigate exposure and conduct epidemiological studies to better understand the health impacts of these substances.

KEYWORDS: non-carcinogenic risk, carcinogenic risk, trihalomethanes, safe water.

AVALIAÇÃO DE RISCO DE TRIHALOMETANOS NO SISTEMA DE ABASTECIMENTO DE ÁGUA URBANA EM NATAL/RN/BRASIL

RESUMO

A água destinada ao consumo humano não deve representar riscos à saúde. Assim, as avaliações quantitativas de risco são ferramentas essenciais para analisar os riscos de contaminação em sistemas públicos de abastecimento de água. Este estudo tem como objetivo avaliar os riscos carcinogênico e não carcinogênico decorrentes da exposição a contaminantes presentes na água tratada distribuída pela Estação de Tratamento da Lagoa de Extremoz. Os resultados demonstraram a formação de trihalometanos (THM) — compostos carcinogênicos — em concentrações superiores aos limites estabelecidos pela legislação durante o processo de tratamento da água. As avaliações quantitativas de risco indicaram que a água distribuída representa um potencial risco à saúde, tanto do ponto de vista carcinogênico quanto não carcinogênico, devido à exposição aos THM. Diante disso, há uma necessidade urgente de mitigar a exposição e realizar estudos epidemiológicos para aprofundar o conhecimento sobre os impactos dessas substâncias na saúde pública.

PALAVRAS-CHAVE: risco não carcinogênico, risco carcinogênico, trihalometanos, água segura.

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1. INTRODUCTION

An effective, safe, and reliable water treatment system is fundamental for public health as well as for socio-economic sustainable development (LINDHE et al., 2011). Thus, the management and risk assessment associated with drinking water consumption are becoming increasingly important worldwide. Risk analysis in drinking water supply systems needs to be comprehensive, including the entire treatment and distribution system, and capable of detecting the complex interactions between components and the nature of risks (Burgman, 2005; Hrudey et al., 2006; Cox, 2008; Bartram et al., 2009; Lindhe et al., 2009; Lindhe et al., 2011; Nascimento et al., 2016; Sorlini et al., 2017).

Therefore, the safety of water for human consumption must ensure that the presence of pathogens and toxic chemical substances does not pose risks to public health, environmental impacts, and the quality of life of consumers, since water is the main vector for the dissemination of microorganisms and carcinogens, such as metals, toxins, and disinfection by-products (WHO, 2011; Brasil, 2013; Jalba et al., 2010; Sanches et al., 2015; Sorlini et al., 2017). This situation may worsen in regions of water scarcity, where there is unequal territorial distribution and incessant consumption demands, especially in productive systems, as there is not enough water available in some regions (Pinheiro et al., 2018). However, in the treatment of drinking water, the water disinfection process can pose potential health risks, since chemical disinfectants, such as chlorine, and ions (mainly bromide and iodide) naturally present in water, produce disinfection by-products (DBPs), mainly trihalomethanes (THMs), which are potentially toxic and carcinogenic (Richarson et al., 2007; Medeiros et al., 2019).

THMs are volatile compounds, so individuals can be exposed not only through oral routes but also through inhalation and dermal absorption during water contact (Nieuwenhuijsen et al., 2009). However, risk assessments of trihalomethanes in drinking water have shown that the oral exposure route contributes more to absorption and increases the risks of THMs (Kumari et al., 2015; Pan et al., 2014; Caylak, 2012). In this context, this study aims to evaluate the carcinogenic and non-carcinogenic risks as a consequence of exposure to trihalomethanes formed after the water treatment process for public supply.

2. METHODOLOGY

2.1. CHARACTERIZATION OF THE STUDY AREA

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The study was conducted in the treated water distribution network of the Extremoz Water Treatment Plant (WTP) located in the municipality of Extremoz, in the metropolitan region of the city of Natal, State of Rio Grande do Norte, in the northeastern semi-arid region of Brazil (Martins, 2015; Marengo et al., 2011; Marengo; Cunha; Alves, 2016) (Figure 1).

