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Investigating the Content of Toxic Metals in the Post-Consumption Fruit-Flavored and Traditional Waterpipe Bowl Water

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Abstract

Introduction: Concerns arises about smoking products waste, which can contain different hazardous pollutants such as toxic metals. This study aimed to survey the toxic metals content of fruit-flavored and traditional waterpipe bowl water.

Methods: The traditional waterpipe bowl water samples were collected from the four most popular fruit-flavored tobacco brands (Al-Mahmoud, Al-Fakher, Nakhl, and Mazaya), as well as from four widely favored flavors (blueberry, Dosib, cream orange, and mint-gum). Additionally, 10 samples of traditional waterpipe bowl water were gathered. The concentrations of toxic metals in these bowl water samples were measured using ICP-MS analysis.

Results: The mean concentration of toxic metals in waterpipe bowl water samples from Al-mahmoud, Al-Fakher, Nakhla, Mazaya, and traditional tobacco ranged from 0.37 (Cd) to 3.36 (Pb); 0.33 (Cd) to 3.27 (Pb); 0.34 (Cd) to 3.02 (Cr); 0.24 (Cd) to 3.09 (Cr), and 1.38 (Cd) to 6.24 (Pb) µg/L, respectively. The mean levels of all toxic metals (except As) in different fruit-flavored tobacco brands and traditional waterpipe bowl water samples were significantly different ($P<0.05$).

Conclusion: The results showed that toxic metal concentrations in waterpipe bowl water vary significantly among different tobacco brands and tobacco types. This highlights the need for monitoring and regulation of toxic metal content in waterpipe tobacco products to reduce potential health risks to users and environment.

Keywords: Environmental pollutants, Toxic metals, Waterpipe bowl water, Tobacco

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Introduction

Waterpipe smoking has become an important overall health concern in various counties including the United States, Eastern Mediterranean countries, and Eastern Europe (1-6). The inhalation of hookah smoke involves drawing air heated by charcoal over tobacco, producing smoke that passes through water to cool and humidify it before entering the lungs. This cooling effect leads users to inhale larger amounts of smoke more deeply and for longer durations (30 to 90 minutes), causing greater exposure to harmful substances than cigarette smoking. Continuous exposure to heavy metals and toxic chemicals in this smoke significantly elevates the risk for respiratory diseases, cancers, and cardiovascular problems due to inflammation, oxidative stress, and direct toxic effects on lung and other tissues (7,8).

Different tobacco products (i.e. traditional and fruit-flavored tobacco) are smoked by the waterpipe device (9). Each waterpipe device consists of four constituent including hose, mouthpiece, stem, and water bowl (10). The tobacco products burn through user puffs and the produced smoke filtered inside the bowl and inhaled through the hose (9). Waterpipe smoking, produces smoke that contains a variety of harmful chemicals (9,11). Therefore, when the smoke passes through the water in the waterpipe bowl, some of chemical contents

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are released in the bowl water and this water would be the possible source of pollutants (12,13). These chemicals are classified as "toxic" or "very toxic" for aquatic life and are hazardous waste per environmental regulatory agencies (14). In addition to numerous health hazards of waterpipe smoking, the environmental impact of waterpipe smoking is significant primarily due to the disposal of waste generated during and after the smoking sessions (9,10,15,16).

Previous studies have shown that waterpipe water contain quantities of toxic chemicals, including heavy metals(11,17), polycyclic aromatic hydrocarbons (PAHs) (10,17), BTEX (benzene, toluene, ethylbenzene and xylene) (11), and primary aromatic amines (16). These chemicals are released into environment and can pose serious health risks (16) and the concentrations of chemicals in the waterpipe bowl water after smoking are worryingly high. The adverse environmental effects of post-consumer tobacco waste have attracted increasing attention in recent tobacco field studies. Research and regulatory efforts aimed at reducing the environmental impact of tobacco product residues have predominantly focused on cigarettes (18-22), but the broader implications of tobacco products on the environment are significant and multifaceted.

