

Assessment of Potential Health Risks Associated with Heavy Metal Contamination in Drinking Water in the Kulim Hi Tech Park (KHTP) Region of Malaysia

Muhamad Radzi Zanon¹, Ahmad Razali Ishak², Maisarah Nasution Waras¹, Muhamad Azwat Abdullah³, Abdul Rohim Tualeka⁴, Rafeezul Mohamed⁵, Hisham Atan Edinur⁶, Siti Aisyah Muallif⁷, *Mohd Yusmaidie Aziz^{1,4}

¹Department of Toxicology, Advanced Medical and Dental Institute, Universiti Sains Malaysia, Bertam 13200 Kepala Batas, Penang, Malaysia

²Center of Environmental Health & Safety, Faculty of Health Sciences, Universiti Teknologi MARA, Puncak Alam 42300, Selangor, Malaysia

³Integrative Pharmacogenomics Institute (iPROMISE), Universiti Teknologi MARA, Puncak Alam, 42300, Selangor, Malaysia

⁴Department of Occupational Health and Safety, Public Health Faculty, Universitas Airlangga, Indonesia

⁵Department of Biomedical Science, Advanced Medical and Dental Institute, Universiti Sains Malaysia, 13200 Bertam, Kepala Batas, Penang, Malaysia

⁶School of Health Sciences, Universiti Sains Malaysia, Health Campus, 16150 Kubang Kerian, Kelantan, Malaysia

⁷School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310, Johor Bahru, Malaysia

Abstract

The presence of heavy metals in the environment can have a negative impact on living beings and the environment. This study aimed to evaluate the potential human health risks associated with exposure to heavy metals in drinking water from Kulim Hi-Tech Park (KHTP), Malaysia. Thirty water samples were collected from different locations within and around KHTP, and the concentration of five heavy metals (iron, manganese, zinc, cadmium, and nickel) was determined using Atomic Absorption Spectroscopy. The mean concentration of these heavy metals ranged from 0.0177 ± 0.0017 mg/L to 0.8652 ± 0.0606 mg/L, with the mean concentration order being Ni > Fe > Zn > Mn > Cd. Fe, Cd, and Ni exceeded the permissible limits. The Hazard Quotient (HQ) values for Fe, Zn, and Mn were ranked in the order of Fe > Zn > Mn. However, the individual and total HQ and Hazard Index (HI) values were below 1, suggesting no expected negative impact on human health. Nevertheless, the Excess Lifetime Cancer Risk (ELCR) values for Cd and Ni in the entire population of adults and children ranged from 2.35E-02 to 5.79E-03, indicating that the levels of Cd and Ni in water resources in KHTP and its surrounding area may be above safe levels and require proper remediation to minimize the risk to human health. The study presents a baseline for heavy metal contamination in water resources at KHTP and its surrounding areas, underlining the necessity for further research to ensure the safety of the environment and the health of the inhabitants of Kulim.

Keywords: Heavy metals, Spectroscopy, Health risk, Hazard quotient, Drinking water

*Corresponding author

DOI <https://doi.org/10.5281/zenodo.8343532#115>



1. Introduction

Heavy metal contamination has become a major environmental concern, affecting not only the environment but also plants, animals, and humans. Heavy metals are naturally occurring elements that can persist in the environment for long periods of time and are not biodegradable, leading to their bioaccumulation in food and the environment. Their toxic nature has made accumulated heavy metals the focus of much attention. Although heavy metals are often found in low concentrations, they can still be harmful to living things and the environment (Mitra et al., 2022). Some of the most toxic heavy metals include arsenic (As), lead (Pb), cadmium (Cd), nickel (Ni), mercury (Hg), and chromium (Cr). The growing presence of heavy metals in our natural resources is becoming a significant source of concern. Many industries discharge metal-containing effluents into bodies of water, such as rivers, lakes, and ponds, without proper treatment. This leads to exposure of people in agriculture, manufacturing, pharmaceuticals, industry, and other settings through food, water, air, or skin contact. Adults are primarily exposed to heavy metals through industrial exposure, while children are most susceptible through ingestion (Al Osman, Yang, & Massey, 2019; Campos, Silva, & Freire, 2019). It is widely accepted that both natural and man-made activities pollute the environment, causing harm to both the environment and human health.

Heavy metals, such as As, Cd, Ni, Hg, Cr, and Pb, have become a significant concern for public health in Malaysia due to their presence in drinking water. These toxic substances persist in the environment and can accumulate in living organisms, leading to long-term health effects such as increased cancer risk in humans (Duan et al., 2020). Furthermore, heavy metals can have adverse impacts on aquatic life, including oxidative stress, hormonal disruption, and weakened immune systems (Ebrahimi et al., 2020). This can result in decreased survival and growth, as well as potential harm to human health through biomagnification. As heavy metals do not decompose, their levels in living organisms can increase over time (Yadav, Chowdhary, Kaithwas, & Bharagava, 2017). Health risk assessments of heavy metal exposure have been conducted in several countries, including China, India, and Iran, to assess the impact on public health (Alidadi et al., 2019; Dong, Zhang, & Quan, 2020; Khan et al., 2021). Heavy metals can be classified as either carcinogenic or noncarcinogenic. Some metals such as mercury (Hg), cadmium (Cd), and lead (Pb) have been shown to cause cancer, while others such as aluminum (Al), iron (Fe), copper (Cu), and zinc (Zn) are considered noncarcinogenic. According to the International Agency for Research on Cancer (Anttila et al., 2006), inorganic arsenic (As) and cadmium (Cd) have been classified as human carcinogens. Chronic exposure to heavy metals can have adverse effects on the human body, potentially leading to various health problems such as muscular dystrophy, Alzheimer's disease, various types of cancer, and multiple sclerosis (Lee, Park, & Seo, 2018; Marie et al., 2017).

