



Research Paper

Health Risk Assessment of Heavy Metals in Tap Water from Northern Iran Rural Areas via USEPA Model



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ABSTRACT

Background: Chronic exposure to heavy metals (HMs) in drinking water poses a significant environmental risk globally and may have serious implications for human health.

Objectives: This study focused on assessing the carcinogenic and non-carcinogenic health risks associated with six HMs in the Anzali lagoon area of northern Iran.

Materials & Methods: We evaluated the average concentrations of cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn) in tap drinking water collected from eleven rural communities. Additionally, we measured pH, total dissolved solids (TDS), and temperature. The health risks related to HM ingestion were assessed for both adults and children based on U.S. Environmental Protection Agency (EPA) guidelines. A total of ninety water samples were analyzed using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Carcinogenic and non-carcinogenic health risks were evaluated through the incremental lifetime cancer risk (ILCR) and hazard quotient (HQ), respectively.

Results: The average level of Pb exceeded the permissible limits set by WHO and Iranian national standards in five communities, affecting 48.8% of the samples. Furthermore, one community had Pb levels surpassing U.S. EPA standards in 22.2% of its samples. The concentrations of other HMs were within acceptable limits established by the U.S. EPA, World Health Organization (WHO), and Iranian standards.

Conclusion: The carcinogenic risk of heavy metal ingestion for both adults and children was estimated to be between 10^{-6} and 10^{-4} , indicating a generally tolerable cancer risk. However, this risk was notably higher in children compared to adults. The non-carcinogenic risk associated with selected HMs was below the safe limit (<1) across all communities for both age groups. Nonetheless, one community's concentrations of HMs and associated non-carcinogenic risks warrant further investigation, particularly concerning children's exposure.

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Introduction

Environmental pollution, particularly water pollution, has emerged as one of the most pressing global challenges. Ensuring a safe drinking water supply is essential for maintaining human health and preventing various health risks worldwide. Water contamination, especially by heavy metals, organic and inorganic compounds, and pathogens, poses significant concerns for both human health and environmental sustainability [1-5]. Public health can be influenced both directly and indirectly by the concentrations of physical, chemical, and microbial parameters in drinking water, regardless of whether these levels are high or low [6-8]. Drinking water typically contains small amounts of trace metals that are essential for the normal functioning of the human body; however, excessive concentrations of these metals can be harmful to health [9-11]. The assessment of trace metal levels, particularly heavy metals, has become a crucial area of research in water quality studies in recent years. This necessity arises from the adverse health effects associated with concentrations exceeding permissible limits. Therefore, continuous monitoring of these metals in drinking water is vital for evaluating human health risks [12].

Due to their high toxicity at low concentrations, non-biodegradable nature, long persistence in ecosystems and organisms, and tendency for bioaccumulation and biomagnification, heavy metals are critical contaminants affecting drinking water quality and are a significant public health concern, as highlighted by recent environmental research. [2, 3, 5, 13-20].

Heavy metal contamination in drinking water affects millions of people globally, contributing to chronic poisoning and the deaths of 1.6 million children each year. This issue is especially acute in developing countries due to inadequate infrastructure and rapid population growth. [21, 22]. Heavy metal contamination has been reported in several regions of Iran [1, 2, 4, 5, 13, 19, 20, 23-31].

Heavy metals can enter the environment and contaminate drinking water through natural processes, such as the denudation of ore deposits and hosting bedrocks, as well as through anthropogenic activities [2, 3, 5, 14, 16, 19, 20, 22, 32, 33]. Most of these metals are naturally present in the Earth's crust [4, 34, 35].

Some metals can become toxic when their concentrations increase and accumulate in the body [1, 3, 5, 19]. Non-essential metals such as cadmium (Cd), lead (Pb),

chromium (Cr) (VI), nickel (Ni), and mercury can contaminate drinking water. They have no metabolic role and are highly toxic or carcinogenic to humans, even at low concentrations, causing harmful effects on body tissues [1, 3, 5, 19, 32]. Chronic exposure to certain heavy metals can have harmful effects, leading to non-carcinogenic risks such as neurological issues, headaches, and liver disease when concentrations exceed safe thresholds, rendering the water unsafe to drink [2, 12, 36].

Concentrations of heavy metals in drinking water exceeding US-EPA, World Health Organization (WHO), or national standards have systematic effects on human health, raising the risk of cancer and chronic diseases in the exposed population [1, 22]. Over time, the consumption of heavy metals can lead to high concentrations in human organs, resulting in carcinogenic, mutagenic, and teratogenic effects [19].

The WHO and various national regulatory agencies have established maximum permissible limits of heavy metals in drinking water to minimize their adverse effects [32].

Direct comparison of the measured values with permissible limits is the conventional approach for assessing health effects, however, the reliability is insufficient to produce detailed data about level of human health risk [33, 37, 38].

Potential health risk from water contamination with heavy metals can be estimated by evaluating carcinogenic or noncarcinogenic health risk assessment methods. Exposure to contaminants can be calculated by chronic daily intake (CDI). Non-cancer risk is assessed by the hazard quotient (HQ) and hazard index (HI). Furthermore, the risk of cancer was estimated using the incremental lifetime cancer risk (ILCR). These methods are all proposed by the United State Environmental Protection Agency (US-EPA) [19, 22].

Measurement of heavy metals in drinking water is requisite for health risk assessment [20, 39]. In accordance with USEPA and Agency for Research on Cancer (IARC), exposure to toxic heavy metals in drinking water is a public health concern around the world, principally owing to their carcinogenic and non-carcinogenic effects on human health [20, 32, 40]. Several studies have reported raised health risks from exposure to these metals through water ingestion [32, 41].