The discharge of waterpipe bowl water into the environment poses significant environmental threats, impacting freshwater systems, aquatic ecosystems, and human health (10,16,23,24). Toxic wastewater released into aquatic bodies may have adverse effects on marine/aquatic organisms (25). Therefore, examining the number of toxic compounds in post-consumption waterpipe bowl water is of great importance. In the present study, the content of some toxic metals such as Pb (Lead), Cd (Cadmium), Cr (Chromium), As (Arsenic), and Ni (Nickel) in the traditional waterpipe bowl water and fruit-flavored waterpipe bowl water samples was examined. This study presented a novel comparison of toxic metals in bowl water from traditional and fruit-flavored waterpipe tobaccos, emphasizing environmental impacts rather than solely health effects. It reveals waterpipe bowl water as a notable source of chemical pollution entering aquatic environments, addressing an overlooked area by highlighting ecological risks of disposal. This research broadened tobacco control focus to include environmental contamination alongside public health.

Materials and Methods

In this study, 10 canteens in Bandar Abbas city where waterpipe was used randomly selected for sampling. After a field survey in the Bandar Abbas city market and inquiries from suppliers, the most recognized brands of fruit-flavored tobacco were Al-mahmoud, Al-Fakher, Nakhl, and Mazaya brands, and the most recognized flavors were Dosib, mint-gum blueberry, and cream orange. The sample size was based on the Dehvari et al. study (17). After visiting hookah shops in Bandar Abbas city, 100 ml waterpipe bowl water samples were collected from each mentioned brands and flavors (4 brands × 4 flavors × 5 samples for each flavor = 80 samples). In addition to fruit-flavored waterpipe bowl water samples, 10 samples of traditional waterpipe bowl water were also collected (Figure 1). All samples were placed in appropriate glass containers, wrapped in foil and transported to the laboratory in an ice box; and the pH of the samples was lowered below 2 by adding nitric acid and kept at 4°C until analysis. It should be mentioned that all waterpipe bowl water samples were at the end of a one smoking session.

ICP Instrumentation

A mixed standard solution containing the elements—Cd, Pb, Ni, As, and Cr— was prepared using standard stock solutions originally concentrated at 1000 µg/L (ppb). To generate the calibration curve, the stock solution was progressively diluted using ultrapure water (Milli-Q) to reach concentrations of 0.1, 0.5, 1, 5, 10, and 50 µg/L. For each concentration, the analyzed signal was noted with an ICP-MS device and calibration curves were prepared for all metals with a coefficient of determination (R^2) greater than 0.995, guaranteeing the accuracy and precision of the quantifications. The levels of toxic metals in waterpipe bowl water samples were analyzed using an ICP-MS (7500CE single quadrupole, Agilent, USA) equipped with a Babington nebulizer. The samples were injected to a high purity argon plasma (0.1 rpm). Li, Y, Ce, and Tl were used to tune the ICP-MS parameters (Table S1). An internal standard containing Bismuth (Bi), Indium (In), Scandium (Sc), Terbium (Tb), and Yttrium (Y) was added to each sample before analysis. All tests were done in triplicate. The limit of detection (LOD) and limit of quantitation (LOQ) were determined. The levels of LOD and LOQ are provided in the supplementary (Table S2) . These values were in the range of 0.02 (Cd)-0.80 (Ni) and 0.06 (Cd)-2.61 (Ni) ppb for toxic metals, respectively. The recovery rates of target elements in the hookah bowl water samples are presented as follows: Cd at 94.41%, Pb at 97.91%, Ni at 95.44%, As at 74.69%, and Cr at 89.93%. As can be seen, all values lying within the experimentally acceptable range of 60 to 115%.

Results

The mean levels of toxic metals in clean water are presented in Table S3. The concentration of metals was significantly different from the metal content of the traditional waterpipe bowl water and fruit-flavored waterpipe bowl water samples ($P < 0.05$). The comparison of heavy metal levels before and after using the waterpipe in the water bowl revealed a significant increase, with the average concentration of metals rising noticeably. The mean levels of toxic metals in the traditional waterpipe bowl water and fruit-flavored waterpipe bowl water samples are represented in Table 1. The mean levels of toxic metals in waterpipe bowl water samples from Al-mahmoud, Al-Fakher, Nakhla, and Mazaya brands tobacco ranged from 0.37 (Cd) to 3.36 (Pb); 0.33 (Cd) to 3.27 (Pb); 0.34 (Cd) to