A recent study by Zhou et al. (Zhou et al., 2020) found that approximately 40% of the world's lakes and rivers are contaminated with heavy metal substances, with human activities such as urbanization, industrialization, and anthropogenic activities contributing to the increased concentration of these pollutants. Heavy metal remediation is an important strategy for mitigating the harmful effects of heavy metals in the environment. While physical and chemical remediation methods exist, they often come with significant costs and may contribute further waste to the environment. In the rapidly developing district of Kulim in Malaysia, pollution is a growing concern due to increasing urbanization and industrialization. Heavy metals in drinking water have been identified as a major source of human exposure and the potential transfer of these elements from the industrial park to residential areas has yet to be fully investigated. To protect human health and the environment, it is crucial to regularly monitor and assess heavy metal levels in the drinking water resources in Kulim. In a study conducted by Ahmad N et al., the presence of heavy metals in drinking water sources in the area was analysed. Results showed elevated levels of several heavy metals in some of the samples, indicating the need for ongoing monitoring and risk assessment. The continuous development of Kulim as an industrial hub highlights the importance of regularly monitoring heavy metal levels in drinking water to ensure that they do not pose a risk to human health and the environment.

2. Materials and Method

2.1 Sample collection and preparation

Water samples were collected at random from various locations within Kulim Hi Tech Park (KHTP) and its surrounding areas. Up to 30 sampling locations were identified, at which tap water, rivers, ponds, and other potential drinking water sources were sampled. All samples were labelled S1 through S30, as shown in Table 1.

Table 1 The location of the water sampling

Sampling point	Location
S1	Residential area
S2	Surau KTC
S3	Industrial zone phase 1
S4	Industrial zone phase 1
S5	Reservoir
S6	Industrial zone phase 1
S7	Industrial zone phase 1
S8	Industrial zone phase 1
S9	Waste disposal centre
S10	Residential area
S11	Public market
S12	Public hall
S13	Hospital
S14	Sport Complex KHTP
S15	Sport Complex KHTP
S16	Shell
S17	Stadium
S18	Mosque
S19	Residential area
S20	Residential area
S21	Eco Park KHTP
S22	Petronas
S23	Industrial zone phase 1
S24	Caltex
S25	Residential area
S26	Residential area
S27	Reservoir industrial zone phase 1
S28	Residential area
S29	Public market
S30	Residential area

During the sampling procedure, the types of water samples and their conditions were noted. For each sampling location, an HDPE bottle was used to collect about 500 mL of water. Water samples were then filtered through 47mm glass fibre GF/F filters, nominal cut-off size of 0.7 μm (Whatman, Fontenay Sous Bois, France) and were acidified with 3 mL nitric acid for pre-treatment before being sealed in HDPE bottles. All water samples were transported in dark, cool containers and at room temperature prior to analysis at the Faculty of Health Science, Universiti Teknologi Mara (UITM), Puncak Alam, Selangor. All samples at each location were collected in triplicate.

2.2 Sample Analysis

Cadmium (Cd), manganese (Mn), nickel (Ni), iron (Fe), and zinc (Zn) in water samples were determined by an atomic absorption spectroscopy (AAS) AA800 (Perkin Elmer, Foster City, CA, USA). A calibration blank and independent calibration and verification standards of Cd, Mn, Ni, Fe, and Zn were analysed together with all samples to confirm the calibration status of the AAS. The calibration curves with $r^2 > 0.999$ were accepted for quantification, and the results were reported as the averages of triple measurements. The limit of quantification (LOQ) for Cd, Mn, Ni, Fe and Zn was 0.05, 0.05, 0.05, 0.5 and 0.5 (mg/L), respectively. Quality controls and blank solutions were also prepared and analysed in the same way as the samples.

2.3 Risk assessment of heavy metals

Risk assessment is the process of estimating the likelihood of an incident happening or the likelihood that exposure to environmental hazards will have a negative health effect on people or other animals. In this study, the chronic daily intake (CDI) parameter for heavy metal intake were estimated using the equations below for non-carcinogenic and carcinogenic metals.

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad \text{Equation 1}$$

The ingestion rate (IR) for children was 0.78 liters per day, while for male and female adults it was 2.26 and 1.97 liters per day, respectively. The exposure frequency (EF) was assumed to be 365 days per year for all age groups, and the exposure duration (ED) was 74 years for adults and 6 years for children. The average body weight (BW) was 69.95 kg for male adults, 62.59 kg for female adults, and 15 kg for children. In terms of time (AT), adults were assumed to have an average of 27,010 days per year, while children had 2,190 days per year (Mohammadi et al., 2019; Razali, Ismail, Awang, Praveena, & Abidin, 2018).

The possibility of non-carcinogenic effects for a specific metal was calculated with the use of hazard quotient (HQ). A HQ is the ratio of a substance's potential exposure to the level at which no unfavourable effects are anticipated. If the HQ is determined to be less than 1, then exposure is not anticipated to have any negative effects on health.

$$HQ = \frac{CDI}{RFD} \quad \text{Equation 2}$$

The Fe, Mn, Zn, Cd, and Ni reference doses were determined as 7.0E-01, 1.4E-01, 3.0E-01, 5.0E-04, and 2.0E-01 mg/kg/day, respectively (Mohammadi et al., 2019).

The following equation of ELCR (Excess Lifetime Cancer Risk) was used in this study to determine the potential for specific elements such as cadmium and nickel to cause cancer in a population. In the normal setting, value range between 1×10^{-4} to 1×10^{-6} is considered as an acceptable risk level.

$$ELCR = CDI \times CSF \quad \text{Equation 3}$$

The Cancer Slope Factor (CSF) was used as an assumption for Cd and Ni at levels of 6.3 and 0.84 mg/kg/day, respectively (Mohammadi et al., 2019).

