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Articles

Potential health risk from drinking water contaminated with chromium in Zimapan, Hidalgo, Mexico

Potencial de riesgo a la salud por consumo de agua contaminada con cromo en Zimapan, Hidalgo, México

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Abstract

The present study estimated the health risk potential associated with chronic chromium (Cr) intake in drinking water of Zimapan, Hidalgo. Cr monitoring was carried out before and after the drinking water treatment system. To estimate the potential for health risk from water consumption with Cr at the population level, the Chronic Daily Intake (CDI), the Hazard Quotient (HQ), the Lifetime Cancer Risk (LCRi) and the Cancer Incidence (IC) were calculated for each population sector. Cr was detected at both pre- and post-treatment monitoring, with a concentration of 0.1 mg/l. HQ values for children, adolescents and older adults are greater than 1, indicating that 17 488 individuals in these population groups are susceptible to developing non-cancer related health conditions. The LCRi associated with exposure to reported Cr concentrations estimated the likelihood of individual cancer development in susceptible groups such as children, adolescents and older adults, by the continuous and prolonged intake of water from drinking water system.

Keywords: Groundwater, chromium, carcinogenic risk, human health.

Resumen

El presente estudio estimó el potencial de riesgo a la salud asociado con la ingesta crónica de cromo (Cr) en agua potable de Zimapan, Hidalgo. Se llevó a cabo el monitoreo de Cr previo y posterior al sistema de potabilización. Para estimar el potencial de riesgo a la salud por consumo

de agua con Cr a nivel poblacional, se calculó la ingesta crónica diaria (CDI), el cociente de peligro (HQ), el riesgo de desarrollo de cáncer individual para toda la vida (LCRi) y la incidencia de cáncer (IC) por cada sector poblacional. Se detectó la presencia de Cr tanto en el monitoreo previo y posterior al sistema de potabilización, con una concentración de 0.1 mg/l. Los valores de HQ para los grupos poblacionales de niños, adolescentes y adultos mayores son mayores a 1, esto indica que 17 488 individuos ubicados en estos grupos poblacionales son susceptibles a desarrollar afectaciones a la salud no relacionadas con el cáncer. Asimismo, el LCRi asociado con la exposición a concentraciones de Cr reportadas estimó la probabilidad de desarrollo de cáncer individual en grupos susceptibles como niños, adolescentes y adultos mayores por la ingesta continua y prolongada de agua proveniente del sistema de potabilización.

Palabras clave: agua subterránea, cromo, riesgo cancerígeno, salud humana.

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Introduction

Chromium (Cr) is an element considered hazardous and is among the eight most common heavy metal contaminants identified by the United States Environmental Protection Agency (USEPA, 2010). This element is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC, 1990; Sedman *et al.*, 2007). It can be found in oxidation states ranging from [Cr(-II)] to [Cr(+VI)] (Valko, Morris, & Cronin, 2005; Lushchak, Kubrak, Nykorak, Storey, & Lushchak, 2008; USEPA, 2010). In its trivalent state [Cr(III)], chromium is not considered an environmental contaminant, whereas hexavalent chromium [Cr(VI)] is considered a potential risk due to its ease of absorption by cells (WHO, 2003; Shaw, Mondal, Bandyopadhyay, & Chattopadhyay, 2019). Chromium is frequently used as a reference toxicant (OECD, 2004). Epidemiological studies have linked exposure to high levels of chromium to an increased incidence of cancer and damage to tissues and organs (Begum, Rao, & Srikanth, 2006; Mishra & Mohanty, 2008), developmental effects (ATSDR, 2012), and disruptions in metabolism (Oner, Atli, & Canli, 2008).

Chromium (Cr) is naturally present in the environment in mineral form and from anthropogenic activities. Its presence in groundwater is attributed to soil and rock erosion or to sources of contamination (Velma, Vutukuru, & Tchounwou, 2009; McNeill, McLean, Parks, & Edwards, 2012). Groundwater constitutes the primary source of water supply worldwide (Sharma, Petrusevski, & Amy, 2008; SCDB, 2010). Various studies have reported the presence of Cr at elevated concentrations in groundwater sources in cities such as León in Mexico (Armienta-Hernández & Rodríguez-Castillo, 1995); in California, Washington,

