Food and Chemical Toxicology 118 (2018) 204–211

Contents lists available at ScienceDirect

Food and Chemical Toxicology

journal homepage: www.elsevier.com/locate/foodchemtox

Carcinogenic and non-carcinogenic health risks of metal(oid)s in tap water from Ilam city, Iran

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ARTICLE INFO

Keywords:
Trace metal(oid)s
Tap water
Risk assessment
Iran
Calculated incremental lifetime cancer risk (ILCR)
Target Hazard Quotient (THQ)

ABSTRACT

One of the most important pathways for exposure to metals is drinking water ingestion. Chronic or acute exposure to metals can endanger the health of the exposed population, and hence, estimation of human health risks is crucial. In the current study for the first time, the concentrations of Mercury (Hg), Arsenic (As), Zinc (Zn), Lead (Pb) and Cobalt (Co) in 120 collected tap water samples (2015, July–November) from Ilam city, Iran were investigated using flame atomic absorption spectrophotometer. Also, the metal-induced carcinogenic and non-carcinogenic risks for consumers exposed to tap drinking water were calculated. The average (range) concentrations of Hg, Zn, As, Pb and Co were defined as 0.40 ± 0.10 μg/L (ND-0.9 μg/L), 5014 ± 5707 μg/L (2900.00–5668.33 μg/L), 21.008 ± 2.876 μg/L (3.5–62 μg/L), 30.38 ± 5.56 μg/L (6–87 μg/L), and 11.34 ± 1.61 μg/L (0.1–50 μg/L), respectively. Average concentrations of all examined metals were significantly higher than WHO and national standard recommended limits. The ranking order of metals concentrations in the tap drinking water was Zn > Pb > As > Co > Hg. Except for Hg and Co, at least one age group consumers were at considerable non-carcinogenic risks induced by Zn, As and Pb [Target Hazard Quotient (THQ > 1)]. The rank order of age groups consumers based on THQ and Incremental lifetime cancer risk (ILCR) was < 1 years > 1–9 years > 20 + years > 10–19 years. The calculated ILCR for As in all age groups were higher than 10^{-3} value. All age groups of consumers in Ilam city, especially infants (< 1 years) and children (1–10 years), are at considerable non-carcinogenic and carcinogenesis risk.

1. Introduction

Economic development, unprecedented industrial revolution, and rapid population growth have raised serious concerns regarding contamination of aquatic environments by various types of contaminants. In this context, some investigations were conducted regarding the measuring of metals (Abtahi et al., 2017; Adel et al., 2016b; Dadar et al., 2017; Fakhri et al., 2017b; Farokhneshat et al., 2016; Longo et al., 2013; Mirzabeygi et al., 2017; Shahsavani et al., 2017; Zafarzadeh et al., 2018), polycyclic aromatic hydrocarbons (PAHs) (Heshmati

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https://doi.org/10.1016/j.fct.2018.04.039
Received 26 November 2017; Received in revised form 8 February 2018; Accepted 18 April 2018
Available online 20 April 2018

et al., 2018; Hosseini et al., 2008; Karyab et al., 2016; Zhang et al., 2014), residues of drugs (Avar et al., 2016; El Fellah et al., 2017; Fakhri et al., 2017a; Franquet-Griell et al., 2016; Peng et al., 2016), pesticides residue (Amirahmadi et al., 2017; Shoeibi et al., 2013; Yadolahi et al., 2012). In recent years, metals contamination of water resources has attracted global attention due to increase in their concentrations, toxic effects, non-biodegradability, highly stable and persistent characteristics among the process (Armitage et al., 2007; Dadar et al., 2016; Miri et al., 2017; Pirsaheb et al., 2016b; Shadborestan et al., 2013; Sin et al., 2001; Yuan et al., 2011). Although some metals in trace amount are essential for proper functioning of living organisms, exposure to a higher concentration of them is harmful to both human and aquatic life (Adel et al., 2016a; Copat et al., 2014; Dórea, 2008; Hadiani et al., 2015). Based on recommended classifications by International Agency for Research on Cancer (IARC); Zn, Cu, Mn, Cr, and Cd were regarded as non-carcinogenic metals, whereas As (group 1), Cr (group 2B), Ni (group 2B), Cd (group 1), and Co (group 2B), Pb (group 2B) were treated as potential carcinogen metals (EPA, 2004; IARC, 2002). Exposure to toxic metals results in several adverse health consequences including cardiovascular and skeletal diseases, neurotoxicity, infertility, numerous liver and kidney problems (EPA, 2011; Fakhri et al., 2018; Ghasemidehkordi et al., 2018; Mazzei et al., 2014; Pirsaheb et al., 2016a). For instance, the elevated exposure to Pb causes gastrointestinal colitis and blood cerebral diseases (Flora et al., 2012), Cd toxicity is responsible for cardiovascular diseases and bone pain (e.g., Itai-Itai disease) (Fagerberg et al., 2017; Kobayashi, 1978), Hg poisoning impairs senses of sight, hearing and touch (Duruibe et al., 2007; Lohren et al., 2015), Cu toxicity damages kidneys and liver, and As poisoning can result in lung, skin and other cancers (EPA, 2011; IARC, 2002).

