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Performance evaluation of point of use water treatment system in health risk reduction of trace metals in drinking water

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ABSTRACT

In this study, the concentrations of six trace metals (TM) are determined in tap water and point of use water treatment system (POU-WTS) water samples of Tehran city. The non-carcinogenic risk with ingestion TM was also assessed in four groups including an infant, children, women, and men. Average concentrations of Cr, Cu, Fe, Mn, Ni, and Zn were 6.03, 12.64, 21.20, 1.42, 2.13, and 291.80 µg/L, respectively in tap water and 1.27, 7.76, 8.59, 0.76, 1.16, and 136.11 µg/L in POU system. All these values were below the permissible limit of WHO and EPA. Cluster analysis result revealed that anthropogenic activities and pipeline corrosion were major source of tap water pollution. The highest hazard quotients (HQ) in the tap water and POU system among trace metals studied were associated to Cr and Zn. The order of hazard Index (HI) in different groups was children > infants > women > men in both two water types. HI in children was more than twice in comparison with other groups, indicating that the children were more vulnerable to TM exposure. Index of HQ and HI was lower than 1.0, suggesting that TM posed negligible hazards to the public health of Tehran residents. Since total HI of the POU-WTS for each group was significantly lower HI of tap water, suggesting that the use of POU-WTS can effectively reduce the non-carcinogenic risk.

Keywords: Trace metals; Point-of-use water treatment system; Tap water; Non-carcinogenic risk; Hazard quotient

1. Introduction

Access to secure drinking water (DW) which has been highlighted in sustainable development goal (SDG) 4, is the right of all humans [1]. In developing countries, lack of access to fresh DW is adversely affecting the general health [2]. World Health Organization (WHO) confirms on the protection of public health by accessing to safe drinking water in its guidelines [3]. Hence, further efforts are needed to provide the DW as safe as possible without any human health risk [4]. Environmental pollution and human exposure to trace metals (TM) are a serious problem in many areas of the world [5].

The TM are remarkable due to their high toxicity in low concentrations [6]. Several studies have shown that exposure to TM are associated with acute damage to human health such as anemia, hypertension and the serious effect on kidneys, lungs, and bones [7]. Some of TM such as copper (Cu), cobalt (Co) and zinc (Zn) are useful for the human body in low doses and can catalyse enzyme activities. However, they are toxic in high doses [8,9]. The TM discuss

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as acute contaminant due to their toxicity, persistent and bio-accumulative character in the ambient [10]. A specific value of Cr is required for general body functions; while its high concentrations lead to toxicity to the organs of the body, such as kidney and liver disorder and carcinogen [10]. High level of Mn and Cu caused mental illness such as Alzheimer in DW [11]. According to Bouchard et al. the high Mn contamination in DW also affects the intellectual functions of 6–13-year-old children [12]. Similarly, the Ni-sulfate and Ni-chloride uptake can cause fetal cardiac arrest [13].

Although clean DW supply is available, compromised public pipes, old distribution systems, and the introduction of anthropogenic contaminants can lead to unsafe DW at the tap. Because of a lack of infrastructure to provide DW, consumers in the developing countries must find alternate strategies to ensure safe DW in the household [14]. Point-of-use water treatment system (POU-WTS) is an alternative to reducing exposure to DW contaminated with TM in the tap water [15,16]. Researchers proposed to improve the quality of DW at the point of use (POU) is more effective than enhances at source treatment plants in achieving a significant decrease in waterborne disease [17]. These systems are a smaller-scale version, which are usually located under the kitchen sink and treat only one tap. POU system represents one of the fastest-growing drinks market in Iran especially in capital of Iran, Tehran. According to a 2002 survey, 37% of Americans use some kind of domestic filtering device. In a study of central Maine residents with well water arsenic (As) levels above, more than 65% of respondents indicated they were using POU system to reduce exposure of As [18]. These devices differ in the types of filter media used, chemicals to be removed, location within the home, ease of operation cost per unit of filter medium maintenance and operating costs. Some of the materials used in the filter media of these devices include activated carbons, ion exchange resins and reverse osmosis (RO) filters [19,20]. However, filter systems with RO filter or activated carbon are the most widely used. The past surveys showed that POU-WTS based on RO filter had been shown relatively to be effective in remove hazardous contaminants [21,22]. This study was conducted to determine (1) concentration of six TM (Cr, Cu, Fe, Mn, Ni, and Zn) in tap water and output water of POU-WTS of Tehran city, (2) estimate and compare non-carcinogenic risk for different group of Tehran city, (3) potential effectiveness POU-WTS in reduction the non-carcinogenic from TM in DW of Tehran.