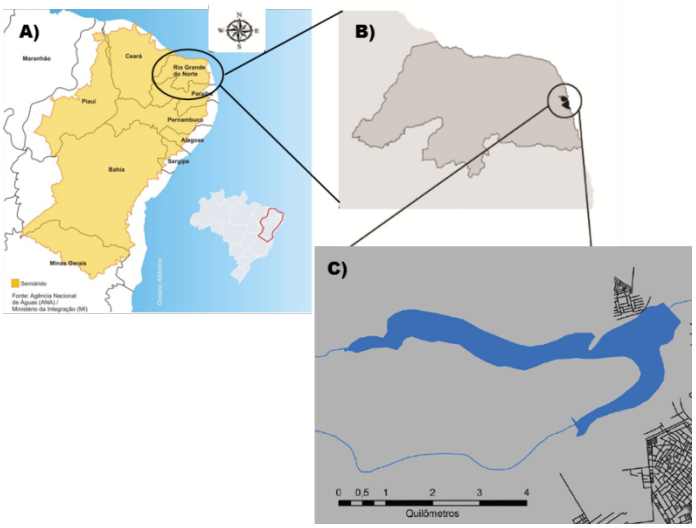

Figure 1 - Map of Extremoz Lake Location/RN – A) Delimitation of the Brazilian Semi-arid Region; B) Location of Extremoz/RN Municipality; C) Extremoz Lake. (Source: Adapted from Brasil, 2005; Pinto and Becker, 2014)

The Extremoz Water Treatment Plant (WTP) treats a flow rate of approximately 650 L/s through direct filtration and supplies water to 60% of the population in the northern zone of Natal (Oliveira et al., 2020). The water treatment process involves pre-oxidation (chlorine addition), coagulation (hydroxyaluminum chloride addition), rapid direct filtration, and disinfection (chlorine addition). Samples were collected monthly from April 2017 to March 2018 at two points in the distribution network: treated water at the beginning of the network (IR) – near the distribution reservoir in Lagoa Azul neighborhood; and treated water at the end of the network (FR) - one of the last collection points in the Redinha neighborhood. These collection points are not influenced by groundwater mixing.

2.2. WATER ANALYSIS

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The procedures for sample collection, preservation, storage, and the methodologies for physical-chemical and biological analyses of the samples were conducted according to the recommendations of APHA et al. (2012). Physical-chemical analyses were performed in duplicate for color, turbidity, temperature, pH, free residual chlorine, trihalomethanes (THMs) and their components, total organic carbon, UV 254nm absorbance, natural organic matter/consumed oxygen (NOM); and microbiological analyses (total coliforms and Escherichia coli). The temperature of the samples was measured in situ with a digital thermometer. pH was determined by potentiometric method using a pH meter, and turbidity was measured using a turbidimeter, by the nephelometric method. Apparent and true color, free residual chlorine, and UV 254 nm absorbance were determined by UV-visible spectrophotometric methodology. Total organic carbon (TOC) was analyzed using high-temperature combustion technique with non-dispersive infrared detection (NDIR). For microbiological analyses, the multiple tube method was used for quantitative determination of total coliforms and Escherichia coli. Total organic carbon and UV 254 nm absorbance (UV254nm) analyses are used as indicators of the presence of organic matter in water.

The determination of natural organic matter/consumed oxygen (NOM) is used in natural and supply waters to determine the amount of oxygen needed to oxidize the carbonaceous organic matter in the sample, based on the titrimetric method with permanganate digestion in hot acidic medium developed by ABNT (1989).

The analysis of THMs and their components uses the Gas Chromatography/Mass Spectrometry (GC/MS) methodology adopted by USEPA 8260B (USEPA, 1996). The detection limits are less than 1.5 µg/L for all trihalomethane compounds.

2.3. HUMAN HEALTH RISK ASSESSMENT

The water distribution to the population supplied by the Extremoz WTP is heterogeneous. Therefore, the concentration data of toxic substances were weighted by the daily supply at two different points in the network, and then the evaluated parameters were compared considering the limits allowed by national and international regulations.

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The toxicological parameters of interest included in this study and above the considered thresholds were included in the risk assessment. Initially, the level of exposure for each substance was determined considering the different exposure routes.

