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Bottled water safety evaluation: A comprehensive health risk assessment of oral exposure to heavy metals through deterministic and probabilistic approaches by Monte Carlo simulation

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Highlights

- Comprehensive health risk assessment of 8 heavy metals in high-consumption bottled water in Iran.
- Utilization of deterministic and probabilistic approaches for non-carcinogenic and carcinogenic risk assessment.
- Sensitivity Analysis (SA) identified key factors influencing non-carcinogenic and carcinogenic risks.

- Using ArcGIS and IDW interpolation for spatial analysis in local health risk management.
- Findings urge ongoing study and rules to manage health risks from heavy metals in bottled water.

Abstract

The consumption of bottled water has witnessed substantial global expansion in recent times. This study aimed to quantitatively evaluate the concentrations of eight heavy metals (As, Ba, Cd, Cr, Mn, Mo, Ni, and Zn) in 71 high-consumption bottled water brands in Iran. Non-carcinogenic and carcinogenic risk assessments were conducted using both deterministic and probabilistic approaches. Point estimation utilizing the Hazard Quotient (HQ) formula and sensitivity analysis employing the Monte Carlo Simulation (MCS) method through 10,000 repetitions in Oracle Crystal Ball® was used to ascertain the health risks associated with heavy metal exposure. Heavy metal concentrations were quantified through Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES). HQ point estimation results indicated that Cr exhibited the highest mean HQ value, whereas Cd demonstrated the lowest. In the probabilistic approach, the highest 95 percentile values were observed for Cr and Mo at 3.9E-01, while the lowest values were recorded for Cr and Mn at 1.10E-02. Heavy metal concentrations emerged as critical factors influencing non-carcinogenic and carcinogenic risks across all groups in the sensitivity analysis. The findings highlight the need for ongoing monitoring, research, and targeted regulations to address health risks from heavy metal exposure in bottled water and ensure public well-being.

Introduction

In the contemporary era, as the welfare of populations remains paramount, the safety and wellness attributes intrinsic to diverse water sources have gained pivotal significance (Fallahati et al., 2020; Karamia et al., 2019). Bottled water has become a pervasive preference in this spectrum, frequently lauded for its perceived pristine nature and convenience as a substitute for conventional tap water (Akbari et al., 2018). Nevertheless, does the integrity of this notion necessitate scrupulous inquiry, considering its potential to instigate substantive queries regarding the safety and broader health ramifications inherent to bottled water consumption?

Bottled water is potable from various origins, such as mineral springs, wells, and springs, packaged and sold in securely sealed containers. Recently, the proliferation of bottled water consumption has witnessed a remarkable expansion. In the US, bottled water consumption experienced continuous growth every year from 1977 to 2016 grew annually from 1977 to 2016 (Rodwan, 2017). China claimed the world's leading bottled water market position in 2013 with a rapid 14.3% increase (Deng et al., 2021). Global growth in bottled water consumption is driven by consumer demand for perceived safety and convenience, fueled by widespread marketing (Doria, 2006). Despite perceived advantages, a thorough investigation is crucial to uncover contamination sources and pathways challenging its assumed safety.

Bottled water's vulnerability to pollutants, including heavy metals, stems from complex interactions between natural processes (weathering, rock decomposition, erosion) and human activities (mining, industry, sewage, and agriculture) (Fei et al., 2017). These processes can contaminate bottled water sources with pollutants like heavy metals. Packaging and transportation also risk degrading water quality as chemicals leach from plastics due to compromised storage (Abolli et al., 2023). Consequently, conducting a thorough evaluation of bottled water quality to identify various pollutants, including heavy metals, becomes imperative in upholding public health standards.

