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Determination of Heavy Metals in Municipal Water Network of Tehran, Iran: A Health Risk Assessment with a Focus on Carcinogenicity

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Abstract

Background: Several contaminants such as trace elements can pollute drinking water sources with subsequent toxic effects on humans. These compounds may also accumulate in target organs and result in carcinogenic reactions.
Objectives: The concentrations of heavy metals, including arsenic (As), nickel (Ni), zinc (Zn), aluminum (Al), copper (1), cobalt (Co), lead (Pb), cadmium (Cd), iron (Cd), tin (2), antimony (Sb), chromium (3), and mercury (Hg) were aimed to determine in the drinking water of Tehran, Iran and to assess the carcinogenic and non-carcinogenic risk for consumers.
Methods: A total of 66 tap water samples were collected from 22 regions of Tehran and their heavy metal contents were measured by inductively coupled plasma mass spectrometry (ICP-MS). The non-carcinogenic and carcinogenic health risks were calculated, using hazard quotient (HQ) and incremental lifetime cancer risk (ILCR), respectively.
Results: The findings revealed that the mean concentrations of measured elements were lower than the maximum permissible limits established by Iranian National Standards, United States Environmental Protection Agency (USEPA), and the World Health Organization (WHO). HQ was less than 1 for all metals except Cr and ILCR was higher than 1×10^{-4} for Cr and Cd, which may cause human health risk.
Conclusions: No carcinogenic effects were posed by heavy metals contamination in the drinking water of Tehran; however, the content of Cr and Cd may cause human health risks because of the high daily intake of tap water throughout the lifetime and the tendency of these metals to accumulate in the human body organs. Therefore, implementing ongoing programs to monitor heavy metals in municipal drinking water and applying appropriate corrective actions to prevent the transfer of these pollutants to drinking water is crucial.

Keywords: Drinking Water, Heavy Metal, Standard Limit, Carcinogenic Health Risk, Non-carcinogenic Health Risk

1. Background

The demand for safe and sanitary drinking water is a basic human right worldwide (1, 2). According to the World Health Organization (WHO), nearly 29% of the global population does not have access to water free from contamination. Several contaminants can pollute drinking water such as toxic substances, microbial contaminants (bacteria and viruses), and chemical compounds (3). The levels of contamination in drinking water are influenced by the quality of the water sources, used tanks for water storage, water distribution systems, pipe corrosion, and household filters. In industrial development areas, many health problems can be caused by exposure to heavy metals (4, 5).

Owing to the non-biodegradable and bioaccumulation properties of heavy metals, their levels can increase in living organisms during life, which affects the function of the organs. There are some mechanisms assumed for heavy metals that may lead to neurotoxicity, the free radical generation which promotes oxidative stress, damaging lipids, proteins, and DNA molecules, and also propagating carcinogenesis (6). These elements enter water resources through industrial activities such as surface water collection, agricultural wastewater, burning fossil fuels, industrial wastewater, mining, and transportation (7-9) or natural ways such as rainfall and soil erosion, and the dissolution of soluble salts (10, 11). Some heavy metals are known to have carcinogenic effects on signaling proteins or cellular regulatory proteins responsible for apoptosis, DNA repair, DNA methylation, cell cycle regulation, and growth. The redox-sensitive transcription factors such as AP-1 can be activated through the recycling of electrons by the antioxidant network, which may be another carcinogenic effect of certain heavy metals. These transcription factors have a key role in controlling the expression of gene, which are protective against apoptosis, prevent the damage of cells, repair DNA, and strengthen the immune system (12-15). Contamination of water with toxic metals could cause morphological disorders, growth retardation, higher mortality, carcinogenicity and genetic adverse effects in humans (10, 13, 14). Cadmium (Cd) could accumulate in many organs with a long half-life of about 10 to 30 years (16), which causes many disorders such as different types of cancer in the kidney, pancreas, nasopharynx, prostate, lung, and breast cancers (17). Also, the most sensitive organs to Cd are the liver and kidneys by their ability to synthesize Cd-inducible proteins (metallothioneins) (18). Lead is a neurotoxin that is responsible for many metal poisonings in humans, and it may block hemoglobin production, reproductive system and circulatory system failure, and acute and chronic damage to the central nervous system (9, 14, 19). Mercury exists in forms of elemental, organic, and inorganic in the environment and all forms have cytotoxic effects (20). People are exposed to elemental mercury through artisanal gold mining and dental amalgam restorations, which can remain in the brain and lead to neurological symptoms (15, 21). Chromium is a silver-colored hard metal with different states of oxidation from +6 to -2. Trivalent (Cr^{+3}) and hexavalent (Cr^{+6}) chromium are the most stable oxidation states of chromium and have toxic effects on microorganisms, plants, animals, and humans (22). Chromium is harmful to health at high concentrations and can cause lung and intestinal cancers, nasal mucous ulcers, stomach distress, nephritis, and liver damage, especially Cr^{+6} (23). Therefore, Cr^{+6} is considered a hazardous ion with high solubility in soil and water and animals; carcinogenic effects were determined when ingested drinking water was polluted with Cr^{+6} (24, 25). Copper is rarely found in natural waters; hence, its presence at high concentrations is an indicator of water pollution through municipal or industrial wastewater (9). Heavy metals contaminated waters have led to a high global toxicity, morbidity, and mortality and the common mechanism of them is the production of reactive oxygen, and the oxidative damage endangers the health of consumers (26).