Thus, hazardous substances above the limits allowed by legislation were estimated for their non-carcinogenic and carcinogenic risks considering the exposure route, the potentially exposed population, the magnitude, duration, and frequency of exposure, based on the behavior of contaminated chemicals and the local population (USEPA, 2002; IBGE, 2017).

Trihalomethanes (THMs) are volatile organic compounds, and health risks from inhalation and dermal exposure during regular indoor activities cannot be ignored; thus, ingestion, inhalation, and dermal contact exposure were considered. Estimates of Chronic Daily Intake (CDI) for different routes were calculated using the equations described (Pan et al., 2014; Caylak, 2012; USEPA, 2002):

$$\text{CDIingestion} = \frac{Cw \; x \; IR \; x \; EF \; x \; CF1}{BW \; x \; AT} \quad (1)$$

Where, CDIingestion = Chronic daily intake by ingestion (mg/kg/day); Cw = chemical concentration in drinking water (µg/L); IR = water ingestion rate (L/day); EF = exposure frequency (days/year); ED = exposure duration (years); BW = body weight (kg); AT = average time; and CF1 = conversion factor from µg to mg (0.001).

For dermal exposure, the CDI for drinking water can be estimated through the equation:

$$\text{CDIdermal} = \frac{Cw \; x \; SA \; x \; Kp \; x \; EB \; x \; EF \; x \; ED \; x \; CF1 \; x \; CF2}{BW \; x \; AT} \quad (2)$$

Where, CDIdermal = Chronic daily intake by dermal contact (mg/kg/day); Cw = chemical concentration in drinking water (µg/L); SA = exposed skin area to water (cm^2); Kp = dermal permeability coefficient (cm/hr); EB = exposure duration during bathing (hours/bath); EF = exposure frequency (days/year); ED = exposure duration (years); BW = body weight (kg); AT = average time; CF1 = conversion factor from µg to mg (0.001); CF2 = unit conversion factor (L/1,000 cm^3) (0.001).

$$\text{CDIinhalation} = \frac{Car \; x \; R \; x \; t \; x \; F \; x \; EF \; x \; ED \; x \; CF1}{BW \; x \; AT} \quad (3)$$

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Where, CDIinhalation = Chronic daily intake by inhalatory contact (mg/kg/day); Car = chemical concentration in contact atmospheric air (μg/cm³); R = volume of air inhaled (cm³/min); t = bathing time (minutes); F = bathing frequency (days); EF = exposure frequency (days/year); ED = exposure duration (years); BW = body weight (kg); AT = average time; and CF1 = conversion factor from μg to mg (0.001).

After the above determinations, the Risk Quotient (HQ) and the Hazard Index (HI) will be calculated for each toxic substance above the permitted limit. HQ is calculated by the ratio of CDI to the reference dose for ingestion, dermal, and/or inhalation as follows:

$$HQ\ (1,2,3) = \frac{CDI}{RfD}$$

Where, RfD = reference dose of the contaminant.

These values are obtained from USEPA (2002) or the Risk Assessment Information System (RAIS) database.

If the HQ values exceed 1, then there is concern about non-carcinogenic effects for humans. However, to assess the potential effect of a substance through various exposure routes, the Hazard Index (HI) is used, which sums all the risk coefficients.

If HI is greater than 1, it indicates a potential harmful effect on human health (Caylak, 2012).

The Carcinogenic Risk (CR) is calculated by multiplying the Chronic Daily Intake (DI) (mg/kg/day) and the carcinogenic slope factor of the contaminant (SF) $(mg/kg/day)^{-1}$. CR values greater than $1.00E^{-05}$ indicate potential carcinogenic risk.

For calculations, the following values were used: Water ingestion rate (IR) of 2 L/day; Exposure frequency (EF) of 350 days/year; Exposure duration (ED) = 26 years; Average body weight (BW) of 80 kg; Average lifespan of a person (AT) of 26,600 days; Exposed skin surface area (SA) of 19,652 cm²; Exposure time during bathing (EB) of 0.67077 hour; Volume of air inhaled (R) = 20 m³/day; and Bathing time (t) of 0.67077 hour.

2.4. DATA ANALYSIS

To interpret the fluctuations of the analyzed toxins throughout the water distribution system, a repeated measures ANOVA was conducted over the monitored period.