In Iran, over 83% of the rural population has access to safe drinking water, but it may still contain heavy metals [20, 42]. While studies have addressed heavy metal contamination in Guilan province's environment, limited data exists on health risks from drinking water. Prior research in Iran and neighboring countries found elevated heavy metal levels. Unlike prior Iranian studies focused on urban water supplies or individual metals, this work quantifies dual health risks (carcinogenic/non-carcinogenic) for six priority heavy metals (Cd, Pb, Cr, Ni, Cu, Zn) in decentralized rural systems—using the USEPA model to evaluate vulnerabilities specific to agriculturally impacted regions of Anzali Lagoon. This study: 1) Measures concentrations of Cd, Pb, Cr, Ni, Cu, and Zn in tap water from 11 rural communities near Anzali Lagoon (unconnected to local utilities' pipelines); 2) Assesses non-carcinogenic and carcinogenic health risks for adults and children via ingestion.

Material and Methods

Study area

This cross-sectional study focused on rural communities in Rasht and Soume'sara districts near Anzali Lagoon, southwestern Caspian Sea, northern Iran's Gilan Province. The sampling area spans geographical coordinates of 49°21'–49°34' E (east longitude) and 37°18'–37°23' N (north latitude), encompassing approximately 150 km². The region features a gentle slope toward Anazali Lagoon. In the selected rural communities, drinking water is sourced exclusively from deep and shallow wells, as residents lack access to a centralized drinking water pipeline system managed by the Water and Wastewater Company. Additionally, the study area has experienced environmental pollution linked to industrial and agricultural activities [28]. The area is in a Mediterranean climate with plenty of precipitation [28, 43]. The map of the study area and sampling sites is shown in Figure 1.

Water sampling/sample collection

Due to the scattered rural population and the lack of access to a centralized, purified drinking water supply, a random sampling method was employed. A total of 90 tap-drinking-water samples were collected from 11 rural communities: Kamakol, Mangoodah, Sheikh-Mahaleh, Matak, Sufiandeh, Nargestan, Nokhaleh-Jafari, Nokhaleh-Akbari, Gazgisheh, Baghelakesh, and Sadat-Mahaleh. After initial evaluations, inquiries were made with two health centers in the counties of Sowme'eh Sara and Rasht, and the names of villages lacking ac-

cess to a centralized water supply network, along with the number of households in each, were obtained. In the next stage, a list of households residing in each village was prepared, and based on the number of households in each village, the required sample size for sampling was determined. Subsequently, using a simple random sampling method, the target household numbers for sampling were selected. Field sampling was conducted in February 2022 using high-density polyethylene (HDPE) bottles. Prior to use, the bottles were prewashed as follows:

Acid rinse: Washed three times with a 1:1 (v/v) nitric acid (HNO₃) and double-distilled water solution.

Final rinse: Thoroughly rinsed with double-distilled water to eliminate residual contaminants.

Analytical-grade nitric acid (Merck, Germany) was used in this study. At each sampling point, 500 mL of tap water was collected. Prior to collection, the tap was allowed to flow for 2–3 minutes to flush stagnant water. Samples were then slowly filled through a 0.45 µm Whatman membrane filter to remove suspended particles. Immediately after filtration, samples were:

Acidified: Treated with 3 mL of HNO₃ to adjust pH to <2, preventing heavy metal adsorption, crystallization, and microbial activity.

Sealed: Bottles were completely filled to minimize air-space and gas accumulation.

At each site, pH, TDS, and temperature were measured in situ using a portable multi-parameter meter. Sampling coordinates were recorded with a global positioning system (GPS). Samples were stored in lightproof, insulated coolers at 4 °C during transport and preserved in a 4 °C refrigerator until laboratory analysis.

Chemical analysis/sample analysis

The concentrations of selected heavy metals—Cd, Pb, Cr, Ni, copper (Cu), and zinc (Zn)—were measured in each sample using an inductively coupled plasma atomic emission spectrometer (ICP-AES; SPECTRO Arcos FHE 12, Germany). Analyses were performed under optimal standard analytical conditions following Standard Methods for the Examination of Water and Wastewater [45]. The limits of detection (LODs) for Cd, Pb, Cr, Ni, Cu, and Zn were 0.0004, 0.00133, 0.005, 0.00112, 0.000409, and 0.000647 mg/L, respectively.