Anthropogenic activities, such as municipal, untreated industrial, and agricultural wastewater discharge, can dramatically increase the metal concentrations (Rahman et al., 2009; Sadeghi et al., 2015; Saha et al., 2016; Srebotnjak et al., 2012; Su et al., 2013). Moreover, the release of toxic metals to drinking water from corroded distribution pipes can trigger metal pollution (Faier et al., 2009; Kavcar et al., 2009; Khan et al., 2015; Pirsaheb et al., 2014; Shanbehzadeh et al., 2014).

In recent years, estimation of carcinogenic and non-carcinogenic health risks (e.g., heart and kidney diseases) has become important, because many clinical symptoms have been observed at concentrations lower than the prescribed limits (Çelebi et al., 2014; Saha and Zaman, 2013), while in some cases, exceedance of prescribed levels have not caused human health problems. However, several studies have reported metal content in drinking waters in Iran (Atapour, 2012; Malakootian et al., 2014; Pirsaheb et al., 2013b), but those studies are only limited to a comparison of metal concentrations with respective standard limits. Therefore, a detailed estimation of carcinogenic and non-carcinogenic health risks is critical to better inform the consumers and decision-makers regarding the metal toxicity of drinking water in Iran.

Therefore, objectives of this study were to (1) determine concentrations of five metals (Hg, As, Zn, Pb, and Co) in tap water of Ilam city, (2) compare their levels with guideline values prescribed by various agencies and (3) estimate and compare carcinogenic and non-carcinogenic risk for different age groups of Ilam city, including < 1, 1–9, 10–19, and > 20 years old consumers.

2. Materials and methods

2.1. Study area

Ilam city (33.6350° N, 46.4153° E), with an area of ~36 km^2, is located in the west of Iran (Fig. 1). It has a population of ~194,000. Weather of this city is temperate mountainous with average precipitation of 619.5 mm/y, and temperature ranges from −13.6 to 41.2 °C (FRW, 2010).

2.2. Water sampling and pre-treatment

In a cross-sectional study in 2015 (July to November) the required sampling procedure according to grab method (Novic et al., 2017) was conducted over the course of five months. A total of 120 (6 × 20) tap water samples were collected from water distribution networks of six water resources, including Gham Gerdalan dam (GGD), Pich-e Ashoori well (PAW), Ghoch Ali wells (GAW), Gol Gol spring (GGS), Haft Cheshmeh well (HCW), and Naghlieh well (NW).

Samples were collected in pre-washed (with 20% HNO_3) plastic bottles and acidified with HNO_3 to reach a pH < 2 to prevent precipitation and adsorption of metals to the inner surface of sample holders (Buschmann et al., 2008). The collected samples were transported to Laboratory of Pharmacology (Ilam University of medical sciences) followed by their preservation at 4 °C until metal analyses (IWA, 2005).

2.3. Sample preparation and apparatus

Each 10 mL water sample was digested with 5 mL HCl and 5 mL HNO_3 (Adel et al., 2016a; b) on a hot plate until yellow color fumes ceased to evolve. The digested solution was subsequently filtered through Millipore filter paper (Whatman filter Merck, 0.45) and diluted with deionized water to a volume of 100 mL. Concentrations of As, Zn, Hg, Co, and Pb were analyzed using flame atomic absorption spectrophotometer (AAS) (BRAIC WFX-130). Moreover, hydride vapor generator (HVG) was used with flame AAS to measure As concentrations. In order to check the measurement precision, standard reference solutions with known concentrations of the analyzed metals were used. The accuracy of the method was checked by running control samples after every three samples. Each sample was measured at least three times to check the reproducibility of the measurement. Samples were reanalyzed if the relative standard deviation of the measurement exceeded 10%.