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To interpret the climatic influence on the level of toxins assessed, a one-way ANOVA was performed categorizing the rainy and dry seasons based on rainfall rates. Risk estimators were calculated using the RAIS program.

3. RESULTS AND DISCUSSION

3.1. WATER CHARACTERIZATION

The physical-chemical results in the water distributed to the population in the northern zone of Natal showed that there is no significant difference between the beginning and the end of the distribution network.

The water is characterized as neutral, with turbidity slightly above the permitted level, and apparent color 2 to 3 times higher than the permitted level at both sampling points, with free residual chlorine concentration below the minimum content for the distribution network at the beginning of the network (0.2 mg.L-1), but with the presence of organic matter (Table 1).

Table 1 - Mean and standard deviation of the physical-chemical parameters in samples from the beginning and end of the distribution network of Route 2 of the Extremoz WTP during the ten months of collection.

		SAMPLES				
Parameter	**VR***	**IR**	**±SD**	**FR**	**±SD**	**p-value**
pH	-	6.89	0.33	6.95	0.17	N.S.
Temp (Cº)	-	28.78	0.44	28.89	0.33	N.S.
Turb (NTU)	5	5.76	2.85	4.69	2.00	N.S.
App Color (Pt-Co)	15	44.48	21.83	35.67	15.55	N.S.
True color (Pt-Co)	-	9.52	6.42	10.63	4.61	N.S.
Chlorine ($mg.L^{-1}$)	0.2 to 5	0.09	0.11	0.45	0.59	N.S.
TOC ($mg.L^{-1}$ C)	2**	7.68	1.73	7.83	1.28	N.S.
NOM ($mg.L^{-1}$ OC)	-	4.31	1.70	5.08	1.14	N.S.
UV_{254nm}	-	<LOD	<LOD	<LOD	<LOD	N.S.

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IR = sample collected at the beginning of the distribution network; FR = sample collected at the end of the distribution network; pH = hydrogen potential; Temp. = temperature; Turb = turbidity; App Color = apparent color; True Color = true color; Chlorine = free residual chlorine; TOC = total organic carbon; NOM = natural organic matter; UV254nm = absorbance at 254 nm.

<LOD = below the limit of detection.
***Values of reference according to Brasil (2021).**
****Reference value according to USEPA (2009).**

The study conducted by Nascimento et al. (2016) evaluated the behavior of free residual chlorine in the distribution network as the main parameter for obtaining safe water.

These authors verified the decrease in chlorine concentration, with values below 0.2 mg.L-1, during water distribution, and observed that it is related to the high reaction rate with organic matter in the liquid mass and sediments accumulated in the pipeline and, mainly, due to batch operation, which favors water stagnation in the feeder and distribution reservoir.

Free residual chlorine (FRC) in the Extremoz WTP distribution network behaved similarly, with a significant decrease related to the reaction with organic matter present in the liquid mass and also in the sediment of the pipeline.

Moreover, the high water temperature also favors this reaction and the decrease in chlorine concentrations (Rodriguez; Serodes, 2001). Thus, it is observed that the presence of organic matter in water and in the pipeline reacts with chlorine throughout the distribution network.

However, at the beginning of the network, chlorine is below the minimum required value, not satisfying the condition of safe water for this parameter, since there is reinforcement of chlorination throughout the network to increase the FRC concentration and thus meet all distribution localities with FRC concentration according to the legislation.

On the other hand, microbiological analyses showed that water from the distribution network has no indication of fecal contamination, as all samples showed absence of Total Coliforms (TC) and Escherichia coli (EC) (Table 3), thus the water chlorination for disinfection satisfactorily fulfills its role in pathogen control in treated water (Guzzella et al., 2004; WHO, 2011), despite the concentration of free residual chlorine being below the minimum limit required by legislation.

Table 2 - Detection of microbiological and hydrobiological parameters in samples from the beginning and end of Route 2 distribution network of the Extremoz WTP during the ten months of collection.

	SAMPLES	

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Parameter	VR*	IR	±SD	FR	±SD	p-value
TC (NMP/100ml)	Absent	<LOD	<LOD	<LOD	<LOD	N.S.
EC (NMP/100ml)	Absent	<LOD	<LOD	<LOD	<LOD	N.S.