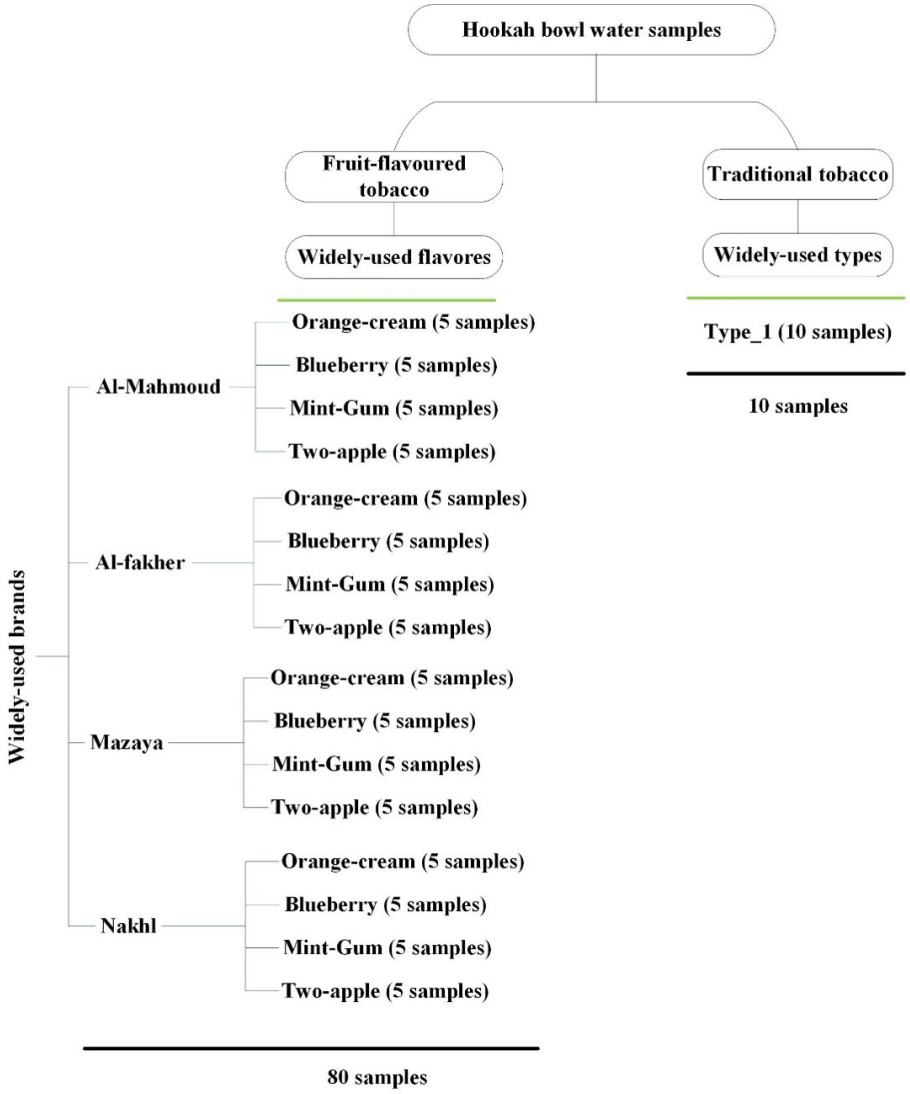

Figure 1. The study design and sample size of both traditional and fruit-flavoured waterpipe bowl water samples

Table 1. The mean ± SD concentration levels (µg/L) of heavy metals in the traditional and fruit-flavored waterpipe bowl water (different brands) samples

Brands	Cd	Pb	Cr	As	Ni
Al-mahmoud	0.37 ± 0.18	3.36 ± 0.79	3.26 ± 1.20	0.38 ± 0.16	1.46 ± 0.39
Al-Fakher	0.33 ± 0.16	3.27 ± 0.66	3.07 ± 1.02	0.41 ± 0.18	1.52 ± 0.30
Nakhl	0.34 ± 0.14	2.95 ± 0.49	3.02 ± 0.96	0.41 ± 0.21	1.68 ± 0.65
Mazaya	0.24 ± 0.08	2.90 ± 0.44	3.09 ± 0.75	0.37 ± 0.14	1.73 ± 0.65
Traditional	1.38 ± 0.42	6.24 ± 0.55	5.14 ± 0.65	1.56 ± 0.32	2.95 ± 0.50