The limit of detection (LOD) for Hg, As, Zn, Pb, and Co were determined as 0.2, 0.05, 1.5, 15 and 0.15 μg/L, respectively. The Limit of quantification (LOQ) for as 0.66, 0.17, 5.25, 42, 0.49 μg/L were for Hg, As, Zn, Pb, and Co, respectively. Also, the range of precision of analysis procedure was 94%–103%.

2.4. Estimation non-carcinogenic risk

2.4.1. Target Hazard Quotient (THQ)

The non-carcinogenic risk of metals in foods and drinking water can be estimated by quantifying THQ using Equation (1) below (EPA, 2010, 2011; Fathabad et al., 2018). THQ value > 1 indicates potential non-carcinogenic health risk of the exposed population (EPA, 2011; Keramati et al., 2018; USEPA, 2000).

$$THQ = \frac{E_F \times E_D \times W_{IR} \times C}{RfD \times AT_n} \times 10^{-3} \tag{1}$$

Where E_F is the exposure frequency (365 days/year), E_D is the exposure duration (average lifetime Iranian population is 70 years), W_{IR} is the water ingestion rate, which is the water consumption per kg body weight per day (mL/kg-d) according to EPA assumptions (EPA, 2011), W_{IR} for < 1, 1–10, 11–19, > 20 years age groups were considered 68, 25, 16, and 20 mL/kg-d, respectively (EPA, 2011; IRIS, 2010). C is the concentration of the analyzed metals (μg/L), RfD is the oral reference dose (mg/kg-d), and AT_n (= $E_F \times E_D$) is the average time for non-carcinogen. RfD is the highest acceptable dose that does not cause any health effect, exceedance of this limit may cause adverse health consequences (EPA, 2018). RfD for Hg, Pb, As, Zn, and Co was 0.0003, 0.0005, 0.0003, 0.3 and 0.02 mg/kg-d, respectively (EPA, 2018; IRIS, 2010).

2.4.2. Total target hazard quotient (TTHQ)

Exposure to more than one metal contaminant may cause additive

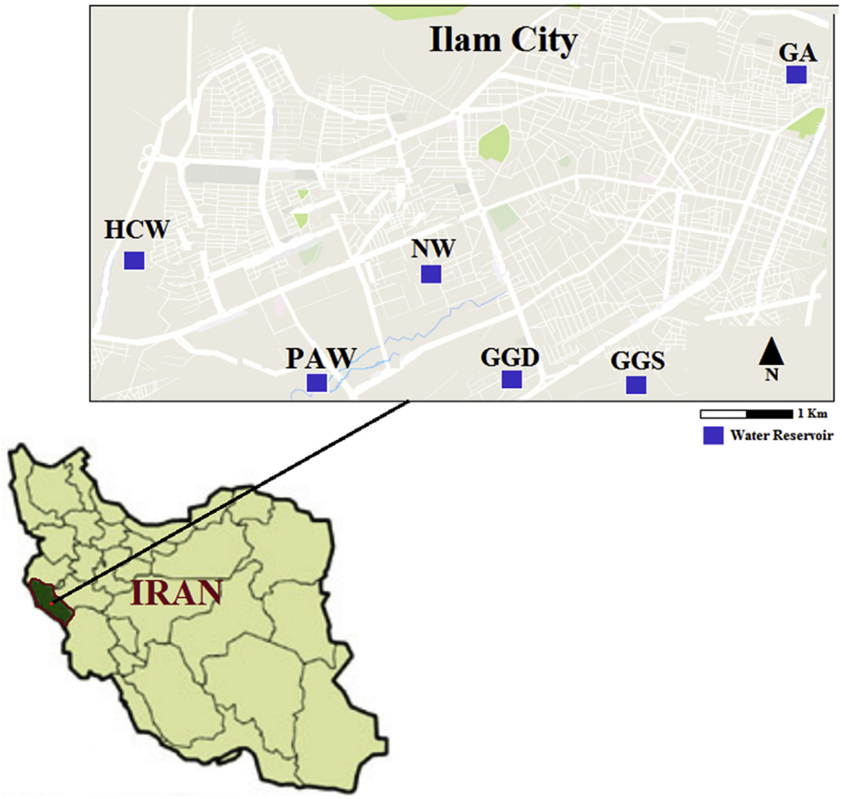

Fig. 1. Locations of water reservoirs in Ilam city, Iran.