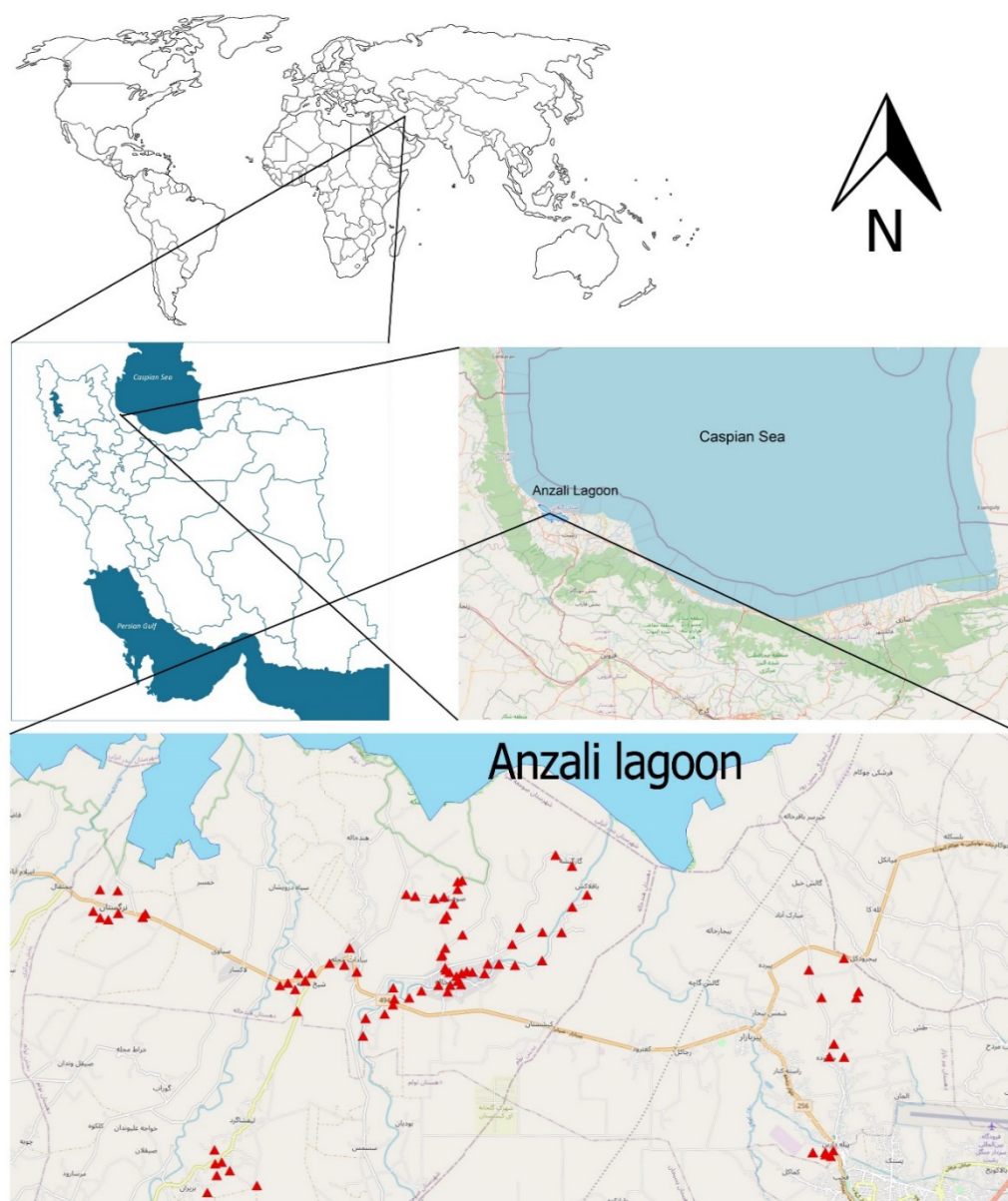


Figure 1. Location map of the study area and sampling points



The experiments were performed in the water and wastewater laboratory of Rasht Health School, [Guilan University of Medical Science](#), Iran. Samples were experimented with in triplicate to ensure the accuracy of the measurements. Initially, the concentration of selected heavy metals in tap drinking water was presented and, then human health risk posed by these metals were assessed.

Health risk assessment

A health risk assessment involves four steps: Hazard identification, dose-response assessment, exposure assessment, and risk characterization [12, 31]. Hazardous

chemicals such as heavy metals have several entries points in the body, including inhalation, dermal contact, and ingestion but the most common way that people are exposed to hazardous chemicals is through the consumption of contaminated water and other routes make a small contribution [2, 12, 34].

This study assessed the carcinogenic and non-carcinogenic health risks attributed to ingestion exposure to some heavy metals, such as Cd, Pb, Cr, Ni, Cu, and Zn in the tap drinking water of eleven rural communities around Anzali lagoon in the north of Iran in order to determine the negative health effects on residents using the

model defined by the United States Environmental Protection Agency (US-EPA). For this reason, the exposed population was classified into two groups: children and adults.

HQ, HI, and ILCR have been assessed by using the criteria set forth by the US-EPA. For the assessment of the risks, it is necessary to calculate CDI for the exposure pathway [31]. Using the formulas expressed below, the CDI (mg/kg/day) values of the chosen heavy metals through the ingestion pathway were calculated (Equation 1).

$$1. \text{CDI}_{\text{ing}} = \frac{C_w \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Where, CDI_{ing} (in mg/kg/day) is the CDI of water (also known as the average Daily Dose of elements) through the ingestion route; C_w (in mg/L) represents drinking water contaminant concentration (heavy metals); IR (in L/day) indicates the daily polluted drinking water ingestion rate; EF (in day/year) stands for annual exposure frequency; ED (in years) is annual exposure duration; BW (in kg) signalized the average body weight and AT (in days) signifies the time period over which the dose is averaged (average lifetime) [13, 20, 32, 45-51].

The values of adult's ingestion rate, children ingestion rate, exposure frequency, adult's exposure duration, children exposure duration, adult's average body weight, children average body weight and average time, used in previous studies are 2 L/day, 1 L/day, 365 days, 70 years, 6 years, 70 kg, 20 kg, respectively [2, 4, 5, 12, 13, 31, 52, 53].

Non-carcinogenic risk assessment

The results demonstrate that the CDI of heavy metals has been higher in children as compared with that adults.

The HQ is a unitless index employed in the current study to assess the potential of non-carcinogenic human health risk for a specific heavy metal and was calculated by the Equation 2:

$$2. \text{HQ}_g = \frac{\text{CDI}_{\text{ing}}}{\text{R}_g\text{D}}$$

Where CDI_{ing} (in mg/kg/day) is the CDI of metal in drinking water for non-carcinogenic effects and R_gD (mg/kg/day) is Reference Dose both through oral ingestion [2, 4, 12, 48, 54]. Oral R_gD values were 0.0005, 0.0035, 0.003, 0.02, 0.04, and 0.3 for Cd, Pb, Cr, Ni, Cu, and Zn, respectively [5, 12, 23, 47, 55-57].

The HQ was perceived as follows: $\text{HQ} \leq 1$: There is no potential for any adverse health effects from exposure to the target contaminant and $\text{HQ} > 1$: There is the potential of non-carcinogenic adverse health effects from exposure to the specific contaminant.

