



Research article

Determination and health risk assessment of trace elements in the tap water of two Sub-Cities of Addis Ababa, Ethiopia

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ABSTRACT

Water is an essential component of all living things on earth and the contamination of water by heavy metals can cause detrimental health effects. This study aimed to determine the health risk posed by trace elements (Fe, Zn, Cu, Mn, Ni, Cr, Cd, Co, Pb, and As) present in the drinking water supplies of Gullele and Akaki-Kality Sub-Cities, upstream and downstream parts of Addis Ababa, respectively. The concentrations of the potentially toxic trace elements in the water samples were determined using inductively coupled plasma optical emission spectroscopy (ICP-OES). The highest concentration of the heavy metals was observed for Iron. Cadmium and cobalt were not detected in any of the tap water samples. Samples from Gullele contained higher levels of Fe and Mn, 220.3 ± 0.17 and 19.78 ± 0.08 $\mu\text{g/L}$, respectively compared to Akaki-Kality, 38.87 ± 0.14 and 2.08 ± 0.01 $\mu\text{g/L}$, respectively. Conversely, tap water from Akaki-Kality contained significantly higher levels of As than that from Gullele. Additionally, Cr and Ni were detected only in samples from Akaki-Kality, which might be due to the various industries in the area. The highest incremental lifetime cancer risk was found for arsenic, with values for children and adults in Akaki-Kality 2.50×10^{-4} and 4.50×10^{-4} , respectively. Likewise, in Gullele Sub-City, it was 5.00×10^{-5} and 1.00×10^{-4} for adults and children, respectively. The results indicate that carcinogenic risk occurrence is probable from As in both studied areas.

1. Introduction

Water pollution is becoming a critical challenge with the increasing industrialization and fast population growth across the world. Naturally, heavy metals in the aquatic environment are present in very small amounts, mainly released from the natural weathering of rocks and soils (Kassegne et al., 2019). As a result of increasing population, urbanization and other anthropogenic activities high indices of heavy metals and other emerging contaminants have been indicated in water, soil, aquatic life, vegetables, fruits, and other food crops (Aschale et al., 2016; Ebrahimi and Barbieri, 2019; Rajasulochana and Preethy, 2016). These elevated concentrations eventually affect human health through various environmental problems.

Currently, the effect of heavy metal pollution on human beings is becoming critical. Heavy metals can cause lethal health effects with various diseases, depending on the nature and quantity of metal, through

ingestion, dermal contact, and inhalation pathways. Heavy metals present at even low concentrations in drinking water can be harmful to humans (Egbueri and Unigwe, 2020). Because of their toxicity, bio-accumulative nature, and persistence in the environment heavy metals contamination in drinking water poses a serious threat to human life (Rasool et al., 2016). Heavy metals can, however, harm organs through accumulation. Several studies have reported the accumulation of As in lungs and liver (Jaishankar et al., 2014); Pb in skeletal bones (Tchounwou et al., 2012); Cu in liver, brain, and kidneys (Treddenick, 1981); Ni in Kidney, skin, and lung (Denkhaus and Salnikow, 2002) and Mn in the brain, gastrointestinal tract, lungs, bone, liver, pancreas, and kidney (Ávila et al., 2014; Chen et al., 2016; O'Neal et al., 2014). Study on health risk estimation of trace elements exposure in drinking water is crucial.

The exposure of trace elements such as Fe, Cu, Zn, Mn, Ni, As and Pb to humans in higher amount or the bio-accumulation of these elements

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in the human organ systems has become a public concern on human health (Mirzabeygi et al., 2017; Nthunya et al., 2017; Rezaei et al., 2019; Ricolfi et al., 2020; Saleh et al., 2019). The health risk assessment of heavy metals in tap water/drinking water has been carried out in different parts of the world. For example, carcinogenic and non-carcinogenic health risk assessment in Iran (Alidadi et al., 2019; Fallahzadeh et al., 2017; Mohammadi et al., 2019; Rezaei et al., 2019; Sadeghi et al., 2018; Saleh et al., 2019; Sarvestani and Aghasi, 2019), compositional and health risk assessment in Pakistan (Muhammad et al., 2011; Murtaza et al., 2019), and water quality and human health risk assessment in China (Ji et al., 2020). Perhaps it is good to conclude by stating the two-sides of the study outcomes: some with low risk and some in alarmingly high risk.

The safety and quality of water is a global critical issue. The guidelines for drinking water quality of the World Health Organization (Cotruvo, 2017; WHO, 2008) and the United States Environmental Protection Agency (USEPA) provide health based guideline values for heavy metal safe limit and their health risk values. Similarly, the government of Ethiopia has established Environmental Protection Authority (EEPA) in 1997 for the overall protection of the environment against all the physicochemical and heavy metals contaminations (Authority, 2003).

In Ethiopia, heavy metals pose a threat to human health from their increasing concentrations in the environment caused by the recent rapid industrialization in the country (Aschale et al., 2015a, 2015b, 2016; Woldetsadik et al., 2017; Yard et al., 2015). Despite the very high levels of heavy metal pollution, there is no adequate water treatment system for the public water supply in the country, except the elimination of pathogenic organisms by the addition of chlorine and particulate matter by filtration (Firdissa and Soromessa, 2016).

In Addis Ababa, the source of drinking water for humans is surface and groundwater. The oldest pipelines of the city are mostly metals and, hence, have fundamental problems such as corrosion, high water hardness, and deposition of sediments on the inner walls, the growth of microorganisms, and the creation of biofilms. In particular, developing countries like Ethiopia faces such challenges due to the poor domestic treatment system, use of chemical materials in the water treatment system, pipeline corrosion and leaching of elements from pipes.

The northern part of Addis Ababa city comprises Gullele Sub-City. This part is the origin of the major river, called Akaki River, which flows through the city. This part of the city is also relatively free of anthropogenic activities, where it is mainly of a residential area. It is covered by cambisols (Alemayehu, 2006). The downstream part of Akaki River in Addis Ababa is Akaki-Kality Sub-City, which is located at the southern outskirts of the city. This part of the city is also relatively high in anthropogenic activities. Additionally, Akaki River traverses through highly populated, industrialized and agricultural areas before reaching Akaki-Kality. The area is covered by vertisol (Alemayehu, 2006). The difference in the level of anthropogenic activities, location with respect to Akaki River and soil type, was the basis of this study, where we attempt to compare the levels of trace elements in the tap waters distributed in the areas.

Several studies were performed previously in different countries assessing the heavy metal contamination in different environmental samples such as water, sediment, soil, and foodstuff (Ahmad et al., 2020; Alidadi et al., 2019; Barbieri et al., 2019; Egbueri and Unigwe, 2020; Jehan et al., 2020; Khalid et al., 2020; Mazhar and Ahmad, 2020; Rasool et al., 2016; Sarvestani and Aghasi, 2019). However, there is no assessment in Addis Ababa, the capital city of Ethiopia, related to the municipal water supplies. The information available on the trace elements in tap water, and the risk they pose to human health in the city is very poor. The aim of this research was, therefore, to determine the levels of trace

elements in the tap water of selected Sub-Cities of Addis Ababa and evaluate the carcinogenic and non-carcinogenic risks of residents' exposure through ingestion and dermal contact pathways.