The cancer incidence, deaths, and death rate resulting from heavy metals exposure by drinking water at the national level were calculated as 213 (95% uncertainty interval: 180 to 254), 87 (73 - 104), and 0.11 (0.09 - 0.13), respectively. Skin cancer had the highest cancer incidence (121 cases); however, because of the high survival rate, the skin cancer share in the attributable deaths was 12.2%. Lung cancer was responsible for the highest share of the attributable burden of disease. The cancer cases, deaths, and death rate raised from exposure to heavy metals in drinking water were, respectively, 73 (59 - 91), 27 (22 - 33), 0.13 (0.10 - 0.18), in rural and 139 (104 - 190), 60 (45 - 82), 0.10 (0.08 - 0.14), in urban areas ($P < 0.05$). In the country, the order of heavy metal ILCRs was as As, Cd, Cr, and Pb, respectively. Cd had the role in about two-thirds of the imputable burden of diseases. The prevalence rate of skin cancer in Newfoundland and Labrador, Canada from 2008 to 2017 by exposure to As through drinking water was 363 to 449 cases per 100 000 people. In Shanghai, the average Cd intakes from 1988 to 97, 1998 to 2007, and 2008 to 2018 were 39.7, 44.7, and 36.4 mg/d, respectively. Annual cancer cases attributed to As exposure in Ontario, Canada was estimated to be 120 (20 - 370) (27).

Planning the ongoing programs about health risk assessments of heavy metals is necessary during a lifetime. Health risks (non-carcinogenic and carcinogenic) are to estimate the possibility of illness and death caused by exposure to pollutants such as heavy metals, which are dependent on dose, duration, and exposure level (28). Cancer risks are associated with exposure to carcinogenic toxic metals over a lifetime (29).

Therefore, due to the tendency of heavy metals to accumulate in the body cells and their toxicities, the risk assessments of human exposure to these contaminants through the intake of drinking water are very crucial. Drinking water is the main route of these contaminants' entrance to the human organs.

2. Objectives

This study aimed to (1) determine the heavy metal concentrations in the drinking tap water of Tehran, Iran; and (2) investigate whether the occurrence of heavy metals in the drinking water of Tehran posed health risks for consumers.