HI was used to calculate the total potential non-carcinogenic human health risk brought on by exposure to a combination of heavy metals in drinking water using Equation 3. Similar to HQ; there is no potential for adverse health effects from exposure to the total contaminants when $\text{HQ} \leq 1$ and it exists the potential of adverse health effects from exposure to total contaminants when $\text{HQ} > 1$. The sum of all HQs (HI) yields an estimation of the whole potential health risks of all heavy metals [4, 48].

$$3. \text{HI} = \sum \text{HQ}$$

Carcinogenic risk assessment

The ILCR is a unitless index used to assess the potential of carcinogenic human health risk for a specific dose of heavy metal in drinking water and was calculated by the Equation 4:

$$4. \text{ILCR} = \text{CDI} \times \text{SF}$$

Which, ILCR is the likelihood that a person developing any type of cancer over their lifetime who is exposed to a specific carcinogen, CDI (in mg/kg/day) is the CDI of carcinogenic heavy metal in drinking water and, SF (in mg/kg/day) is cancer slope factor and is defined as the contaminant-specific risk caused by a lifetime average amount of one mg/kg/day of a carcinogen heavy metal [2, 4, 12, 14, 48]. Where its values for Cd, Pb, Cr, and Ni are 0.38, 0.0085, 0.5 and 0.91, respectively [1, 24, 33, 55, 58-65]. This study compared the amount of estimated ILCR to the USEPA-suggested acceptable maximum risk ($\leq 1 \times 10^{-6}$) established by the US-EPA [5, 66-68].

The accepted carcinogenesis risk criteria for human fatality hazards are as outlined in USEPA guidelines: carcinogenesis risk between 10^{-6} to 10^{-4} is generally tolerable. Carcinogenesis risk is considered low for ELCR values below 10^{-6} . It is considered that ELCR values greater than 10^{-4} have an unacceptably high cancer risk [31]. In this study Cd, Pb, Cr, and Ni are considered as having carcinogenic properties [63, 69-76]. Therefore, in this research, the HQ and excess lifetime cancer risk (ELCR) were used to determine the non-carcinogenic and carcinogenic effects of heavy metals.

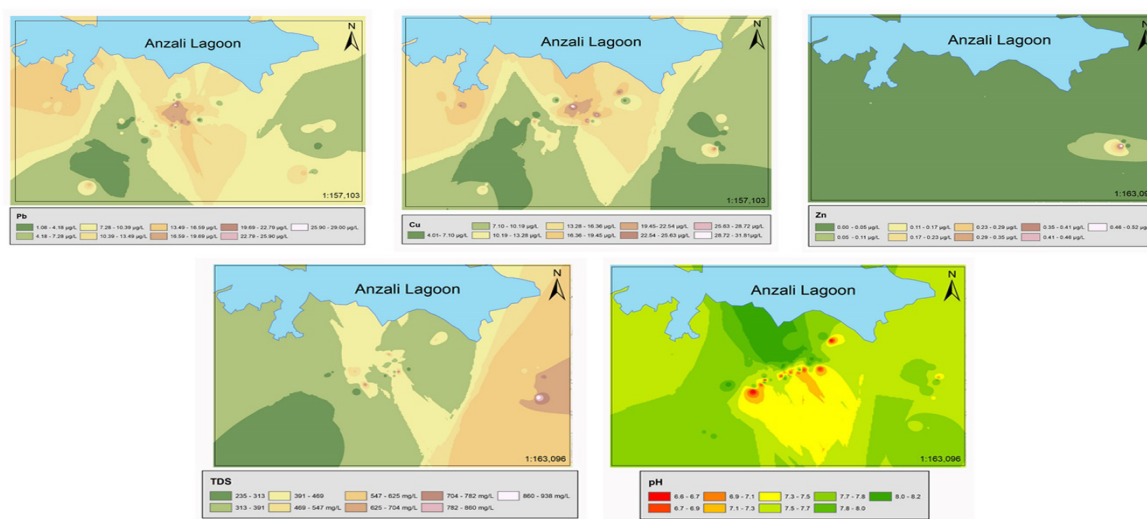


Figure 2. Spatial distribution of pH, TDS and heavy metal concentration ($\mu\text{g/L}$) in tap drinking water of study area



Statistical analysis

All statistical analyses were performed using SPSS software, version 24 and Microsoft Excel software, version 2016, while maps of the study area were generated with ArcGIS software, version 10.8.2.

Result

The following describes the results of tap drinking water contamination caused by selected heavy metals in the study area, as well as an assessment of non-carcinogenic and carcinogenic human health risk. In this research, the concentration of the six heavy metals (Cd, Pb, Cr, Ni, Cu, and Zn) was quantified in mg/L and compared to US-EPA, WHO and, Iran national standards guidelines [45-47]. Table 1 reveals the pH, TDS, and concentration of heavy metals determined in the tap drinking water in this study.

The average pH value of water from sampled communities varied from 7.47 to 8.11 and were in the following order: Sufiandeh (8.11)>Matak (7.87)>Sheikh-mahaleh (7.86)> Sadat-mahaleh (7.82)>Kamakol and Nokhaleh-jafari (7.73)>Mangoodeh (7.67)>Baghelakesh (7.66)>Gazgisheh and Nargestan (7.60)>Nokhaleh-akbari (7.47) (Figure 2).

The total dissolved solid (TDS) average value of water from sampled communities varied from 298 to 637.75 mg/L and were in the following order: Mangoodeh (637.75)>Kamakol (573.33)>Sadat-mahaleh (507.67)>Nokhaleh-jafari (423.68)>Gazgisheh (397)>Sufiandeh (374.29)>Nokhaleh-akbari (371.72)>Baghelakesh

(353.5)>Nargestan(352.33)>Sheikh-mahaleh (325)>Matak (298) (Figure 2).

The highest measured average value for TDS (637.75 mg/L) was seen in Mangoodeh. Among heavy metals studied in this work, Cd, Cr and, Ni were not identified in samples due to their values were lower than the LODs of ICP-AES. Pb, Cu and Zn were seen in 90%, 81.1% and 7.7% of the samples, respectively.