2. Materials and methods

2.1. Study area

Addis Ababa is the capital and largest city of Ethiopia. The population of the city is projected to five million people in 2021, with an estimated population density of 6000 people per km² (Colombani et al., 2018). The city is subdivided into ten administrative Sub-Cities, which is located at 8°58'50.17"N and 38°45'27.94"E (Figure 1). The southern part of the city is mainly covered by vertisol while the northern, western, and eastern parts by cambisols (Alemayehu, 2006). The daily average temperature ranges from 9.9 to 24.6 °C and the mean annual rainfall is 1254 mm (Demlie and Wöhnlich, 2006). Sample sites were purposely selected taking the level of anthropogenic activities into consideration. Two Sub-Cities: Akaki-Kality (downstream of Akaki River) in comparison to tap water of Gullele (upstream of Akaki River) in terms of toxic elements in tap water. After obtaining informed consent from the heads of the households, 56 and 45 tap water samples were collected from Akaki-Kality and Gullele Sub-Cities, respectively (Figure 1). Across the two Sub-Cities, the tap water originate either from the surface or groundwater sources or a mix of both sources.

2.2. Chemicals and reagents

Analytical grade Ar (99.99%), HNO₃ (65%) (Kanto Chemical Corp., Tokyo, Japan), and multi-element standard solutions (1000 mg/L) from Perkin Elmer (USA) were used in the study. All working solutions were made in a 0.5% HNO₃ using high-purity water (18.2 MΩ/cm).

2.3. Tap water sampling and preparation

Tap water (50 mL) was collected from each of the 101 study participant's house outlets of the tap, after flushing water for 5–10 min to remove the stagnant water. A global positioning system (GPS) was used to locate the sampling positions (Figure 1). Tight-capped 60 mL polyethylene bottles were used for the sample container. Each container was washed with 2% nitric acid before sample collection. The water samples were acidified with nitric acid to pH lower than 2 and stored at 4 °C. The heavy metal contents of samples were measured based on the protocol in American Public Health Association (APHA) (Callan et al., 2013).

2.4. Heavy metal analysis

The total concentrations of potentially toxic trace elements in the water samples were determined using Perkin Elmer 8000 Optima ICP-OES (Perkin Elmer, USA) available in the laboratory of Abbay Basin Development office, Ethiopia. The instrument was conditioned for 30 min and optimized by running the daily performance check solution. Analysis of samples was carried out after adjusting the various operating parameters such as the position of the torch, the nebulizer flow rate, RF power, and the interference corrections. Quantification of elements was made after the construction of calibration curves with series of standard solutions corresponding to each element. Good linearity was obtained for all the determining elements with correlation coefficients >0.998. Accuracy and limits of detection were determined to assess the validity of the methods used for the digestion and analysis of the tap water samples. The accuracy of the method was assessed by using spiking experiments in every batch of sample digestion and analysis. For this, a known amount of the element of interest, which is 100% of the amount found in the

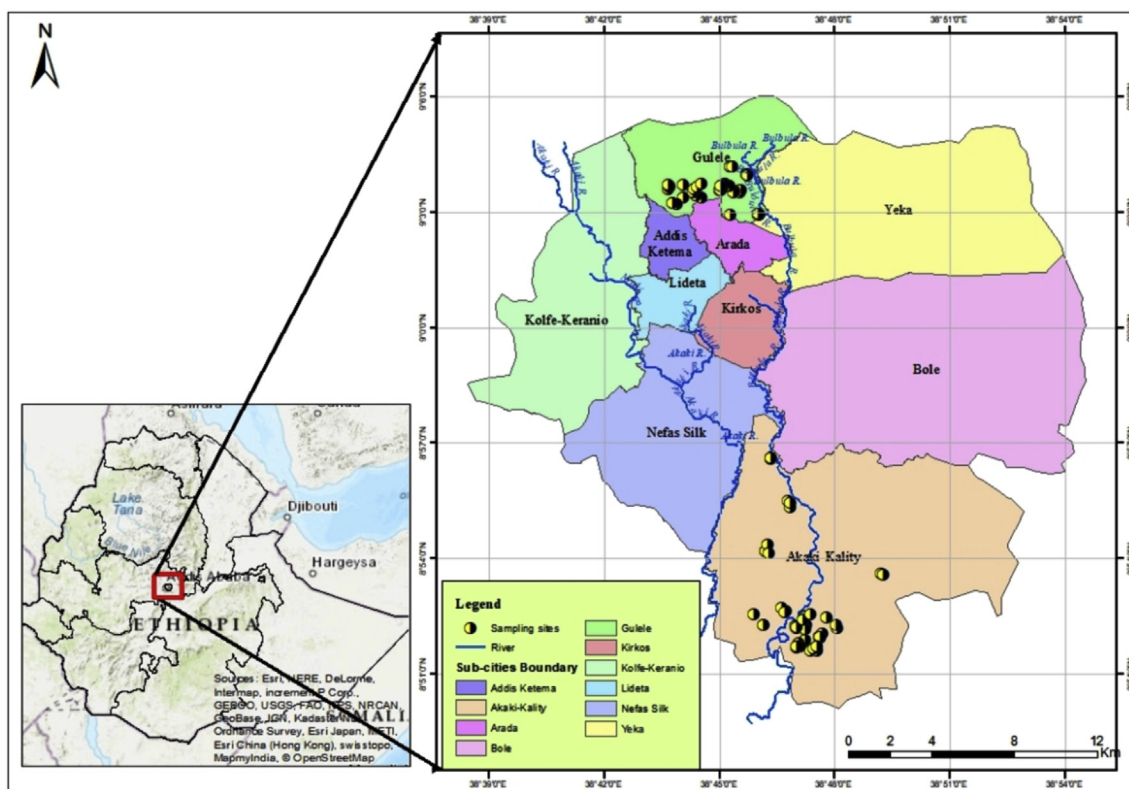


Figure 1. Location map of tap water sampling sites in Akaki-Kality and Gullele Sub-Cities of Addis Ababa, Ethiopia.

sample, was added to the tap water sample and subjected to the digestion using APHA method. The percentage recoveries ranged from 94% to 108.5%, assuring the accuracy of the method for determining each element. The limit of detection (LOD) of the method was determined from the measurement of three blank samples that were digested and analyzed along with samples, which were 0.161, 0.036, 0.012, 0.099, 0.201, 0.013, 0.012 and 0.026 µg/L for Fe, Zn, Cu, Mn, As, Pb, Cr and Ni, respectively.

