https://doi.org/10.15255/KUI.2025.048
KUI-27/2026
Original scientific paper
Received October 17, 2025
Accepted November 24, 2025

Exposure to Cd, Cr, and Pb through Bottled Water Consumption: A Preliminary Health Risk Assessment

A. Turalić,[a*] *J. Đeđibegović,*[a] *D. Krešić,*[b] *E. Muftić,*[a]
A. Čaušević,[c,d] and *E. Omeragić*[a]

[a] University of Sarajevo – Faculty of Pharmacy, Zmaja od Bosne 8, 71 000 Sarajevo, Bosnia and Herzegovina
[b] Institute for Public Health of Sarajevo Canton, Dr. Mustafe Pintola 1/III, 71 210 Ilidža-Sarajevo, Bosnia and Herzegovina
[c] Institute for Public Health of the Federation of Bosnia and Herzegovina, Maršala Tita 9, 71 000 Sarajevo, Bosnia and Herzegovina
[d] University of Sarajevo – Faculty of Health Studies, Bardakčije 1, 71 000 Sarajevo, Bosnia and Herzegovina

Abstract

Cd, Cr, and Pb concentrations were analysed in 18 bottled drinking water samples from the Bosnia and Herzegovina (B&H) market, classified as natural spring water or still natural mineral water. Metal concentrations were determined using atomic absorption spectrometry with electrothermal atomisation in a graphite furnace. Cr was quantified in two samples, Pb in four samples, while Cd concentrations were below the limit of detection in all samples. All concentrations were below national regulatory limits.

Health risks associated with Cr and Pb exposure through bottled water consumption were assessed for adolescents, adults, and pregnant women by calculating the hazard quotient (HQ), hazard index (HI), carcinogenic risk (CR), and total carcinogenic risk (TCR). Some exposure scenarios exceeded HQ and HI thresholds, suggesting potential non-carcinogenic effects, primarily due to Pb exposure. CR and TCR values across all exposure scenarios were below established thresholds, indicating generally acceptable or negligible carcinogenic risk.

Given the limited sample set, the data on Cd, Cr, and Pb content, along with the health risk assessment, should be regarded as preliminary, serving as a starting point to guide future research. Considering the health implications of heavy metal exposure, continuous water-quality monitoring and a more comprehensive health risk assessment, including additional heavy metals and a larger sample set, are essential, as regulatory compliance does not necessarily imply the absence of health risks.

Keywords

Bottled drinking water, heavy metals, health risk assessment, non-carcinogenic risk, carcinogenic risk

1 Introduction

Bottled drinking water has become widely and increasingly consumed due to its availability, low cost, and the perception of higher quality compared to tap water.[1–3] Although commonly considered a safe beverage, it must be thoroughly assessed to ensure compliance with established safety and quality standards. One key aspect of this assessment is determining the metal content, as certain metals can be toxic and pose serious health risks upon exposure. Essential trace metals are necessary for metabolic functions but are usually considered toxic or carcinogenic when present in excess, whereas non-essential heavy metals have no established biological role and are associated with adverse health effects.[1,4,5] Heavy metals are among the most concerning environmental pollutants, particularly in water sources, due to their high toxicity even at low concentrations, environmental persistence, and potential for bioaccumulation and biomagnification.[6,7] Drinking water is considered one of the primary sources of exposure to heavy metals.[1] These metals may contaminate water sources through multiple pathways, including both anthropogenic activities and natural processes.[6,8,9]

Exposure to heavy metals through the food chain, water consumption, inhalation, or dermal absorption can lead to severe health effects.[7] Human health risk assessment is a fundamental approach for evaluating the potential health effects of heavy metal exposure, and provides essential insights for researchers and policymakers to guide risk-management strategies.[10] These assessments are typically categorised into carcinogenic and non-carcinogenic risks based on established risk levels.[11]

Cadmium (Cd), chromium (Cr), and lead (Pb) are among the highest-priority contaminants in drinking water, and are included as monitoring parameters in water-quality regulations due to their well-known toxicity and adverse effects on human health.[6] Prolonged exposure to Cd may lead to chronic kidney failure, anaemia, cardiovascular disorders, hypertension, bone demineralisation (such as osteoporosis), olfactory dysfunction, and cancer.[3,6,8] Exposure to Cr can adversely affect the respiratory system and is associated with an increased risk of lung cancer.[12] Acute exposure to Pb can cause symptoms such as headache, loss of appetite, fatigue, abdominal pain, and high blood pressure. Prolonged or chronic exposure is associated with more severe health effects, including neurological and developmental disorders, long-term cognitive impairments, kidney damage, and muscle weakness.[13]

* Corresponding author: Amila Turalić, PhD
Email: amila.turalic@ffsa.unsa.ba

The extent of heavy metal exposure through bottled drinking water and the associated health risks remain largely unexplored for the population of Bosnia and Herzegovina (B&H) due to limited research. This study aimed to evaluate the concentrations of Cd, Cr, and Pb in domestic and imported bottled drinking water, and to assess the carcinogenic and non-carcinogenic health risks among adolescents, adults, and pregnant women in B&H. The findings provide valuable insights into exposure and potential health risks, and emphasise the importance of addressing this public health concern.

2 Materials and methods

2.1 Sampling

In July 2025, a total of 18 commercially available bottled drinking water samples from various brands were purchased on the B&H market. The sample set included 11 natural spring water samples and 7 still natural mineral water samples. All samples were within their expiration dates and had volumes ranging from 0.33 to 1 l. The samples originated from B&H, Croatia, Serbia, and Italy, and represented the brands available during the sampling period. Each sample was kept in its original plastic bottle, stored away from direct sunlight, isolated from solvents and chemicals, and opened immediately prior to analysis.

2.2 Determination of heavy metal concentrations

A volume of 0.1 ml of concentrated nitric acid (69 %, Supelco, Merck KGaA, Darmstadt, Germany) was added per 100 ml of water sample to acidify the samples (pH < 2). The concentrations of Cd, Cr, and Pb were determined using atomic absorption spectrometry (AAS) with electrothermal atomisation in a graphite furnace, following the EN ISO 15586:2003 international standard for water quality (adopted as BAS EN ISO 15586:2005).[14] Measurements were performed using an Agilent 280Z AA atomic absorption spectrometer (Agilent Technologies, Santa Clara, CA, USA). The results were expressed in $\mu g\,l^{-1}$ as the average of two duplicate measurements. Analytical method parameters are shown in Table 1.