Indiana, South Carolina, North Carolina, and New Jersey in the United States (USEPA, 2000; USGS, 2004); Ludhiyana, Kanpur, and Lucknow in India (Bellander & Peterson, 2002); and Wuhan in China (Li, 2004). Additionally, the potential health risk from exposure to total Cr in drinking water has been assessed worldwide (ATSDR, 2012; IPCS, 2013; Haney, 2015; TCEQ, 2015; Thompson *et al.*, 2018). The toxicity of Cr depends on its chemical speciation and the exposure route Mishra & Mohanty, 2008; Sharma *et al.*, 2008). Due to its toxicity, the World Health Organization (WHO) recommends permissible limits of 0.05 mg/l of Cr in water intended for human use and consumption (WHO, 2011). The USEPA recommends a maximum contaminant level for total Cr of 0.1 mg/l (USEPA, 2000). In Mexico, the NOM-127 standard establishes a maximum permissible limit of 0.05 mg/l of total Cr in water for human use and consumption (DOF, 2022). These values are based on intestinal toxicity data derived from animal bioassays (Ahmed & Mokhtar, 2020). Chronic exposure to elevated concentrations of Cr(VI) in drinking water may increase the risk of several health problems, including gastrointestinal cancer, and liver and kidney damage in cases of prolonged exposure (ATSDR, 2012). Effects reported by international agencies include damage such as nodular lymphoid hyperplasia, considered a non-cancerous precursor to tumor formation (NTP, 2008). In this context, assessing potential health risks from exposure to environmental pollutants becomes crucial for implementing regulatory actions and developing standards. Based on the considerations detailed above, this study set out to estimate the potential health risk to the population exposed to Cr concentrations in drinking water in Zimapán, Hidalgo.

Materials and methods

Study area

The city of Zimapán is located between 20° 39' and 20° 58' N latitude, and 99° 11' and 99° 33' W longitude, in the western region of the state of Hidalgo, Mexico (Figure 1). According to the National Inventory of Municipal Water Treatment Plants in operation (Conagua, 2015), the municipality of Zimapán has three water treatment plants located in the towns of Benito Juárez (Detzani), El Muhí, and Zimapán-Tanque Central. This study was conducted at the water treatment plant located at the Dra. María Aurora Armienta Hernández well in El Muhí. The monitoring of influent and effluent during the removal process and of monthly variability were carried out from March 2019 to February 2020.