3.02 (Cr) and 0.24 (Cd) to 3.09 (Cr) µg/L, respectively. In the case of traditional waterpipe bowl water samples, the mean levels of toxic metals ranged from 1.38 (Cd) to 6.24 (Pb) µg/L. The box plot view of toxic metals concentration (µg/L) in the traditional waterpipe bowl water and fruit-flavored waterpipe bowl water samples are shown in Figure 2. This box plot compares the concentrations of five heavy metals including Cd, Pb, Cr, As, and Ni in two types of waterpipe bowl waters: fruit-flavored tobacco (top panel) and traditional tobacco (bottom panel). In fruit-flavored waterpipe bowl waters, Cd and As had relatively low concentrations, with medians around or below 1.0. Pb and Cr had higher concentrations; medians around 3–4, with Pb and Cr exhibiting notable spread and several outliers. Ni had moderate concentrations, generally lower than Pb/Cr but higher than Cd/As. The Cd and As concentration in traditional waterpipe bowl waters was slightly higher than that in fruit-flavored overall, especially for Cd. Also, the Pb and Cr concentrations in traditional waterpipe bowl waters were significantly higher than those in the fruit-flavored tobacco; with medians well above 5.0. But Ni concentration was higher in traditional tobacco, with a median above 3.0. The traditional tobacco samples generally show higher concentrations of all five metals compared to fruit-flavored tobacco, especially for Pb and Cr. Fruit-flavored tobacco exhibits more frequent outliers in the lower concentrations of metals (Cd, As, Ni), suggesting variation among samples. Traditional

tobacco consistently has high concentrations and less spread, indicating less variation but elevated levels across all metals sampled.

The mean concentration levels of toxic metals in the traditional waterpipe bowl water and fruit-flavored waterpipe bowl samples are presented in Table 2. The mean concentration of toxic metals in the fruit-flavored waterpipe bowl samples from Dosib, mint-gum, blueberry, and orange-cream flavors, and traditional waterpipe bowl water samples ranged from 0.31 (Cd) to 2.98 (Pb), 0.30 (Cd) to 3.38 (Pb), 0.28 (Cd) to 3.72 (Cr), 0.33 (As) to 3.48 (Cr), and 1.38 (Cd) to 6.24 (Pb) µg/L, respectively.

The comparison of toxic metals concentration levels in the traditional waterpipe bowl water and fruit-flavored waterpipe bowl water samples (different brands) are summarized in Table 3. The average levels of all toxic metals (except As) in different brands and traditional tobacco were significantly different ($P<0.05$). The findings show that the concentrations of toxic metals (except As) in the traditional waterpipe bowl water samples were significantly higher than those in the fruit-flavored waterpipe bowl water samples (different brands). The multiple/post-hoc group comparisons of toxic metals concentrations in the fruit-flavored waterpipe bowl water (different brands) and traditional waterpipe bowl water samples also are presented in Table S4. As shown in this table, the concentrations of all toxic metals (except As) in the traditional waterpipe bowl water samples were significantly different from those in the fruit-flavored waterpipe bowl water samples (different brands).

The comparison of toxic metals levels in the fruit-flavored waterpipe bowl water samples (different flavors) and traditional waterpipe bowl water samples are summarized in Table 4. The average levels of all toxic metals (except As) in the fruit-flavored waterpipe bowl (different flavors) and traditional waterpipe bowl water samples were significantly different ($P<0.05$). The findings show that the concentrations of toxic metals (except As) in the traditional waterpipe bowl water samples were significantly higher than those in the fruit-flavored waterpipe bowl water samples (different flavors). The multiple/post-hoc group comparisons of toxic metals concentration levels in the fruit-flavored waterpipe bowl (different flavors) and traditional waterpipe bowl water samples are presented in Table S5. As shown in this table, the concentrations of all toxic metals (except As) in the traditional waterpipe bowl water samples were significantly different from those in the fruit-flavored waterpipe bowl (different flavors) samples.

