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ORIGINAL ARTICLE

Occurrence, origin, and risk assessment of metals in drinking water from a tropical suburban area (Jengka, Malaysia)

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Abstract

Information about metal contamination in drinking water remains inadequate, especially for semi-urban areas. This study determines the concentrations of metals in drinking water in Jengka, Pahang, Malaysia. It also attempts to assess the potential health risks and to identify the possible sources of metal contamination. Metal concentration was analysed using inductively coupled plasma optical emission spectrometry. The results included the mean concentrations of Zn (1.7×10^{-1} mg/L), Pb (2.4×10^{-2} mg/L), and Cr (1.75×10^{-3} mg/L). In general, the concentration of metals was below the drinking water limitation standards set by the Malaysia Ministry of Health and the World Health Organization, except for Pb. This work estimates low potential non-cancer (HQ < 1) and low cancer risks (LCR < 1) from metal exposure. However, children appear to be more susceptible to metal exposure via drinking water than adults. Based on multivariate analysis, metal in drinking water could come from two sources. The findings suggest comprehensive continuous monitoring of metal concentrations from potable water, especially for semi-urban regions, to minimise health risks.

Keywords Contamination · Drinking water · Health risk · Metal · Suburban

Introduction

The increasing demand for safe drinking water is proportional to the increase in the human population (Lu et al. 2015). The United Nations highlights the importance of clean water supply in the Sustainable Development Goals (SDGs): Goal 6, clean water and sanitation (UN 2015). The World Health Organization (WHO 2020) reports that 90% of the global population consumes improved drinking water with at least basic service to enhance the quality. Piped treated water, protected wells, and public standpipes are examples of improved drinking water sources (Ritchie and Roser 2019). However, these enhanced sources of potable water may still be polluted by metals from different sources. For example, the conventional water treatment itself does not sufficiently eradicate Cd residue in drinking water (Yuan et al. 2016). Metal concentrations are affected by the quality of river water. Agricultural and industrial activities along a river may contribute to metal contamination (Khan et al. 2015). Metal contamination may also come from pipeline materials leakages such as steel pipes, copper pipes, and galvanized iron pipes (Chowdhury et al. 2016). Improper maintenance of filtration systems and unsuitable storage containers for drinking water is another factor in drinking water contamination (Ab Razak et al. 2016; Kioko and Obiri 2012).

In recent years, numerous studies worldwide have revealed that metal concentrations in potable water are below permissible limits set by WHO (Moldovan et al. 2020; Ghahramani et al. 2020; Yousaf et al. 2019; Liu et al. 2018; Azlan et al. 2012). However, it is impossible to rely entirely on comparisons with drinking water standards to consider the risks of metal toxicity. The health risk assessment (HRA) model is useful to gain information on metal exposure from drinking water. HRA can estimate the non-cancer and cancer risks via the calculation of hazard quotient (HQ) and lifetime cancer risk (LCR) based on a report by USEPA (2011). Exposure to Cr, Cd, and Pb via drinking water can result

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in non-cancer and cancer effects on humans (Muhammad et al. 2011).

In Malaysia, drinking water is mainly supplied by treated river water. Unfortunately, in most cases, the technology used for water purification in water treatment plants cannot entirely remove inorganic and organic impurities. Some trace heavy metals and chemical compounds, for example, have previously been discovered in tap water (Lim et al. 2013; Sulaiman et al. 2016). Some studies hint drinking water maybe contaminated with heavy metal. Several studies in Malaysia have been applied HRA in drinking water research (Wee et al. 2020; Ab Razak et al. 2016; Lim et al. 2013; Dzulfakar et al. 2011). These studies also described comprehensive information on heavy metal concentrations from drinking water and their pollution sources, especially for the urban regions. Pollution research in urban areas is quite extensive, but inadequate suburban information has been reported, particularly in Malaysia (Sulaiman et al. 2020). A study on drinking water quality in tropical semi-urban areas integrating health risk assessment (HRA) is still limited. Therefore, this study aims to (i) determine the concentration of metal (Cd, Cr, Pb, and Zn), (ii) evaluate the non-cancer and cancer risks of metal exposure via drinking water, and (iii) ascertain the sources of metal contamination in drinking water source in a suburban area of Jengka, Pahang, Malaysia.