Blank samples (100 ml of deionised water and 0.1 ml of concentrated nitric acid, 69 %) were prepared following the same procedures used for each metal for quality-control purposes. Calibration curves were generated using a series of standard solutions prepared from a certified reference material (GF AAS Multi Element Standard XVIII, Ref. No. 109500.L1, CPAchem Ltd., Bogomilovo, Bulgaria), with concentration ranges of 0.25–5 $\mu g\,l^{-1}$ for Cd, 1–20 $\mu g\,l^{-1}$ for Cr, and 2–40 $\mu g\,l^{-1}$ for Pb. Method recovery was determined by analysing six replicate measurements of a standard solution with nominal concentrations of Cd (3 $\mu g\,l^{-1}$), Cr (8 $\mu g\,l^{-1}$), and Pb (9.98 $\mu g\,l^{-1}$). Repeatability was assessed using six replicate measurements of the same metals at these concentrations. The limits of detection (LOD) were calculated as three times (3×) the standard deviation of repeated measurements of a blank solution, while the limits of quantification (LOQ) were calculated as ten times (10×) the standard deviation of repeated measurements of a blank solution.

2.3 Health risk assessment

2.3.1 Exposure assessment

The health risk assessment was based on the estimated chronic daily intake (CDI) of heavy metals (µg/kg body weight/day) through the consumption of bottled drinking water. Two approaches were applied for the estimation. The first approach used water-intake data obtained from the EFSA Comprehensive European Food Consumption Database,[15] while the second approach applied the EFSA adequate intake (AI) values for water[16].

In the first approach, CDI was estimated using Eq. (1):

$$\mathrm{CDI} = C \cdot DI \cdot 10^{-3} \qquad (1)$$

where CDI is the chronic daily intake of a heavy metal through bottled drinking water consumption (µg/kg body weight/day); C is the individual, average, or maximum heavy metal concentration in a specific water category ($\mu g\,l^{-1}$); DI is the daily bottled water intake expressed as the 5th percentile, average, or 95th percentile for each water category across different population groups (g/kg body weight/day); and 10^{-3} is the unit conversion factor.

Daily intake data (g/kg body weight/day) for two water categories across different population groups in B&H were obtained from the database and included only consumers[15]. Samples were classified as "still bottled drinking water" or "still natural mineral water" (exposure hierarchy L7). The database provides food consumption data for adolescents, adults, and pregnant women in the B&H population, which were assessed separately due to their physiological differences.

Table 1 – Chemical modifiers, instrument settings, and analytical method parameters

Metal	Chemical modifier	Wavelength / nm	Coefficient of determination (R^2)	Recovery / %	Repeatability (%RSD)	Limit of detection / $\mu g\,l^{-1}$*	Limit of quantification / $\mu g\,l^{-1}$
Cd	–	228.8	0.995	106	4.4	0.01	0.25
Cr	–	357.9	0.99	105	3.4	0.05	1
Pb	H_3PO_4/H_2O (1 : 4)	283.3	0.998	91	6.7	0.06	2

* Instrument LOD

In the second approach, the CDI was assessed using Eq. (2):

$$\text{CDI} = \frac{C \cdot AI}{BW} \tag{2}$$

where CDI is the chronic daily intake of a heavy metal through bottled drinking water consumption (µg/kg body weight/day); *C* is the individual, average, or maximum heavy metal concentration in a specific water category (µg l^{-1}); *AI* is the adequate daily water intake for adolescents and adults (2.1 l/day for boys and 1.9 l/day for girls aged 9–13 years; 2.5 l/day for boys and 2 l/day for girls aged 14–18 years; 2.5 l/day for adult males and 2 l/day for adult females)[16]; and *BW* is the default body weight value (43.4 kg for adolescents aged 10–14 years; 61.3 kg for adolescents aged 14–18 years; 70 kg for adults)[17].

The EFSA Scientific Committee does not propose default body weight values for specific population subgroups, such as pregnant women[17]; therefore, pregnant women were not included in the second approach.

2.3.2 Non-carcinogenic risk assessment

Non-carcinogenic health risk was characterised by calculating the hazard quotient (HQ) using Eq. (3):

$$\text{HQ} = \frac{CDI}{HBGV} \tag{3}$$

where HQ is the hazard quotient; *CDI* is the chronic daily intake of a heavy metal through bottled drinking water consumption (µg/kg body weight/day); and *HBGV* represents the health-based guidance value (µg/kg body weight/day).

The health-based guidance values (*HBGV*) included the oral reference dose (RfD) for Cr and the $BMDL_{10}$/10 and $BMDL_{01}$/10 for Pb. The RfD represents the daily intake rate estimated to pose no appreciable risk of adverse health effects, including for sensitive populations, over a specific exposure period.[11] The RfD for Cr is 0.9 µg/kg body weight/day.[18,19]

Neither EFSA nor the U.S. EPA provides a tolerable intake level or RfD for Pb. Therefore, a $BMDL_{10}$ value of 0.63 µg/kg body weight/day (linked to the prevalence of chronic kidney disease) and a $BMDL_{01}$ value of 1.5 µg/kg body weight/day (linked to systolic blood pressure effects) were used.[20] EFSA considers a margin of exposure ≥ 10 to indicate no appreciable risk, corresponding to a daily exposure lower than one-tenth of the BMDL.[20,21]

The hazard index (HI), a quantitative tool used to assess the cumulative non-carcinogenic risks from exposure to multiple heavy metals, was calculated using Eq. (4):

$$\text{HI} = \sum_{i=1}^{n} \text{HQ}_i \tag{4}$$

where HQ_i represents the hazard quotient of each individual metal.

HQ (or HI) values > 1 indicate a potential for non-carcinogenic health effects, whereas values < 1 suggest no expected non-carcinogenic health risks.[11]

2.3.3 Carcinogenic risk assessment

The carcinogenic risk (CR) was calculated using Eq. (5):

$$\text{CR} = CDI \cdot CSF \tag{5}$$

where CR is the carcinogenic risk; *CDI* is the chronic daily intake of a heavy metal through bottled drinking water consumption (µg/kg body weight/day); and *CSF* is the oral cancer slope factor (µg/kg body weight/day)$^{-1}$.

The oral cancer slope factors used for the calculation were: $2.7 \cdot 10^{-4}$ *per* µg/kg body weight/day for Cr and $8.5 \cdot 10^{-6}$ *per* µg/kg body weight/day for Pb.[18,19]

The total carcinogenic risk (TCR) was calculated by summing the risks associated with carcinogenic heavy metals, as indicated in Eq. (6):

$$\text{TCR} = \sum_{i=1}^{n} CDI \cdot CSF \tag{6}$$

The U.S. EPA has established the range of generally acceptable risks for known or suspected carcinogens as $1 \cdot 10^{-6}$ to $1 \cdot 10^{-4}$.[11] Risks less than $1 \cdot 10^{-6}$ generally are of no concern, whereas risk levels exceeding $1 \cdot 10^{-4}$ are usually considered unacceptable.[11]

2.4 Data analysis

Microsoft Excel (Office Professional Plus 2016, Version 2504) was used to calculate CDI and human health risk indices. Graphical representations were created using GraphPad Prism 10.5.0.

3 Results and discussion

3.1 Heavy metal concentrations

The determined concentrations of heavy metals in the bottled water samples are presented in Table 2.