2.4 Statistical Analysis

All tests were carried out in triplicates, and their mean value was considered the result. Microsoft Excel 2016 was used to tabulate and analyse the data. Data were presented as mean \pm standard deviation (SD), and suitable analysis was done according to the type of data obtained for each parameter.

3. Results

Thirty (30) water samples were collected from 30 different locations within and around Kulim Hi Tech Park (KHTP) (Fig.1). The water samples included water tap, rivers, and ponds that have potential as drinking water. Table 1 shows the description of the collected water samples and their condition during the sampling.



Fig. 1 Location of the sampling site in Kulim, Malaysia

Table 1 Description of the water sample collected from different locations in Kulim, Malaysia

Sampling point	Latitude	Longitude	Description of sample water	Location	Water condition
S1	5.39414	100.57284	Rivers	Residential area	Slightly turbid and clear
S2	5.39382	100.57021	Tap water	Surau KTC (Muslim prayer place)	Clear
S3	5.41706	100.58508	Rivers	Industrial zone phase 1	Clear
S4	5.40878	100.58886	Rivers	Industrial zone phase 1	Clear
S5	5.38826	100.57282	Flood Ponds	Reservoir	Slightly turbid with light brown
S6	5.426254	100.58355	Industrial Ponds	Industrial zone phase 1	Highly turbid and dark colour
S7	5.40980	100.59143	Rivers	Industrial zone phase 1	Slightly turbid and clear
S8	5.435216	100.567267	Rivers	Industrial zone phase 1	Slightly turbid and clear
S9	5.424847	100.616860	Rivers	Waste disposal centre	Slightly turbid and clear
S10	5.37649	100.57951	Tap water	Residential area	Clear
S11	5.38991	100.56589	Tap water	Public market	Clear
S12	5.39062	100.56470	Tap water	Public hall	Clear
S13	5.39339	100.57303	Tap water	Hospital	Clear
S14	5.42420	100.57800	Tap water	Sport Complex KHTP	Clear
S15	5.425412	100.577681	Rivers	Sport Complex KHTP	Slightly turbid and clear
S16	5.38585	100.55963	Tap water	Shell (petrol station)	Clear
S17	5.38594	100.55597	Tap water	Stadium	Clear
S18	5.39135	100.56270	Tap water	Mosque	Clear
S19	5.37261	100.57024	Tap water	Residential area	Clear
S20	5.37353	100.57135	Tap water	Residential area	Clear
S21	5.42498	100.59543	Tap water	Eco Park KHTP	Clear
S22	5.37448	100.53547	Tap water	Petronas (petrol station)	Clear
S23	5.42509	100.59575	Rivers	Industrial zone phase 1	Slightly turbid and clear
S24	5.37606	100.55407	Tap water	Caltex (petrol station)	Clear
S25	5.36202	100.54673	Tap water	Residential area	Clear
S26	5.37429	100.53536	Tap water	Residential area	Clear
S27	5.41602	100.58638	Flood ponds	Reservoir industrial zone phase 1	Slightly turbid and clear
S28	5.37172	100.55558	Tap water	Residential area	Clear
S29	5.37054	100.53240	Tap water	Public market	Clear
S30	5.35812	100.54263	Tap water	Residential area	Clear

Table 2 shows the mean concentrations of Fe, Mn, Zn, Cd, and Ni for each location and as an overall mean concentration. They were divided into river, tap water, pond, residential, and industrial areas. All concentrations were compared to the permissible limit values established by guidelines and authorities.

Table 2 Concentration of heavy metals from water samples in Kulim, Malaysia (mean \pm SD; n=30)

Water Sample	Iron (Fe) (mg/L)	Manganese (Mn) (mg/L)	Zinc (Zn) (mg/L)	Cadmium (Cd) (mg/L)	Nickel (Ni) (mg/L)
S1	3.860 0.0485	\pm 0.043 \pm 0.0063	0.047 \pm 0.0018	0.021 \pm 0.0026	0.530 \pm 0.0092
S2	2.183 1.9456	\pm 0.001 \pm 0.0035	0.030 \pm 0.0008	0.018 \pm 0.0024	0.728 \pm 0.0332
S3	1.071 0.0354	\pm 0.041 \pm 0.0032	0.039 \pm 0.0016	0.018 \pm 0.0011	1.231 \pm 0.0751
S4	0.817 0.0148	\pm 0.036 \pm 0.0039	0.035 \pm 0.0032	0.017 \pm 0.0015	0.849 \pm 0.0499
S5	0.491 0.0208	\pm 0.010 \pm 0.0016	0.345 \pm 0.0053	0.020 \pm 0.0013	1.993 \pm 0.0369
S6	0.024 0.0060	\pm 0.006 \pm 0.0026	0.024 \pm 0.0013	0.021 \pm 0.0010	0.637 \pm 0.0503
S7	1.419 0.7799	\pm 0.069 \pm 0.0021	0.040 \pm 0.0024	0.021 \pm 0.0009	0.762 \pm 0.0252
S8	0.374 0.2833	\pm 0.003 \pm 0.0043	0.037 \pm 0.0016	0.019 \pm 0.0023	0.801 \pm 0.0956
S9	0.238 0.0120	\pm 0.012 \pm 0.0027	0.041 \pm 0.0027	0.021 \pm 0.0022	0.832 \pm 0.0787
S10	0.716 0.0462	\pm 0.045 \pm 0.0021	0.070 \pm 0.0025	0.017 \pm 0.0014	1.283 \pm 0.0443
S11	1.144 0.0073	\pm 0.096 \pm 0.0012	0.037 \pm 0.0010	0.020 \pm 0.0003	0.786 \pm 0.0245
S12	0.051 0.0153	\pm 0.004 \pm 0.0019	0.033 \pm 0.0030	0.019 \pm 0.0025	0.767 \pm 0.0595
S13	0.046 0.0010	\pm 0.010 \pm 0.0033	0.031 \pm 0.0027	0.019 \pm 0.0025	0.705 \pm 0.0738
S14	0.084 0.0043	\pm 0.018 \pm 0.0017	0.173 \pm 0.0035	0.019 \pm 0.0032	0.794 \pm 0.0254
S15	0.234 0.0171	\pm 0.006 \pm 0.0042	0.201 \pm 0.0060	0.015 \pm 0.0007	0.741 \pm 0.0582
S16	0.063 0.0053	\pm 0.011 \pm 0.0022	0.230 \pm 0.0011	0.014 \pm 0.0010	0.781 \pm 0.0381
S17	0.212 0.0859	\pm 0.072 \pm 0.0017	0.826 \pm 0.0036	0.020 \pm 0.0007	0.910 \pm 0.0111
S18	0.091 0.0305	\pm 0.020 \pm 0.0017	0.033 \pm 0.0019	0.020 \pm 0.0027	0.704 \pm 0.0297
S19	0.058 0.0048	\pm 0.018 \pm 0.0044	0.460 \pm 0.0054	0.020 \pm 0.0019	0.730 \pm 0.0465
S20	0.045 0.0072	\pm 0.015 \pm 0.0017	0.027 \pm 0.0015	0.018 \pm 0.0022	0.807 \pm 0.1003
S21	0.070 0.0062	\pm 0.017 \pm 0.0003	0.020 \pm 0.0044	0.016 \pm 0.0025	0.913 \pm 0.0968
S22	0.087 0.0118	\pm 0.016 \pm 0.0012	0.017 \pm 0.0036	0.016 \pm 0.0004	0.856 \pm 0.1091
S23	0.446 0.0194	\pm 0.021 \pm 0.0024	0.156 \pm 0.0021	0.013 \pm 0.0024	0.850 \pm 0.0223