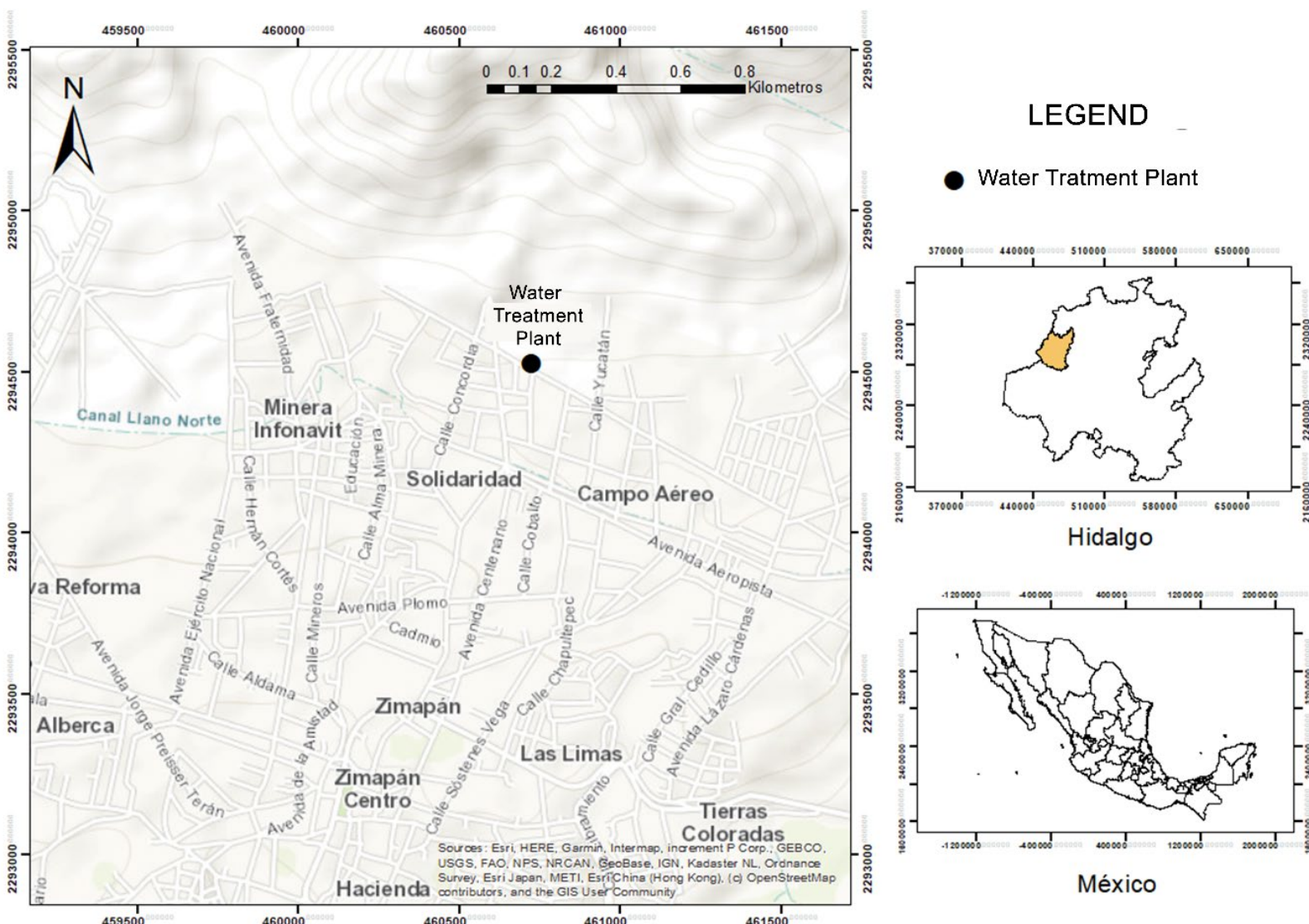


Figure 1. Location of the study area.

Sample preparation and analysis

Water samples were collected according to the guidelines established in NOM-014-SSA1-1993 (DOF, 1993), which stipulates the sanitary procedures for water sampling for human use and consumption in public and private water supply systems. Samples were subsequently analyzed

in the Analytical Testing Laboratory of the Chemical Research Center at the Autonomous University of the State of Hidalgo.

Three 45 ml aliquots were taken from both pre- and post-treatment points of the water supply system. To each aliquot, 5 ml of distilled HNO_3 was added, and the samples were digested in a microwave oven (Questron, model Q. Wave 1000) following the acid digestion method assisted by microwaves for aqueous samples (USEPA, 2007b). The digested and cooled water samples were then brought to an appropriate volume, and the elemental analysis was performed using a Varian atomic absorption spectrophotometer, model Spectr AA 880, with a detection limit of 0.01 mg/l for total chromium. Calibration curves for the element were created using standard multi-element and/or single-element high-purity solutions, IPC Analytic Mixture 5 High Purity Std.

Population data

Population data from the INEGI 2020 Population and Housing Census (INEGI, 2020) were used. Based on this data, the total population of Zimapán was calculated to be 39 927 inhabitants, and it was divided into four demographic groups: children (0–12 years), adolescents (13–18 years), adults (19–64 years), and elderly adults (≥ 65 years).

Estimation of daily chronic intake, hazard quotient, cancer risk, and cancer incidence

The concentration of daily intake (CDI) was estimated based on the concentration of chromium in the drinking water and the daily water

intake rates for each population group (USEPA, 2011), using the following formula:

$$CDI = \frac{(C)(TI)(DE)}{(BW)(AET)} \quad (1)$$

Where:

CDI = Concentration of daily intake (mg/kg/day)

C = Chromium concentration in water (mg/l)

TI = Daily drinking water intake rate (L/day)

DE = Duration of exposure in years

BW = Body weight (kg)

AET = Average exposure time

TI (daily chronic water intake rate) for each population group and the exposure dose were conservatively assumed for each group to be: a) children (0–12 years) 1 liter/child with an average weight of 14 kg; b) adolescents (13–18 years) 1.5 liters/adolescent with an average weight of 40 kg; c) adults (19–64 years) 2 liters/adult with an average weight of 70 kg; and d) elderly adults (>65 years) 2 liters/adult with an average weight of 65 kg (INSP, 2021; USEPA, 2001).

The hazard quotient (HQ) was calculated using CDI data and the reference dose for chromium (USEPA, 2007a). HQ values ≥ 1 indicate non-carcinogenic adverse health effects from the continuous and prolonged intake of water. The reference dose data for chromium were obtained from the IRIS database (EPA, 2005; USEPA, 2011):

$$HQ = \frac{CDI(\text{mg/kg/d})}{RfD(\text{mg/kg/d})} \quad (2)$$

Where:

RfD = reference dose for oral Cr (0.003 mg/kg/day) (USEPA, 2010)

The lifetime cancer risk (LCRi) associated with ingestion was calculated using CDI data and the reported cancer slope factor (CSF) (USEPA, 2001):

$$LCRi = \left[CDI \left(\frac{\text{mg}}{\text{kg}} \right) \right] \times \left[CSF \left(\frac{\text{mg}}{\text{kg}} \right) \right] \quad (3)$$

Where:

LCRi = Lifetime cancer risk for an individual

CDI = Concentration of daily intake (mg/kg/day)

CSF = Cancer slope factor for oral Cr (0.05 mg/kg/day) (USEPA, 2010)

The risk for developing cancer (LCRi) for an individual is between 10^{-4} and 10^{-6} . Most highly exposed populations should not exceed a risk level of 10^{-5} ; however, if the cancer risk value exceeds 10^{-5} , measures should be taken to protect the population (USEPA, 2001). Similarly, any value of ($HQ \geq 1$) indicates the presence of non-carcinogenic risk to humans.