The difference between natural spring water and still natural mineral water lies primarily in their source, composition, and regulatory definitions. Spring water is bottled at the source and intended for consumption in its natural form. Natural mineral water is characterised by its purity at the source and a constant level of minerals.[22]

Water quality varies depending on the source and is largely influenced by both natural processes and human activities.[23] In particular, the chemical composition of groundwater, as the main source of bottled water, is influenced by a combination of anthropogenic activities such as urbanisation, industrialisation, mining, and agriculture, as well as natural processes including soil erosion, volcanism, rock

Table 2 – Heavy metal concentrations in bottled drinking water

Water category	Country of origin	Cd / µg l^{-1}	MCL for Cd	Cr / µg l^{-1}	MCL for Cr	Pb / µg l^{-1}	MCL for Pb
natural spring water	B&H	<LOD	5	<LOD	50	5.16	10
	B&H	<LOD		<LOD		<LOD	
	B&H	<LOD		<LOD		4.41	
	B&H	<LOD		<LOD		<LOD	
	B&H	<LOD		<LOD		<LOQ	
	B&H	<LOD		<LOD		8.63	
	B&H	<LOD		<LOD		<LOD	
	B&H	<LOD		1.56		<LOD	
	B&H	<LOD		<LOD		<LOD	
	B&H	<LOD		<LOD		<LOD	
	Croatia	<LOD		<LOD		<LOD	
still natural mineral water	Serbia	<LOD	3	<LOD	50	<LOD	10
	Serbia	<LOD		<LOD		<LOD	
	Serbia	<LOD		1.40		<LOD	
	Italy	<LOD		<LOQ		<LOD	
	B&H	<LOD		<LOD		<LOD	
	B&H	<LOD		<LOQ		4.29	
	Croatia	<LOD		<LOD		<LOD	

[*] MCL – maximum contaminant level

weathering, and evaporation.[3,6,7,9] These factors determine the quality of drinking water and, consequently, influence human health.

Cd, Cr, and Pb, as some of the most significant heavy-metal contaminants in drinking water, may enter water sources through various pathways, including industrial effluents, agricultural runoff containing pesticides and chemical fertilisers, corrosion within water distribution systems, and other environmental and anthropogenic sources.[6,8]

A key requirement for marketing bottled drinking water is compliance with the parametric values set by regulatory authorities. The maximum contaminant levels (MCL) defined in the Regulation on Natural Mineral and Natural Spring Waters (Official Gazette of Bosnia and Herzegovina, No. 26/10)[24] are as follows: 3 µg l^{-1} for Cd in still natural mineral water and 5 µg l^{-1} in natural spring water, 50 µg l^{-1} for Cr, and 10 µg l^{-1} for Pb. These values are consistent with the limits established in Directive (EU) 2020/2184[25] on the quality of water intended for human consumption. This regulation serves as a key reference for evaluating drinking water quality and guiding regulatory measures to protect public health.

Cd, Cr, and Pb levels in all samples complied with the regulatory limits. Cd concentrations were below the LOD in all samples, consistent with the results reported by *Ristić et al.*[2] for bottled waters from the Serbian market, and *Ungureanu et al.*[3] for bottled waters from the Romanian market.

Cr was quantified in one natural spring water and one still natural mineral water, with concentrations well below the established MCL for Cr (Table 2). The determined Cr content was similar in both water types. In all other samples, Cr levels were below the LOD or the LOQ.

Pb was quantified in three natural spring waters and one still natural mineral water, while in the other samples it was below the LOD or LOQ (Table 1). The determined Pb concentration of 8.63 µg l^{-1} in one natural spring water is close to the MCL for Pb. *Mirzaei et al.*[26] reported a similarly high Pb concentration of 7 µg l^{-1} in bottled water from the Iranian market. According to Directive (EU) 2020/2184[25], the parametric value for Pb in drinking water is 10 µg l^{-1} until 2036, after which a stricter limit of 5 µg l^{-1} will apply. This makes the result particularly important in the context of future regulatory compliance. Anthropogenic activities such as mining, industrial manufacturing, and the combustion of fossil fuels have significantly contributed to the accumulation of Pb and its compounds in various environmental compartments, including the air, water, and soil.[13]

In general, variations in heavy metal concentrations in bottled waters can be attributed to differences in pollution levels of water sources (especially springs), as well as the treatment methods used (*e.g.,* water purification processes).[1]

While the determined heavy metal concentrations remained within regulatory limits, potential health risks cannot be entirely ruled out, as the frequency and duration of consumption are also key factors in health risk assessment.

3.2 Health risk assessment

The potential non-carcinogenic and carcinogenic risks from Cr and Pb exposure through bottled drinking water consumption were assessed for adolescents, adults, and pregnant women in B&H. To estimate these risks, the CDI of heavy metals, HQ, HI, CR, and TCR were calculated. The health risk assessment was based exclusively on the concentrations of heavy metals quantified in the samples, which accounted for approximately 30 % of the total number of analysed samples. Therefore, the average Cr concentrations were assumed to be equal to the individual quantified concentrations within each water category. For Pb, the average concentration in natural spring water was calculated from the three quantified values, while in still natural mineral water, it was considered equal to the individual quantified Pb concentration. This approach is considered more conservative than assuming zero concentrations for samples with heavy metal levels below the LOD or LOQ. Cd was excluded from the assessment since all samples contained levels below the LOD.

3.2.1 Non-carcinogenic risk analysis

HQ values were calculated for each metal exposure scenario to evaluate whether the exposed population groups are at risk of potential non-carcinogenic health effects. To assess the total non-carcinogenic risk, HI values were calculated for each scenario as the sum of individual HQs for Cr and Pb. HI values > 1 indicate a potential for non-carcinogenic health effects, while values HI < 1 suggest that such effects are unlikely.[11]

When the CDIs of selected heavy metals were estimated using water intake data from the EFSA Comprehensive European Food Consumption Database, almost all HI values across exposure scenarios and population groups were below 1 for both natural spring water (Fig. 1a) and still natural mineral water (Fig. 1b). The only exception (HQ and HI > 1) was observed for adolescents in the exposure scenario where the CDI was estimated using the maximum Pb concentration and the 95th percentile of natural spring water intake, related to the effects on the prevalence of chronic kidney disease. In this case, only the highest water intake level, when combined with the maximum Pb concentration, lead to non-carcinogenic risk exceeding the threshold. A similar result was observed for adults in the same exposure scenario (HQ and HI ≈ 1). In all other exposure scenarios, Pb-related effects on the prevalence of chronic kidney disease are unlikely. HQ and HI values indicate that non-carcinogenic effects of Cr, as well as Pb-related effects on systolic blood pressure, are also unlikely across all exposure scenarios.

As expected, the use of EFSA adequate intake values for water in the CDI calculations resulted in higher HQ and HI values compared to the first approach. In this approach, almost all HI values across exposure scenarios and population groups were above 1 for both natural spring water (Fig. 2a) and still natural mineral water (Fig. 2b). The only two exceptions (HI < 1) were observed in female adolescents (14–18 years) and adult females, specifically in relation to the consumption of still natural mineral water. In these cases, the HI values, calculated as the sum of the HQ for Cr and the HQ for Pb related to effects on systolic blood pressure, remained below the threshold.