S24	0.073 0.0039	± 0.029 ± 0.0042	0.052 ± 0.0021	0.016 ± 0.0033	0.774 ± 0.0438
S25	0.212 0.0097	± 0.016 ± 0.0016	0.069 ± 0.0005	0.018 ± 0.0011	0.751 ± 0.1822
S26	0.150 0.0033	± 0.026 ± 0.0020	0.063 ± 0.0005	0.017 ± 0.0003	0.807 ± 0.0606
S27	1.272 0.2593	± 0.055 ± 0.0038	0.011 ± 0.0007	0.014 ± 0.0020	0.851 ± 0.1015
S28	0.177 0.0013	± 0.032 ± 0.0021	0.088 ± 0.0043	0.016 ± 0.0007	0.866 ± 0.0763
S29	0.070 0.0092	± 0.015 ± 0.0011	0.269 ± 0.0014	0.012 ± 0.0008	0.950 ± 0.1025
S30	0.146 0.0256	± 0.044 ± 0.0031	0.046 ± 0.0022	0.015 ± 0.0017	0.967 ± 0.0572
All	0.5308 0.1240	± 0.0269 ± 0.0026	0.1183 0.0025	± 0.0177 ± 0.0017	0.8652 0.0606
River	1.0574 0.1513	± 0.0289 ± 0.0036	0.0745 0.0027	± 0.0181 ± 0.0017	0.7616 0.0518
Tap water	0.2988 0.1171	± 0.0266 ± 0.0022	0.1355 0.0024	± 0.0174 ± 0.0017	0.8357 0.0639
Pond	0.5957 0.0954	± 0.0237 ± 0.0027	0.1267 0.0024	± 0.0183 ± 0.0014	1.1603 0.0629
Residential area	0.4776 0.1092	± 0.0266 ± 0.0023	0.1412 0.0025	± 0.0177 ± 0.0017	0.8763 0.0600
Industrial area	0.655 0.1586	± 0.0277 ± 0.0032	0.0649 0.0024	± 0.0177 ± 0.0016	0.8393 0.0619
USEPA standards (mg/L)	0.3	0.05	5.0	0.005	0.1
MRRWQ (mg/L)	1.0	0.2	3.0	0.003	-
MDWQS (mg/L)	0.3	0.1	3.0	0.003	0.02

USEPA, United States Environmental Protection Agency; MRRWQ, Malaysia Recommended Raw Water Quality; MDWQS, Malaysia Drinking Water Quality Standards (Fig. 2) shows the values of chronic daily intake for heavy metals in male and female adults and children.

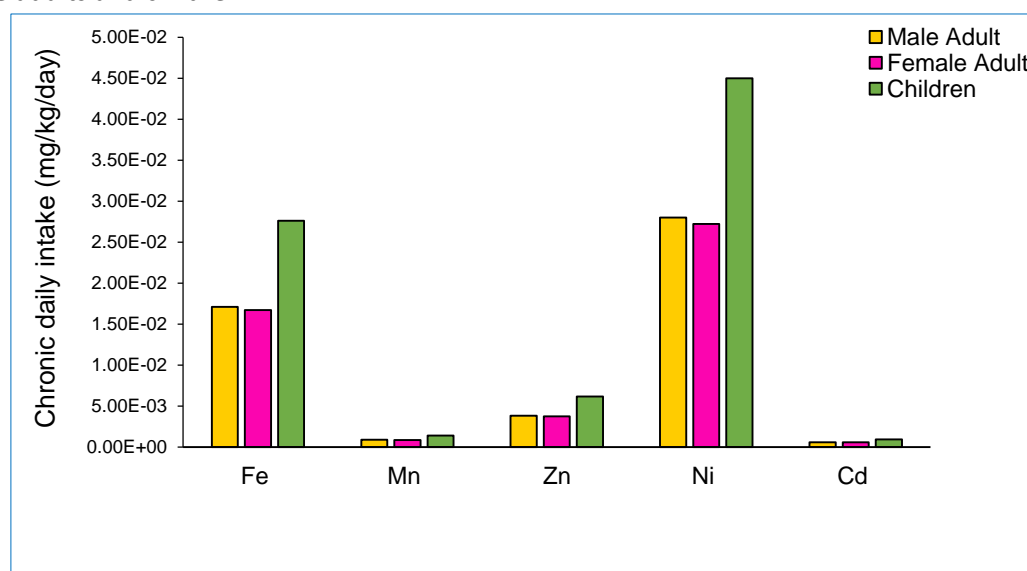


Fig. 2 Chronic daily intake (CDI) of each heavy metal elements in sub population groups

In Table 3, the hazard quotient (HQ), hazard index (HI) and excess lifetime cancer risk (ELCR) for each heavy metals and different populations were tabulated.