Cancer incidence (CI) was estimated by multiplying the cancer risk for each population group by the total number of individuals in each group. The value obtained represents a hypothetical scenario that should

be interpreted as the number of cancer cases that would occur in a population (CEPIS & OPS, 2005):

$$CI = [LCRi \text{ (mg/kg/d) }] \times PT \quad (4)$$

Where:

LCRi = Lifetime cancer risk for an individual

PT = Total population by population group

Statistical analysis

Once the data on total chromium concentration in the drinking water of Zimapán were obtained, a Kruskal-Wallis analysis was performed to identify whether there were statistically significant differences among sampling months and between sampling sites (IBM, 2017).

Results

Monthly sampling of the water was conducted both before and after the water had passed through the treatment system. During the twelve months of sampling, total chromium was only detected in the water from the well in March, April, May, June, July, and February, at a concentration of 0.1 mg/l. In the supply water, total chromium was detected in April, May, June, July, August, September, October, November, and February, at a concentration of 0.1 mg/l (Table 1). This demonstrates exposure to this element due to its presence in the well water, as total chromium is retained within the treatment plant, appearing in the water supply from

August to November, which implies that this element was present in 10 of the twelve months sampled. The values reported at both sites exceed the maximum allowable limit established by NOM-127-SSA1-2021, which is 0.05 mg/l for total chromium. In the Kruskal-Wallis analysis, significant differences in the total chromium concentration were found among sampling months, where $H(11, N=72) = 45.02497$, $p < 0.0001$. No significant differences were observed between sampling sites.

Table 1. Total chromium concentration in the analyzed sampling months (March 2019–February 2020) expressed in mg/l.

Month	Concentration mg/l $\pm$ S	
	Well	Supply
March	0.1 $\pm$ 0.01	ND
April	0.1 $\pm$ 0.01	0.1 $\pm$ 0.01
May	0.1 $\pm$ 0.01	0.1 $\pm$ 0.01
June	0.1 $\pm$ 0.01	0.1 $\pm$ 0.01
July	0.1 $\pm$ 0.01	0.1 $\pm$ 0.01
August	ND	0.1 $\pm$ 0.01
September	ND	0.1 $\pm$ 0.01
October	ND	0.1 $\pm$ 0.01
November	ND	0.1 $\pm$ 0.01
December	ND	ND
January	ND	ND
February	0.1 $\pm$ 0.01	0.1 $\pm$ 0.01

(S) Standard deviation; (NOM-127) NOM-127-SSA1-2021; (LMP) Maximum allowable limit; (WHO) World Health Organization; (ND) Not detected, below the detection limit of the equipment.

The population receiving water from the water treatment plant was estimated to be 39 927 inhabitants according to the Population and Housing Census (INEGI, 2020). The HQ values for total chromium (Table 2) are greater than 1 for the population groups of children, adolescents, and elderly adults. This indicates that these groups are susceptible to developing health effects not related to cancer (WHO, 2011); it is estimated that 17 488 individuals belong to these susceptible population groups. The lifetime cancer risk (LCRi) from total chromium intake was used to estimate the probability of the population developing cancer due to chromium exposure, with children, adolescents, and elderly adults showing the highest probability of developing individual cancer (Table 2). At the municipal level, the cancer incidence probability for the total population was observed in the children and adult groups, with values of 3.2074 and 3.1414, respectively.

Table 2. Estimation of daily chronic intake, non-carcinogenic risk, lifetime cancer risk in the population exposed to total chromium in water, and cancer incidence.

Population Group	No. of persons	% of population	CDI (mg/kg/day)	HQ	LCRi (mg/kg/day)	IC
Children	9 164	22.95	0.007	2.33	3.5×10^{-4}	3.2074
Adolescents	4 330	10.84	0.0037	1.23	1.85×10^{-4}	0.8010
Adults	22 439	56.21	0.0028	0.93	1.4×10^{-4}	3.1414
Elderly Adults	3 994	10	0.0030	1.00	1.5×10^{-4}	0.5991
Total	39 927	100				

(CDI) Chronic daily intake; (HQ) Non-carcinogenic risk; (LCR) Cancer risk; (CI) Cancer incidence.