Note:
- VR: Value Reported
- IR: Initial Reading
- ±SD: Standard Deviation
- FR: Final Reading
- N.S.: Not Significant
- <LOD>: = less than the limit of detection.

***Reference values according to Brazil (2021).**

The results of trihalomethanes in the distribution network of the Extremoz Water Treatment Plant show high levels of total THMs, 10 times above the allowed limit by legislation, mainly chloroform. In several studies, chloroform is the most predominant THM species in treated water (Fujie et al, 1990; Baytak et al, 2008; KumarI et al, 2015).

Bromodichloromethane was slightly above the limit permitted by the WHO (2011), while dibromochloromethane was below the permitted limit. The study by Oliveira et al. (2020) in the Extremoz WTP distribution network also detected concentrations of Total THM 7 times above the permitted level. This author also found the highest concentrations of chloroform (80% of THMt), followed by dichlorobromomethane, dibromochloromethane, and bromoform.

The latter species was not detected in the present study, probably due to differences in the quantification limit of the methodology used (Table 3).

Table 3 - Detection of toxic substances in samples from the beginning and end of Route 2 distribution network of the Extremoz WTP during the ten months of collection.

		SAMPLES				
Parameters	VR*	IR	±SD	FR	±SD	p-value
TCM ($\mu g.L^{-1}$)	300*	959.67	1273.78	1082.14	1287.15	N.S.
BDCM ($\mu g.L^{-1}$)	60*	58.94	20.16	68.80	28.83	N.S.
DBCM ($\mu g.L^{-1}$)	100*	15.52	6.53	16.30	8.26	N.S.

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TBM (µg.L^{-1})	100*	<LOD	<LOD	<LOD	<LOD	N.S.
THMt (µg.L^{-1})	100**	1034.12	1280.47	1167.24	1284.66	N.S.

Note:
- VR: Value Reported
- IR: Initial Reading
- SD: Standard Deviation
- FR: Final Reading
- N.S.: Not Significant
- <LOD>: = less than the limit of detection.
***Reference values according to Brazil (2021).**

When evaluating the formation of trihalomethanes under climatic influence in a tropical region, the results showed that chloroform and Total THM values differed according to the dry and rainy seasons, presenting significantly higher values during periods of high rainfall: (TCM: 185.6 vs. 1689.1 ANOVA <0.010; THMt: 257.1 vs. 1775.5 ANOVA p <0.010). These results, when compared to those found by Oliveira et al. (2020) in the same location, show that during the rainy season, THM concentration increases, which may be related to the increase in dissolved organic turbidity in raw water.

In the same vein, in temperate regions, the highest THM values were found in the spring and winter seasons due to the increase in non-purgeable organic carbon concentration, while values below the permitted limit (100 µg.L^{-1}) were observed in summer and autumn, even with more constant temperatures (Baytak et al., 2008). It is evident that the high concentrations of THMs detected in the distribution network of a tropical region, in addition to being associated with the quality of raw water, may be linked to the presence of biofilms along the pipelines and the high water temperatures.

According to Wang et al. (2013), the microbial carbon present in the biofilm contributes to the formation of DBPs, with THMs detected in higher concentrations compared to other byproducts. The authors also attribute the formation of higher quantities of THMs, at the expense of other DBPs, to the biochemical composition of the biofilm when it is present in polyvinyl chloride (PVC) pipes. Therefore, the fact that the material of the pipelines, at the points where the samples were collected from the distribution network, is possibly PVC, may contribute to the alteration of the characteristics of the biofilm that may exist and consequently contribute to the formation of THMs, as well as other classes of DBPs.

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3.2 QUANTITATIVE RISK ASSESSMENT

Considering the results of the water in the distribution network, it was found that the toxicological parameters above the considered thresholds were the THMs, distinguishing between their compounds, which were included in the quantitative risk assessment in the inhalation, dermal, and oral exposure routes, when possible.

This method allows comparing the level of risk to acceptable levels in absolute terms and quantitatively estimating the effect of risk reduction measures.