Table 3 Carcinogenic and non-carcinogenic risk of heavy metals from water intake of different sub-population in Kulim, Malaysia

Risk	Male Adult		Female Adult		Children	
<i>Non-carcinogenic</i>	CDI (mg/kg/day)	HQ	CDI (mg/kg/day)	HQ	CDI (mg/kg/day)	HQ
<i>Fe</i>	1.71E-02	2.45E-02	1.67E-02	2.39E-02	2.76E-02	3.94E-02
<i>Mn</i>	8.69E-04	6.21E-03	8.47E-04	6.05E-03	1.40E-03	9.99E-03
<i>Zn</i>	3.82E-03	1.27E-02	3.72E-03	1.24E-02	6.15E-03	2.05E-02
<i>Hazard Index (HI)</i>	-	4.34E-02	-	4.24E-02	-	6.99E-02
<i>Carcinogenic</i>	CDI (mg/kg/day)	ELCR	CDI (mg/kg/day)	ELCR	CDI (mg/kg/day)	ELCR
<i>Ni</i>	2.80E-02	2.35E-02	2.72E-02	2.28E-02	4.50E-02	3.78E-02
<i>Cd</i>	5.71E-04	3.60E-03	5.56E-04	3.50E-03	9.19E-04	5.79E-03

CDI, Chronic daily intake; HQ, Hazard quotient; ELCR, Total excess lifetime cancer risk

4. Discussion

In this study, a total of thirty water samples were collected and analyzed, with nine samples obtained from the industrial area and twenty-one samples from the residential area. The samples were collected from three different sources, including the river, tap water, and a pond, with eight, nineteen, and three samples collected from each source, respectively. The turbidity of the water samples varied considerably, with tap water samples being clear while river and pond samples displayed low to high turbidity. To analyze the water samples, turbid samples were filtered multiple times to produce colorless water. While various water quality parameters, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH₃N), nitrate nitrogen (NO₃N), total suspended solids (TSS), pH, oil and grease (OG), and temperature, are critical in assessing water quality, this study did not inspect them due to the unavailability of necessary equipment. It has not been established that these parameters contribute to the distribution of heavy metals in water bodies and are thus considered of negligible importance in this study (Ruzi et al., 2023).

In this study, we investigated the presence of five heavy metal elements in water samples: iron (Fe), manganese (Mn), zinc (Zn), cadmium (Cd), and nickel (Ni). The mean concentration of these elements ranged from 0.0177 ± 0.0017 mg/L to 0.8652 ± 0.0606 mg/L. The order of mean heavy metal concentrations in all water samples was Ni > Fe > Zn > Mn > Cd. We observed that tap water and pond water samples showed a similar heavy metal concentration trend. However, in river samples, Fe was found to be the most abundant, with Fe > Ni > Zn > Mn > Cd. We compared heavy metal concentrations in residential and industrialized areas and found only minor differences, with Zn being more prevalent in residential areas and Fe being more prevalent in industrial areas. When we compared all of the concentrations to the standards set by the United States Environmental Protection Agency (USEPA), the Malaysian Recommended Raw Water Quality (MRRWQ), and the Malaysian Drinking Water Quality Standards (MDWQS), we found that the mean concentrations of Fe, Cd, and Ni exceeded the limits.

Iron (Fe) concentrations exceeding the limits set by USEPA, MRRWQ, and MDWQS were discovered in seven (7) of the sampled areas. These concentrations ranged from 0.374 to 3.86 mg/L, and all samples were collected from the river, except for those within the normal range, which were collected from tap water. Our findings on Fe were consistent with previous studies, such as one conducted in the Tangail River in Bangladesh, which found iron concentrations ranging from 1030 to 24,500 ppb, exceeding the WHO guidelines of 300 ppb (Hossain, Islam, Sultana, & Tusher, 2013). Additionally, a study in the Tatsawarki River in Kano, Nigeria, found iron concentrations of 1500 ppb in groundwater and 1000 ppb in surface water, rendering it unsuitable for nearby residents' drinking water (Bichi, Bello, & No, 2013). Trace Fe amounts found in the Moradabad area surrounding the Gangan River were within the range of 9840 to 15,850 ppb, according to a study by Rastogi G et al. , who attributed the contamination to metal handicraft factories

discharging waste into the river. These findings were supported by previous research, which discovered high iron concentrations in residential areas, ponds, rivers, and industrial zones. The levels of Fe in tap water, however, were within the standards established by USEPA and MDWQS. Iron (Fe) is an essential mineral for the body, particularly for blood components like haemoglobin, myoglobin, and various enzymes, and its deficiency may lead to anaemia and a loss of well-being. However, if it exceeds the body's requirements, it may cause a variety of health issues, including liver tumours, metabolic diseases, liver infections or damage, heart disease, and impotence. Heavy Fe concentrations alter water's colour, taste, and odour, leave marks on clothes, and deteriorate plumbing (Behera, Das, & Rana, 2012). Our results suggest that the river water samples were unsuitable for consumption due to excessive Fe levels, and our study may encourage individuals in the surrounding region to seek alternative drinking water sources.