and/or interactive effects, and hence, cumulative health effect from multiple metals' exposure was calculated by summing THQ value of individual metal and expressed as TTHQ as follows (Equation (2)) (EPA, 2011; Fakhri et al., 2017b; USEPA, 2016):

$$TTHQ = THQ_{Pb} + THQ_{As} + THQ_{Zn} + THQ_{Co} + THQ_{Hg} \quad (2)$$

TTHQ value > 1 indicates the probability of adverse health effects and suggests the need for undertaking a farther investigation and possible remedial action. However, TTHQ < 1 represents no possible health consequence from exposure of examined metals at current consumption rate (EPA, 2010).

2.5. Estimation of carcinogenic risk

2.5.1. Estimated daily intake (EDI)

The EDI values for As was calculated using) (EPA, 2011):

$$EDI = W_{IR} \times C \quad (3)$$

W_{IR} is the water ingestion rate (mL/kg-d); C is the average concentrations of metals (μg/L).

2.5.2. Incremental lifetime cancer risk (ILCR)

Based on EPA human health risk models, the carcinogenic risk for As was calculated using ILCR in) (Cao et al., 2014; EPA, 2011; Sultana et al., 2017; USEPA, 1997):

$$ILCR = EDI \times CSF \quad (4)$$

EDI is the estimated daily intake (mg/kg BW/day), and CSF is the cancer slope factor (IRIS, 2010). The CSF values for As is 1.5 (mg/kg-d)$^{-1}$, respectively (EPA, 2010; IRIS, 2010). It is worth mentioning that, CSF values are only available for As and thus, this study estimated ILCR for As. The range of acceptable cancer risk to regulatory goals is 10^{-4} to 10^{-6} (EPA, 2011).

2.6. Statistical analysis

One sample T-test was performed to statistically compare the metal concentrations with safe limits prescribed. The statistical significance was considered at $p < 0.05$. All statistical tests were performed using IBM SPSS Statistics 23.0 (IBM Corporation, Armonk, NY).

3. Result and discussion

3.1. Concentration of metals

The overall ranking order of the concentration of analyzed metals in the tap water of Ilam city was Zn > Pb > As > Co > Hg. Additionally, the constant exposure to Hg can pose some adverse effects on the nervous, immune, and digestive systems along with kidneys, lungs, eyes, and skin (WHO, 2017). Average concentration of Hg in the tap drinking water was 0.40 ± 0.10 μg/L (ranged from ND to 0.9 μg/L) (Table 1), which is ~4 times higher than WHO recommended level (0.1 μg/L) (WHO, 2004) but lower than national standard limit of 0.6 μg/L (IRISI, 1996) (Fig. 2). Concentrations of Hg in water samples from four water resources were below instrumental detection limit, while its concentration in samples from other two resources (GGD and GGS) were higher than WHO recommended values (Table 1).

Zn is one of the essential elements for the health of the human body in higher concentrations may cause diarrhea depression, hair loss, and poor wound healing (Deshpande et al., 2013). Concentrations of Zn varied from 2900.00 to 5668.33 μg/L with an average concentration of 5014 ± 564 μg/L (Table 1), which is higher than both WHO guideline and national standard limit (500 μg/L) for drinking water (Fig. 2) (IRIS, 2010; IRISI, 1996; WHO, 2017). Based on Zn concentrations water resources are ranked as NW > PAW > HCW > GGS > GAW > GGD (Table 1).

Arsenic is one of the most toxic metalloids that originated from both anthropogenic and natural sources (Muhammad et al., 2010). Its

Table 1
Concentrations of heavy metal (μg/L) in the tap drinking water related to water resources supply of Ilam city.