Pb concentration in tap drinking water samples ranged from 0.003 to 0.019, 0.002 to 0.012, 0.001 to 0.015, 0.006 to 0.017, 0.003 to 0.013, 0.012 to 0.017, 0.012 to 0.03, 0.008 to 0.013, 0.001 to 0.018, 0.005 to 0.01 and, 0.007 to 0.016 in Kamakol, Mangoodeh, Sheikh-mahaleh, Matak, Sufiandeh, Nargestan, Nokhaleh-jafari, Nokhaleh-akbari, Gazgisheh, Baghelakesh and Sadat-mahaleh, respectively (Table 1). The Pb concentration of samples was in order of Nokhaleh-jafari>Nargestan>Matak>Sadat-mahaleh>Gazgisheh>Kamakol>Nokhaleh-akbari>Baghelakesh>Sufiandeh>Sheikh-mahaleh>Mangoodeh. The highest Pb concentration (0.03 mg/L) was observed in the water samples collected from Nokhaleh-jafari.

Similarly, the Cu concentration in samples ranged from 0.004 to 0.009, 0.004 to 0.024, 0.004 to 0.018, 0.012 to 0.014, 0.012 to 0.021, 0.013 to 0.026, 0.007 to 0.035, 0.013 to 0.024, 0.006 to 0.018, 0.006 to 0.011 and 0.009 to 0.021 in Kamakol, Mangoodeh, Sheikh-mahaleh, Matak, Sufiandeh, Nargestan, Nokhaleh-jafari, Nokhaleh-akbari, Gazgisheh, Baghelakesh, and Sadat-mahaleh, respectively (Table 1).

Table 1. pH, TDS and mean concentrations (mg/L) of heavy metals in tap drinking water in study area

Sampling Site	Statistics	Cd	Pb	Cr	Ni	Cu	Zn	pH	TDS
Kamakol (n=6)	Mean±SD	UDL	0.010±0.006	UDL	UDL	0.006±0.002	0.077	7.73±0.09	573.33±26.61
	Max.	-	0.019	-	-	0.009		7.85	613
	Min.	-	0.003	-	-	0.004		7.56	541
Mangoodeh (n=8)	Mean±SD	UDL	0.006±0.003	UDL	UDL	0.013±0.008	0.529	7.67±0.27	637.75±143.36
	Max.	-	0.012	-	-	0.024		8.02	945
	Min.	-	0.002	-	-	0.004		7.12	536
Sheikhmahaleh (n=8)	Mean±SD	UDL	0.006±0.006	UDL	UDL	0.008±0.007	UDL	7.86±0.15	325.00±226.63
	Max.	-	0.015	-	-	0.018		8.21	378
	Min.	-	0.001	-	-	0.004		7.73	303
Matak (n=7)	Mean±SD	UDL	0.012±0.008	UDL	UDL	0.013±0.001	0.002	7.87±0.03	298.00±6.40
	Max.	-	0.017	-	-	0.014		7.92	306
	Min.	-	0.006	-	-	0.012		7.83	287
Sufiandeh (n=7)	Mean±SD	UDL	0.007±0.003	UDL	UDL	0.016±0.003		8.11±0.13	374.29±24.72
	Max.	-	0.013	-	-	0.021		8.22	429
	Min.	-	0.003	-	-	0.012		7.87	354
Nargestan (n=6)	Mean±SD	UDL	0.014±0.002	UDL	UDL	0.017±0.004	0.1	7.60±0.07	352.33±9.06
	Max.	-	0.017	-	-	0.026		7.75	374
	Min.	-	0.012	-	-	0.013		7.54	344
Nokhaleh Jafari (n=19)	Mean±SD	UDL	0.019±0.005	UDL	UDL	0.019±0.007	0.054	7.91±1.08	423.68±155.71
	Max.	-	0.030	-	-	0.035		11.7	865
	Min.	-	0.012	-	-	0.007		6.75	250
Gazgisheh (n=3)	Mean±SD	UDL	0.011±0.003	UDL	UDL	0.017±0.006	UDL	7.60±0.79	397.00±78.35
	Max.	-	0.013	-	-	0.024		8.14	487
	Min.	-	0.008	-	-	0.013		6.69	344
Nokhaleh Akbari (n=18)	Mean±SD	UDL	0.009±0.004	UDL	UDL	0.011±0.004	0.06	7.47±0.58	371.72±102.16
	Max.	-	0.018	-	-	0.018		8.15	735
	Min.	-	0.001	-	-	0.006		6.59	231
Baghelakesh (n=2)	Mean±SD	UDL	0.008±0.004	UDL	UDL	0.009±0.004	UDL	7.66±0.01	353.50±10.61
	Max.	-	0.010	-	-	0.011		7.66	361
	Min.	-	0.005	-	-	0.006		7.65	346
Sadat Mahaleh (n=3)	Mean±SD	UDL	0.011±0.005	UDL	UDL	0.015±0.008	UDL	7.82±0.15	507.67±88.91
	Max.	-	0.016	-	-	0.021		7.99	559
	Min.	-	0.007	-	-	0.009		7.73	405

Table 2. Estimated CDI of heavy metals for adults and children through tap drinking water ingestion pathway