Materials and methods

Study site, sample collection, and analysis

Water samples were collected from selected restaurants in Jengka, a semi-urban area in the Pahang state, Malaysia (3°76′98″ N, 102° 54′77″ E). The eating places with the highest number of customers were chosen, based on observations from a previous study (Kamarudin 2013). Jengka has witnessed a growing number of residential and commercial zones over the 2000–2020 period. This town has an average of 2000 mm annual rainfall, with a mean daily temperature range between 24°C to 35°C. Clay soils predominate, and limestone, siltstone, and sandstone cover the area geologically. Jengka gets its drinking water from the Pahang River, which is processed using a conventional water treatment system at the Batu Sawar treatment facility. The Pahang River is susceptible to water pollution due to economic activities such as agriculture, mining, and upstream logging (Rashid et al. 2018). Drinking water is distributed through a pipeline system consisting of HDPE pipes and mild steel to this area, perhaps due to their low corrosion.

A total of 48 drinking water samples were collected from selected restaurants in Jengka town. The water samples were taken from the kitchen tap using a clean polyethylene plastic bottle after 2 min of flushing. Drinking water samples were filtered through a 0.45 μm pore membrane filter, and 2 ml of 5% HNO_3 was added to each water sample. Then, the filtered samples were placed in a dark and cool container, brought to the laboratory, and then kept at 4°C for further analysis. Heavy metals (Cd, Cr, Pb, Zn) in the samples were analysed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, Agilent 5100).

Quality assurance

All apparatus used for sampling and analysis were prewashed with 5% nitric acid, then rinsed with deionized water to avoid cross-contamination. Blank samples were prepared using the same matrix as water samples to minimise error. Triplicates samples were prepared and analysed after each batch of ten samples to ensure accuracy. The limit of quantification (LOQ) and limit of detection (LOD) were also determined. Recoveries for each metal were between 82 and 110%. The detection limits were 0.005, 0.01, 0.20, and 0.50 mg/L for Cd, Cr, Pb, and Zn, respectively. The correlation coefficients for Cd, Cr, Pb, and Zn were 0.999 ± 1.50%.

Health risk estimation

The U.S. Environmental Protection Agency suggests that Cd, Cr, Pb, and Zn intake can cause non-cancer effects, whilst Cd, Cr, and Pb are categorised as carcinogens (USEPA 2002). The average daily dose (ADD) (mg/kg/day) was applied to estimate the HRA via oral ingestion as in Eq. 1

$$ADD = (Cw \times IR \times ED \times EF)/(BW \times AT) \quad (1)$$

where Cw represents the metal concentration in drinking water (mg/L), IR is the ingestion rate of 2 L/day, ED is the exposure duration (24 years for adults, 6 years for children), EF is the exposure frequency (365 days/year), BW is the body weight (62.65 kg for adults, 15 kg for children), and AT is the averaging time (ED × 365 days) (USEPA 2002; Malaysian Adult Nutrition Survey 2009).

For non-carcinogenic risk, a hazard quotient (HQ), in which ADD value divided to a reference dose value (RfD) as seen in Eq. 2, was used. A lifetime cancer risk (LCR) was computed by multiply the ADD value with a slope factor value (SF) (Eq. 3). The RfD (mg/kg/day) via oral intake are 0.001 for Cd, 0.003 for Cr, 0.0035 for Pb, and 0.3 for Zn (USDOE 2011). The SF (mg/kg/day) values are 0.5 for Cr and 0.0085 for Pb (USDOE 2011). However, oral ingestion of Cd is inadequate to assess carcinogen risk to humans (USEPA 2002). A population is assumed to have low non-cancer risk if the HQ < 1. The tolerable level of LCR is $10^{-6} < LCR < 10^{-4}$:

$$HQ = ADD/RfD \tag{2}$$

$$LCR = ADD \times SF \tag{3}$$

Statistical analyses

Pearson's correlation was used to examine the relationship between the average concentrations of heavy metal. Cluster analysis (CA) and principal component analysis (PCA) were adopted to determine the contributions of various factors for possible metal source identification. All statistical analyses were performed using Statistical Package for the Social Sciences (IBM SPSS version 20).

Table 1 Statistical summary of heavy metals in drinking water of Jengka (mg/L)

Metal	Minimum	Maximum	Mean	Standard deviation	CV (%)
Cr	1.0×10^{-3}	6.0×10^{-3}	1.75×10^{-3}	1.0×10^{-3}	57
Pb	1.0×10^{-2}	1.2×10^{-1}	2.40×10^{-2}	3.1×10^{-2}	127
Zn	1.0×10^{-2}	4.0×10^{-1}	1.70×10^{-1}	1.41×10^{-1}	83

$n = 48$

Results and discussion

Concentration of metals

The statistics of heavy metal concentrations (Cr, Pb, and Zn) are presented in Table 1. These heavy metals have high coefficient of variation (CV) values. Pb has the highest CV value at 127%. Heavy metals with high CV values (CV more than 50%) are likely influenced by anthropogenic sources (Guo et al. 2012). Mean concentrations of metals were found in the order of Zn (0.17 mg/L) > Pb (0.024 mg/L) > Cr (0.00175 mg/L).