Discussion

The content of toxic metals (Pb, Cd, Cr, As and Ni) in the traditional waterpipe bowl water and fruit-flavored waterpipe bowl samples were examined. The

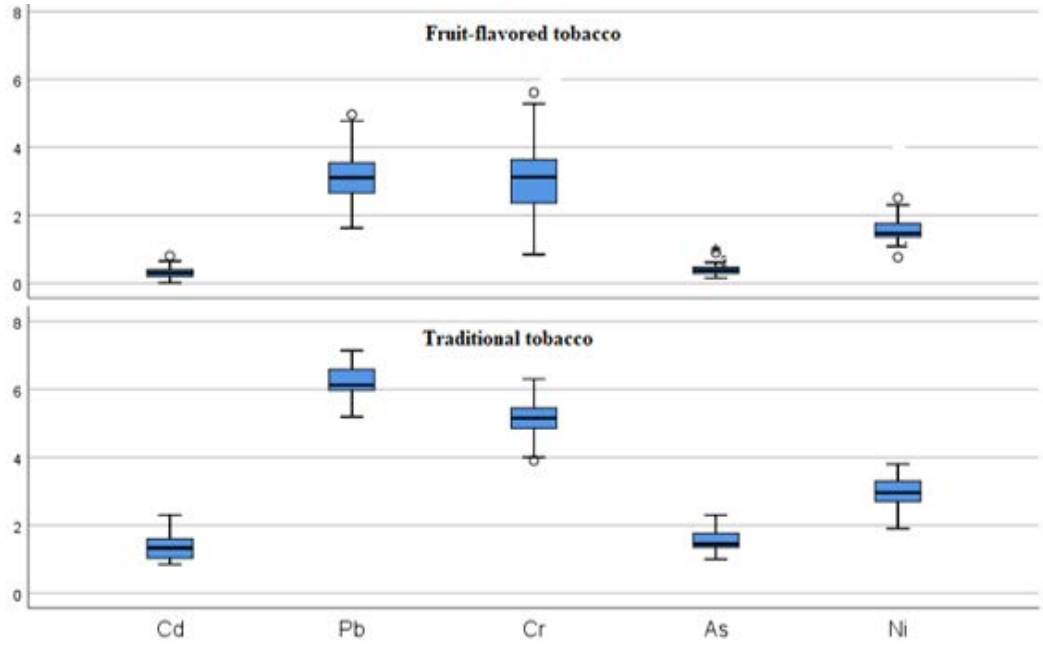

Figure 2. The toxic metal concentration (µg/L) in the traditional and fruit-flavored waterpipe bowl water samples

Table 2. The mean ± SD concentration levels (µg/L) of heavy metals in the traditional and fruit-flavored waterpipe bowl water (different flavors) samples

Flavors	Cd	Pb	Cr	As	Ni
Dosib	0.31 ± 0.06	2.98 ± 0.45	2.08 ± 0.7	0.43 ± 0.27	2.05 ± 0.87
Mint-Gum	0.30 ± 0.19	3.38 ± 0.88	3.16 ± 0.81	0.48 ± 0.10	1.50 ± 0.19
Blueberry	0.28 ± 0.17	2.95 ± 0.67	3.72 ± 1.27	0.33 ± 0.13	1.31 ± 0.22
Orange-cream	0.37 ± 0.14	3.18 ± 0.45	3.48 ± 0.34	0.33 ± 0.09	1.53 ± 0.22
Traditional	1.38 ± 0.42	6.24 ± 0.55	5.14 ± 0.65	1.56 ± 0.32	2.95 ± 0.50

Table 3. The comparison of toxic metals concentration levels in the traditional and fruit-flavored waterpipe bowl water (different brands) samples

		Sum of Squares	df	Mean Square	F	*P*-value
Pb	Intergroup	127.083	4	31.771	82.845	<0.001
	Intragroup	28.762	75	0.383		
	Total	155.846	79			
Cd	Intergroup	13.929	4	3.482	19.385	<0.001
	Intragroup	13.472	75	0.180		
	Total	27.401	79			
As	Intergroup	33.288	4	8.322	1.080	0.372
	Intragroup	577.847	75	7.705		
	Total	611.135	79			
Cr	Intergroup	53.104	4	13.276	14.187	<0.001
	Intragroup	70.185	75	.936		
	Total	123.289	79			
Ni	Intergroup	24.080	4	6.020	21.092	<0.001
	Intragroup	21.406	75	0.285		
	Total	45.486	79			

Table 4. The comparison of toxic metals concentration levels in the traditional and fruit-flavored waterpipe bowl water (different flavors) samples