Variables	Pb		Cu		Zn	
	Adults	Children	Adults	Children	Adults	Children
Kamakol	2.85714E-4	0.5E-3	1.71429E-4	0.3E-3	2.2E-3	3.85E-3
Mangoodeh	1.71429E-4	0.3E-3	3.71429E-4	6.5E-4	1.5114286E-2	2.645E-2
Sheikh-Mahaleh	1.71429E-4	0.3E-3	2.28571E-4	0.4E-3	-	-
Matak	3.42857E-04	0.6E-3	3.71429E-4	6.5E-4	5.71429E-5	0.1E-3
Sufiandeh	0.2E-3	3.5E-4	4.57143E-4	0.8E-3	2.085714E-3	3.65E-3
Nargestan	0.4E-3	0.7E-3	4.85714E-4	8.5E-4	2.857143E-3	0.5E-2
Nokhaleh-jafari	5.42857E-04	9.5E-4	5.428571E-3	9.5E-3	1.542857E-3	2.7E-3
Gazgisheh	3.14286E-04	5.5E-4	4.85714E-4	8.5E-4	-	0
Nokhaleh-akbari	2.57143E-04	4.5E-4	3.14286E-4	5.5E-4	1.714286E-3	0.3E-2
Baghelakesh	2.28571E-04	0.4E-3	2.57143E-4	4.5E-4	-	-
Sadat-mahaleh	3.14286E-04	5.5E-4	4.28571E-4	7.5E-4	-	-
Average	3.42857E-04	0.6E-3	4.57143E-4	0.8E-3	3.657143E-3	6.40E-3

E: The term “E-” means “multiplied by 10 to the power of”.



The Cu concentration of samples was in the order of Nokhaleh-jafari>Nargestan and Gazgisheh>Sufiandeh>Sadat-mahaleh>Mangoodeh and Matak> Nokhaleh-akbari>Baghelakesh>Sheikh-mahaleh>Kamakol. The highest Cu concentration (0.031 mg/L) also was tracked in the water samples collected in Nokhaleh-jafari. It was demonstrated that the levels of Cu in all samples were within the limits set by the EPA, the WHO, and the Iranian National Standard.

The Zn concentration in samples was 0.077, 0.529, 0.002, 0.073, 0.1, 0.054, 0.06, and 0.009 in Kamakol, Mangoodeh, Matak, Sufiandeh, Nargestan, Nokhaleh-jafari, and Nokhaleh-akbari, respectively. This metal was not identified in other communities (Table 1). The Zn concentration of samples was in the order of Mangoodeh> Nargestan> Kamakol> Sufiandeh> Nokhaleh-akbari> Nokhaleh-jafari> Matak> Sheikh-mahaleh, Gazgisheh, Baghelakesh, and Sadat-mahaleh. The highest Zn concentration (0.529 mg/L) was seen in the water sample collected from Mangoodeh. The results showed that the levels of Zn in studied samples were within the range recommended by the US-EPA, WHO, and Iranian national standards.

Health risk assessment

Table 2 summarises the CDI of Pb, Cu, and Zn in tap drinking water samples in both adults and children via ingestion pathway collected from 11 studied rural communities. Since the concentration of Cd, Cr, and Ni were reported under detection limits of AES-ICP, their CDIs were not calculated.

The non-carcinogenic risk of the heavy metals in the drinking water was calculated by Equation 2 and 3. Table 3 summarizes the estimated HQ and HI of target heavy metals for the ingestion of tap drinking water in the study area.

Therefore, the HQ and HI indices of heavy metals in the study area were found in the order of Pb>Cu and Zn> Cd, Cr, and Ni. The HQ indices and subsequently HI index were found Pb, Cu, and Zn in two age groups (children and adults), suggesting no possibility of non-carcinogenic adverse health effects to the local population in long-time exposure.

The non-carcinogenic health risk (HQ value) of Pb were in descending order of Nokhaleh-jafari> Nargestan> Matak> Gazgisheh and Sadat-mahaleh> Kamakol> Nokhaleh-akbari> Baghelakesh> Sufiandeh> Mangoodeh and Sheikh-mahaleh in both age groups, respectively.

Table 3. HQ and HI of heavy metals via tap drinking water in rural communities around Anzali lagoon (adults and children)

Variables	HQ _{Ingestion}						HI _{Ingestion}	
	Pb		Cu		Zn		Adults	Children
	Adults	Children	Adults	Children	Adults	Children		
Kamakol	0.08	0.14	0.00	0.01	0.01	0.01	0.09	0.16
Mangoodeh	0.05	0.09	0.01	0.02	0.05	0.09	0.11	0.19
Sheikh-Mahaleh	0.05	0.09	0.01	0.01	0	0	0.05	0.10
Matak	0.10	0.17	0.01	0.02	0	0	0.11	0.19
Sufiandeh	0.06	0.10	0.01	0.02	0.01	0.01	0.08	0.13
Nargestan	0.11	0.20	0.01	0.02	0.01	0.02	0.14	0.24
Nokhaleh-jafari	0.16	0.27	0.14	0.24	0.01	0.01	0.30	0.52
Gazgisheh	0.09	0.16	0.01	0.02	0	0	0.10	0.18
Nokhaleh-akbari	0.07	0.13	0.01	0.01	0.01	0.01	0.09	0.15
Baghelakesh	0.07	0.11	0.01	0.01	0	0	0.07	0.13
Sadat-mahaleh	0.09	0.16	0.01	0.02	0	0	0.10	0.18
Average	0.10	0.17	0.01	0.02	0.01	0.02	0.12	0.21



The non-carcinogenic health risk (HQ value) of Cu were in descending order of Nokhaleh-jafari>Nargestan and Gazgisheh>Sufiandeh and Sadat-mahaleh>Mangoodeh and Matak>Nokhaleh-akbari>Baghelakesh and Sheikh-mahaleh>Kamakol in the adult group, respectively.

The non-carcinogenic health risk (HQ value) of Cu were in descending order of Nokhaleh-jafari> Nargestan and Gazgisheh>Sufiandeh>Sadat-mahaleh>Mangoodeh and Matak>Nokhaleh-akbari>Baghelakesh and Sheikh-mahaleh> Kamakol in the children group, respectively.