Heavy metals	Water resources	Sample size	Average (SD)	Minimum	Maximum
Hg	Gham Gerdalan dam	20	0.605 ± 0.19	0.30	0.90
	Pich Ashoori well	20	ND	ND	ND
	Haf Cheshmeh well	20	ND	ND	ND
	Ghoch Ali wells	20	ND	ND	ND
	Naghlieh well	20	ND	ND	ND
	Gol Gol spring	20	0.21 ± 0.02	ND	0.90
	Average		**0.40 ± 0.10**	**ND**	**0.90**
Zn	Gham Gerdalan dam	20	4404 ± 1022	2900.00	5800.00
	Pich Ashoori well	20	5094 ± 206	4800.00	5500.00
	Haf Cheshmeh well	20	5074 ± 493	4700.00	5710.00
	Ghoch Ali wells	20	4694 ± 396	4000.00	5600.00
	Naghlieh well	20	6044 ± 680	4500.00	5800.00
	Gol Gol spring	20	4794 ± 622	3600.00	5600.00
	Average		**5014 ± 564**	**2900.00**	**5668.33**
As	Gham Gerdalan dam	20	50.75 ± 7.15	35.00	62.00
	Pich Ashoori well	20	9.50 ± 1.53	7.00	12.00
	Haf Cheshmeh well	20	6.20 ± 0.34	5.80	7.00
	Ghoch Ali wells	20	5.10 ± 0.74	3.50	6.10
	Naghlieh well	20	3.80 ± 0.20	30.00	4.20
	Gol Gol spring	20	50.70 ± 7.29	3.50	36.00
	Average		**21.00 ± 2.87**	**3.50**	**62.00**
Pb	Gham Gerdalan dam	20	67.70 ± 10.67	50.00	85.00
	Pich Ashoori well	20	16.88 ± 1.16	15.00	18.60
	Haf Cheshmeh well	20	7.50 ± 0.82	6.00	8.90
	Ghoch Ali wells	20	15.91 ± 3.53	10.00	22.00
	Naghlieh well	20	7.89 ± 0.91	6.00	8.90
	Gol Gol spring	20	66.40 ± 16.82	45.00	87.00
	Average		**30.38 ± 5.56**	**6.00**	**87.00**
Co	Gham Gerdalan dam	20	14.12 ± 4.07	9.00	20.00
	Pich Ashoori well	20	8.90 ± 0.83	7.00	10.00
	Haf Cheshmeh well	20	1.89 ± 0.16	1.30	2.20
	Ghoch Ali wells	20	0.45 ± 0.08	0.30	0.60
	Naghlieh well	20	42.30 ± 4.35	35.00	50.00
	Gol Gol spring	20	0.37 ± 0.16	0.10	0.70
	Average		**11.34 ± 1.61**	**0.10**	**50.00**