Thus, quantitative risk assessments are necessary tools to complement and/or support risk analyses in public water supply systems (Lindhe et al., 2009; Burgman, 2005; Cox, 2008).

After the calculations quantifying the hazard in each exposure route, the non-carcinogenic risk and the carcinogenic risk calculated for each species of trihalomethanes, and the summation of them, the total risks, these multi-exposure indices were obtained at the beginning and at the end of the distribution network of treated water from Extremoz Lake (Table 4).

Table 4 - Hazard Quotient (HQ) in each exposure route, Hazard Index (HI), and Carcinogenic Risk (RC) of each THM species and THMt at the two sampling points of the distribution network of treated water from Extremoz Lake.

	Samples							
	IR				FR			
	HQ_{ig}	HQ_{d}	HQ_{in}	HI	HQ_{ig}	HQ_{d}	HQ_{in}	HI
TCM	3.32	0.286	4.71	8.31	3.74	0.322	5.31	9.37
BDCM	0.102	0.00688	-	0.109	0.119	0.00803	-	0.127
DCBM	0.0268	0.00173	-	0.0286	0.0282	0.00182	-	0.03
THMt	3.45	0.294	4.71	8.45	3.89	0.332	5.31	9.53
Total RC	0.00442				0.005			

TCM = Chloroform; BDCM = Bromodichloromethane; DBCM = Dibromochloromethane; THMt = Total Trihalomethanes; HI = Hazard Index; RC = Carcinogenic Risk; HQig = Hazard Quotient for ingestion; HQd = Hazard Quotient for dermal contact; HQin = Hazard Quotient for inhalation.

The results revealed that the exposure to water containing THM, especially chloroform, has a high potential for adverse health effects, as the HI was 8 to 9 times higher than the allowed value at both sampling points (RAIS, 2018; Caylak, 2012) (Table 4).

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The brominated forms of THM contributed little to these indices, as their concentrations were within the legal limits. Kumari et al. (2015) also found that chloroform was the compound with the greatest impact on health risk analyzed in five water treatment plants in India; however, these authors concluded that ingestion was the route that contributed most to the high water risk.

On the other hand, studies have indicated that THM present in drinking water did not pose significant risks to the population through oral (López-Roldán et al., 2016) and dermal routes (Caylak, 2012), albeit without considering the inhalation route.

The present study showed that the inhalation and oral routes were the most significant for population health risk. This fact may be related to the amount of water used for other purposes, such as bathing, and the high concentration of chloroform, which is a highly volatile compound. Chloroform is the only THM species that poses an inhalation risk due to its characteristic of easy volatilization (RAIS, 2018).

The carcinogenic risk (RC) of the treated water consumed by the population supplied by the Extremoz Water Treatment Plant was also 400 to 500 times above the permitted level (<1.00E-05) (RAIS, 2018; Caylak, 2012), indicating a high carcinogenic risk in the distribution water for the population of the northern zone of Natal city through exposure routes by THMs.

Carcinogenic risk can be defined as the probability of an individual developing cancer in their lifetime due to exposure to a potential carcinogen. Thus, the RC of THMs is directly related to the exposure route, the quantity, and the frequency of exposure to each compound. Kumari et al. (2015) presented results consistent with the present study, in which chloroform was the species that most impacted carcinogenic risk, albeit through the oral route.

On the other hand, Pan et al. (2014) obtained a carcinogenic risk of THMs in treated water in China below the WHO limit (10-6), but the authors did not consider chloroform values.

Similarly, Caylak (2012) found lower chloroform values in drinking water from eleven cities in Turkey; however, the concentrations of BDCM and DBCM were high, and the carcinogenic risk of these samples was slightly above the limit. The assessment of carcinogenic risk from exposure to environmental chemicals, such as THMs, has been extensively discussed and evaluated by scientists, managers, and policymakers (GOLDEN et al., 1997).

Epidemiological studies in humans have provided strong evidence of the relationship between THM exposure in drinking water and bladder and colorectal cancer, as well as reproductive problems (Nieuwewenhuijsen et al., 2009; Richardson et al., 2007; Villanueva et al., 2017).