Pb was found to be the main contributor to the observed HI values, as the HQ values for Cr were negligible across all exposure scenarios and under both assessment approaches. Therefore, this approach indicates that non-carcinogenic effects of Cr are unlikely, while suggesting a potential for Pb-related effects on the prevalence of chronic kidney disease in all exposure scenarios, as well as Pb effects on systolic blood pressure in most exposure scenarios.

Since not all heavy metals were analysed in this study, the obtained HI values provide an initial insight rather than a definitive assessment. As the HI estimates the cumulative risk from exposure to multiple non-carcinogenic substances, it is important to note that other heavy metals potentially present in drinking water may additionally influence the overall risk profile and contribute to an even more pronounced health risk.

However, it should be pointed out that the reference values for total water intake established by EFSA include water from drinking water (tap and bottled), all types of beverages, and food moisture.[16] In the second approach, metal exposure was assessed under the assumption that the adequate intake is achieved exclusively through bottled drinking water. This may explain the higher CDI, HQ, and HI values observed when using adequate intake values for water, compared to those from the first approach, which relied on EFSA data with clearly specified intake values for different types of drinking water. Nevertheless, it is unlikely that the entire daily water intake will be obtained solely from bottled sources, and this approach may therefore lead to an overestimation of metal intake through bottled water.

It is also important to consider the possibility of water consumption exceeding the adequate intake, which could potentially result in even higher HQ and HI values. Additionally, since water is not the primary source of Pb exposure, elevated HQ values or values close to 1 are of concern, especially when taking into account other significant sources that contribute more substantially to the overall exposure.

3.2.2 Carcinogenic risk analysis

Carcinogenic risk (CR) represents the incremental probability that an individual will develop cancer over a lifetime due to exposure to a carcinogenic substance.[11] CR values were calculated for each exposure scenario to evaluate whether the exposed population groups are at risk of potential carcinogenic health effects associated with the presence of Cr and Pb in bottled water. Total carcinogenic risk (TCR) was obtained by summing the CR values for each exposure scenario. TCR (or CR) values between $1 \cdot 10^{-6}$ and $1 \cdot 10^{-4}$ represent generally acceptable risks for known or suspected carcinogens. Risks below $1 \cdot 10^{-6}$ are generally considered negligible, while risk levels exceeding $1 \cdot 10^{-4}$ are usually regarded as unacceptable.[11]

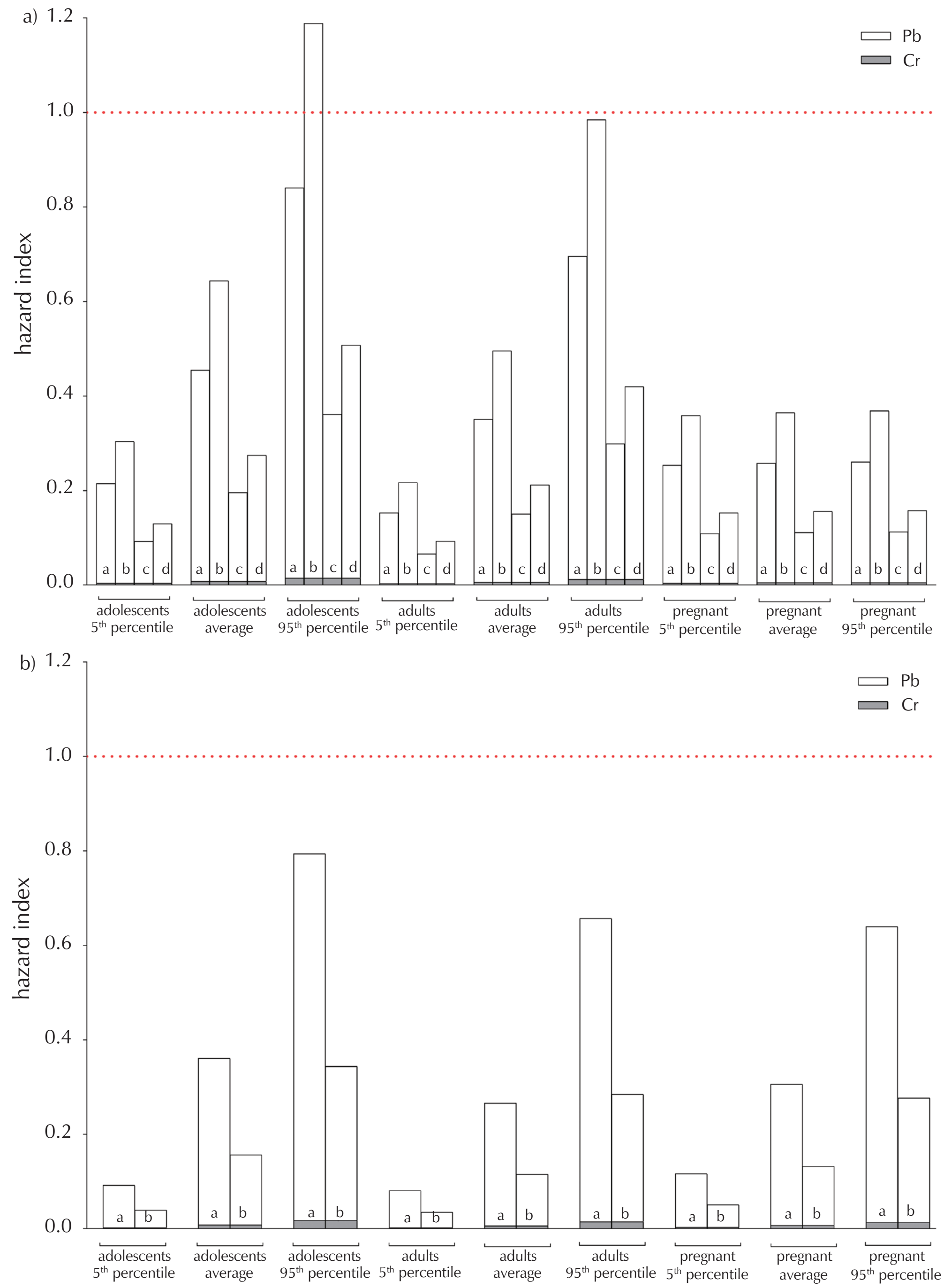

Fig. 1 – HI values across exposure scenarios and population groups, based on CDI estimates for selected heavy metals using water intake data from the EFSA Comprehensive European Food Consumption Database for (a) natural spring water, and (b) still natural mineral water. Bars are labelled as follows, for (a): a = $HQ_{Cr} + HQ_{Pb\ average\ (effects\ on\ prevalence\ of\ chronic\ kidney\ disease)}$; b = $HQ_{Cr} + HQ_{Pbmax\ (effects\ on\ prevalence\ of\ chronic\ kidney\ disease)}$; c = $HQ_{Cr} + HQ_{Pb\ average\ (effects\ on\ systolic\ blood\ pressure)}$; d = $HQ_{Cr} + HQ_{Pbmax\ (effects\ on\ systolic\ blood\ pressure)}$; for (b): a = $HQ_{Cr} + HQ_{Pb\ (effects\ on\ prevalence\ of\ chronic\ kidney\ disease)}$; b = $HQ_{Cr} + HQ_{Pb\ (effects\ on\ systolic\ blood\ pressure)}$

When the CDIs of selected heavy metals were estimated using water intake data from the EFSA Comprehensive European Food Consumption Database, most of the TCR values across different exposure scenarios and population groups fell within the generally acceptable risk range for both natural spring water (Fig. 3a) and still natural mineral water (Fig. 3b).