The non-carcinogenic health risk (HQ value) of Zn were in descending order of Mangoodeh>Nargestan>Kamakol and Sufiandeh>Nokhaleh-akbari>Nokhaleh-jafari>Matak, Sheikh-mahaleh, Gazgisheh, Baghelakesh and Sadat-mahaleh in the adult group, respectively.

The non-carcinogenic health risk (HQ value) of Zn were in descending order of Mangoodeh>Nargestan>Kamakol>Sufiandeh>Nokhaleh-akbari>Nokhaleh-jafari> Matak, Sheikh-mahaleh, Gazgisheh, Baghelakesh and Sadat-mahaleh in children group, respectively.

The chronic HI of total heavy metals HI was in descending order of Nokhaleh-jafari>Nargestan>Mangoodeh>Matak>Gazgisheh>Sadat-mahaleh>Kamakol>Nokhaleh-akbari>Sufiandeh>Baghelakesh>Sheikh-mahaleh in both adults and children groups, respectively.

According to the US-EPA guideline mentioned earlier, there is no significant risk of adverse health effects since the HQ level of any heavy metal and HI in the drinking water in the study area is less than one. However, the concentration of heavy metals in Nokhaleh-jafari needs more attention in future research. Table 4 provides a summary of the ELCR indices of HMs in the study area's tap drinking water.

The ILCR of Pb were in descending order of Nokhaleh-jafari>Nargestan>Matak>Gazgisheh>Sadat-mahaleh>Kamakol>Nokhaleh-akbari>Baghelakesh>Sufiandeh>Mangoodeh>Sheikh-mahaleh in both adults and children group, respectively (Figure 3).

While the carcinogenesis risk of Pb in all communities was between 10^{-6} to 10^{-4} and considered as having tolerable carcinogenic risk, the ILCR has been higher in the children group as compared with the adults group. Since

Table 4. ILCR of heavy metals via tap drinking water in rural communities around Anzali lagoon (adults and children)

Variables	Cd		Pb		Cr		Ni	
	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Kamakol	-	-	2.43E-6	4.25E-6	-	-	-	-
Mangoodeh	-	-	1.46E-6	2.55E-6	-	-	-	-
Sheikh-Mahaleh	-	-	1.46E-6	2.55E-6	-	-	-	-
Matak	-	-	2.91E-6	5.10E-6	-	-	-	-
Sufiandeh	-	-	1.70E-6	2.98E-6	-	-	-	-
Nargestan	-	-	3.40E-6	5.95E-6	-	-	-	-
Nokhaleh-jafari	-	-	4.61E-6	8.08E-6	-	-	-	-
Gazgisheh	-	-	2.67E-6	4.68E-6	-	-	-	-
Nokhaleh-akbari	-	-	2.19E-6	3.83E-6	-	-	-	-
Baghelakesh	-	-	1.94E-6	3.40E-6	-	-	-	-
Sadat-mahaleh	-	-	2.67E-6	4.68E-6	-	-	-	-
Average	-	-	2.49E-6	4.37E-6	-	-	-	-

E: The term "E-" means "multiplied by 10 to the power of".



the concentration of Cd, Cr and, Ni were reported under the detection limits of AES-ICP, their ILCR was not calculated. Overall, the carcinogenic risk of tap drinking water in the study area was in permitted level for both the adult and children groups.

Discussion

This study provides the first comprehensive assessment of combined carcinogenic and non-carcinogenic risks from heavy metals in tap water of rural communities near Anzali Lagoon, Iran, addressing critical gaps in data for groundwater-dependent areas with aging infrastructure.

The results showed that drinking water samples are slightly alkaline. Despite the fact that the pH of drinking water typically has no direct effects on consumers, it is one of the most crucial operational water quality parameters [45]. However, pH values of all drinking water samples were within the permissible limit of the US-EPA, WHO and, Iran National Standard [45-47]. All TDS values meet Iran National Standard But some of them (Mangoodeh, Kamakol, Sadat mahaleh) exceeded the permissible limits set by US-EPA [46, 47]. There is no recommended TDS value based on WHO guideline [45].

It was seen that 48.8% of the samples and 5 communities had Pb concentrations above the WHO and Iran National Standard set permissible limits (0.01 mg/L). Additionally, The US-EPA's permissible limits (0.015 mg/L) were also exceeded in 22.2% of the samples and one community. One of the important reasons that could cause this high level of heavy metals is the proximity of this villages to the Anzali wetland and possibly related to the entry of industrial wastewater into the wetland.

In this study, 5 heavy metal (e.g. Cd, Cr, Ni, Cu, and Zn) concentrations were found to be below the maximum permitted levels by US-EPA, WHO and Iran National Standard, but Pb concentration in the some samples exceeds the limit set by these guidelines.

Compared to Zahedan (HI=0.38) and Khorramabad (HI=0.43), our lower average HI (0.21) suggests reduced cumulative risk, yet Pb-driven hazards in Nokhaleh-jafari (HI=0.52) approach critical thresholds seen in Pakistani mining communities (HI>1) [6, 24].

The non-carcinogenic human health risk assessment indices (HQ and HI) for all metals through the ingestion pathway were found less than the safe limit (<1) in all communities in both adults and children groups. However, the concentration of heavy metals in one community