2. Materials and methods

This study was conducted in two phases: (1) water quality investigation of most common five brands of six stages POU system in 100 water sampling zones and POU consumer households of selected city, the capital of Iran (Fig. 1) [23], (2) Performance evaluation of POU water treatment systems for TM removal and reduction of health risk.

2.1. Sample collection and analysis

The samples in the present study include (1) tap water, (2) output water of five POU-WTS brands. A total of 200 water samples were analyzed, consisting of 100 samples of tap water and 100 output water samples of the POU-WTS. At the sampling site, the polyethylene sampling bottles were rinsed several times before sampling was done. The water samples were filtered through a 0.45 mm filter at the time

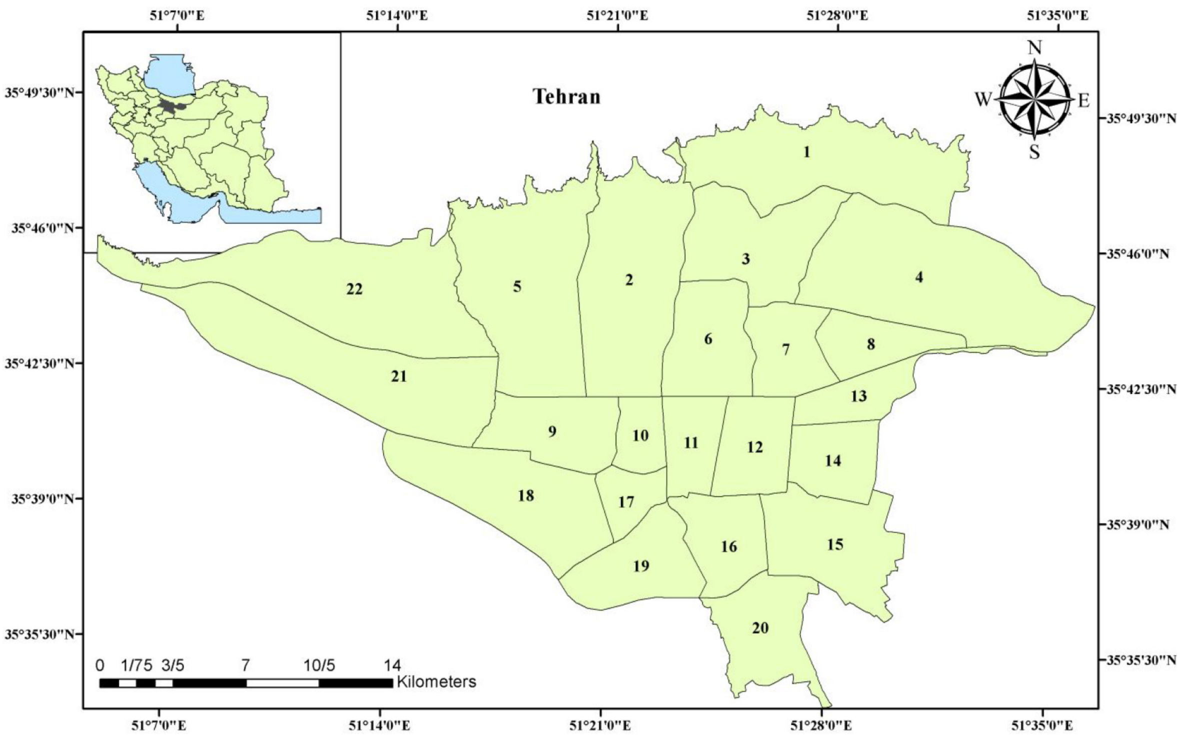

Fig. 1. Map of location of Tehran city in Iran and its regions.