2.5. Statistical analysis

All data analysis were carried out using the statistical software package SPSS 23 (IBM Corporation, USA). Kruskal-Wallis test was applied to determine if there are statistically significant differences between the trace elements concentrations of the tap water of the Sub-Cities. Principal component analysis was constructed to visualize sample trends between the two Sub-Cities. Furthermore, the Pearson correlation coefficient matrix was computed to assess the strength of

correlation between elements. During the result interpretation, the statistical significance of a variable was based on a p-value < 0.05.

2.6. Health risk assessment

2.6.1. Exposure assessment

The chronic daily intakes (CDI) was applied to estimate exposure to potentially toxic trace elements in children (sensitive group) and adult (as the general population) via direct ingestion and dermal contact exposure pathways as following in Eqs. (1) and (2) (EPA, 2004; Yu et al., 2014).

$$CDI_{ing} = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{1}$$

$$CDI_{der} = \frac{C \times SA \times Kp \times EF \times ED \times ET \times ABS \times CF}{BW \times AT} \tag{2}$$

Table 1. The constant values used in risk calculation.

Parameters	Fe	Zn	Cu	Mn	Ni	Cr	Pb	As	References	
RfD	Ing.	300	300	40	20	20	3	3.5	0.3	(Khalid et al., 2020; Mirzabeygi et al., 2017; Mohammadi et al., 2019; Sarvestani and Aghasi, 2019; Wu et al., 2009)
	Der.	45	60	12	0.8	5.4	0.075	0.42	0.285	(Mohammadi et al., 2019; Wu et al., 2009)
CSF	-	-	-	-	84	500	8.5	1500	(Khalid et al., 2020; Sarvestani and Aghasi, 2019)	
ABS	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	(EPA, 2004)	
Kp	0.001	0.0006	0.001	0.001	0.0002	0.002	0.004	0.001	(EPA, 2004; Mohammadi et al., 2019)	

RfD (µg/kg/day); CSF (µg/kg/day) and ABS (unitless).

Table 2. Trace elements concentrations ($\mu\text{g/L}$) and their comparison with international reported data for drinking water.

Reference, country		Heavy metal								Water sources
		Fe	Cu	Zn	Mn	Ni	As	Pb	Cr	
This study	Akaki-Kality	38.87 \pm 0.14 (LOD - 500.40)	3.31 \pm 0.02 (LOD-26.33)	37.93 \pm 0.17 (LOD-391.10)	2.08 \pm 0.01 (LOD-9.58)	0.92 \pm 0.13 (LOD-3.5)	1.68 \pm 0.38 (LOD-8.13)	4.42 \pm 0.32 (LOD-19.6)	1.75 \pm 0.07 (LOD-4.27)	S&G
	Gullele	220.30 \pm 0.17 (LOD-1073)	4.53 \pm 0.01 (LOD-62)	73.08 \pm 0.22 (LOD-1065.00)	19.78 \pm 0.08 (LOD-351.00)	<LOD	0.39 \pm 0.11 (LOD-4.07)	5.34 \pm 0.40 (LOD-52.80)	<LOD	
Saleh et al. (2019), Iran		10.13 (1.09–29.70)	8.28 (1.15–53.81)	6.47 (<0.01–11.01)	-	-	3.87 (<0.01–9.86)	11.00 (1.00–12.00)	6.83 (<0.003–20.00)	GW
Sadeghi et al. (2018), Iran		-	-	-	-	-	6.80 (0–99.00)	-	-	S&G
Rezaei et al. (2019), Iran		-	-	-	-	-	6.80 (1.10–36.00)	2.60 (2.00–3.00)	-	GW
Mirzabeygi et al. (2017), Iran		-	-	-	-	-	-	6.70 \pm 6.10– 20.40 \pm 9.29 (<0.15–80.00)	3.30 \pm 2.50– 20.30 \pm 5.90 (0.15–79.30)	-
Hu et al. (2019), Canada		85.30 \pm 25.40–329.00 \pm 120.00	-	-	13.40 \pm 7.02–51.40 \pm 26.10	-	1.76 \pm 0.96 –7.05 \pm 1.37	2.47 \pm 0.59 –8.25 \pm 1.75	8.78 \pm 1.87 –40.20 \pm 10.10	SW
Alidadi et al. (2019), Iran		-	-	-	-	1.69 \pm 2.15 (0.185–3.63)	0.18 \pm 0.05 (0.10–0.39)	0.18 \pm 0.05 (0.31–1.33)	4.94 \pm 5.53 (0.36–23.25)	S&G
Muhammad et al. (2011), Pakistan		-	36.33 \pm 21.51–115.76 \pm 99.94	21.27 \pm 44.76 –1376.11 \pm 1607.35	5.24 \pm 3.11 –19.43 \pm 21.49	2.18 \pm 2.90 –5.94 \pm 8.48	-	2.34 \pm 0.44–24.05 \pm 24.05 (0.70–43.17)	0.90 \pm 1.05 –12.83 \pm 21.01	S&G
Vetrimurugan et al. (2017), India		80 \pm 80 (50–550)	0.00 \pm 10 (0.00–50.00)	0.00 \pm 10 (0.00–30.00)	310.00 \pm 1120.00 (10.00–700.00)	120.00 \pm 20.00 (90.00–170.00)	-	380.00 \pm 100.00 (190.00–660.00)	ND	GW
Rasool et al. (2016), Pakistan		46.00–3255.00	1.60–273.00	11.00–4877.00	1.00–89.00	11.00–97.00	12.00–812.00	30.00–230.00	13–64	GW
Nawab et al. (2018), Pakistan		-	-	6.00 \pm 10.00– 21.00 \pm 370.00	-	45.00 \pm 40.10 –74.00 \pm 47.00	-	53.10 \pm 56.10 –100.00 \pm 64.00	88.00 \pm 67.10 –117.00 \pm 66	S&G
Khalid et al. (2020), Pakistan		1.34 \pm 0.56–1.86 \pm 0.4	0.10–0.03 - 0.44 \pm 0.16	0.55 \pm 0.12–0.64 \pm 0.08	0.13 \pm 0.01 –0.22 \pm 0.02	0.04 \pm 0.0 –0.13 \pm 0.03	-	0.11 \pm 0.01 –0.18 \pm 0.02	BDL	GW
Huq et al. (2019), Bangladesh		-	-	-	<0.01–56.20	<0.01–8.00	6.05–590.70	0.60 - 8.00	-	S&G
Gupta et al. (2017), India		160.40 \pm 371.40 (12.00–1557.00)	4.30 \pm 10.20 (0.00–36.00)	250.60 \pm 857.10 (7.00–3874.00)	14.30 \pm 17.30 (0.00–138.00)	-	-	3.30 \pm 2.70 (0.00–9.50)	5.10 \pm 11.40 (0.00–15.80)	GW
Fallahzadeh et al. (2017), Iran		3.12 \pm 1.10–1459.25 \pm 21.48	8.07 \pm 1.06 –21.43 \pm 4.01	10.51 \pm 1.19 –428.61 \pm 13.44	1.00 \pm 0.04 –47.19 \pm 3.95	ND - 7.71 \pm 2.05	-	ND - 5.91 \pm 2.14	5.88 \pm 4.94 (1.22–582.00)	GW
Egbueri and Unigwe (2020), Nigeria		0.35 \pm 0.58 (0.04–1.74)	0.55 \pm 0.78 (0.00–3.14)	0.72 \pm 0.48 (0.05–1.73)	0.01 \pm 0.03 (0.00–0.13)	0.04 \pm 0.16 (0.00–0.73)	-	0.001 \pm 0.01 (0.00–0.02)	32.10 \pm 85.40 (0.00–320.00)	GW
Mazhar and Ahmad (2020), India		-	11.00–305.00	750.00–2245.00	11.00–1360.00	247.00–1246.00	-	-	0.01–1.64	GW
Mohammadi et al. (2019), Iran		-	0.10–39.31	7.41–104.77	-	0.06–19.45	-	0.35 -8.27	5.08 (0.39–10.76)	GW
Ahmad et al. (2020), Pakistan		-	-	-	-	5.06 \pm 1.19	1.80 \pm 0.64	5.58 \pm 1.23	3.21 \pm 0.75	GW
WHO		300	2000	3000	400	70	10	10	50	
USEPA		300	1300	500	500	20	10	15	100	