In adults, exposure scenarios where the CDI for Cr was calculated using the 5th percentile natural spring water intake combined with the determined Cr concentration, and the CDI for Pb calculated using the 5th percentile intake combined with either the average or maximum Pb concentration, resulted in TCR values below $1 \cdot 10^{-6}$, indicating a risk generally considered negligible. Similarly, the 5th percentile still natural mineral water intake resulted in TCR values corresponding to risk generally considered negligible in adolescents, adults, and pregnant women. Therefore, none of the TCR values exceeded the threshold of $1 \cdot 10^{-4}$.

The use of EFSA adequate intake values for water in the CDI calculations resulted in higher TCR values compared to the first approach; however, all values remained within the generally acceptable risk range. All TCR values remained below $1 \cdot 10^{-4}$ across all exposure scenarios and both water categories in this approach as well (Fig. 4a and 4b).

The observations from the first approach were supported, with Cr identified as the main contributor to the observed TCR values.

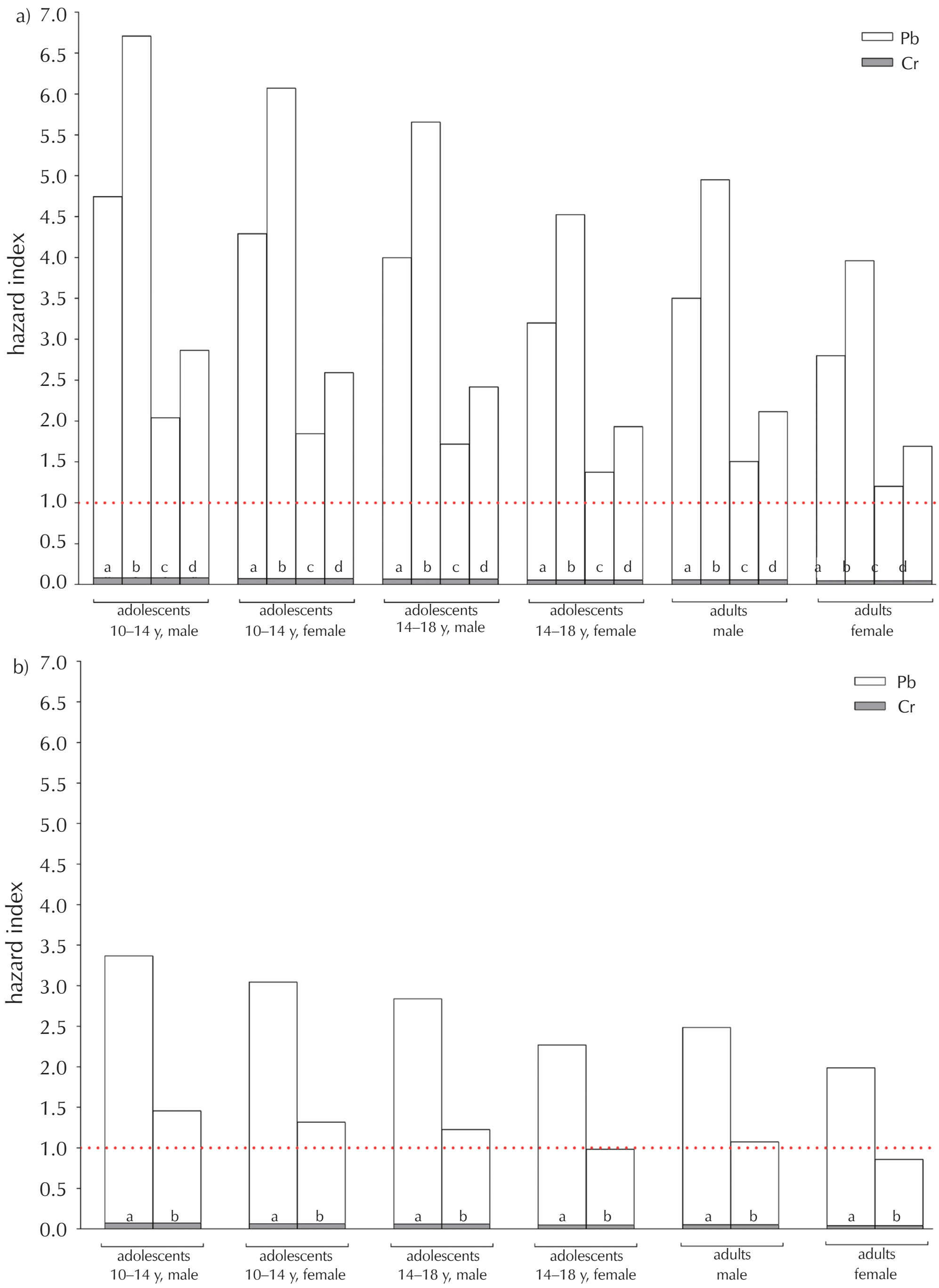

Fig. 2 – HI values across exposure scenarios and population groups, based on CDI estimates for selected heavy metals using EFSA adequate intake values for (a) natural spring water, and (b) still natural mineral water. Bars are labelled as follows, for (a): a = $HQ_{Cr} + HQ_{Pb\ average\ (effects\ on\ prevalence\ of\ chronic\ kidney\ disease)}$; b = $HQ_{Cr} + HQ_{Pb\ max\ (effects\ on\ prevalence\ of\ chronic\ kidney\ disease)}$; c = $HQ_{Cr} + HQ_{Pb\ average\ (effects\ on\ systolic\ blood\ pressure)}$; d = $HQ_{Cr} + HQ_{Pb\ max\ (effects\ on\ systolic\ blood\ pressure)}$; for (b): a = $HQ_{Cr} + HQ_{Pb\ (effects\ on\ prevalence\ of\ chronic\ kidney\ disease)}$; b = $HQ_{Cr} + HQ_{Pb\ (effects\ on\ systolic\ blood\ pressure)}$