Manganese (Mn) concentrations were evaluated in rivers, tap water, ponds, residential and industrial areas, and ranged from 0.001 to 0.096 mg/L, with an overall mean concentration falling below the MRRWQ and MDWQS standard limits of 0.2 and 0.1, respectively. Notably, there was no significant difference in the results between residential and industrial areas. It is important to note that Mn is an essential metal for proper immunological function, blood sugar regulation, cellular energy, reproduction, digestion, bone growth, blood coagulation, hemostasis, and defense against reactive oxygen species (Aschner & Erikson, 2017). This study provides valuable information regarding Mn concentrations in various sources of water and their compliance with regulatory limits.

The presence of Zinc (Zn) in water was investigated, and the results obtained did not indicate a significant concentration of this element. The range of Zn concentration reported varied between 0.011 mg/L and 0.826 mg/L, with a mean value of 0.1183 ± 0.0025 mg/L, which is well below the allowable limits established by regulatory bodies. The current limits set by the USEPA, MRRWQ and MDWQS for Zn are 5.0 mg/L and 3.0 mg/L, respectively. A comparative analysis of Zn concentration levels in different water samples, including residential, industrial, river, pond, and tap water, was conducted. The results showed that mean Zn concentrations in residential areas correlated with those found in tap water and pond at 0.1412, 0.1355, and 0.1267 mg/L, respectively. On the other hand, the Zn concentrations in industrial areas and rivers were similar, at 0.0649 and 0.0745 mg/L, respectively. It is possible that the Zn present in tap water originated from the wastewater treatment plant that supplies water to residents, while the source of Zn in rivers may be related to industrial activity or sewage. Zinc is an essential element required by the body in the right amount. Non-optimal levels of Zn in drinking water could have detrimental effects on health. However, most studies found that the Zn concentration level in water is below the permissible limit. A study by Bhutiani R et al. and Li P et al. showed low levels of Zn in groundwater and suggests that human activities contribute more to the disposal of Zn in the environment than natural causes. This finding contrasts with the current study, which found that Zn concentrations were lower in industrial areas than in residential areas and our result was consistent with the previous study in African region (Lwimbo, Komakech, & Muzuka, 2019; Oyem, Oyem, & Usese, 2015).

Cadmium (Cd) concentrations observed in this study were found to be above the allowable limit, with a mean concentration of 0.0177 ± 0.0017 mg/L. The Cd concentrations detected in water samples from various sources, such as residential, industrial, river, pond, and tap water, were similar, indicating that these factors could potentially contribute to the distribution of Cd in water bodies. In a similar study conducted in Iran, Qasemi M et al. reported a higher concentration of Cd that exceeded the allowable limit. They concluded that the excessive use of chemical pesticides and phosphorus-containing fertilisers in agriculture was responsible for the rise in Cd content in drinking water. Another study in Varamin City, Iran, revealed a high permissible limit of Cd due to water returned from agricultural, industrial, and domestic wastewater (Nejatjahromi, Nassery, Nakhaei, & Alijani, 2018). As Kulim houses various industries from agro-tech to electronics, it is possible that the water resources in this study were contaminated by Cd. Elevated levels of Cd in water are undesirable and can lead to severe health consequences. Acute cadmium exposure can cause symptoms such as diarrhoea, vomiting, fever, lung damage, and muscle soreness. Chronic cadmium exposure can lead to illnesses, including renal disease, bone damage, reproductive issues, and potentially cancer (Jamshaid, Khan, Ahmed, & Saleem, 2018). The high concentration of Cd observed in this study highlights the need for strict regulations and efficient monitoring of industrial and agricultural activities to prevent water contamination. Further studies are necessary to determine the sources of Cd contamination and to mitigate its harmful effects on human health and the environment. The concentration of Nickel (Ni) in the samples collected from Kulim has been found to be above the limit set by regulatory bodies such as the United States Environmental Protection Agency (USEPA) or the Malaysian Drinking Water Quality Standard (MDWQS). The concentration of Ni was higher in pond water as compared to river or tap water. This

could be attributed to the industrial activities in the area, which involve the use of Ni in various applications such as battery production, steel production, and electrical components. However, the presence of high levels of Ni in the water samples is a cause for concern as it can have detrimental health effects on humans. Ni is known to be immunotoxic and carcinogenic and prolonged exposure to it can lead to a variety of health problems such as contact dermatitis, cardiovascular disease, asthma, lung fibrosis, and respiratory tract cancer (Genchi, Carocci, Lauria, Sinicropi, & Catalano, 2020). Therefore, it is essential to take necessary measures to reduce the concentration of Ni in the water bodies in Kulim. This could include regulating the discharge of industrial effluents and promoting the use of alternative materials in industrial processes that do not involve Ni. It is crucial to monitor the concentration of Ni in the water bodies regularly and take prompt action to prevent any further health hazards to the public.

Assessing the probability of unfavorable health outcomes over a specific period is known as health risk assessment. In this study, health risk assessments were possible due to the concentrations of heavy metals found in water samples. The health risk assessment of each contaminant is typically based on an estimate of the risk level and classified as either posing carcinogenic or non-carcinogenic health risks. The assessment involved the use of several parameters, including hazard quotients (HQ), hazard index (HI), and excess lifetime cancer risk (ELCR), to determine heavy metal contamination and potential carcinogenic and non-cancer health risks caused by heavy metal ingestion in the water distribution network of Kulim Hi Tech Park and its surrounding areas. The target population of the study consisted of both adults and children. The USEPA approach was utilized to assess risk and exposure by considering daily drinking water ingestion as a route of heavy metal administration.