of collection and were transferred into polyethylene bottle. They were acidified immediately using HNO_3 63% (W/W) to pH ≤ 2. The TM measurement method was based on the Standard Method [24], and was analyzed by inductively coupled plasma-mass spectroscopy (ICP-MS; Perkin Elmer, model 730-ES) [24]. A water standard reference material (SRM 1640e; National Institute of Standards and Technology, NIST, USA) was studied to support quality assurance and quality control (QA/QC) of water sample measurements. Replicate analysis of these reference materials showed a fine accuracy, with recovery ranging from 95–105% with a standard deviation of ±5%. Triplicate analyses of blanks, spike samples, and reference materials varied from each other within an acceptable range of ±15%. Relative standard deviation (RSD) values of all elements were found (less than 5%). The detection limits (LOD) in μg L^{-1} based on three times the standard deviation of the blank signal was 0.01, 0.01, 0.03, 0.05, 0.06 and 0.06 for Ni, Mn, Cr, Fe, Cu and Zn, respectively [25].

2.2. Statistical analysis

All the statistical analyses were performed using SPSS 16.0 and Excel software, and a p-value of less than 0.05 represents a significant difference between groups (confidence level 95%). One-way analysis of variances (ANOVA) was performed to the data comparison of the national and international authorities, across the POU-WTS brands with each other. Hierarchical cluster analysis (HCA) was performed on data to identify homogenous groups. The Ward's method was used to obtain hierarchical associations. A dendrogram was also created to assess the relation of the clusters formed. Pearson's correlation was applied to describe the degree of relation between the all parameters.

2.3. Health risk assessment

The potential non-cancer risk assessment for TM may be described with a hazard quotient (HQ). The potential ingestion risks were calculated for four population subgroups i.e. infant, children, adult women and men. In this study, reference dose (RfD) used to calculate the HQ and HI values were: 3, 40, 300, 20, 20, and 300 μg/kg/d for Cr, Cu, Fe, Mn, Ni, and Zn, respectively [26]. water consumption (ingestion) have been calculated based as one central ways of metals exposure to human on the Chronic Daily Intake (CDI Ingestion), Hazard Quotient (HQ ingestion), and Hazard Index (HI Ingestion) equations. These equations were computed to evaluate the degree of ingestion rate of TM in a human body through water according to USEPA, which is given below:

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

$$HQ = \frac{(Intake)}{(R_f D)} \quad (2)$$

where C: TM concentration in tap water and POU-WTS (μg/L), IR: ingestion rate in this study (2.2 L/d for adults; 1.8 L/d for children and 0.3 L/d for infant); EF: is exposure frequency (365 d/y), ED: exposure duration (30 y for adults; 12 y for children and 1 y for infants); BW: average body weight (58 kg for men; 52 kg for women, 15 kg for children and 5 kg for infants); AT: averaging time (365 d/y × 30 y for an adult; 365 d/y × 12 y for a child and 365 d/y × 1 y for infant) [27].

The details about input parameters such as IR, EF, ED, BW, AT and RfD to derive the intake values and risk are explained in Table 1. Furthermore, Hazard Index (HI) values for the integrated risk of TM in tap water and POU-WTS were obtained by addition of total HQ value of each trace metal [Eq. (3)]. Obtained results of these indices less than (<1) is considered as no risk for human health but higher than one (>1) is considered as long term health hazard effects of heavy metals on human health [28].

$$HI = HQ_{Cr} + HQ_{Cu} + HQ_{Fe} + HQ_{Mn} + HQ_{Ni} + HQ_{Zn} \quad (3)$$

3. Results and discussion

3.1. Trace metal (TM) concentration in DW

3.1.1. TM concentration in tap water

In this study, the concentration of six trace metals (TM) in tap water samples and output water samples of POU-WTS in Tehran city (Iran) were determined in μg/L and compared with USEPA and WHO guidelines (Fig. 2). The TM concentrations in tap water samples were relatively high and in some samples were seven times larger than the POU-WTS water samples. For instant, Cr, Cu, Fe and Ni has the mean value of 6.03, 12.64, 21.2 and 2.1 μg/L which were 5, 7, 2.5 and 2.6 times larger than the value of POU-WTS brands (1.24, 1.79, 8.59 and 0.8 μg/L, respectively, Table 2 and Fig. 2). The mean value of Mn was 1.4 μg/L (2.5 times larger than the value of 0.56 in POU-WTS), while the mean value of Zn was 291.8