GW = Groundwater, SW = surface water, S&G = surface and groundwater.

where CDI_{ing} is chronic daily intake through ingestion of water ($\mu\text{g}/\text{kg}/\text{day}$); CDI_{der} is chronic daily intake through dermal absorption ($\mu\text{g}/\text{kg}/\text{day}$); C is the average concentration of the estimated metals in water ($\mu\text{g}/\text{L}$); IR is ingestion rate used in this study (2 L/day for adults; 1 L/day for children); EF is exposure frequency (365 days/year); ED is exposure duration (70 years for adults; and 10 years for children); BW is average body weight (72 kg for adults; 32.7 kg for children); AT is averaging time (365 days/year \times 70 years for an adult; 365 days/year \times 10 years for a child); SA is exposed skin area (18,000 cm^2 for adults; 6600 cm^2 for children); Kp is dermal permeability coefficient in water, (cm/h), 0.001 for As, Cu, Mn, and Fe, while 0.0006 for Zn; 0.002 for Cr, 0.0002 for Ni and 0.004 for Pb; ET is the exposure time (0.58 h/day for adults; 1 h/day for children) and CF is unit conversion factor (0.001 L/cm^3). The values of the constants for oral and dermal reference dose (RfD), cancer slope factor of hazardous substances (CSF), dermal absorption factor (ABS), and Kp corresponding to each element are listed in Table 1.

2.6.2. Non-carcinogenic risk assessment

The probability of non-carcinogenic risk from an individual potential toxic trace element can be expressed as the hazard quotient (HQ) factor, in which non-carcinogenic CDI is based on the oral reference dose (RfD). To estimate the total potential non-cancer risks of potentially toxic trace elements by oral and dermal exposure, the hazard index (HI) was calculated (Eq.3). If the HQ or HI is found to be > 1 , there might be a risk for human health by non-cancer effects of the element in question.

$$HQ = HQ_{ing} + HQ_{der} = \frac{CDI_{ing}}{RfD_{ing}} + \frac{CDI_{der}}{RfD_{der}} \quad (3)$$

where the non-cancer hazard quotient (HQ) is the ratio of exposure to hazardous elements, and RfD is the chronic reference dose of the toxicant ($\mu\text{g}/\text{kg}/\text{day}$).

Non-carcinogenic potential risk to human health through exposure to a multiple of potential toxic trace elements was assessed by hazard index (HI), which is the sum of all HQ calculated for individual trace elements and calculated as in Eq. (4) (Bamuwamy et al., 2015; Liu et al., 2013):

$$HI = \sum_{k=1}^n HQ = HQ_{Fe} + HQ_{Zn} + HQ_{Cu} + HQ_{Mn} + HQ_{Ni} + HQ_{Cr} + HQ_{Pb} + HQ_{As} \quad (4)$$

The value of HQ or HI > 1 indicates that there is a possibility of

adverse effects on human health and HI < 1 the opposite applies (Wei et al., 2015).

2.6.3. Carcinogenic risk assessment

The carcinogenic risk from the potential toxic elements through drinking water is evaluated using incremental lifetime cancer risk (ILCR) (Eq.5) (Liu et al., 2013). It shows the mean daily dose of exposure to the carcinogenic substances in a lifetime:

$$ICLR = CDI \times CSF \quad (5)$$

where cancer risk represents the probability of individual lifetime health risks from carcinogens; CDI is the chronic daily intake of carcinogens ($\mu\text{g}/\text{kg}/\text{day}$); CSF is the slope factor of hazardous substances ($\mu\text{g}/\text{kg}/\text{day}$).

The cumulative cancer risk, as a result of exposure to multiple carcinogenic potentially toxic trace elements, due to the consumption of water can be calculated from Eq. (6):

$$ILCR = \sum_1^4 ILCR = ILCR_{Ni} + ILCR_{Cr} + ILCR_{Pb} + ILCR_{As} \quad (6)$$

The level of acceptable cancer risk (ILCR), for regulatory purposes, is considered between 10^{-4} and 10^{-6} (Li and Zhang, 2010; Liu et al., 2013).

3. Results and discussion

3.1. Distribution of potentially toxic trace elements in the drinking water samples

The trace elements concentrations determined in the tap water collected from Gullele and Akaki-Kality Sub-Cities are summarized in Table 2. Among the studied elements, Cd and Co were not detected in any of the tap water samples. Additionally, Ni and Cr were found only in the tap water samples from Akaki-Kality Sub-City. The highest concentration was measured for Fe, with a mean concentration in the range of 38.87 ± 0.14 – 220.3 ± 0.17 $\mu\text{g}/\text{L}$ across the two Sub-Cities, followed by Zn (37.93 ± 0.17 – 73.08 ± 0.22).

Iron is the third abundant element in the earth's crust (Taylor, 1964), and it can be found in high amounts in soil and water. The major anthropogenic sources of iron contaminations are industrial wastes, urban wastes/sewage, agricultural and mining activities (Hasan et al., 2019). As summarized in Table 2, the mean concentrations of Fe measured in the Akaki-Kality Sub-City were lower than most of the reported values for drinking water from Iran (Fallahzadeh et al., 2017), India (Gupta et al., 2017; Vetrinurugan et al., 2017), Pakistan (Khalid et al., 2020; Rasool et al., 2016) and Canada (Hu et al., 2019), but higher

Table 3. Kruskal-Wallis H test analysis of the variation of elemental concentrations between tap water samples from Gullele and Akaki-Kality Sub-Cities of Addis Ababa.