		Sum of Squares	df	Mean Square	F	*P*-value
Pb	Intergroup	124.725	4	31.181	75.147	<0.001
	Intragroup	31.120	75	0.415		
	Total	155.846	79			
Cd	Intergroup	14.276	4	3.569	20.394	<0.001
	Intragroup	13.125	75	0.175		
	Total	27.401	79			
As	Intergroup	39.214	4	9.803	1.286	0.283
	Intragroup	571.922	75	7.626		
	Total	611.135	79			
Cr	Intergroup	54.415	4	13.604	14.814	<0.001
	Intragroup	68.874	75	0.918		
	Total	123.289	79			
Ni	Intergroup	24.623	4	6.156	22.130	<0.001
	Intragroup	20.863	75	0.278		
	Total	45.486	79			

concentrations of all toxic metals (except As) in the traditional waterpipe bowl water samples were significantly different from those in the fruit-flavored waterpipe bowl samples (different brands and flavors). The absence of a significant difference in the As levels could indicate that arsenic contamination sources are consistent across both types of waterpipe bowls, likely originating from baseline environmental or raw material factors rather than the flavoring agents. However, the varying levels of other toxic metals demonstrate that the introduction of fruit flavorings may alter the exposure risk profile for users. The higher levels of toxic metals in traditional waterpipe bowl water samples could probably be associated to agriculture soil contents, because the presence of heavy metals in soil directly correlates with their concentration in tobacco leaves. Soils with higher metal contents will generally produce tobacco with elevated levels of these contaminants (26-30). It has been also reported that the levels of metals in tobacco indeed vary significantly based on the geographical area of production (31).

In a study by Yousefinejad et al (2017), Pb, Cd, and As were detected in the waterpipe water bowl samples (32). In another study by Jafari et al (2020), the levels of Pb, Cd, Ni, and Cr were higher than those in our results, while the level of As was lower (11). Different compounds have been investigated in waterpipe bowl water. For example, in a study by Rashidi et al (2024), the concentrations of PAHs and BTEX compounds in the fruit-flavored tobacco waterpipe (FWP) bowl water samples were higher than those in the traditional tobacco waterpipe bowl water samples, and these values were higher than water quality standards set by the World Health Organization (WHO) and other international organizations (10). In another study by Heydari et al (2024), the mean concentrations of primary aromatic amines in the fruit-flavored waterpipe bowl water samples were considerably greater than those in the traditional tobacco water samples (16). Due to the appearance characteristics, broad leaves, and fast growth of the tobacco plant, the possibility of absorbing various pollutants in this plant increases (29). Another reason for the presence of toxic metals in tobacco and hookah bowl water can be due to the use of agricultural materials (fertilizers and pesticides) containing these compounds in the cultivation stages, which are absorbed by the plant (29,33). Fertilizers, especially phosphate fertilizers, and pesticides used in tobacco cultivation typically contain elevated concentrations of heavy metals (34,35). Their repeated and large-scale application enriches the soil with these metals, thereby increasing the metals available for plant uptake (35,36).

In a study by Taati et al (2020), the main source of toxic metals (i.e. Pb and Cr) was the charcoal used for hookah smoking (37). Studies have identified that waterpipe/hookah charcoal contains substantial amounts of these heavy metals, which can increase in concentration upon burning and contribute significantly to the exposure of smokers and environmental contamination (37-40).

Tobacco plants are known for their high capacity to absorb and accumulate toxic metals from the soil (41), which poses significant health risks to consumers. The accumulation of these metals occurs through various mechanisms, primarily involving the uptake of metal ions from contaminated soil or deposition from the air onto the leaves (41). Regarding cation exchange capacity (CEC), which is a measure of soil's ability to hold and exchange cations essential for plant nutrient uptake and heavy metal binding, tobacco fields tend to show varying CEC values. Studies indicate tobacco soils can have different CEC compared to non-tobacco soils, influencing the retention and mobility of heavy metals affecting absorption by tobacco plants. CEC is typically measured by ammonium acetate extraction at pH 7.0

and is critical in understanding how soils affect heavy metals uptake by tobacco (42). Heavy metal absorption by tobacco is rapid initially and can be influenced by soil amendments or treatments like biochar, which may reduce metal bioavailability to the plant. The rate also depends on metal concentration, soil pH, and the plant's physiological factors (43). Water quality and irrigation methods can influence heavy metal accumulation by introducing metals from polluted water sources or altering soil chemistry (44). Also, heavy metals released into the atmosphere from industrial pollution, vehicle exhaust, and other anthropogenic sources can settle on tobacco leaves, further increasing metal concentrations (45). The location-specific environmental conditions and pollution levels result in variations in heavy metal contamination in tobacco grown in different regions (44). Tobacco plant physiology have also the inherent ability to absorb and translocate metal ions from soil to leaves, where they accumulate.