Table 1
Input assumption parameters to derive the intake value and RfDs for the risk assessment due to exposure to DW [27]

Parameters	Value	TM	RfD (μg/kg/d)
Body weight, as BW	5 kg for infant	Cr	3
	15 kg for children		
	52 kg for women		
	58 kg for men		
Exposure frequency, as EF	365 d y^{-1}	Cu	40
Exposure duration, as ED	1 y for infant	Fe	300
	12 y for children		
	30 y for adults		
Average time as AT	EDX 365 y	Mn	20
Daily water intake as IngR	0.3 L/d for infant	Ni	20
	1.8 L/d for children		
	2.2 L/d for adults		
		Zn	300

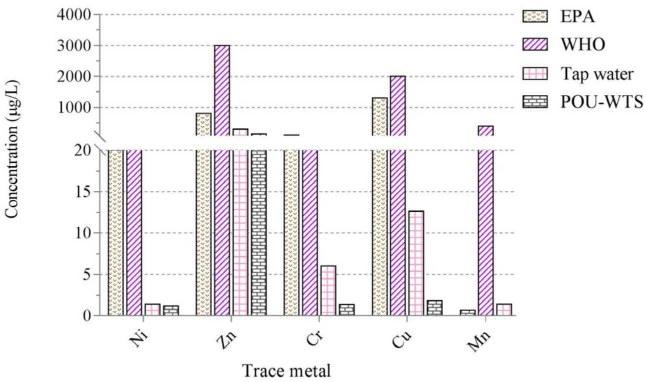

Fig. 2. Comparison of TM concentration in water samples of the tap water and POU-WT with EPA and WHO.

μg/L in tap water samples, nearly two times larger than the Zn in POU-WTS (136.10 μg/L) (Table 2 and Fig. 2). In all TM, the obtained mean concentrations in tap water was smaller than the value reported by Javed Nawab [29].

3.1.2. TM concentration in POU-WT water samples

The TM concentrations in 5 selected brands of POU-WT water samples (B1, B2, B3, B4, and B5) have been shown in Table 2 and Fig. 2. The highest (1.42 μg/L) and lowest (1.12 μg/L) mean concentrations for Cr were in B3 and B1, respectively. Moreover, Maximum (2.11 μg/L) and minimum (1.45 μg/L) mean concentrations of Cu were in B3, and B1 respectively. Furthermore, For Fe, The highest (12.08 μg/L) and lowest (6.62 μg/L) were in B3 and B2, respectively. According to our results, the maximum (140.03 μg/L) and minimum (130.17) mean concentrations of Zn were detected in B3 and B4, respectively. Also, the highest (1.41 μg/L) and lowest (1.22) mean Ni concentrations were found in B2 and B3. Besides, the highest (1.26 μg/L) and lowest (0.23 μg/L) mean concentrations of Mn was found in B3 and B2, respectively. The value of Ni and Mn was not observed in the brand of B5 and B1, respectively. In all POU-WTS water samples, the concentrations of all selected trace metals were lower than maximum contaminations level (MCL) listed by EPA and WHO. Mirzabeygi et al., quantified three metals in DW of Sistan and-Baluchistan at southeastern Iran and found that Pb was of the highest concentration [30]. In another research by Fallahzadeh et al., Ni was not recognized in DW of Ardakan while the Pb was not seen in DW of Abarkouh, Meibod, and Bafgh. Totally, As, Cd, and Hg were found in none of the samples; Cr, Cu, Fe, Mn and Zn were seen in 100% of the samples; and Ni and Pb were found in 58.92 and 10.25% of the samples, respectively [6].

3.2. Statistical analysis

No significant difference (P > 0.05) was obtained for the average concentrations of the TM between brands of POU-

Table 2
Concentration of TM (μg/L) in water samples of the tap water and POU-WT.