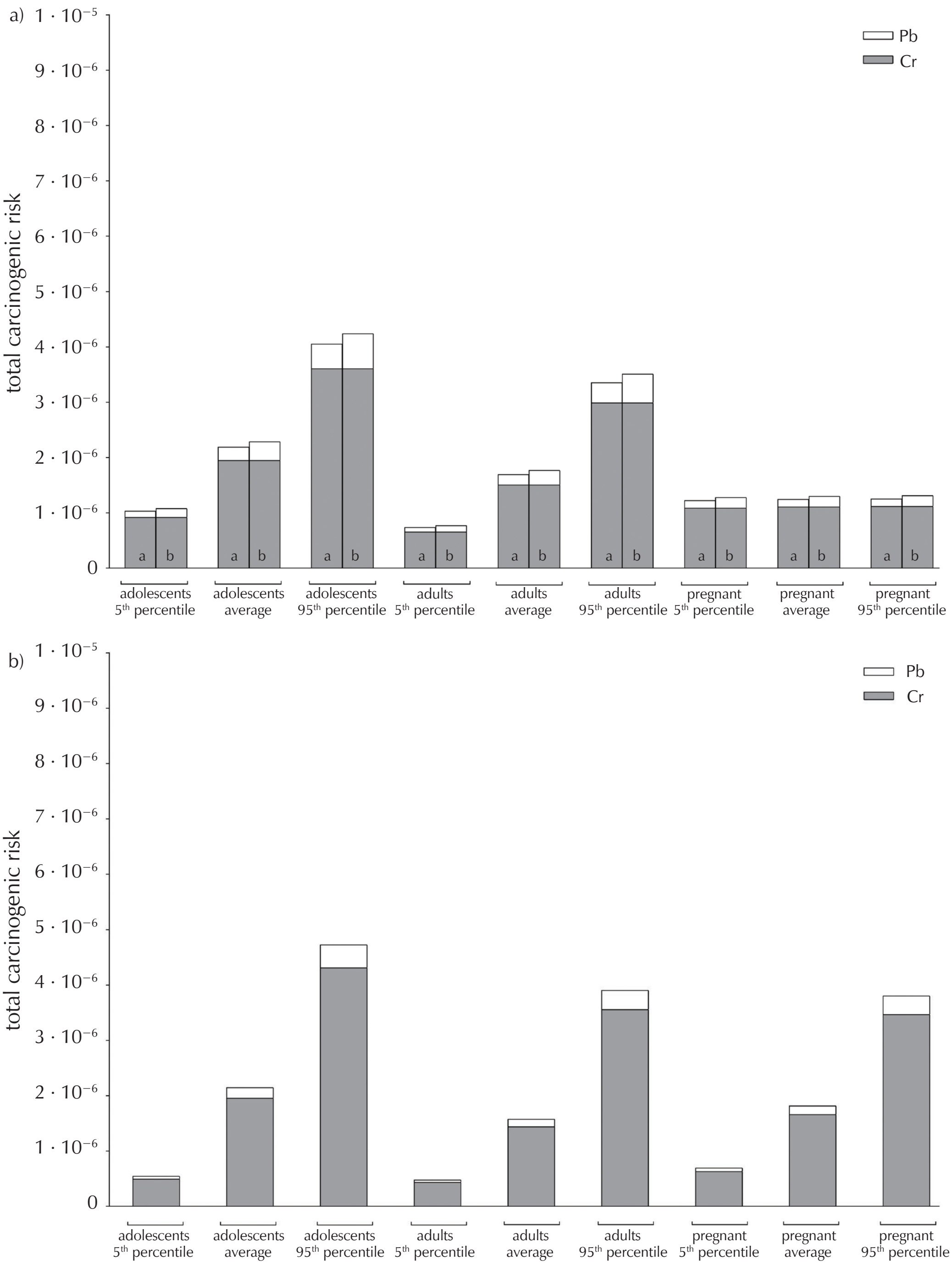

Fig. 3 – TCR values across exposure scenarios and population groups, based on CDI estimates for selected heavy metals using water intake data from the EFSA Comprehensive European Food Consumption Database for (a) natural spring water, and (b) still natural mineral water. Bars are labelled as follows, for (a): a = $CR_{Cr} + CR_{Pbaverage}$; b = $CR_{Cr} + CR_{Pbmax}$; for (b): $CR_{Cr} + CR_{Pb}$

It should be acknowledged that a comprehensive health risk assessment requires the inclusion of other heavy metals and parameters relevant to water safety, as well as a larger, more representative sample set. The limited number of samples in this study makes this assessment preliminary; however, it serves as a valuable starting point and provides important insight for future research. Moreover, other potential sources and exposure pathways should also be considered for a more reliable total risk assessment. A broader analysis covering the B&H population would contribute to a clearer understanding of this important public health issue. Notably, most of the quantified heavy metals were detected in bottled waters originating from B&H. Therefore, these results are relevant not only for domestic consumers, but also for neighbouring countries that commonly import these products.