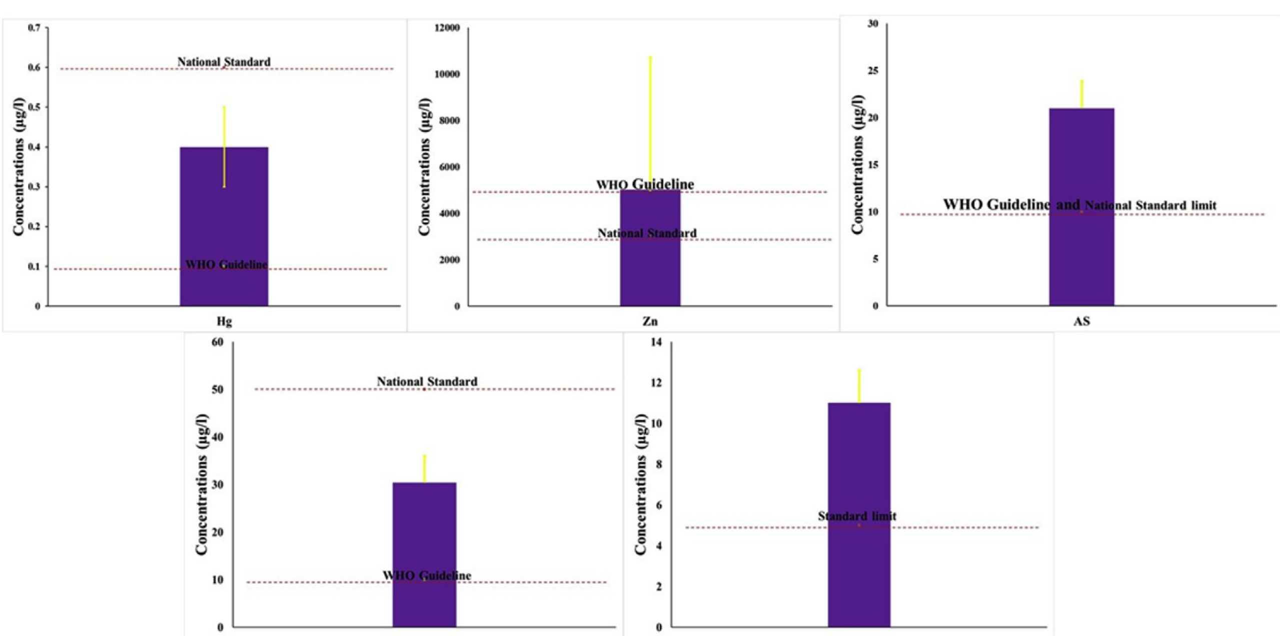

Fig. 2. Comparison of metal concentrations in tap drinking water of Ilam city with WHO guideline and national standard limits.

Table 2
Non-carcinogenic risk of heavy metals in population of different age groups of Ilam city.

Age consumer	THQ					TTHQ
	Pb	As	Hg	Co	Zn	
< 1	4.131	4.760	0.090	0.038	1.136	10.157
1–10	1.519	1.750	0.033	0.014	0.417	3.734
11–19	0.972	1.120	0.021	0.009	0.267	2.390
> 20	1.215	1.400	0.026	0.011	0.334	2.987
All age	**1.960**	**2.258**	**0.043**	**0.018**	**0.539**	**4.817**

elevated concentration in drinking water can cause melanosis, skin lesion, vascular disease, hypertension, hyperkeratosis and cancer (Ali and Tarafdar, 2003; Muhammad et al., 2011; Rahman et al., 2009). The average (± SD) concentration of As in the analyzed tap water was 21.008 ± 2.876 μg/L (range 3.5–62 μg/L) (Table 1). The concentration of As in tap drinking water was higher than WHO and national standard limit (10 μg/L) (Fig. 2) (IRISI, 1996; WHO, 2004). Based on As concentrations, the water resources are ranked as: GGD ≈ GGS > PAW > HCW > GAW > NW (Table 1).

High Pb concentrations in drinking water may be attributed to agriculture, industrial activities or domestic wastewater discharges in Ilam city. Lead is one of the most toxic metals, and infants are very sensitive to Pb toxicity. It may cause memory problems, behavioral disturbances, anemia, lung cancer, nerve damages, hypertension, stomach cancer, headache, kidney damage, asthma and abdominal pain irritability (Farkhondeh et al., 2015; Järup, 2003; Patrick, 2006; Steenland and Boffetta, 2000). The average (± SD) concentration of Pb in the tap water was 30.38 ± 5.56 μg/L (ranged from 6 to 87 μg/L) (Table 1), which is higher than WHO guideline (10 μg/L) but lower than national standard limit (50 μg/L) (Fig. 2) (IRISI, 1996; WHO, 2017). The ranking order of water resources, based on concentrations of Pb, is GGD > GGS > PAW > GAW > NW > HCW (Table 1).

Although cobalt has been mentioned as an essential element in vitamin B12 synthesis, it's high concentration can have adverse health effects, including endocrine and cardiovascular deficits and neurological (e.g., visual and hearing) impairment (Leyssens et al., 2017). The average (± SD) concentration of Co in the tap water was 11.34 ± 1.61 μg/L with minimum and maximum concentrations of 0.1 μg/L and 50 μg/L, respectively (Table 1). The concentration of Co was higher than the national standard limit (5 μg/L) (Fig. 1) (IRISI, 1996). The ranking order of water resources based on Co concentrations is NW > GGD > PAW > HCW > GAW > GGS (Table 1).