Parameters	Statistics	Tap water (n = 100)	Brand				
			B1 (n = 25)	B2 (n = 25)	B3 (n = 25)	B4 (n = 25)	B5 (n = 25)
Cr	Range	2.30–10.30	0.92–1.43	0.86–1.52	0.90–1.62	0.81–1.48	0.87–1.43
	Mean	6.03	1.12	1.20	1.42	1.30	1.31
	SD	0.84	0.07	0.20	0.12	0.05	0.13
Cu	Range	1.40–95	0.74–1.64	1.15–2.30	0.87–2.73	0.72–1.85	0.71–1.76
	Mean	12.64	1.45	1.63	2.11	1.88	1.75
	SD	0.72	0.81	0.55	1.31	1.33	1.04
Fe	Range	7.30–47.12	1.24–7.24	0.97–7.14	1.67–14.80	1.57–10.64	1.63–8.74
	Mean	21.20	7.23	6.62	12.08	9.14	7.89
	SD	2.64	4.42	2.89	5.73	3.71	2.48
Zn	Range	153–454	85–142	91–157	108–197	82–153	89–167
	Mean	291.80	138.95	137.65	140.03	130.17	133.75
	SD	10.40	13.09	14.05	14.91	12.95	12.22
*Ni	Range	ND–2.40	0.2–1.62	0.31–1.65	0.72–2.13	0.43–1.67	ND
	Mean	2.13	0.81	1.41	1.22	1.23	ND
	SD	0.05	0.35	0.91	0.81	0.082	ND
Mn	Range	ND–2.00	ND	0.20–1.14	0.31–1.50	0.33–1.41	0.32–1.51
	Mean	1.42	ND	0.20	1.26	1.18	0.43
	SD	0.46	ND	0.11	0.86	0.81	0.23

*P-value is significant at the 0.05 level.
** ND not detected

WTS except Ni (Table 2). Tables 3 and 4 have been indicated the Pearson's correlation between TM in water samples of tap water and POU-WTS, respectively. A significant correlation was found between Ni and Zn (r = –0.2) in samples tap water, while no significant correlation were showed in water samples of POU-WTS. Hierarchical cluster analysis (HCA) was performed on the trace metals in both tap water and POU system samples. The results are illustrated in the dendrograms (Fig. 3). The degree of association between the TM is display the distance between clusters. Fig. 3 shows that there was a wide distance between Ni and Zn, suggesting the influence of an anthropogenic source. The concentrations of Cu and Zn in both tap water and POU system samples were similar, indicating an origin. Fig. 3A shows that the TM in the tap water samples was grouped into three main clusters (A, B and C). Cluster A contains Ni, Mn and Cr, which was probably associated with source water contamination. Cluster B consisted of Cu and Fe while cluster C is also a standalone (Zn). However, in addition, Fig. 3B shows that the TM in the POU system samples was grouped into three main clusters (A, B and C). Cluster A contains Cr, Ni, Cu and Mn; Cluster B and C include a standalone Fe and Zn, respectively. Furthermore, the correlation analysis for TM concentrations in tap water samples showed some significant associations (Table 3). A two-way synergy between Zn and Ni was observed, which was also confirmed by HCA (Fig. 3A).

Table 3
Pearson's correlation coefficient in samples of the tap water

	Cr	Cu	Fe	Zn	Ni	Mn
Cr	1.00					
Cu	0.03	1.00				
Fe	–0.01	–.09	1.00			
Zn	–.02	.07	.06	1.00		
Ni	–.04	–.15	–.00	–.20*	1.00	
Mn	.021	.010	.06	.049	.019	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4
Pearson's correlation coefficient in in POU-WT samples water

	Cr	Cu	Fe	Zn	Ni	Mn
Cr	1.00					
Cu	0.07	1.00				
Fe	–0.06	0.82	1.00			
Zn	–0.25	–0.08	0.08	1.00		
Ni	0.01	0.09	–0.07	0.02	1.00	
Mn	–0.18	0.06	0.49	0.44	0.77	1.00