3. Methods

3.1. Sampling

Sampling was performed in all 22 municipal districts of Tehran and 3 public places with different geographical locations were randomly selected from each district in 2021. Three samples of drinking water were collected from tap waters at each district and kept in a sterile 50 mL falcon tube. A total of 66 drinking water was collected. Before sampling, the acid wash of falcon tubes was done, using 20% acid nitric for 24 h. Then, falcon tubes were rinsed with deionized water at least 3 times. Before filling the tubes, tap water was permitted to flow for 2 min. Next, the falcon tubes were filled with drinking water and, then, their water was poured. This process was repeated twice and finally, the falcon tubes were filled again. To inhibit the adsorption and crystallization of toxic metals before the examination, the collected drinking water was acidified with 3 mL nitric acid (HNO_3, 69%) and stored at 4°C until laboratory analysis (30).

3.2. Sample Preparation and Metal Analysis

Chemicals including internal standard solutions, multi-metal solutions, standard stock solutions, reagents, and acids were supplied from Merck (Darmstadt, Germany). Inductively coupled plasma mass spectrometry (ICP-MS, 7700 series) was used to detect the concentration of heavy metals such as arsenic (As), nickel (Ni), zinc (Zn), aluminum (Al), copper (1), cobalt (Co), lead (Pb), cadmium (Cd), iron (Cd), tin (2), antimony (Sb), chromium (3), and mercury (Hg) in drinking tap water samples according to EPA Method 6020 (31). To find the calibration graph, the blank (analytic-free media) and standard solutions of metal ions were applied. The solutions of the standard were prepared by various metal levels following a range of metal ions and the detection limit (LOD). The correlation coefficients of the calibration lines were obtained higher than 0.99 for each metal.

3.3. Control and Assurance of Quality

All used containers during the analysis process were acid-washed in diluted HNO_3 for 24 h and then washed with deionized water. The limit of detection (LOD) and limit of quantification (LOQ) for each heavy metal ion, which was calculated using a standard method, is shown in Table 1. Each sample was evaluated in triplicate to survey the reproducibility of the analysis. To assure the quality and accuracy of the findings, certified reference materials (CRMs) and standard reference solutions with known element concentrations were used. In addition, the control sample was investigated to check the accuracy of the analysis. Acceptable recovery is between 80% and 120%; the rates of recovery in the present study were in the range of 94% to 105%. The number of heavy metals was announced in mgL^{-1} on a fresh weight basis and the mean of their concentration was used for further commentary since the reproducibility was at a confidence level of 95%.

3.4. Health Risk Assessment

3.4.1. Non-carcinogenic Risk Assessment

Chronic daily intake (CDI) of heavy metals in adult consumers and hazard quotient (HQ) for non-carcinogenic risks were calculated, using the below equations:

$$CDI = \frac{(C \times IR \times ED \times EF)}{(BW \times AT)} \quad (1)$$

$$HQ = \frac{CDI}{RFD} \quad (2)$$

Where CDI: Chronic daily intake (mg/kg/day), C: Concentration of heavy metals in samples of water (mg/L), IR: Ingestion rate per capita consumption of water, ED: Duration of exposure, EF: Frequency of exposure, BW: Body weight, AT: Average time for no carcinogen assessment; RFD: Oral reference dose. According to the reports, IR has reached about 2 liters per capita; EF is 365 days/year; ED is 70 years and also BW is 70 kg for adults and AT is equal to 25,550 days (EF×ED). RFD and CSF of each metal are presented in Table 2 (32, 33).

3.4.2. Carcinogenic Risk Assessment

Equation number 3 was used to evaluate carcinogenicity.

$$ILCR = CDI \times CSF \quad (3)$$

Where ILCR is incremental lifetime cancer risk and CSF is cancer slope factor (mg/kg/day) (Table 2).

3.5. Statistical Analysis

All descriptive statistics (average, standard deviation, and ranges for the target parameters) were calculated, using the Excel 2010 software. Statistical analysis was performed by SPSS V.22 software.

This study is approved under the ethical approval code of IR.SBMU.CRC.REC.1399.040.