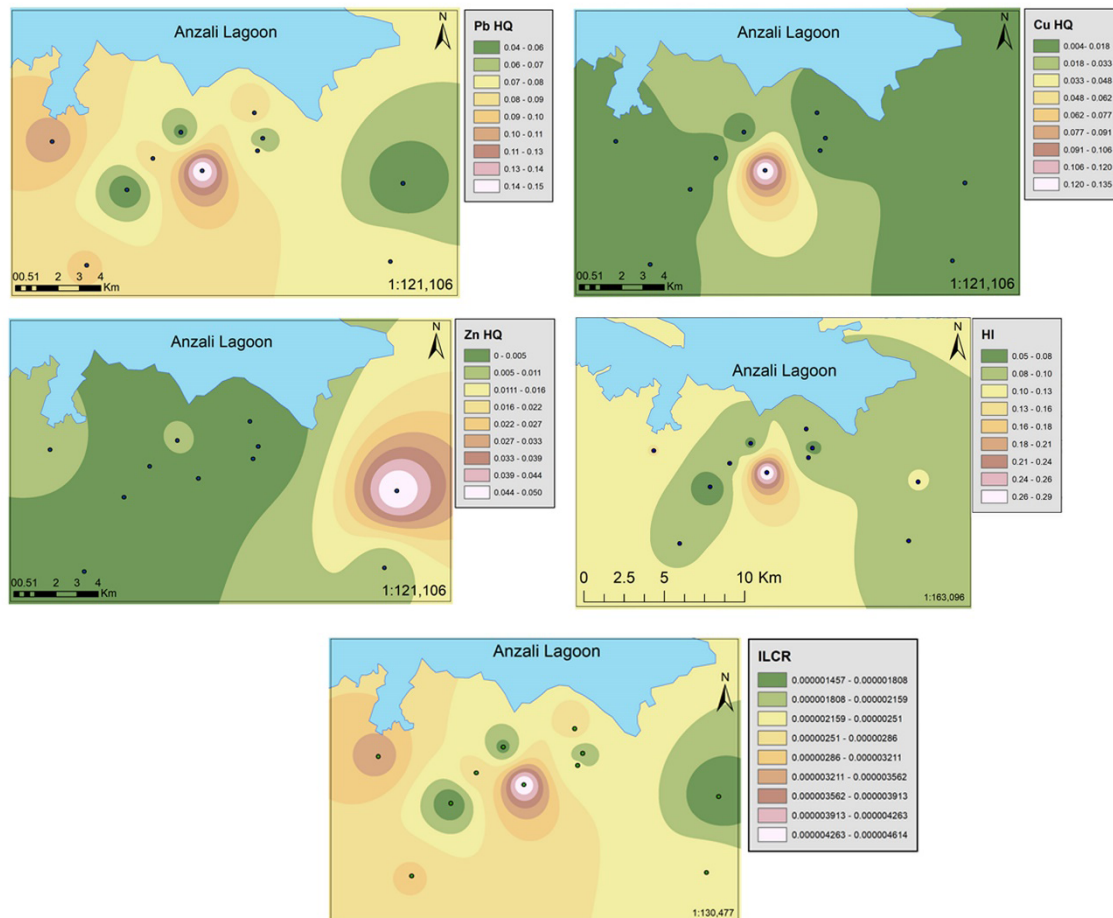


Figure 3. Spatial distribution map HQ of Pb, Cu and Zn, HI and ILCR



(Nokhaleh-jafari) and their non-carcinogenic risk needs more attention in the future, especially in the children group. Risk assessment signified that Pb was the considerable contributor to non-carcinogenic health risk.

Based on the results of this work, the chronic HI of total heavy metals (HI) in tap drinking water was in descending order of Nokhaleh-jafari>Nargestan>Mangoodeh>Matak>Gazgisheh>Sadat-mahaleh>Kamakol>Nokhaleh-akbari>Sufiandeh>Baghelakesh>Sheikh-mahaleh in both adults and children group, respectively.

Moreover, it was indicated that the carcinogenic risk associated with carcinogenic heavy metals (Cr, Pb, Cr and, Ni) in tap drinking water through the ingestion pathway was tolerable. The ILCR of Pb were in descending order of Nokhaleh-jafari>Nargestan>Matak>Gazgisheh>Sadat-mahaleh>Kamakol>Nokhaleh-akbari>Baghelakesh>Sufiandeh>Mangoodeh>Sheikh-mahaleh in both adults and children group, respectively.

Overall, this study proposed that particular attention must be paid to the probability of drinking water contamination due to heavy metals in communities that have no access to drinking water pipeline systems prepared by authorized water supply companies. Furthermore, special precautions are needed for the administration of water resources. This work provides initial information on the human health risk of 6 heavy metals through ingestion in adults and children group, which can be utilized for future drinking water quality monitoring and advanced studies on drinking water contamination. Eventually, it is suggested that a comprehensive assessment of all exposure pathways and associated risks be carried out.

Unlike groundwater-heavy studies (e.g. Ghana [55]), our tap water assessment implicates aging pipes/wells as Pb sources, urging infrastructure upgrades—notably absent in Iran's rural health policies.



Prioritize Nokhaleh-jafari for pipe replacement and quarterly Pb monitoring, mirroring Bangladesh's successful mitigation in arsenic zones [22].

Conclusion

In this study, the concentration of six heavy metals including Cd, Pb, Cr, Ni, Cu and, Zn was determined in ninety tap water which is used for ingestion in February 2022 from 11 rural communities around Anzali lagoon in the north of Iran. These communities have no access to the drinking water pipeline system prepared by Water and Wastewater Company. Furthermore, the carcinogenic and non-carcinogenic potential health risk of exposure to target heavy metals were assessed using US-EPA guideline.

The results indicated that the concentration of Pb in 48.8% of samples was above the WHO and Iran national standard. In addition, the concentration of Pb in 22.2% of samples was above the US-EPA maximum permissible limit. The concentration of other heavy metals (Cd, Cr, Ni, Cu and, Zn) were below the permissible limit set by US-EPA, WHO and, Iran national standard.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Guilan University of Medical Sciences, Rasht, Iran (Code: IR.GUMS.REC.1400.566).

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Authors' contributions

Conceptualization and methodology: Seyed Davoud Ashrafi and Jalil Jaafari; Investigation, data collection and writing the original draft: Rasol Khodaju; Review, editing and Supervision: Seyed Davoud Ashrafi; Data analysis: Jalil Jaafari.

Conflict of interest

The authors declared no conflict of interest.

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