The consideration of Chronic Daily Intake (CDI) was a crucial aspect of the assessment undertaken in this study. CDI refers to the average daily dose of heavy metals that a population is exposed to over their lifetime. This study specifically focused on three distinct subpopulations, namely male and female adults, as well as children. Our analysis revealed that irrespective of age or gender, Nickel (Ni) and Iron (Fe) were the most commonly ingested heavy metals. Furthermore, the order of heavy metal CDI values was determined as follows: Ni > Fe > Zn > Mn > Cd. These findings have significant implications for the potential health risks associated with chronic heavy metal exposure, highlighting the need for targeted interventions to mitigate these risks. The latest assessment has concluded that Fe, Mn, and Zn are not carcinogenic. Instead, the study determined the HQ and HI values for these metals. The HQ values for Fe, Zn, and Mn were ranked in the order of Fe > Zn > Mn. However, both the individual and total HQ and HI values were below 1, indicating that exposure to these elements is not expected to have any negative impact on human health. Consequently, the presence of these heavy metals in water bodies in the KHTP and surrounding areas poses no threat at present. This evaluation provides evidence to support the lack of carcinogenicity and the minimal health risks associated with these metals.

Exposure to heavy metals may increase the risk of cancer in human health. Prolonged exposure to relatively low concentrations of hazardous metals can potentially result in various forms of cancer. In this study, Cd and Ni were identified as carcinogenic metals. The cancer slope factor (CSF) derived from literature indicated a CSF of 6.3 mg/kg/day for Cd and 0.84 mg/kg/day for Ni, which served as the basis for evaluating the carcinogenic properties of each metal (Mohammadi et al., 2019; Razali et al., 2018). A single heavy metal with an ELCR of less than 1×10^{-6} is considered negligible, and the cancer risk can be disregarded. Conversely, an ELCR of more than 1×10^{-4} is deemed detrimental, and the cancer risk is concerning. In this study, the ELCR for both Cd and Ni in the entire population of adults and children ranged from 2.35E-02 to 5.79E-03. These values suggest that the levels of Cd and Ni in the water resources in KHTP and the surrounding area may be above the safe level and require proper remediation to reduce the risk to human health. The findings of Razali et al. (2018) were similar, stating that the total carcinogenic risk at the Highland River Watershed in Cameron Highland is unacceptable, with a carcinogenic risk of 3.06E-03 for Cd in male adults, 2.98E-03 in female adults, and 4.92E-03 in children. Both KHTP and Cameron may be dealing with the same environmental pollution problem resulting from anthropogenic and industrial activities. Therefore, it is crucial to address and mitigate the adverse effects of heavy metal exposure on human health through effective strategies and actions. Further research and monitoring are needed to ensure the safety and well-being of the population.

The health risk assessment conducted in this study revealed that there is a high likelihood of Cd and Ni levels being harmful and carcinogenic. Conversely, the levels of some other heavy metals, such as iron, manganese, and zinc, were below the acceptable threshold. Nonetheless, this study may have some limitations. Firstly, the sample size used is considered relatively small. Secondly, the study only investigated five types of heavy metals, while there are numerous

other heavy metals that should also be examined, including lead (Pb), arsenic (As), copper (Cu), among others. Thirdly, in order to monitor the pattern of bioaccumulation of heavy metals in the region, it is necessary to carry out regular and systematic sampling. These constraints call for the urgent need for more comprehensive research.

5. Conclusion

The study conducted at Kulim Hi Tech Park and its surrounding areas on heavy metals in water resources has revealed that certain elements exceed the permissible limit and should not be used for drinking water without proper treatment. The tested heavy metals include Iron (Fe), Cadmium (Cd), Nickel (Ni), Zinc (Zn), and Manganese (Mn). The results indicate that Fe was the most abundant element found in the samples, with the mean heavy metal concentration being Fe > Ni > Zn > Mn > Cd. The Hazard Quotient (HQ) and Hazard Index (HI) values were found to be below 1, indicating no risk to health from the non-carcinogenic substances. However, Cd and Ni were found to be carcinogenic, posing a risk to health with an Excess Lifetime Cancer Risk (ELCR) value greater than baseline value. Overall, the study provides a baseline for heavy metal contamination in water resources at KHTP and its surrounding areas. Further research is required to ensure the safety of the environment and the health of the residents of Kulim.

Funding Information

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Conflict

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.

References

1. Ahmad, N., Jaafar, M., Nasir, T., & Rafique, M. (2018). Determination of radon concentration and heavy metals (Ni, Pb, Cd, As, Cr) in drinking and irrigated water sampled from Kulim, Malaysia. *International Journal of Radiation Research*, 16(3), 341-349.
2. Al Osman, M., Yang, F., & Massey, I. Y. (2019). Exposure routes and health effects of heavy metals on children. *Biometals*, 32, 563-573.
3. Alidadi, H., Tavakoly Sany, S. B., Zarif Garaati Oftadeh, B., Mohamad, T., Shamszade, H., & Fakhari, M. (2019). Health risk assessments of arsenic and toxic heavy metal exposure in drinking water in northeast Iran. *Environmental Health and Preventive Medicine*, 24, 1-17.
4. Anttila, A., Apostoli, P., Bond, J. A., Gerhardsson, L., Gulson, B. L., Hartwig, A., . . . Landrigan, P. J. (2006). IARC monographs on the evaluation of carcinogenic risks to humans: Inorganic and organic lead compounds.
5. Aschner, M., & Erikson, K. (2017). Manganese. *Adv Nutr*, 8(3), 520-521. doi: 10.3945/an.117.015305
6. Behera, B., Das, M., & Rana, G. (2012). Studies on ground water pollution due to iron content and water quality in and around, Jagdalpur, Bastar district, Chattisgarh, India. *Journal of chemical and Pharmaceutical research*, 4(8), 3803-3807.
7. Bhutiani, R., Kulkarni, D. B., Khanna, D. R., & Gautam, A. (2016). Water quality, pollution source apportionment and health risk assessment of heavy metals in groundwater of an industrial area in North India. *Exposure and Health*, 8, 3-18.
8. Bichi, M., Bello, U., & No, P. (2013). Heavy metal pollution in surface and ground waters used for irrigation along river Tatsawarki in the Kano, Nigeria. *IOSR Journal of Engineering*, 3(8), 1-9.
9. Campos, É., Silva, I., & Freire, C. (2019). Exposure to metals in adult population residing in industrial areas: a systematic review. *Environmental Epidemiology*, 3, 368.
10. Dong, W., Zhang, Y., & Quan, X. (2020). Health risk assessment of heavy metals and pesticides: A case study in the main drinking water source in Dalian, China. *Chemosphere*, 242, 125113.
11. Duan, W., Xu, C., Liu, Q., Xu, J., Weng, Z., Zhang, X., . . . Gu, A. (2020). Levels of a mixture of heavy metals in blood and urine and all-cause, cardiovascular disease and cancer mortality: A population-based cohort study. *Environmental Pollution*, 263, 114630.