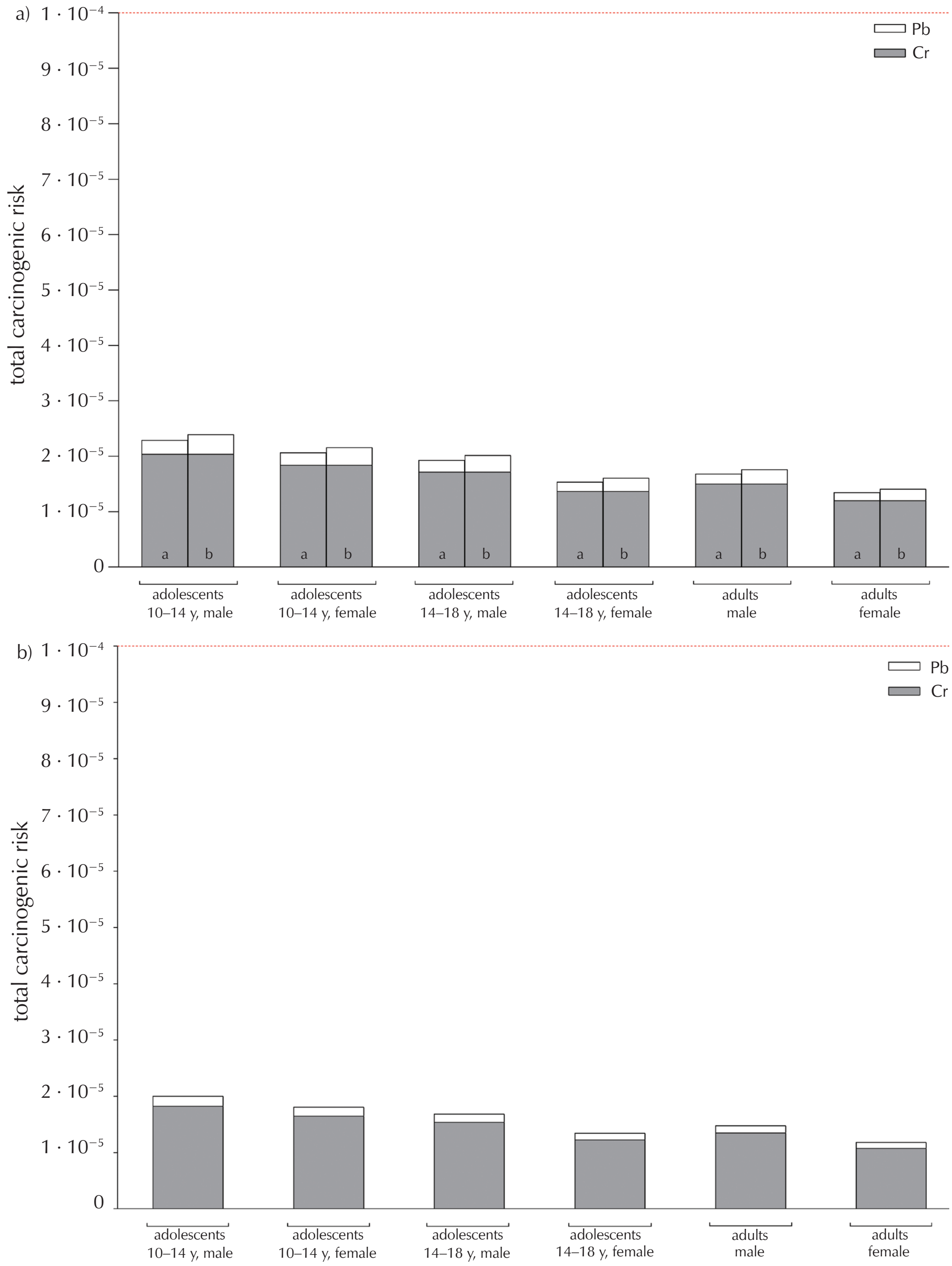

Fig. 4 – TCR values across exposure scenarios and population groups, based on CDI estimates for selected heavy metals using EFSA adequate intake values for (a) natural spring water, and (b) still natural mineral water. Bars are labelled as follows, for (a): a = $CR_{Cr} + CR_{Pbaverage}$; b = $CR_{Cr} + CR_{Pbmax}$; for (b): $CR_{Cr} + CR_{Pb}$

4 Conclusion

Concentrations of Cd, Cr, and Pb in bottled waters available on the B&H market complied with current regulatory requirements. However, regulatory compliance does not preclude potential health risks, underscoring the need for thorough health risk assessment. The potential for non-carcinogenic effects depended strongly on the water intake values used, particularly for Pb, since non-carcinogenic effects were unlikely for Cr due to its HQ values consistently below 1. Some exposure scenarios indicated potential Pb-related effects on systolic blood pressure and the prevalence of chronic kidney disease, whereas other scenarios suggested these effects were unlikely. The carcinogenic risk across all exposure scenarios and population groups remained within the generally acceptable or negligible risk ranges.

Assessing the risks of both carcinogenic and non-carcinogenic effects associated with heavy metal exposure requires continuous monitoring and comprehensive analysis of water quality to ensure public health safety. Health risk assessment serves as a valuable tool for guiding regulatory decisions and prioritising remediation efforts aimed at reducing heavy metal exposure from drinking water. The findings of this study underscore the persistent challenges posed by heavy metals and highlight the need for continuous monitoring and effective management strategies to protect public health, with particular emphasis on Pb. Importantly, the development of effective and sustainable strategies depends on strong collaboration among researchers, public health professionals, and policymakers.