Heavy metals	sub-city	Sample size	Mean rank	Chi-square	p
Fe	Akaki-Kality	56	45.68	4.155	0.042*
	Gullele	45	57.62		
Zn	Akaki-Kality	56	55.75	3.402	0.065
	Gullele	45	45.09		
Cu	Akaki-Kality	56	55.66	4.873	0.027*
	Gullele	45	45.20		
Mn	Akaki-Kality	56	46.80	2.867	0.090
	Gullele	45	56.22		
Pb	Akaki-Kality	56	51.86	0.114	0.736
	Gullele	45	49.93		
As	Akaki-Kality	56	56.73	8.638	0.003*
	Gullele	45	43.87		

* Indicates significant difference in heavy metal concentrations between Sub-Cities

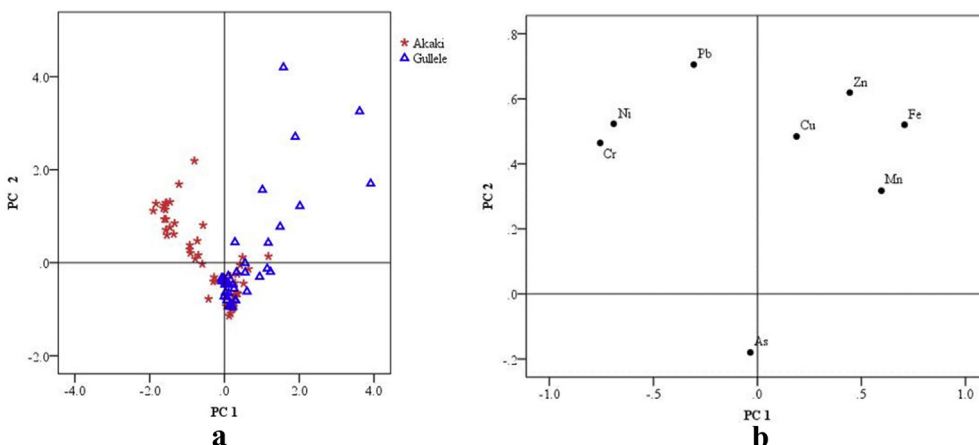


Figure 2. Scores plot of the first two principal components, indicating the distribution of the tap water samples from Akaki-Kality and Gullele Sub-Cities of Addis Ababa (A). Loadings plot for the first two principal components (B).

Table 4. Pearson correlation coefficients calculated for the elements determined in the tap water sample from the Akaki-Kality Sub-City of Addis Ababa.

Element	Fe	Zn	Cu	Mn	Ni	Cr	Pb	As
Fe	1							
Zn	0.176	1						
Cu	-0.046	0.202	1					
Mn	0.636*	0.064	-0.058	1				
Ni	-0.122	0.055	0.128	-0.160	1			
Cr	-0.206	-0.071	-0.073	-0.271	0.682*	1		
Pb	-0.225	-0.039	-0.003	-0.321	0.610*	0.722	1	
As	-0.071	-0.022	0.023	-0.102	-0.216	-0.395	-0.090	1

* Correlation is significant at the 0.05 level.

than the reported values from Iran (Saleh et al., 2019) and Nigeria (Egbueri and Unigwe, 2020). On the other hand, the concentration of Fe in the Gullele Sub-City was higher than the reported values by Gupta et al. and Hu et al. (Gupta et al., 2017; Hu et al., 2019), but lower than the study conducted in groundwater (Vetrimurugan et al., 2017). The average concentration of Fe in Akaki-Kality were 2–4 times lower than the reported data from India (Gupta et al., 2017; Vetrimurugan et al., 2017). However, in most cases, the concentrations of Fe in the tap water samples from Gullele were about 118 times higher than the reported amount by Khalid et al. (2020) and 70 times higher than the reported data by Fallahzadeh et al. (2017). Availability of excess Fe in the body causes aesthetic and health effects (Saleh et al., 2019), hemochromatosis, liver cirrhosis, and siderosis, membrane lipid damaging (Jaishankar et al., 2014).

The measured concentration of Zn in the drinking water samples ranged from LOD to 391.10 µg/L. When compared to literature values, the level of Zn in this study was lower than the reported value from Pakistan (Muhammad et al., 2011; Rasool et al., 2016), India (Gupta

et al., 2017; Mazhar and Ahmad, 2020), and Iran (Fallahzadeh et al., 2017). However, the level of Zn in this study was found to be higher than the value reported by other researchers from Iran (Saleh et al., 2019), India (Vetrimurugan et al., 2017), Pakistan (Khalid et al., 2020), Nigeria (Egbueri and Unigwe, 2020). Even if Zn is essential for our body, excess Zn in the body can cause diarrhea, vomiting, and neurological damage (Hasan et al., 2019; Izah et al., 2016).

Naturally, Mn is found with Fe ores and can be found with several oxidation states depending on soil and water pH (Izah et al., 2016). The concentration of Mn in tap water from Gullele was found to be higher than that of Akaki-Kality. The maximum recorded values from Gullele were higher than some of the values reported elsewhere (Hu et al., 2019; Muhammad et al., 2011; Rasool et al., 2016). Excess intake of Mn can cause reproductive deficits, skeletal abnormalities, increased muscle tone tremor, lethargy, and mental disturbances (Ávila et al., 2014; O’Neal et al., 2014).

Natural and anthropogenic activities such as paint, plating, mining, copper polishing, printing operations can be the sources of Cu (Awa

Table 5. Pearson correlation coefficients calculated for the elements determined in the tap water sample from the Gullele Sub-City of Addis Ababa.

Element	Fe	Zn	Cu	Mn	Pb	As
Fe	1					
Zn	0.340	1				
Cu	0.271	0.629*	1			
Mn	0.552*	0.181	-0.029	1		
Pb	0.172	0.768*	0.640*	-0.092	1	
As	-0.138	-0.044	0.309	-0.121	-0.006	1

* Correlation is significant at the 0.05 level.

Table 6. Mean chronic daily intake (CDI, µg/kg/day) of heavy metals for Akaki-Kality and Gullele tap water through drinking water ingestion (CDI_{ing}) and dermal contact (CDI_{der}).

Element	Akaki Kality sub-city						Gullele sub-city					
	CDI _{ing}		CDI _{der}		CDI _{total}		CDI _{ing}		CDI _{der}		CDI _{total}	
	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child
Fe	1.08	1.98	5.64×10^{-5}	7.85×10^{-5}	1.08×10^0	1.98×10^0	6.12	11.23	3.19×10^{-4}	4.44×10^{-4}	6.12×10^0	1.12×10^1
Zn	1.05	1.93	3.30×10^{-5}	4.59×10^{-5}	1.05×10^0	1.93×10^0	2.03	3.72	6.36×10^{-5}	8.85×10^{-5}	2.03×10^0	3.72×10^0
Cu	0.09	0.17	4.79×10^{-6}	6.67×10^{-6}	9.00×10^{-2}	1.70×10^{-1}	0.13	0.23	6.57×10^{-6}	9.14×10^{-6}	1.30×10^{-1}	2.30×10^{-1}
Mn	0.06	0.10	2.96×10^{-6}	4.12×10^{-6}	6.00×10^{-2}	1.00×10^{-1}	0.54	0.99	2.80×10^{-5}	3.90×10^{-5}	5.40×10^{-1}	9.90×10^{-1}
Ni	0.03	0.05	2.67×10^{-7}	3.72×10^{-7}	3.00×10^{-2}	5.00×10^{-2}	-	-	-	-	-	-
Cr	0.05	0.09	5.06×10^{-6}	7.05×10^{-6}	5.00×10^{-2}	9.00×10^{-2}	-	-	-	-	-	-
Pb	0.12	0.23	2.56×10^{-5}	3.57×10^{-5}	1.20×10^{-1}	2.30×10^{-1}	0.15	0.27	3.10×10^{-5}	4.31×10^{-5}	1.50×10^{-1}	2.70×10^{-1}
As	0.05	0.09	7.29×10^{-6}	1.02×10^{-5}	5.00×10^{-2}	9.00×10^{-2}	0.01	0.02	1.70×10^{-6}	2.36×10^{-6}	1.00×10^{-2}	2.00×10^{-2}