3.3. Health risk analysis due to TM contamination

DW can be considered as one of the most important sources of exposure to TM. Health risk assessment is useful to notice the probability of harmful health effects in humans who may be exposed to chemicals in contaminated water [31,32]. It is often the first step in safety and health [33]. The result of the non-carcinogenic health risks based on tap water and POU-WTS due to TM exposures by ingestion for the groups of the infant, children, women, and men are shown in Fig. 4. Hazard Quotients (HQ) values are greater than 1, suggesting that the persons using DW are exposed to health risks, whereas HQ <1 indicates minimal or no risk to the local residents [34,35]. Based on Fig. 4, the highest risk in the tap water and POU-WTS among TM studied is associated with Cr and Zn. The HQ of Cr was in the value of 0.0410, 0.0830, 0.029 and 0.026 in the tap water and 0.023, 0.046, 0.016 and 0.014 in the POU-WTS for infant, children, women, and men, respectively. Due to the low RfD values of Cr and the high concentration of Zn, these metals showed a higher non-carcinogenic risk for all studied groups than other TM. The results revealed that the levels of HQ of Cr in children were the highest value in both tap water and POU-

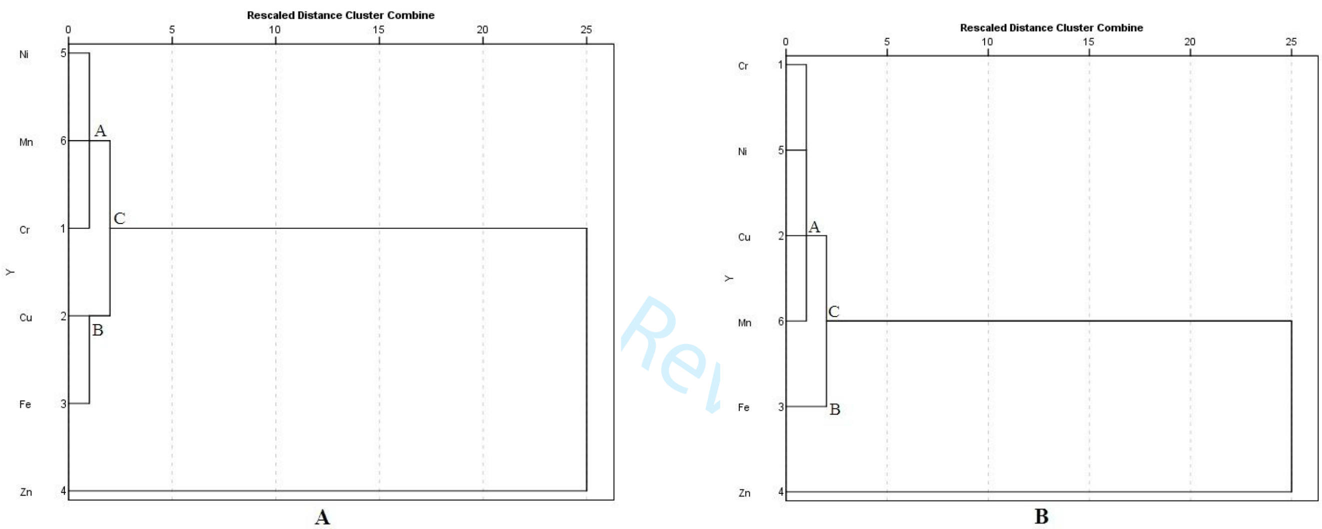

Fig. 3. Hierarchical cluster analysis dendrogram showing the relationship between six TM in the tap water (A) and POU-WT (B) samples respectively.