References
Literatura

1. *Y. Fakhri, A. Mousavi Khaneghah, M.R. Hadiani, H. Keramati, R. Hosseini Pouya, B. Moradi, B. S. da Silva*, Non-carcinogenic risk assessment induced by heavy metals content of the bottled water in Iran. Toxin Rev. **36** (4) (2017) 313–321, doi: https://doi.org/10.1080/15569543.2017.1358747.
2. *M. Ristić, I. Popović, V. Pocajt, D. Antanasijević, A. Perić-Grujić*, Concentrations of selected trace elements in mineral and spring bottled waters on the Serbian market. Food Addit. Contam. Part B **4** (1) (2011) 6–14, doi: https://doi.org/10.1080/19440049.2010.535216.
3. *E. L. Ungureanu, A. D. Soare, A. L. Mocanu, S. C. Iorga, G. Mustatea, M. E. Popa*, Occurrence of potentially toxic elements in bottled drinking water - carcinogenic and non-carcinogenic risks assessment in adults via ingestion. Foods **11** (10) (2022) 1407, doi: https://doi.org/10.3390/foods11101407.
4. *M. R. Hadiani, S. Dezfooli-Manesh, S. Shoeibi, P. Ziarati, A. Mousavi Khaneghah*, Trace elements and heavy metals in mineral and bottled drinking waters on the Iranian market. Food Addit. Contam. Part B **8** (1) (2015) 18–24, doi: https://doi.org/10.1080/19393210.2014.947526.
5. *K. Naseri, F. Salmani, M. Zeinali, T. Zeinali*, Health risk assessment of Cd, Cr, Cu, Ni and Pb in the muscle, liver and gizzard of hens marketed in East of Iran. Toxicol. Rep. **8** (2021) 53–59, doi: https://doi.org/10.1016/j.toxrep.2020.12.012.
6. *I. Afzal, S. Begum, S. Iram, R. Shabbir, A. A. Shahat, T. Javed*, Comparative analysis of heavy metals toxicity in drinking water of selected industrial zones in Gujranwala, Pakistan. Sci. Rep. **14** (1) (2024) 30639, doi: https://doi.org/10.1038/s41598-024-82138-8.
7. *T. Dippong, M. A. Hoaghia, C. Mihali, E. Cical, M. Calugaru*, Human health risk assessment of some bottled waters from Romania. Environ. Pollut. **267** (2020) 115409, doi: https://doi.org/10.1016/j.envpol.2020.115409.
8. *B. Gautam*, Chemical evaluation of trace elements in bottled water. J. Health. Eng. **2020** (1) (2020) 8884700, doi: https://doi.org/10.1155/2020/8884700.
9. *M. Radfard, M. Yunesian, R. Nabizadeh, H. Biglari, S. Nazmara, M. Hadi, N. Yousefi, M. Yousefi, A. Abbasnia, A. H. Mahvi*, Drinking water quality and arsenic health risk assessment in Sistan and Baluchestan, Southeastern Province, Iran. Hum. Ecol. Risk Assess. **25** (4) (2019) 949–965, doi: https://doi.org/10.1080/10807039.2018.1458210.
10. *S. Demissie, S. Mekonen, T. Awoke, B. Teshome, B. Mengistie*, Examining carcinogenic and noncarcinogenic health risks related to arsenic exposure in Ethiopia: A longitudinal study. Toxicol. Rep. **12** (2024) 100–110, doi: https://doi.org/10.1016/j.toxrep.2024.01.001.
11. U.S. Environmental Protection Agency, RCRA delisting technical support document: Chapter 4 – Risk and hazard assessment. U.S. Environmental Protection Agency, (2020), URL: https://www.epa.gov/.
12. *A. Badeenezhad, H. Soleimani, S. Shahsavani, I. Parseh, A. Mohammadpour, O. Azadbakht, P. Javanmardi, H. Faraji, K. Babakrpur Nalosi*, Comprehensive health risk analysis of heavy metal pollution using water quality indices and Monte Carlo simulation in R software. Sci. Rep. **13** (1) (2023) 15817, doi: https://doi.org/10.1038/s41598-023-43161-3.
13. *M. Jaishankar, T. Tseten, N. Anbalagan, B. B. Mathew, K. N. Beeregowda*, Toxicity, mechanism and health effects of some heavy metals. Interdiscip. Toxicol. **7** (2) (2014) 60, doi: https://doi.org/10.2478/intox-2014-0009.
14. Institute for Standardization of Bosnia and Herzegovina, BAS EN ISO 15586:2005, Water quality – Determination of trace elements by atomic absorption spectrometry with graphite furnace (EN ISO 15586:2003), 2005.
15. EFSA, Comprehensive European Food Consumption Database [Dataset]. European Food Safety Authority, n.d. URL: https://www.efsa.europa.eu/en/data-report/food-consumption-data.
16. EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA), Scientific opinion on dietary reference values for water. EFSA J. **8** (3) (2010a) 1459, doi: https://doi.org/10.2903/j.efsa.2010.1459.
17. EFSA Scientific Committee, Guidance on selected default values to be used by the EFSA Scientific Committee, Scientific Panels and Units in the absence of actual measured data. EFSA J. **10** (3) (2012) 2579, doi: https://doi.org/10.2903/j.efsa.2012.2579.
18. U.S. EPA, IRIS, Integrated Risk Information System (IRIS). U.S. Environmental Protection Agency, n.d. URL: http://cfpub.epa.gov/ncea/iris/index.cfm (14. 9. 2025.)
19. U.S. EPA, RAIS, The Risk Assessment Information System. U.S. Environmental Protection Agency, n.d. URL: https://rais.ornl.gov/ (14. 9. 2025.)
20. EFSA Panel on Contaminants in the Food Chain (CONTAM), Scientific opinion on lead in food. EFSA J. **8** (4) (2010b) 1570, doi: https://doi.org/10.2903/j.efsa.2010.1570.
21. *J. Suomi, P. Tuominen*, Cumulative risk assessment of the dietary heavy metal and aluminum exposure of Finnish adults. Environ. Monit. Assess. **195** (7) (2023) 809, doi: https://doi.org/10.1007/s10661-023-11427-y.
22. European Commission, Natural mineral waters and spring water. European Commission, n.d. URL: https://food.ec.europa.eu/food-safety/labelling-and-nutrition/natural-mineral-waters-and-spring-water_en (30. 9. 2025.)
23. *J. O. Olowoyo, U. Chiliza, C. Selala, L. Macheka*, Health risk assessment of trace metals in bottled water purchased from various retail stores in Pretoria, South Africa. Int. J. Environ. Res. Public Health. **19** (22) (2022) 15131, doi: https://doi.org/10.3390/ijerph192215131.
24. Council of Ministers of Bosnia and Herzegovina, Regulation on natural mineral and natural spring waters. Official Gazette of Bosnia and Herzegovina, No. 26/10 (2010).
25. European Parliament and the Council of the European Union, Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast), Off. J. Eur. Union **L 435** (2020) 1–62 URL: https://eur-lex.europa.eu/eli/dir/2020/2184/oj.
26. *N. Mirzaei, S. Kalteh, H. Zamani-Badi, H. Moradpour, Z. Parmoozeh, M. Baziar*, Estimating human health risks associated with heavy metal exposure from bottled water using Monte Carlo simulation. Heliyon **9** (10) (2023), doi: https://doi.org/10.1016/j.heliyon.2023.e20647.

SAŽETAK

Izloženost Cd, Cr i Pb kroz konzumaciju flaširane vode za piće: preliminarna procjena zdravstvenog rizika

Amila Turalić,[a*] *Jasmina Đeđibegović*,[a] *Dragan Krešić*,[b] *Emina Muftić*,[a] *Amir Čaušević* [c,d] i *Elma Omeragić* [a]

Koncentracije Cd, Cr i Pb analizirane su u 18 uzoraka flaširane vode za piće s tržišta Bosne i Hercegovine (BiH), klasificirane kao prirodna izvorska voda ili prirodna negazirana mineralna voda. Koncentracije metala određene su pomoću atomske apsorpcijske spektrometrije s elektrotermičkom atomizacijom u grafitnoj peći. Cr je kvantificiran u dva uzorka, Pb u četiri uzorka, dok su koncentracije Cd bile ispod granice detekcije u svim uzorcima. Sve izmjerene koncentracije bile su unutar granica propisanih važećim pravilnikom.
Zdravstveni rizici povezani s ekspozicijom Cr i Pb putem konzumacije flaširane vode procijenjeni su za adolescente, odrasle osobe i trudnice izračunavanjem kvocijenta opasnosti (HQ), indeksa opsanosti (HI), karcinogenog rizika (CR) i ukupnog karcinogenog rizika (TCR). U određenim scenarijima izloženosti bile su prekoračene granične vrijednosti za HQ i HI, što ukazuje na potencijalne nekarcinogene učinke, prvenstveno uslijed izloženosti Pb. Vrijednosti CR i TCR su u svim scenarijima izloženosti bile ispod granične vrijednosti, što upućuje na prihvatljiv ili zanemariv karcinogeni rizik.
S obzirom na ograničenu veličinu uzorka, podatci o sadržaju Cd, Cr i Pb, kao i procjena zdravstvenog rizika, mogu se smatrati preliminarnim te poslužiti kao polazna točka za buduća istraživanja. Imajući u vidu zdravstvene implikacije izloženosti teškim metalima, kontinuirani monitoring kvalitete vode i sveobuhvatnija procjena zdravstvenog rizika koja uključuje i druge teške metale i veći uzorak su neophodni jer usklađenost s propisima ne podrazumijeva nužno odsutnost zdravstvenih rizika.

Ključne riječi
Flaširana voda za piće, teški metali, procjena zdravstvenog rizika, nekarcinogeni rizik, karcinogeni rizik

[a] *Univerzitet u Sarajevu – Farmaceutski fakultet, Zmaja od Bosne 8, 71 000 Sarajevo, Bosna i Hercegovina*
[b] *Zavod za javno zdravstvo Kantona Sarajevo, Dr. Mustafe Pintola 1/III, 71 210 Ilidža-Sarajevo, Bosna i Hercegovina*
[c] *Zavod za javno zdravstvo Federacije Bosne i Hercegovine, Maršala Tita 9, 71 000 Sarajevo, Bosna i Hercegovina*
[d] *Univerzitet u Sarajevu – Fakultet zdravstvenih studija, Bardakčije 1, 71 000 Sarajevo, Bosna i Hercegovina*

Izvorni znanstveni rad
Prispjelo 17. listopada 2025.
Prihvaćeno 24. studenoga 2025.