CDI total = CDI_{ing} + CDI_{der}.

and Hadibarata, 2020). The contents of Cu in Akaki Kality tap water were about 2 times lower than that reported from Iran (Fallahzadeh et al., 2017), whereas, similar results were obtained with the reported data from India (Gupta et al., 2017). The content of Cu in Gullele tap water was 8–10 times higher than the reported data by Khalid et al. (2020) and Egbueri and Unigwe (2020). Despite the health benefit of small amount of Cu, excess Cu causes hemolytic anemia, amino-acid, membrane lipid damaging and hepatic cirrhosis (Ayangbenro and Babalola, 2017).

Vehicular emissions, disposal of household wastes, municipal and industrial waste, steel manufacturing, and cement industry are some possible sources of Ni (Awa and Hadibarata, 2020). In this study, the concentrations Ni ranged from LOD - 3.5 µg/L in the Akaki-Kality Sub-City drinking water samples. Whereas, Ni was not detected in the Gullele Sub-City samples. While the average concentrations of Ni in the Akaki-Kality Sub-City were found to be 0.92 ± 0.13 µg/L. The recorded concentration of Ni content in the Akaki-Kality Sub-City was approximately 23 times (Khalid et al., 2020), 5 times (Ahmad et al., 2020), and 2 times (Alidadi et al., 2019; Muhammad et al., 2011) greater than the current value. On the contrary, the results of other studies showed values were 24 times (Egbueri and Unigwe, 2020) and 15 times (Mohammadi et al., 2019) lower level of Ni than the current value. Cardiovascular chest pain, dermatitis, diseases, dizziness, dry cough and shortness of breath, headache, kidney diseases, lung and nasal cancer, nausea are among the side effects of excess Ni (Ayangbenro and Babalola, 2017).

The main pollution sources of Cr in the environment can be dyeing, electroplating, paints, steel fabrication, tannery, and textile (Awa and Hadibarata, 2020; Dessie et al., 2020). The mean and range of Cr concentrations in drinking water samples were 1.75 ± 0.07 and LOD - 4.27 µg/L, respectively. In contrast, the Cr level in Gullele Sub-City's drinking water was below the detection limit. Comparably, the average Cr content in the other study reported values was 18 times (Egbueri and Unigwe, 2020) and 50 times (Nawab et al., 2018) far less than the Akaki-Kality Sub-City drinking water. Moreover, the average concentrations of Cr in the Akaki-Kality Sub-City was found to be 5 times (Hu et al., 2019), 3 times (Mohammadi et al., 2019), 3 times (Fallahzadeh et al., 2017; Gupta et al., 2017) and 2 times (Ahmad et al., 2020) less than the reported data elsewhere.

Natural sources such as coal deposition, petroleum, rock sedimentation, smelting, and man-made sources such as mining, coal combustion, batteries wastes, electroplating, paint, and pigments can be the potential sources of Pb and As in the environment (Awa and Hadibarata, 2020; Dessie et al., 2020). High toxic non-biological essential elements (Pb and As) have been found in both Gullele and Akaki-Kality Sub-Cities drinking water samples. The concentrations of Pb and As in the current study drinking waters were found in the range of LOD - 19.6 and LOD - 8.13 µg/L for Akaki-Kality Sub-City, respectively. The maximum concentration of Pb, in this study, was found to be 86 times lower than the reported values of other researchers (Vetrimurugan et al., 2017). Whereas, As was found to be equal or less than most of the reported data. Pb and As are

Table 7. The mean Hazard Quotient (HQ) of heavy metals for adults and children through drinking water ingestion (HQ_{ing}) and dermal contact (HQ_{der}).

HQ _{ing} and HQ _{der} of individuals toxic elements											
Sub-City	Individuals		Fe	Zn	Cu	Mn	Ni	Cr	Pb	As	Total
AK	Adult	HQ _{ing}	3.60×10^{-3}	3.5×10^{-3}	2.50×10^{-3}	3.00×10^{-3}	1.5×10^{-3}	1.67×10^{-2}	3.43×10^{-2}	1.67×10^{-1}	2.20×10^{-1}
	Child	HQ _{ing}	6.60×10^{-3}	6.43×10^{-3}	4.25×10^{-3}	5.00×10^{-3}	2.5×10^{-3}	3.00×10^{-2}	6.57×10^{-2}	3.00×10^{-1}	4.04×10^{-1}
	Adult	HQ _{der}	1.25×10^{-6}	5.50×10^{-7}	4.00×10^{-7}	3.70×10^{-6}	4.95×10^{-8}	6.75×10^{-5}	6.10×10^{-5}	2.56×10^{-5}	1.60×10^{-4}
	Child	HQ _{der}	1.74×10^{-6}	7.66×10^{-7}	5.56×10^{-7}	5.14×10^{-6}	6.89×10^{-8}	9.40×10^{-5}	8.50×10^{-5}	3.56×10^{-5}	2.23×10^{-4}
GU	Adult	HQ _{ing}	2.04×10^{-2}	6.7×10^{-3}	3.25×10^{-3}	2.70×10^{-2}	-	-	4.29×10^{-2}	3.30×10^{-2}	1.36×10^{-1}
	Child	HQ _{ing}	3.73×10^{-2}	1.2×10^{-2}	5.75×10^{-3}	4.95×10^{-2}	-	-	7.71×10^{-2}	6.60×10^{-2}	2.49×10^{-1}
	Adult	HQ _{der}	7.10×10^{-6}	1.06×10^{-6}	5.47×10^{-7}	3.51×10^{-5}	-	-	7.38×10^{-5}	5.96×10^{-6}	1.23×10^{-4}
	Child	HQ _{der}	9.88×10^{-6}	1.48×10^{-6}	7.62×10^{-7}	4.88×10^{-5}	-	-	1.03×10^{-4}	8.29×10^{-6}	1.72×10^{-4}