Heavy metals are paradoxical, encompassing essential elements like cobalt, copper, iron, manganese, and zinc - vital for human health and non-essential toxic elements like cadmium, arsenic, and lead - posing significant risks (Huang et al., 2020). Elevated concentrations of heavy metals in potable water can be attributed to their inherent stability and bioaccumulation (Onyele and Anyanwu, 2018). Notably, high chromium links to liver/kidney cancer (Linos et al., 2011), excess manganese to parkinsonism; lead affects fertility/ovulation and causes malformations/miscarriages. Unsafe copper and zinc levels lead to non-carcinogenic issues, like neurological problems and liver diseases (Couto and Ribeiro, 2022). Given this information, a thorough health risk assessment (HRA) of consumed water sources becomes imperative to mitigate potential adverse health effects (Ghalhari et al., 2022).

HRA is a crucial tool for evaluating the potential health hazards of various environmental contaminants, including water resources (Jamshidi et al., 2021). It systematically analyzes exposure pathways, toxicity data, and population vulnerability to estimate risks accurately. Various methodologies, encompassing deterministic and probabilistic approaches, contribute to HRA. Deterministic methods rely on point estimates for exposure and toxicity, offering a simplified risk perspective (Badeenezhad et al., 2021). Probabilistic approaches, such as Monte Carlo Simulation (MCS), factor in uncertainty by considering ranges of exposure parameters and generating probability distributions that contribute to a more comprehensive assessment of potential health risks. MCS, a widely adopted technique, offers a comprehensive platform for quantifying carcinogenic and non-carcinogenic risks associated with heavy metal exposure in drinking water (Sharafi et al., 2022).

Given Iran's global rise in bottled water consumption and escalating worries about heavy metal pollution, a comprehensive and systematic inquiry is imperative to assess and evaluate the health risks of these metals quantitatively. The primary objective of this study was to conduct a comprehensive risk evaluation of both carcinogenic and non-carcinogenic effects associated with heavy metals in bottled water, encompassing all 32 provinces of Iran in 2021. The study employed two distinct methods: 1. deterministic and 2. probabilistic approach by Monte Carlo Simulation (MCS) coupled with Sensitivity Analysis (SA). Additionally, geographic information system (GIS) techniques were employed to map the heavy metal concentration of bottled water across different regions within Iran.

Section snippets

Study area

Iran, located in Western Asia, spans approximately 1.64 million square kilometers (0.63 million square miles) and is divided into 32 provinces with distinct characteristics and water availability (Fig. 1). With a population of around 89.2 million (2023), Iran is the 17th most populous country globally and the second-largest in the Middle East, with a significant urban population of 74.2% (66,139,220 people in 2023) (Worldmeter, 2023). The country exhibits diverse geographical and climatic…

Heavy metals concentration

One of the primary objectives of this study was to investigate the concentration of heavy metals in bottled water and to compare these concentrations against both the Iranian national standard and the international standard set by the US Environmental Protection Agency (EPA). This research focused solely on the potential cancer risks associated with arsenic (As) in water. According to the International Agency for Research on Cancer (IARC), consuming 1 L of water daily containing 50 μg/L of…

Conclusion

In conclusion, our study aimed to comprehensively evaluate the safety of bottled water through a meticulous risk assessment of heavy metal exposure. We used deterministic and probabilistic approaches to determine Hazard Quotients (HQ) across various age groups for arsenic, barium, cadmium, chromium, manganese, molybdenum, nickel, and zinc. Our findings reveal varying health risks associated with these heavy metals, emphasizing the importance of age-specific considerations in risk assessment.…

Availability of data and materials

The data generated and analyzed during this study are available within the study.…

Ethical approval

Not applicable.…

Consent to participate

Not applicable - No human participants were involved in this study.…

Consent to publish

Not applicable - The data and information presented in this study do not contain any elements that require specific consent from individuals for publication.…

CRediT authorship contribution statement

Masoomeh Askari: Writing – original draft, Investigation, Data curation, Conceptualization. **Hamed Soleimani:** Writing – review & editing, Validation, Software, Methodology, Formal analysis, Conceptualization. **Kamal Babakrpur Nalosi:** Writing – review & editing, Software, Investigation. **Reza Saeedi:** Writing – original draft, Visualization, Methodology, Data curation. **Samaneh Abolli:** Writing – review & editing, Validation, Software, Investigation, Formal analysis, Conceptualization. **Maryam Ghani:**…

Declaration of competing interest

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

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