12. Ebrahimi, M., Khalili, N., Razi, S., Keshavarz-Fathi, M., Khalili, N., & Rezaei, N. (2020). Effects of lead and cadmium on the immune system and cancer progression. *Journal of Environmental Health Science and Engineering*, 18, 335-343.
13. Genchi, G., Carocci, A., Lauria, G., Sinicropi, M. S., & Catalano, A. (2020). Nickel: Human health and environmental toxicology. *International journal of environmental research and public health*, 17(3), 679.
14. Hossain, D., Islam, M., Sultana, N., & Tusher, T. (2013). Assessment of iron contamination in groundwater at Tangail municipality, Bangladesh. *Journal of Environmental Science and Natural Resources*, 6(1), 117-121.
15. Jamshaid, M., Khan, A. A., Ahmed, K., & Saleem, M. (2018). Heavy metal in drinking water its effect on human health and its treatment techniques-a review. *Int. J. Biosci*, 12(4), 223-240.
16. Khan, R., Saxena, A., Shukla, S., Sekar, S., Senapathi, V., & Wu, J. (2021). Environmental contamination by heavy metals and associated human health risk assessment: a case study of surface water in Gomti River Basin, India. *Environmental Science and Pollution Research*, 28(40), 56105-56116.
17. Lee, H. J., Park, M. K., & Seo, Y. R. (2018). Pathogenic mechanisms of heavy metal induced-Alzheimer's disease. *Toxicology and Environmental Health Sciences*, 10, 1-10.
18. Li, P., Wu, J., Qian, H., Lyu, X., & Liu, H. (2014). Origin and assessment of groundwater pollution and associated health risk: a case study in an industrial park, northwest China. *Environmental Geochemistry and Health*, 36, 693-712.
19. Lwimbo, Z. D., Komakech, H. C., & Muzuka, A. N. (2019). Impacts of emerging agricultural practices on groundwater quality in Kahe catchment, Tanzania. *Water*, 11(11), 2263.
20. Marie, I., Gehanno, J., Bubenheim, M., Duval-Modeste, A., Joly, P., Dominique, S., . . . Benichou, J. (2017). Systemic sclerosis and exposure to heavy metals: A case control study of 100 patients and 300 controls. *Autoimmunity reviews*, 16(3), 223-230.
21. Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khushro, A., . . . Alhumaydhi, F. A. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University-Science*, 101865.
22. Mohammadi, A. A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M. H., . . . Ghaderpoori, M. (2019). Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. *MethodsX*, 6, 1642-1651.
23. Nejatjahromi, Z., Nassery, H., Nakhaei, M., & Alijani, F. (2018). Assessment of the quality of groundwater for drinking purposes in Varamin aquifer: heavy metals contamination. *Iranian Journal of Health and Environment*, 10(4), 559-572.
24. Oyem, H. H., Oyem, I. M., & Usese, A. I. (2015). Iron, manganese, cadmium, chromium, zinc and arsenic groundwater contents of Agbor and Owa communities of Nigeria. *SpringerPlus*, 4(1), 1-10.
25. Qasemi, M., Shams, M., Sajjadi, S. A., Farhang, M., Erfanpoor, S., Yousefi, M., . . . Afsharnia, M. (2019). Cadmium in groundwater consumed in the rural areas of Gonabad and Bajestan, Iran: occurrence and health risk assessment. *Biological trace element research*, 192, 106-115.
26. Rastogi, G. K., & Sinha, D. (2008). Metal toxicity in underground drinking water at Moradabad, Uttar Pradesh, India. *Int J Chem Sci*, 6(2), 1074-1080.
27. Razali, A., Ismail, S. N. S., Awang, S., Praveena, S. M., & Abidin, E. Z. (2018). Heavy metals contamination and potential health risk in highland river watershed (Malaysia). *Malaysian Journal of Medicine and Health Sciences*, 45-55.
28. Ruzi, I. I., Ishak, A. R., Abdullah, M. A., Zain, N. N. M., Tualeka, A. R., & Aziz, M. Y. (2023). Assessment of Heavy Metal Concentrations in Penang, Malaysia's Wastewater Treatment Plants: A Wastewater-Based Epidemiology Approach. *Trends in Sciences*, 20(5), 6523-6523.
29. Yadav, A., Chowdhary, P., Kaithwas, G., & Bharagava, R. N. (2017). Toxic metals in the environment: Threats on ecosystem and bioremediation approaches *Handbook of metal-microbe interactions and bioremediation* (pp. 128-141): CRC Press.
30. Zhou, Q., Yang, N., Li, Y., Ren, B., Ding, X., Bian, H., & Yao, X. (2020). Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017. *Global Ecology and Conservation*, 22, e00925.