THQ = HQ_{ing} + HQ_{der} of individuals elements

Sub-City	Individuals		Fe	Zn	Cu	Mn	Ni	Cr	Pb	As	HI
AK	Adult	THQ	3.60×10^{-3}	3.50×10^{-3}	2.25×10^{-3}	3.00×10^{-3}	1.50×10^{-3}	1.67×10^{-2}	3.43×10^{-2}	1.67×10^{-1}	2.31×10^{-1}
	Child	THQ	6.60×10^{-3}	6.43×10^{-3}	4.25×10^{-3}	5.00×10^{-3}	2.50×10^{-3}	3.00×10^{-2}	6.57×10^{-2}	3.00×10^{-1}	4.20×10^{-1}
GU	Adult	THQ	2.04×10^{-2}	6.77×10^{-3}	3.25×10^{-3}	2.70×10^{-2}	-	-	4.29×10^{-2}	3.30×10^{-2}	1.34×10^{-1}
	Child	THQ	3.73×10^{-2}	1.24×10^{-2}	5.75×10^{-3}	4.95×10^{-2}	-	-	7.71×10^{-2}	6.67×10^{-2}	2.49×10^{-1}

Ak = Akaki-kality and GU = Gullele

Table 8. Incremental lifetime cancer risks (ILCR) in children and adults for drinking water in Akaki-Kality and Gullele Sub-Cities of Addis Ababa.

Elements	Akaki-Kality		Gullele	
	Adult	Child	Adult	Child
Ni	1.26×10^{-7}	2.10×10^{-7}	-	-
Cr	8.33×10^{-6}	1.50×10^{-5}	-	-
Pb	2.91×10^{-7}	5.59×10^{-7}	3.64×10^{-7}	6.56×10^{-7}
As	2.50×10^{-4}	4.50×10^{-4}	5.00×10^{-5}	1.00×10^{-4}
$\sum_{i=1}^n ILCR$	2.59×10^{-4}	4.66×10^{-4}	5.04×10^{-5}	1.01×10^{-4}

ranked among the priority metals that are of interest in public health concerns. They are classified as toxicants and human carcinogens and induce multiple organ damage even at low concentrations (Ahmad et al., 2020; Nthunya et al., 2017; Tyler and Allan, 2014; WHO, 2008). Pb and As contents in the two Sub-Cities were also lower than the reported values (Huq et al., 2019; Mirzabeygi et al., 2017; Nawab et al., 2018; Rasool et al., 2016; Sadeghi et al., 2018), but similar values were reported from Pakistan (Ahmad et al., 2020). Even if these metals were found in small amounts in both selected research areas, the long-term exposures of these toxic metals may cause detrimental health effects on humans.

The concentration of most of the determined elements in the tap water samples from both Sub-Cities were found to be within the WHO and USEPA guideline values. One exception for this is the presence of some samples from both Sub-Cities that exhibited considerably higher concentration of Fe than the guideline values. Additionally, some of the samples from Gullele Sub-City contained higher concentration of Mn and Pb than guideline values.

Kruskal-Wallis H test revealed that Fe ($\chi^2 = 4.16$, $p = 0.042$), Cu ($\chi^2 = 4.87$, $p = 0.027$) and As ($\chi^2 = 8.64$, $p = 0.003$) differ significantly between the tap waters from the two Sub-Cities (Table 3). The mean concentrations of Fe determined in Gullele was higher than that of Akaki-Kality Sub-City. This may be due to the difference in geological sources such as the naturally occurring rock-water interaction (Vetrimurugan et al., 2017) and chemical weathering of rocks (Nawab et al., 2018; Rasool et al., 2016). On the other hand, the concentration of As was found to be significantly higher in Akaki-Kality Sub-City than Gullele Sub-City. Even though both study sites have tap waters from different natural sources, the degree of water contamination depends on both anthropogenic and natural sources. The anthropogenic sources of heavy metals around Akaki-Kality may be due to the various industrial activities including leather processing, paints, abattoir, textile, agriculture, and pharmaceutical products (Aschale et al., 2016). In addition, the percolating wastewater picks up a large number of heavy metals and reaches the aquifer system and contaminates groundwater sources (Bhutiiani et al., 2017).

The pattern of the distribution of elements between water samples from Gullele and Akaki-Kality Sub-Cities was investigated using principal component analysis (PCA). Three PCs with Eigenvalues higher than 1 were extracted. The first two PCs accounted for 60% of the variation in the data set. As shown in Figure 2, the tap water samples from the two Sub-Cities tend to occupy the opposite sides of PC1. Samples from Akaki-Kality are characterized by higher contents of Cr and Ni, while those from Gullele Sub-City by higher contents of Fe and Mn (Figure 2).

Computation of Pearson correlation coefficients indicated that Fe and Mn had a significant positive correlation across samples from the two Sub-Cities (Tables 4 and 5). A significant positive correlation was also found between Ni–Cr ($r = 0.682$) and Ni–Pb ($r = 0.610$) in samples from Akaki-Kality (Table 4). The results of Gullele Sub-City also showed positive correlations between Pb–Zn ($r = 0.768$), Pb–Cu ($r = 0.640$), and Cu–Zn ($r = 0.629$). Positive correlations in the concentration of the elements is a possible indicator of having a common source, mutual dependence, and identical behaviour during transportation (Dessie et al.,

2020; Li et al., 2013). Additionally, these observations confirm the information obtained from the PCA loadings plot (Figure 2).

3.2. Health risk assessments

In this study, chronic daily intake (CDI), hazard quotient (HQ), total hazard quotient (THQ), and incremental lifetime cancer risks (ILCR) of trace elements for children and adult age groups were estimated in Akaki-Kality and Gullele Sub-Cities drinking water through ingestion and dermal contact pathways.

3.2.1. Chronic daily intake

Health risk assessments were not performed for Cd and Co, as the concentrations of these elements were below the detection limits of the method. The mean, minimum, and maximum CDI values of the trace elements via ingestion (CDI_{ing}) and dermal contact (CDI_{der}) routes and the total (CDI_{total}) were calculated based on the determined concentration of each elements in the water samples from both study sites. The decreasing order of CDI_{ing} , CDI_{der} , and CDI_{total} , for both children and adults, were $Fe > Zn > Pb > Cu > Mn > As = Cr > Ni$ among the mean daily consumption rates across the Sub-Cities (Table 6).

The maximum daily consumption rate for children and adults through ingestion pathways was observed as 1.98 and 1.08 $\mu\text{g}/\text{kg}/\text{day}$, respectively, for Fe in the drinking water of Akaki-Kality. The maximum daily consumption rates ($\mu\text{g}/\text{kg}/\text{day}$) of Fe for children in Akaki-Kality via dermal pathways was 7.85×10^{-5} , while it was 5.64×10^{-5} for adults. The total CDI of Fe in the tap water of Akaki-Kality for children and adults were 1.98 and 1.08 $\mu\text{g}/\text{kg}/\text{day}$, respectively. Similarly, the maximum daily consumption rate of Fe for children and adults, through ingestion pathways, was observed as 6.12 and 11.23 $\mu\text{g}/\text{kg}/\text{day}$, respectively, in the tap water samples from Gullele Sub-City. Whereas, for the dermal pathway, the CDI values of Fe in Gullele for children and adults were 4.44×10^{-4} and 3.19×10^{-4} $\mu\text{g}/\text{kg}/\text{day}$, respectively. Regarding the calculated CDI values, a similar trend was observed between Gullele and Akaki-Kality Sub-Cities, where $Fe > Zn > Mn > Pb > Cu > As$.