Table 2 shows the comparison of the metal concentrations in drinking water from Jengka and previous studies. The findings differ from those of previous studies in Turkey, China, and Iran (Lu et al. 2015; Poyraz and Taspinar 2014; Ghahramani et al. 2020). The results for the metal levels also show dissimilar concentrations from other studies in Malaysia (Khoo et al. 2011; Azlan et al. 2012; Ab Razak et al. 2016). The Cr, Pb, and Zn concentrations in the current study are slightly higher than in other studies. For example, Pb concentrations are almost double those discovered by Khoo et al. (2011). However, Pb and Zn concentrations were similar to previous studies in an urban area of Pakistan (Khan et al. 2015) and a semi-urban of Malaysia (Sulaiman et al. 2016). Cd, by contrast, was below the detection limit in all samples analysed.

A variety of water resources and differences in the supply pipeline systems affect treated drinking water quality. Many drinking water sources are vulnerable to heavy metal contamination due to anthropogenic activities and geological factors (Chowdhury et al. 2016). Due to the inadequate wastewater treatment and management of fertilizer runoff, anthropogenic activities such as manufacturing and

Table 2 Comparison between the metal concentrations in drinking water (mg/L) in this study and selected previous studies

	Main potential contaminant source	Region	Location	Cd	Cr	Pb	Zn
This study	Agricultural	S	Malaysia	BDL	1.75×10^{-3}	2.4×10^{-2}	1.7×10^{-1}
Ab Razak et al. (2016)	Agricultural	U	Malaysia	$<2.0\times10^{-6}$	1.0×10^{-4}	8.0×10^{-5}	3.6×10^{-3}
Azlan et al. (2012)	Geological	U	Malaysia	8.5×10^{-4}	$<4.0\times10^{-6}$	3.8×10^{-3}	3.0×10^{-2}
Khoo et al. (2011)	Plumbing	U	Malaysia	–	–	3.2×10^{-4}	3.4×10^{-2}
Lu et al. (2015)	Industrial	U	China	3.8×10^{-5}	1.45×10^{-4}	–	2.54×10^{-1}
Poyraz & Taspinar (2014)	Agricultural	U	Turkey	–	3.8×10^{-4}	3.0×10^{-4}	3.2×10^{-2}
Khan et al. (2015)	Industrial	U	Pakistan	–	–	2.0×10^{-2}	1.0×10^{-2}
Sulaiman et al. (2016)	Agricultural	S	Malaysia	–	–	–	1.7×10^{-2}
Ghahramani et al. (2020)	Natural	S	Iran	–	0.68×10^{-3}	9.8×10^{-3}	–
WHO (2008)				3.0×10^{-3}	5.0×10^{-2}	1×10^{-2}	3
MMOH (2009)				3.0×10^{-3}	5.0×10^{-2}	1×10^{-2}	3

BDL-Below detection limit, S-suburban, U-urban agricultural activities also lead to heavy metal contamination in water bodies (Belabed et al. 2017; He & Charlet 2013). For example, drinking water in an urban area in Kelantan, Malaysia was slightly contaminated by Cr and Pb due to extensive agricultural activities based in Table 2 (Ab Razak et al. 2016). Poyraz and Taspinar (2014) reported the same findings in a study in Turkey. Another potential source of metals such as Pb to be leached out is an old pipeline system (Tracy et al. 2020). A study in an urban area in Malaysia by Khoo et al. (2011) suggested Pb and Zn concentrations came from old piping systems. The pipe materials are affected by lifespan and typically deteriorated over time, causing corrosion when contacting water (Barkatt et al. 2009). Other studies found that drinking water is contaminated by metal due to industrial activities (Lu et al. 2015; Khan et al. 2015). Natural and geological factors also could contribute to the metal composition in drinking water as indicated in Table 2 (Azlan et al. 2012; Ghahramani et al. 2020).

The metal concentrations in drinking water were compared to the acceptable limit suggest by the Malaysia Ministry of Health (MMOH) and WHO (Table 2). Cr and Zn concentrations were below the limits. However, Pb concentrations from sampling locations in this study (0.024 mg/L) were higher than the permissible limits (0.01 mg/L). By comparing to the limits alone, the exposure level of metal via drinking water is unclear. Perhaps, the level of metal exposure from potable water, particularly from this semi-urban area, could be evaluated by a health risk assessment.