Discussion

Globally, research has been conducted on the main health effects of consuming water contaminated with heavy metals (Mendoza-Cano *et al.*, 2015; Chebeir, Chen, & Liu, 2016; Naz, Mishra, & Gupta, 2016). In fact, most mortality and morbidity are associated with diseases caused by the consumption of water contaminated with substances such as chromium (Nadeem, Aslam, Haque, Badar, & Mughal, 2009). However, although epidemiological studies do not support direct effects of total chromium content in drinking water, it has been proven that the continuous consumption of water with concentrations above 0.025 mg/l poses a significant toxicological risk (NTP, 2008). Authors such as Ahmed and Mokhtar (2020), and Nadeem *et al.* (2009) suggest that the values established by the World Health Organization (WHO) of 0.5 mg/l are accepted maximum concentrations, and any amount exceeding this limit could result in chronic toxicity from continuous intake.

In the determination of total chromium in the drinking water of Zimapán, the results showed that for the 12 months of sampling, its presence was detected both in the well water and in the treated water at a concentration of 0.1 mg/l. This value exceeds the maximum allowable limit (MAL) established by NOM-127-SSA1-2021 and the World Health Organization, which is 0.05 mg/l of total chromium. Previously, Pérez-Moreno (2004) reported a total chromium concentration of 0.006 mg/l for El Muhí well.

Total chromium was present in the water from the well during the first five months of sampling (March–July), and simultaneously in the treated water. Moreover, total chromium continued to affect the plant

during the following four months. In December and January, the water in Zimapán was free from contamination, meeting the quality standards set by NOM-127. However, in February, total chromium concentrations were again detected at both sites, indicating simultaneous contamination of both the well and the water supply. Previous reports from the area have indicated the presence of arsenic, cadmium, lead, and mercury in the water from the wells in the municipality of Zimapán. However, in this study, during the 12 months of sampling, these elements were not detected, as they were below the detection limit of the equipment. A possible hypothesis for the absence of these elements in the annual monitoring could be the lack of precipitation in the area, which, being scarce, prevents the aquifers from reaching their maximum capacity, thereby limiting contact with some mineral deposits and avoiding contamination. Pérez-Moreno (2004) states that for El Muhí well, there are seasonal variations dependent on the rainy and dry seasons, which coincides with the absence of other elements in the analyzed sites. The presence of chromium in the water is attributed to contact with mineral deposits, and additionally, the physical and chemical conditions of the well water enable the metal to be dissolved, leading to its presence.

At the Muhí well, the water treatment plant has infrastructure equipped for a coagulation-flocculation process and a 16-step treatment train (Conagua, 2015). The World Health Organization (WHO, 2011) states that this process has an effectiveness of over 96 % removal, combined with processes such as filtration, flocculation, and chlorination. While the WHO (2011) recommends the application of these methods in conjunction in order to achieve efficiency in the removal of contaminants such as arsenic and fluoride, emergency situations can arise, such as the presence of other contaminants for which a water treatment plant may

not be prepared. This highlights an opportunity for improvement, with the possibility of creating plans and strategies that respond to current potential issues arising from the presence of other contaminants that pose a risk to public health.

In the study area, exposure to total chromium could be a contributing factor to some of the health problems associated with the consumption of contaminated water. However, to monitor the effects caused by exposure to contaminated water, precise measurements are required, through a system for recording symptoms and epidemiological studies conducted by the health sector. Each of these measures should aim to estimate the incidence of diseases or health issues associated with the ingestion of total chromium from groundwater sources. This will enable the problem to be quantified in order to allocate resources and implement public policies and regulations to protect the health of the exposed population.

The population vulnerable to the presence of total chromium in water consists of groups made up of children, adolescents, and older adults ($HQ > 1$), as the reported total chromium concentration could cause adverse health effects in at least these population sectors. These groups represent 43.79 % of the municipal population according to the population census (INEGI, 2020).

The probability of cancer risk was higher in children and adults compared to adolescents and older adults. Both groups are potentially at risk of developing some form of cancer associated with the chronic consumption of total chromium, so their protection should be a priority in the development of public health policies aimed at mitigating this issue.

Conclusions

Total chromium was present in both the pre- and post-treatment monitoring with a concentration of 0.1 mg/l, with some months showing no presence. This value exceeds the maximum permissible limit (MPL) established by the Mexican Official Standard and the World Health Organization. As a result, the estimated risk factor increased. Therefore, it would be advisable to assess the health impact caused by chronic consumption of total chromium in the study region.

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