Table 1. Analytical Characteristics of the Heavy Metals Studied

Metals	(mg/L)			% Recovery
	LOD [a]	LOQ [b]	Sensitivity	
Pb	0.000045	0.000135	0.000018	101
Cd	0.00006	0.00018	0.000024	99
As	0.00003	0.00009	0.000012	94
Ni	0.0000525	0.0001575	0.000021	97
Zn	0.000045	0.000135	0.000018	102
Al	0.000055	0.000165	0.000022	103
Cu	0.0000675	0.0002025	0.000027	105
Co	0.0000225	0.0000675	0.000009	100
Sb	0.00006	0.00018	0.000024	97
Cr	0.0000475	0.0001425	0.000019	99
Fe	0.0000825	0.0002475	0.000033	105
Sn	0.0000225	0.0000675	0.000009	103
Hg	0.000065	0.000195	0.000026	101

[a] LOD: Limit of detection
[b] LOQ: Limit of quantification

Table 2. RFD and CSF of Monitored Heavy Metals

CSF/RFD Factor	Metals												
	Pb	Cd	As	Ni	Zn	Cr	Cu	Co	Sb	Hg	Fe	Sn	Al
RFD* (mg/kg/day)	0.0035	0.0005	0.0003	0.02	0.003	0.0003	0.04	0.03	0.0004	0.0003	0.007	-	-
CSF (mg/kg/day)**	0.0085	6.1	1.5	0.84	-	41	-	-	-	-	-	-	-

4. Results

4.1. Concentrations of Heavy Metals in Drinking Water

The levels of analyzed heavy metals (Pb, Cd, As, Ni, Zn, Al, Cu, Co, Sb, Cr, Fe, Sn, and Hg) in tap water samples collected from Tehran (capital of Iran) and their maximum permissible limits by the Iranian National Standards (INS), United States Environmental Protection Agency (USEPA), and WHO were summarized in Table 3. Based on the obtained results, the concentrations of Al and Co were below the detectable level in all tap water samples, whereas the ranges of the Pb, Cd, As, Ni, Zn, Cu, Sb, Cr, Fe, Sn, and Hg levels were 0.0009-0.0094, 0.0008-0.0048, 0.0004-0.0011, ND-0.0019, 0.0004-.0702, ND-0.0017, ND-0.00072, ND-0.078, 0.003-0.056, 0.010-0.024, ND-0.0012 mg/L, respectively. The mean concentrations (mg/L) of detected elements were in the order of Fe > Cr > Zn > Sn > Pb > Cd > As > Ni > Sb = Hg > Cu and they were lower than the maximum permissible limits by the INS, WHO, and USEPA for drinking water (13).

4.2. Noncarcinogenic Risk Assessment

The non-carcinogenic risk (HQ) of each heavy metal via the consumption of drinking tap water was determined and presented in Table 4. The findings indicated that HQ was less than 1 for all monitored metals except Cr. Based on the US-EPA recommendations, HQ lower than 1 means no health risk for human consumption. Hence, HQ value was not within the safe limits for only Cr, whereas non-carcinogenic health risks related to the consumption of drinking water were not found for other metals.

4.3. Carcinogenic Risk Evaluation

The carcinogenic risk (ILCR) of each heavy metal through the consumption of drinking tap water is summarized in Table 4. Incremental lifetime cancer risk lower than 10^{-6} shows a safe zone for cancer risk, ILCR more than 10^{-4} indicates a significant potential health risk, and $10^{-6} < \text{ILCR} < 10^{-4}$ suggests tolerable carcinogenic risk (34). The ILCR posed by Cr and Cd consumption surpassed the threshold risk limit ($>1\times10^{-4}$). The concentrations of Cr and Cd in Tehran drinking water might cause carcinogenic risks for human health; therefore, more attention is recommended by monitoring heavy metals