Tobacco leaves have a high ability to absorb some toxic metals from the soil, and the processing of tobacco leaves enriches the metal content (17,46). The content of heavy metals in waterpipe water is caused by tobacco and charcoal (38,40), which enter the water bowl through waterpipe smoke (17). In a study by Al-Kazwini et al. (2015), it was reported that 3% of the metals in tobacco were released into hookah water (47), and others released in different compartments of the waterpipe setup including smoke, ash (47), and even burnt tobacco. Although only a small fraction (about 3%) may transfer into the waterpipe bowl water and have limited environmental impact, this finding indicates that waterpipe water does not protect users from exposure to the majority of potentially toxic metals.

International Association for Research in Cancer (IARC) has classified several heavy metals as human carcinogens specifically Cd, As, Cr, Ni, and Pb. The order of toxic metals levels in the both fruit-flavored and traditional waterpipe bowl water samples were Pb > Cr > Ni > As > Cd. In addition to numerous health hazards of waterpipe smoking, the environmental impact of waterpipe smoking is primarily significant due to the disposal of waste generated during and after the smoking sessions (9,10,16,48,49). The waste materials from the waterpipe smoking (i.e. bowl water, burnt tobacco, charcoal, and ash) are discarded after smoking (17). Heavy metal concentrations in waterpipe bowl water rise after smoking and may harm users' health via smoke inhalation and direct contact with the contaminated water. As a result, the chemicals of waterpipe waste materials (bowl water and/or burnt tobacco) are released into the environment and becomes a significant source of environmental contamination (9,10,16,48,49). These toxic compounds enter different matrix such as water, soil, and sediment, and can disturb the ecosystem (17). Toxic metals in aquatic environments pose significant risks to living organisms even at low concentrations (49). Toxic metals' ability to accumulate and persist in the environmental matrix makes it critical to monitor and manage metals contamination to protect aquatic organisms and human health. The attention to these challenges needs a complete understanding of the sources, toxicity mechanisms, and environmental effects of metals in aquatic organisms.

Conclusion

The concentrations of toxic metals were determined in the fruit-flavored waterpipe bowl (different flavors and brands) and traditional waterpipe bowl water samples. The present study showed that the concentration of toxic metals (except As) in the traditional waterpipe bowl water samples was significantly higher than that in the fruit-flavored waterpipe bowl samples. This study highlights the environmental hazards of waterpipe bowl water and their potential impacts on environmental health. Based on the current data and smoking patterns in different regions, the environmental impacts of waterpipe bowl water may seem insignificant, but further studies are needed to estimate the environmental impacts of waterpipe smoking and subsequent disposal of post-consumer wastes (waterpipe bowl water and burnt waste). Regarding the spread of waterpipe consumption among the beach visitors, the discharged waterpipe bowl water may contain toxic chemicals that may leach into the water and sediment resources especially in coastal areas, and subsequently, cause environmental pollution, affect aquatic organisms, and threaten life below water.

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Formal Analysis: Farshid Soleimani, Hossein Arfaeinia.
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Investigation: Farshid Soleimani, Hossein Arfaeinia, Ammar Maryamabadi.
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Supervision: Farshid Soleimani.
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Writing–Original Draft: Hossein Arfaeinia.
Writing–Review & Editing: Hossein Arfaeinia, Sara Dadipoor, Farshid Soleimani, Vali Alipour, Ammar Maryamabadi, Hamid Reza Ghaffari, Fatemeh Barzin.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval

This study was approved by the Ethics Committee of Hormozgan

University of Medical Sciences (Ethical code: IR.HUMS.REC.1403.015).

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Supplementary Files
Supplementary file 1 contains Tables S1-S5.

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