(Kavcar et al., 2009) study indicated that corrosion of distribution water systems is an important source metal in tap drinking water. (Alidadi et al., 2014) reported the concentration of Pb (11.95 ± 6.68 μg/L) in tap drinking water in Mashhad city in the northeast Iran, which was lower than our study. (Pirsaheb et al., 2013a) examined metal concentrations in tap drinking water of Kermanshah city, Iran and reported that average concentrations of As, Pb, Hg, Zn, and Co was 0.328 ± 0.70, 2.22 ± 1.97, 0.006 ± 0.021, 45.29 ± 72.8, and 2.25 ± 8.22 μg/L, respectively. Their values were lower than the values found in this study (Pirsaheb et al., 2013c). The ranking order of metals in the tap water of Kermanshah city was Zn > Co > Pb > As > Hg, which is almost similar to our study. (Khan et al., 2015) reported that concentration of As, Zn, and Pb in tap drinking water of Nowshera District, Pakistan ranged from 0.01 to 17.5, 10–500, 20–300 μg/L, respectively. The concentration of Pb in our study is lower than (Khan et al., 2015). However, concentrations of As and Zn were higher (Khan et al., 2015). Orhan (Gunduz et al., 2010) presented As concentrations data in tap water in Simav plain, Turkey. Their average As concentration was 99 μg/L and maximum concentration was 561 μg/L, which is higher than our study. Similar to our study (Mosaferi et al., 2003),reported As concentrations higher than standard limits in the tap water of 50 villages in Hashtrood, Iran. (Karim, 2011), examined the metal concentrations in the tap drinking water of the Karachi, Pakistan. The results of that study indicated that concentrations of Pb and Co were 6.05 ± 4.14 and 2.24 ± 1.23 μg/L, respectively, which was lower than our study. (Nguyen et al., 2009), reported the average concentration of As in drinking water of three regions of Ha Nam province, Vietnam and their values (211, 348 and 325 μg/L, respectively) were higher than our study.

High concentration of metals in tap drinking water of Ilam city may be correlated to natural geologic and/or human-made sources (Fallahpour, 2016). High levels of metal in groundwater of Kurdistan province, the neighboring city of Ilam, was attributed to geologic sources (Aldin Ebrahimi et al., 2015; Mosaferi et al., 2003). Overutilization of agrochemicals and industrial discharge may have a minor influence on higher metal concentrations in drinking water sourced from groundwater. Also, corrosion of pipes in water supply network may have significant influence in metal contamination of tap water.

3.2. Non-carcinogenic risk assessment

Except for 11–19 years old consumers, THQ values of Pb for other three groups were higher than 1 (Table 2). A striking feature of this study is that THQ values of As for all age groups exceeded the noncarcinogenic threshold value of 1, indicating that population should consume water from this area with caution. Estimated THQ values of other metals were lower than 1, except for Zn in < 1-year-old group (Table 2).

Based on THQ, the age groups are ranked as: < 1 years > 1–10 years > 20+ years > 11–19 years. Since W_{IR} for < 1-year consumers was lower than others age groups, their THQ value was higher. Since W_{IR} for 11–19 year age group was lower than 20 + age groups (U.S.EPA, 2004), they had higher THQ. The contribution of metals to TTHQ is ranked as (47.9%) > Pb (40.7%) > Zn (11.2%) > Hg (0.9%) > Co (0.4%) (Table 2, Fig. 3). THQ of metals in the drinking water depends on ingestion rate, toxicity, and concentration (Kapaj et al., 2006). Similar to our study (Muhammad et al., 2010), Muhammad et al. (2010) and Khan et al. (2015) found THQ higher than 1 value in Pakistan (Kapaj et al., 2006; Muhammad et al., 2011). TTHQ in all age groups was higher than 1 (Table 2, Fig. 3). Since WIR in the 11–19 years age group was lower than 20 + age groups, they had lower THQ. Since the RfD value of AS is much lower than other metals

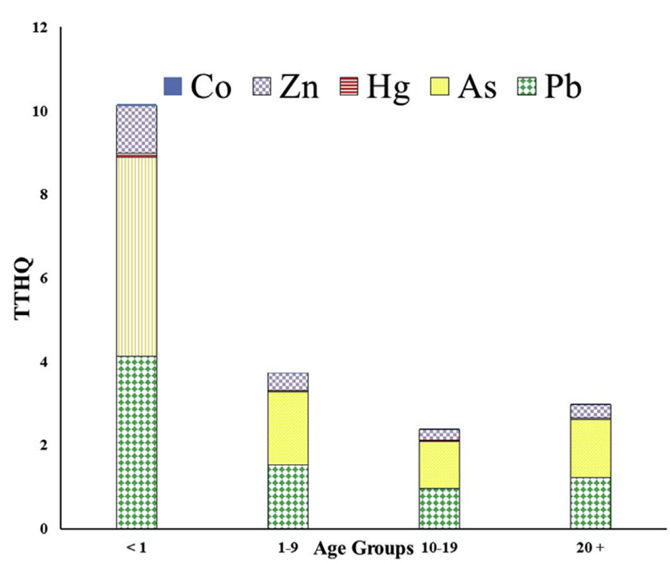

Fig. 3. TTHQ of metals (Pb, As, Hg, Zn, and Co) for consumers of different age groups in Ilam city.