Table 3. Concentrations (mg/L) of Heavy Metals in Drinking Water

Metals	Min	Max	Mean ± SD	Drinking Water Standards		
				INS	WHO	US-EPA
Pb	0.0009	0.0094	0.00237 ± 0.0014	0.01	0.01	0.015
Cd	0.0008	0.0048	0.001 ± 0.0005	0.003	0.003	0.005
As	0.0004	0.0011	0.00076 ± 0.00013	0.01	0.01	0.01
Ni	ND [a]	0.0019	0.00018 ± 0.00027	0.07	0.07	-
Zn	0.0004	0.0702	0.013 ± 0.0164	-	-	-
Al	ND	ND	ND ± 0.0000	0.1 - 0.2	0.1	0.2
Cu	ND	0.0017	0.00013 ± 0.0002	2	2	1.3
Co	ND	ND	ND ± 0.0000	-	-	-
Sb	ND	0.00072	0.00014 ± 0.00013	0.02	-	-
Cr	ND	0.078	0.025 ± 0.0173	0.05	0.05	0.1
Fe	0.003	0.056	0.028 ± 0.0135	-	-	-
Sn	0.010	0.024	0.012 ± 0.003	-	-	-
Hg	ND	0.0012	0.00014 ± 0.00015	0.006	0.006	0.002

Abbreviations: INS, Iranian national standards; WHO, World Health Organization; US-EPA, U.S. environmental protection agency
[a] ND = Non-detect (lower than detection limit)

Table 4. Carcinogenic and Non-carcinogenic Risk Assessment

Parameters	Metals										
	Pb	Cd	As	Ni	Zn	Cr	Cu	Co	Sb	Hg	Fe
HQ	0.019	0.057	0.072	0.0002	0.12	2.3	0.00009	0.00009	0.01	0.01	0.11
ILCR	5.6×10^{-7}	1.7×10^{-4}	3.1×10^{-5}	4.2×10^{-6}	-	0.029	-	-	-	-	-

Abbreviations: HQ, hazard quotient; ILCR, incremental lifetime cancer risk.

risk assessment in ongoing programs at different age groups. Incremental lifetime cancer risk values of other trace elements were in the acceptable range and were in the order of As > Ni > Pb for adults.

5. Discussion

According to the standard guidelines, the findings of the current study revealed that the tap water in Tehran was safe to drink; however, this is not enough and the health risk assessments of each of the heavy metals need to be calculated.

5.1. Concentrations of Heavy Metals in Drinking Water

The findings of the present study agree well with the investigation of Ravanipour et al. (2021), about the occurrence of trace elements in drinking water sources of Iran, which has demonstrated that Fe had the highest mean concentration among the measured concentrations of heavy metals (26). Thus, the high level of Fe in drinking water can be attributed to its high level of the main resource and insufficient water treatment. Similar to our results, in another survey conducted in Zahedan (a city in the southeast of Iran), the mean concentrations of As, Cd, Cr, Pb, Ni, Al, Hg, Zn, Cu, and Fe in tap water were lower than standard recommendations and the highest concentration was related to the iron (32). Moreover, Mohammadi et al. (2019) assayed the concentrations of Pb, Cd, Ni, Zn, and Cu in the drinking water of Khorramabad City, Iran. They stated that levels of metals were satisfactory in the drinking water samples, but except for Cd, the concentrations of other metals were higher than those obtained in the present study (33). In an approximate comparison of metal concentrations in the drinking water of Tehran with other countries, the average As and Ni content in the drinking water of this study was much lower than that reported for drinking water from Malaysia, India, and Thailand (35-37). The mean concentration of Cr (0.58 μg/L), Hg (0.1 μg/L), and Cd (0.15 μg/L) in drinking water were lower in Thailand, while Pb (3.9 μg/L) and Cu (364 μg/L) concentration were higher in Australia (38). Overall, the difference in the drinking water quality of various regions could be attributed to several factors including the source of water, sanitation programs, purification system, and pipeline corrosion (39, 40).