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Thus, the quantitative assessment of carcinogenic risks for THMs reflects a more realistic toxicological scenario, considering the actual concentration, exposure route, and mode of action of each halogenated compound on human health.

Consequently, there is a better sanitary understanding of THMs related to remaining uncertainties regarding their potential health risks when compared to analyses with laboratory experimental models (Medeiros et al., 2019).

4. CONCLUSION

Risk assessment and management methodologies, coupled with good practices in the operation and maintenance of water supply systems, aim to protect public health, acting as precursors to water quality incidents.

Quantitative assessment of human health risk and carcinogenic risk are important tools for realistically understanding the vulnerability of a population's exposure to a harmful substance. However, epidemiological studies and laboratory analyses should be used to complement the knowledge and impact of such substances on population health.

In conclusion, trihalomethanes are substances that pose non-carcinogenic and carcinogenic risks to the exposed population, particularly chloroform, as its volatile characteristic contributes to both inhalation and oral exposure, which are the exposure routes with the highest risks of human contamination.

Therefore, there is an immediate need for monitoring and measures to mitigate the exposure of the supplied population to reduce or eliminate exposure and/or formation of these THM concentrations.

REFERENCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 10739:1989. Água – Determinação de oxigênio consumido. Método do permanganato de potássio. Rio de Janeiro, 1989.

AMERICAN PUBLIC HEALTH ASSOCIATION; AMERICAN WATER WORKS ASSOCIATION; WATER ENVIRONMENT FEDERATION. Standard methods for the examination of water and wastewater. 22. ed. Washington, D.C.: APHA, 2012.

BARTRAM, J. et al. Water safety plan manual: step-by-step risk management for drinking-water suppliers. Geneva: World Health Organization, 2009.

BURGAMN, M. A. Risks and decisions for conservation and environmental management. Cambridge: Cambridge University Press, 2005.

BRASIL. Ministério da Saúde. Portaria GM/MS nº 888, de 4 de maio de 2021. Dispõe sobre os procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. Diário Oficial da União, Brasília, DF, 5 maio 2021.

BRASIL. Ministério da Saúde. Plano de segurança da água: garantindo a qualidade e promovendo a saúde: um olhar do SUS. Brasília, DF: Ministério da Saúde, 2013.

CAYLAK, E. Health risk assessment for trace metals, polycyclic aromatic hydrocarbons and trihalomethanes in drinking water of Cankiri, Turkey. E-Journal of Chemistry, v. 9, n. 4, p. 1976-1991, 2012.

COX, A. L. What's wrong with risk matrices? Risk Analysis, v. 28, n. 2, p. 497-512, 2008.

GUZZELLA, L. et al. In vitro potential genotoxic effects of surface drinking water treated with chlorine and alternative disinfectants. Mutation Research, v. 564, p. 179–193, 2004.

HRUDEY, S. E.; HRUDEY, E. J.; POLLARD, S. J. T. Risk management for assuring safe drinking water. Environment International, v. 32, p. 948–957, 2006.

IBGE – Instituto Brasileiro de Geografia e Estatística. Tábuas completas de mortalidade para o Brasil – 2016: breve análise da evolução da mortalidade no Brasil. Rio de Janeiro: IBGE, 2017. Disponível em: ftp://ftp.ibge.gov.br/Tabuas_Completas_de_Mortalidade/Tabuas_Completas_de_Mortalidade_2016/tabua_de_mortalidade_2016_analise.pdf. Acesso em: 15 maio 2024.

JALBA, D. I. et al. Safe drinking water: critical components of effective inter-agency relationships. Environment International, v. 36, n. 1, p. 51-59, 2010.

KUMARI, M.; GUPTA, S. K.; MISHRA, B. K. Multi-exposure cancer and non-cancer risk assessment of trihalomethanes in drinking water supplies – a case study of Eastern region of India. Ecotoxicology and Environmental Safety, v. 113, p. 433–438, 2015.

LINDHE, A. et al. Fault tree analysis for integrated and probabilistic risk analysis of drinking water systems. Water Research, v. 43, n. 6, p. 1641–1653, 2009.

LINDHE, A. et al. Cost-effectiveness analysis of risk-reduction measures to reach water safety targets. Water Research, v. 45, p. 241–253, 2011.