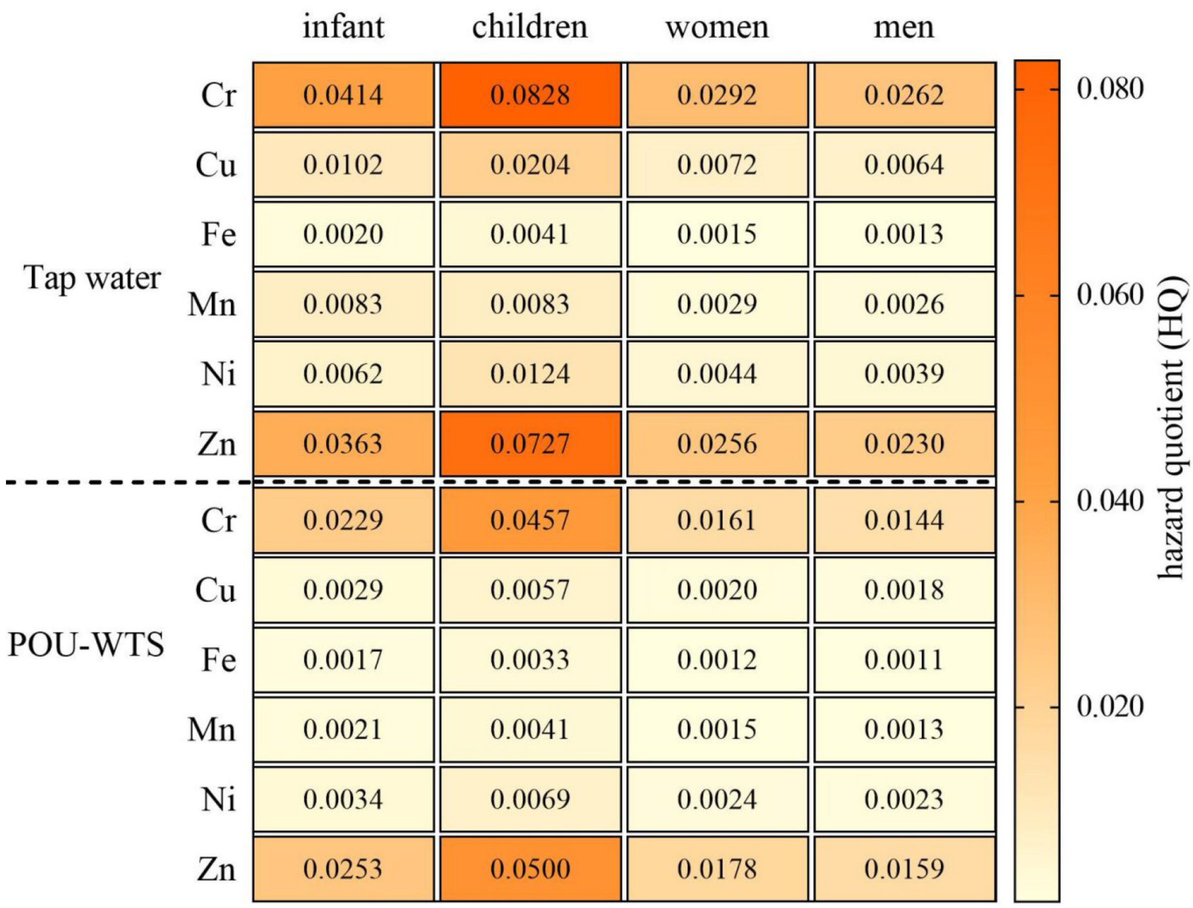

Fig. 4. Calculated hazard quotient (HQ) of TM for different group in tap water and POU-WTS.

WTS. Since low RfD values of Cu and high water ingestion in children, the observed HQ was higher. Children are especially vulnerable to acute, sub-acute, and chronic effects of uptake of TM since they consume more than adults per unit of body weight. The potential health risk of Cr was minimal in all four groups in comparison to other TM investigation [36]. The maximum HQ of Zn in the tap water for the different group was found in the amount of 0.0727 for children (Fig. 4), were lower Limit allowed (HQ < 1). For POU-WTS, the findings showed that the values of HQ of Zn in all age group were lower than 0.050.