5.2. Non-carcinogenic Risk Assessment

The studies of Naddafi et al. and Sadeghi et al. found HQ lower than 1 for Pb, Cd, and As in drinking water (27, 41). In another research in Ilam (a city in the west of Iran), there was no non-carcinogenic health risk for Hg, Co, and Zn via consumption of drinking tap water, while exposure to As and Pb displayed high health risks (42). In agreement with our observations, in Dehgolan Villages of Iran, the HQ content of As, Pb, and Cd were within the safe limits for drinking groundwater consumers (43). A study about the health risk assessment of exposure to Cr in wells of drinking water in Birjand, Iran reported that the HQ value of Cr was more than 1 for adults, teens, and children that demonstrated non-carcinogenic risks for them (44). Also, in a survey, the non-carcinogenic health risk assessment showed that the HQ value for Cr was higher than 1 in 9.63% of South Khorasan (eastern Iran) Qanats (45). Therefore, the data of these researches are in accordance with our findings. It seems that since the RfD value of Cr is much lower and its measured concentration was high in comparison to other metals in the present study, the obtained HQ for Cr was much higher than other metals.

5.3. Carcinogenic Risk Evaluation

The study conducted in Gonabad and Bajestan, Iran by Qasemi et al. similarly showed that Cd occurrence in 42% and 16% of the rural areas of Bajestan and Gonabad, respectively, had potential risks for adults via the consumption of drinking water with carcinogenic risk $> 10^{-4}$ (46). Similar results were also found for heavy metals of Cr, Cd, As, and Pb in terminal tap water in south China, where for As and Pb the cancer risk values were within the safe limits, while there were carcinogenic health risks for Cr and Cd (47). Kazemi et al. (2022) reported that the cancer risk of Cr was more than 1×10^{-4} in 81.93% of the Qanat waters of Khorasan, Iran, which demonstrated a considerable carcinogenic risk for consumers of water (45). In a study conducted by Maleki and Jari, the arsenic and nitrate risk assessment in resources of drinking water in Kurdistan Iran was performed. Results showed that there was a risk of carcinogenic As via the consumption of drinking water resources in some of Kurdistan villages (48). Moreover, Vasseghian et al. in 2022 reported that the carcinogenic risk of exposure to Pb through tap drinking water in Kermanshah City, Iran was greater than 1×10^{-6} in age groups of $>$ 20, 11–19, 1–10, and $<$ 1 year there was no cancer risk associated with the consumption of drinking water for Pb. Meanwhile, in all the age groups, the carcinogenicity risk of As was higher than Pb (49). The data of this study are in line with our results.

Regarding the limitations of our research, the findings provide a set of data and compare it to the related standards for the current state of different heavy metals in the municipal drinking water of Tehran. Also, the carcinogenicity and non-carcinogenicity risk assessment may complete this evaluation and provide a more realistic approach for future studies.

5.4. Conclusions

The results of the present study showed that the concentrations of heavy metals (Pb, Cd, As, Ni, Zn, Fe, Al, Cu, Co, Sb, Cr, Sn, and Hg) were below the permissible limits established by Iranian National Standards (INS), USEPA, and WHO in the drinking tap water of Tehran, Iran. Although heavy metal contamination in the drinking water of Tehran does not pose carcinogenic effects, considering the daily intake of drinking water and the accumulative exposure to heavy metals in the human body, the findings indicate that these trivial levels of contamination especially Cd and Cr in the drinking water may threaten the health of consumers in the long term and leads to carcinogenic effects. Therefore, it is suggested to plan the widespread and ongoing programs on the health risk assessment of heavy metals in drinking water at different age groups. It is also necessary to identify effective critical points in the transfer of heavy metals to the water resources (dams and groundwater) to the outlet of drinking water taps in different regions of Tehran to implement the corrective actions to reduce this pollutant in drinking water.

Footnotes

Authors' Contribution: Study concept and design: S. E., M. E. A., E. M. A., acquisition of data: E. Kh., N. A., R. A., analysis, and interpretation of data: S. E., E. Kh., N. A., E. M. A., drafting of the manuscript: E. Kh., N. A., E. M. A, critical revision of the manuscript for important intellectual content: S. E., M. E. A., EMA, statistical analysis: NA, E. Kh, PS, administrative, technical, and material support: S. E., E. M. A, M. E. A., S. S., P. S., study supervision: S. E., M. E. A., E. M. A, S. S.

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Data Reproducibility: All data generated during this study are included in this published article. The dataset presented in the study is available on request from the corresponding author during submission or after its publication.

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