LÓPEZ-ROLDÁN, R. et al. Assessment of the water chemical quality improvement based on human health risk indexes: application to a drinking water treatment plant incorporating membrane technologies. Science of the Total Environment, v. 540, p. 334–343, 2016.

MARENGO, J. A. et al. Variabilidade e mudanças climáticas no semiárido brasileiro. In: INSA – Instituto Nacional do Semiárido. Semiárido brasileiro: pesquisas e desenvolvimento. Campina Grande: INSA, 2011. p. 383–422.

MEDEIROS, L. C. et al. Toxicological aspects of trihalomethanes: a systematic review. Environmental Science and Pollution Research, v. 26, n. 6, p. 5316–5332, 2019.

NASCIMENTO, R. S. et al. Changes simulation in a conventional ETA midsize to safe water production. Revista Brasileira de Recursos Hídricos, v. 21, n. 2, p. 439–450, 2016.

NIEUWENHUIJSEN, M. et al. The epidemiology and possible mechanisms of disinfection by-products in drinking water. Philosophical Transactions of the Royal Society A, v. 367, p. 4043–4076, 2009.

OLIVEIRA, R. R.; ARAÚJO, A. L. C.; DUARTE, M. A. C. Estudo do potencial de formação de trihalometanos na água da Lagoa de Extremoz-RN. Engenharia Sanitária e Ambiental, v. 25, n. 2, 2020. https://doi.org/10.1590/S1413-41522020181889.

PAN, S. et al. Cancer risk assessment on trihalomethanes and haloacetic acids in drinking water of China using disability-adjusted life years. Journal of Hazardous Materials, v. 280, p. 288–294, 2014.

PINHEIRO, L. G. et al. Avaliação da sustentabilidade do processo de dessalinização de água no semiárido potiguar: estudo da comunidade Caatinga Grande. Sociedade e Natureza, v. 30, n. 1, p. 132–157, 2018.

Pinto, T. S.; Becker, V. Diel dynamic of phytoplankton functional groups in a tropical water supply, Extremoz Lake, northeastern Brazil. Acta Limnologica Brasiliensia, v. 26, n. 4, p. 356-366, 2014.

RAIS - The Risk Assessment Information System. Disponível em: http://rais.ornl.gov/index.shtml. Acesso em: 10 maio 2024.

RODRIGUEZ, M. J.; SÉRODES, J.-B. Spatial and temporal evolution of trihalomethanes in three water distribution systems. Water Research, v. 35, n. 6, p. 1572–1586, 2001.

SORLINI, S. et al. Water Safety Plan for drinking water risk management: the case study of Mortara (Pavia, Italy). Revista Ambiente & Água, v. 12, n. 4, 2017.

SANCHES, S. M. et al. Chemical and microbiological analysis of public school water in Uberaba Municipality. Revista Ambiente & Água, v. 10, n. 3, 2015.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. EPA 8260B: Volatile Organic Compounds by Gas Chromatography/ Mass Spectrometry (GC/MS). Washington, D.C., 1996.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. National Primary Drinking Water Regulation. Stage 1 and 2 Disinfectants and Disinfection Byproducts Rules. Washington, D.C., 2009.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual (Part A). Washington, D.C., 2002. Disponível em: https://www.epa.gov/risk/risk-assessment-guidance-superfund-volume-i-human-health-evaluation-manual-supplemental. Acesso em: 15 maio 2024.

VILLANUEVA, C. M. et al. Colorectal cancer and long-term exposure to trihalomethanes in drinking water: a multicenter case–control study in Spain and Italy. Environmental Health Perspectives, v. 125, n. 1, 2017.

WANG, Z.; CHOI, O.; SEO, Y. Relative contribution of biomolecules in bacterial extracellular polymeric substances to disinfection byproduct formation. Environmental Science and Technology, v. 47, n. 17, p. 9764-9773, 2013.

WORLD HEALTH ORGANIZATION. Guidelines for drinking-water quality. 4. ed. Geneva: WHO, 2011. Disponível em: https://www.who.int/publications/i/item/9789241549950. Acesso em: 15 maio 2024.

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