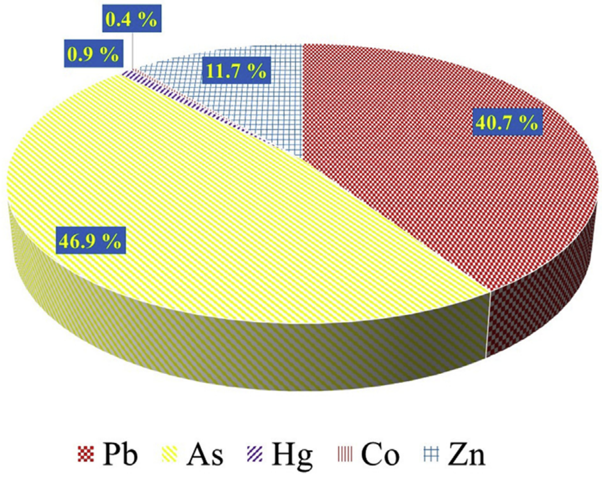

Fig. 4. The contribution of each metal in the calculated TTHQ for drinking water.

Table 3
Estimated cancer risk induced by As in drinking water consumed by different age groups of Ilam city.

	Age Groups	EDI (mg/kg-d)	ILCR
As	< 1	0.00143	8.44E-01
	1–9	0.00053	3.10E-01
	10–19	0.00034	1.99E-01
	20 +	0.00042	2.48E-01

(USEPA, 1997a, 2016), estimated THQ for As is much higher than that of other metals, although its measured concentration was comparatively lower than other metals (see Fig. 4).

3.3. Carcinogenic risk assessment

As is categorized as carcinogens by the IARC (IARC, 2004). Since CSF value for Cd is not available, we excluded Cd from quantifying ILCR. The minimum and maximum ILCR of As was observed in the 10–19 (1.99E-01) and < 1 (8.44E-01) year age group consumers, respectively (Table 3). Since W_{IR} in the < 1 years consumers were higher than the other age groups, the ILCR was high in them (EPA, 2011). When ILCR > 10^{-3}, ILCR > 10^{-4}, and ILCR < 10^{-6} consumers are in the considerable risk range, threshold risk range and safe range, respectively (EPA, 2011). ILCR for all age group consumers from As were > 10^{-3} (Table 3). Similar to our study, CR of As in (Khan et al., 2015) (ranged from 1.5E-09 to 1.3E+06) and (Nguyen et al., 2009) (average 4E-4) was higher than 10^{-6}.

4. Conclusions

In the current study for the first time, the concentrations of Mercury (Hg), Arsenic (As), Zinc (Zn), Lead (Pb) and Cobalt (Co) in 120 collected tap water samples (2015 July–November) from Ilam city, Iran were investigated using flame atomic absorption spectrophotometer. Also, the metal-induced carcinogenic and non-carcinogenic risks for consumers exposed to tap drinking water were calculated. Average concentrations of all metals investigated (Zn, Pb, As, Co, and Hg) in tap drinking water of Ilam city were significantly higher than WHO and national standard recommended limits. Moreover, the rank order of metals based on quota in the TTHQ was As > Pb > Zn > Hg > Co. All age consumers are at considerable non-carcinogenic risk of metals in the tap drinking water (TTHQ > 1). Additionally, all age consumers are at considerable carcinogenic risk of As in the tap drinking water of Ilam (ILCR > 10^{-3}). Generally speaking, the results of this study indicated that drinking water consumers in Ilam, especially infants (< 1 years) and children (1–10 years), are at serious non-carcinogenicity and carcinogenesis risks. To minimize the health threats of the local population of Ilam city, appropriate water treatment policy should be implemented to ensure safe water supply. Integrated water management approach should be employed to prevent contamination of water supply system and to protect the source water from anthropogenic metal pollution, which can be achieved by identifying the uses of chemicals through regular inspection of the catchment areas.

Declaration of interest

There is no conflict of interest.

Acknowledgement

The authors would like to thank student research committee, Ilam University of Medical Sciences for the financial grants of this study (code 938045/150). Amin Mousavi Khaneghah gratefully acknowledges the support of CNPq-TWAS Postgraduate Fellowship (Grant #3240274290).

Transparency document

Transparency document related to this article can be found online at http://dx.doi.org/10.1016/j.fct.2018.04.039.

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