Fig. 4 shows that the HQ of Cu, Fe, Mn and Ni in tap water were lower than 0.02 in all four groups. The HQ values of groups were in the following order: children > infant > women > men. The HQ of all TM in the women was higher than men, that contrast to the investigation of Fakhri et al. [37]. Minimum and maximum HQ of all TM was reported for children and men, respectively. The results of Fakhri investigation showed that the HQ values in women were significantly higher than men ($p < .05$). The minimum and maximum HQ in the men were observed in age groups of 65 and 1–3 years old, respectively [38]. The HQ for Cr, Cu, Fe, Mn, Ni and Zn were lowers than 1 for tap water and POU-WTS. The findings of the present study indicated that according to the HQ of TM the non-carcinogenic hazard is acceptable for all age group. Mirzabeygi et al., showed that based on the calculated Index of HQ, the drinking water in southeastern of Iran does not have any adverse effects on the human health [30]. HQ values for the this study were noted to be lower than those reported by Muhammad et al. [10] for DW in Pakistan. The HQ of all TM in POU-WTS was significantly lower than HQ of tap water (Fig. 4). Low amount of TM in POU-WTS could be due to treatment processes (RO filter) used in devices, which is effectively to remove TM the from water. Therefore, according to the result of our study, POU-WTS can reduce the potential non-carcinogenic risk of TM in drinking water. Fig. 5 explained the total non-carcinogenic hazard index (HI) in the four groups of infant, children, women, and men. The average HI of tap water for infant, children, women, and men obtained 0.1623, 0.1885, 0.0707 and 0.0631, respectively, while there was 0.099, 0.1138, 0.0409 and 0.0363 in POU-WTS for infant, children, women, and men, respectively. The maximum and minimum level of HI was obtained for children and men. More importantly, infants and children are also vulnerable to neurotoxic effects of TM due to more rapid bone growth and differences in physiology, even at low levels of exposure [39]. The POU-WTS had a significantly lower HI, compared with tap water (Fig. 5) The order of the HI for four groups are children > infant > adult women > adult men for all tow tap water and POU-WTS. Level of HI was less than one, so the population in Tehran city is in a safe area according to the concept of HI.

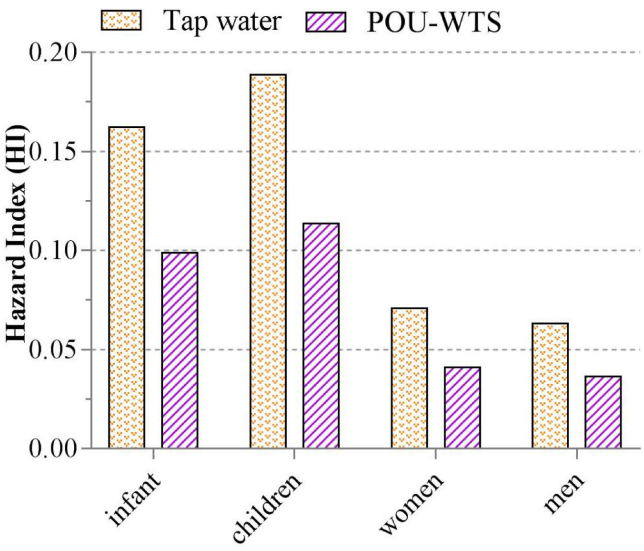

Fig. 5. Calculated hazard index (HI) for different groups in tap water and POU-WTS.

4. Conclusion

The present work investigated on the concentration of TM such as Cr, Cu, Fe, Mn, Ni, and Zn in tap water and POU-WTS and assesses the non-carcinogenic risk of TM among the four groups of the infant, children, women, and men. Average concentrations of Cr, Cu, Fe, Mn, Ni, and Zn were 6.03, 12.64, 21.20, 1.42, 2.13 and 291.80 µg/L in tap water and were 1.27, 7.76, 8.59, 0.76, 1.16 and 136.11 µg/L in POU-WTS, respectively. The results indicated that among the six detected TM, Zn had the highest concentration in two type's water. The concentration of each TM was below the water quality standard required by EPA and WHO. Cluster analysis combined the six TM as three clusters with similar source, indicating anthropogenic activities and pipeline corrosion were major source of tap water pollution. The HQ for all categories in tap water and POU-WTS were found in the order of Cr > Zn > Cu > Ni > Mn > Fe and Cr > Zn > Ni > Cu > Mn > Fe, respectively. The level of HQ and HI in both types of water for children and infant are higher than women and men, indicating children were the most vulnerable groups to TM contaminants exposure through drinking. Based on the calculated Index of HQ and HI, it can be concluded that the DW of the studied area is suitable for drinking. Also considering the remarkable reduction in the level of HQ and HI in POU-WTS rather than tap water, suggesting POU-WTS can effectively reduce the non-carcinogenic risk. Since the present study is based on the ingestion pathway i.e. dietary intakes of DW only, therefore, other exposure pathways such as dermal intake may also be considered in future research.

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