The CDI_{der} for all the potentially toxic trace elements and both Sub-Cities were lower than the CDI_{ing} , and the mean daily consumption rate of the elements was low. These suggested that the tap water supplies for Akaki-Kality and Gullele Sub-Cities have no possibility of being carcinogenic. The CDI values of the determined elements in the drinking water samples from Akaki-Kality and Gullele were in accordance with the reported data of other researchers in Khorramabad, Iran (Mohammadi et al., 2019). According to Nawab et al. (2018), the mean CDI values (adults, children) of Cr (3.61, 3.98 $\mu\text{g}/\text{kg}/\text{day}$), Pb (2.78, 3.06 $\mu\text{g}/\text{kg}/\text{day}$), Ni (2.07, 2.28 $\mu\text{g}/\text{kg}/\text{day}$) and Zn (0.59, 0.65 $\mu\text{g}/\text{kg}/\text{day}$) were higher than the determined values for the drinking water samples from Akaki-Kality and Gullele Sub-Cities. On the other hand, the CDI estimated values for the drinking water samples from Akaki-Kality and Gullele were higher than Pb (6.30×10^{-5} to 9.45×10^{-5} $\mu\text{g}/\text{kg}/\text{day}$) and As (3.66×10^{-5} to 1.20×10^{-3} $\mu\text{g}/\text{kg}/\text{day}$) reported by Rezaei et al. (2019). Moreover, data reported by Saleh et al. (2019) were far lower (Cr = 1.07×10^{-6} , As = 2.5×10^{-7} , Pb = 6.3×10^{-7} , Zn = 1.38×10^{-6} , Cu = 1.33×10^{-6} and Fe = 2.03×10^{-6} $\mu\text{g}/\text{kg}/\text{day}$) than the values determined in this study.

3.2.2. Hazard Quotient and hazard index

Health risk evaluation of trace elements in terms of hazard quotient (HQ) and total hazard quotient (THQ) indices for children and adults in the Akaki-Kality and Gullele Sub-City drinking water were calculated and presented in Table 7. Regarding all of the determined trace elements, higher HQ values were observed for children compared to adults. The highest HQ value for children was 0.3 (As) in Akaki-Kality through the ingestion pathway. The lowest calculated value of HQ was 4.95×10^{-8} (Ni) for adults in Akaki-Kality through dermal contact. The estimated HQ index, for both through ingestion and dermal pathways in Akaki Kality Sub-City, was $As > Pb > Cr > Fe > Zn > Mn > Cu > Ni$ with the same fashion for both children and adults.

Both HQ and THQ in the two studied Sub-Cities, through both dermal and ingestion pathways, were lower than unity. Hence, as the USEPA guidelines for the HQ is less than one, it is possible to conclude that there is no non-carcinogenic risk in the tap waters from both Akaki-Kality and Gullele Sub-Cities of Addis Ababa, for both ingestion and dermal contact pathways. There were similar reports for tap water in the other countries, where HQ is lower than one (Alidadi et al., 2019; Fakhri et al., 2017; Hu et al., 2019; Mohammadi et al., 2019; Muhammad et al., 2011; Sarvestani and Aghasi, 2019). The studied mean values of heavy metals in drinking water reported by Saleh and his co-workers (Saleh et al., 2019) were lower ($HQ = 3.96 \times 10^{-5}$ - 247.825×10^{-4} (Fe), 1.00×10^{-7} - 44.59×10^{-4} (Cr), 1.951×10^{-4} - 367.306×10^{-4} (Cu), 6.139×10^{-4} - 66.996×10^{-4} (Pb), 2.00×10^{-8} - 1.46×10^{-5} (As) and 1.533×10^{-4} - 52.186×10^{-4} (Zn)) than the current study sites. HI is a way of estimating the overall probability for non-carcinogenic impacts posed by more than one element (Rezaei et al., 2019). As shown in Table 7, the mean values of ingestion and dermal HI for studied trace elements were 2.31×10^{-1} for adults and 4.20×10^{-1} for children in Akaki-Kality. Similarly, the mean values of ingestion and dermal HI for studied elements were observed as 1.34×10^{-1} for adults and 2.49×10^{-1} for children in Gullele. Since the HI value is less than one ($HI < 1$), there is no possibility of being non-carcinogenic risks of potentially toxic trace elements via ingestion or dermal contact pathway for both children and adults.

3.2.3. Incremental lifetime cancer risks

The range of calculated incremental lifetime cancer risk (ILCR) values of drinking water for children and adults in the studied Sub-Cities is shown in Table 8. According to the database of USEPA reference dosage of carcinogens, a risk level of 1×10^{-4} and 1×10^{-6} indicates 1 per 10,000 and 1,000,000 chances of getting cancer via consumption of drinking water containing elements such as Ni, Cr, Pb and As elements in $\mu\text{g/L}$ for 70 years. The cancer risk assessments of the rest of the potentially toxic trace elements were not calculated because of non-cancer risk properties.

The cumulative carcinogenicity risks of trace elements in the drinking water of Akaki-Kality for adults and children were in the range of 2.59×10^{-4} and 4.66×10^{-4} , respectively. Besides, the ICLR value of As in the drinking water of Akaki-kality for Adults and children was 2.50×10^{-4} and 4.5×10^{-4} , respectively. These results indicate that carcinogenic risk occurrence is probable from As in the lifetime of a person in Akaki-kality Sub-City. However, there is a very low probability of cancer risk incidence from As in Gullele for both age groups. Cadmium was not detected in all of the samples, while Cr and Ni were not detected in the water samples from Gullele. According to the results of this study, children are more exposed and sensitive to carcinogenicity risk than adults. According to some epidemiological studies (Tyler and Allan, 2014) due to As exposure children may have some disorders against brain intelligence, cognitive skills, and mental health.

4. Conclusion

Comparative assessments of the trace element contents and their health risks were made for the first time in the tap waters of Gullele and Akaki-Kality Sub-Cities, upstream and downstream parts of Addis Ababa,

respectively. The maximum concentration was recorded for Fe, while Cd and Co were not detected. Higher Fe and Mn were found in samples from Gullele, presumably from natural sources, while higher As, Cr, and Ni from Akaki-Kality could be due to high industrial activities occurring in the area. Based on the risk assessment results, there is no health risk for humans from the studied trace elements, except As, in the tap waters through both ingestion and dermal contact pathways.

Declarations

Author contribution statement

Bitew K. Dessie: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; analysis tools or data; Wrote the paper.

Sirak Robele Gar, Adey F. Desta and Bewuketu Mehari: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Adane Mihret: Contributed reagents, materials, analysis tools or data; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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