Health risks of metal exposure via drinking water

Figure 1 shows the non-cancer risk or hazard quotient (HQ) for adults and children exposed to metal from drinking water in Jengka. HQ values were below unity for all metals (HQ < 1), suggesting a low potential risk of non-cancer. Other studies in Malaysia have reported similar results (Ab Razak et al. 2016; Sulaiman et al. 2016; Lim et al. 2013). Notably, the HQ values for children were higher than those for adults, in particular the HQ values for Pb from S1. As seen in Table 2, Pb concentrations were higher than the limits. Although this value suggests low non-carcinogenic effects, the value is close to one. This result indicates that children are more susceptible to metal exposure from drinking water, especially in this semi-urban area.

The lifetime cancer risk (LCR) for adults and children was within the acceptable level ($<1\times10^{-4}$) for Pb and Cr exposure (Fig. 2). However, exposure to Cr shows a higher potential of cancer risk to the population than Pb exposure. There is a potential cancer risk amongst the local people exposed to Cr contamination in drinking water, even though the Cr concentrations were below the permissible limit (Table 2). Children are likely to have doubled risk as compared to adults for Cr exposure. About 8 children out of 100 000 individuals are vulnerable to be suffered adverse cancer effects in their life, with 4 per 100 000 persons for adults. Accordingly, this study suggests urgent attention from the authorities on this matter.

Potential sources of metal contamination

Table 3 presents the Pearson's correlation of metal concentration in Jengka's drinking water. There is a moderate correlation of Cr–Pb ($r = 0.5940$, $p < 0.05$), indicating that these metals are related. No linked found for Zn–Cr and Zn–Pb due to the weak correlations ($r < 0.3000$, $p < 0.05$). This finding implies that Cr–Pb and Zn may have several possible

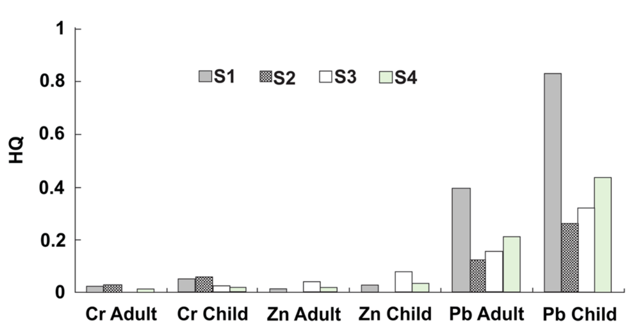

Fig. 1 Hazard quotient (HQ) representing the non-cancer risk

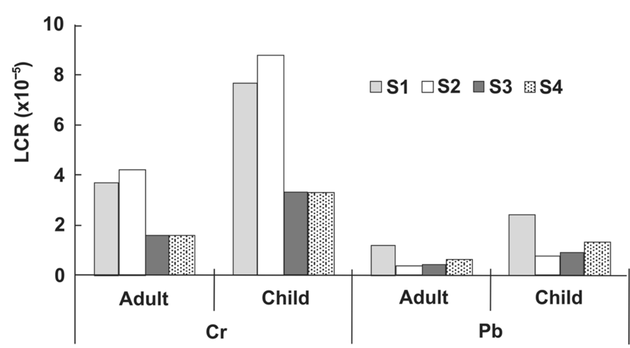

Fig. 2 Lifetime cancer risk (LCR) indicating the carcinogenic risk

Table 3 Correlation of Cr, Pb, and Zn concentrations in drinking water from Jengka

	Cr	Pb	Zn
Cr	1	0.5940*	− 0.2050
Pb		1	0.1710
Zn			1

*correlation is significant at the 0.05 level (2-tailed) sources. Further multivariate analysis confirms the potential sources of these metals.

Cluster analysis was employed in this study to investigate the groupings of metals. This approach is prevalent in which clusters are formed consecutively. This method divides variables, cases, and observations into classes based on similarities within a class and differences across classes from the predefined dataset. Euclidean distances for similarities computed in cluster analysis (CA) with two clusters identified, namely Cluster 1, C1 (Cr and Pb) and Cluster 2, C2 (Zn), as seen in Fig. 3. These results support the correlation between the Cr, Pb, and Zn, as shown in Table 3. It indicates that these metals potentially contributed from two sources, which are natural and anthropogenic origin.

Principal component analysis (PCA) breaks down the variance of connected elements into a smaller number of independent variables and reduces data into a single component. PCA was used to pre-cluster datasets by extracting the eigenvalues and eigenvectors from a square matrix created by multiplying the data matrix. The most significant components were selected to limit the influence of factors with low significance. The components obtained were then subjected to varimax rotation to develop varimax factors and maximise the discrepancies between the variables, allowing for easier data interpretation. PCA was used to differentiate between potential pollution sources that contribute to water quality.

Table 4 shows the rotated factor analysis results for metal concentrations in drinking water. Two main factors, with a total variance of 89.85%, were identified. Factor 1 contributed 53.11% to the total variance, with strong positive loadings Cr ($r = 0.88$) and Pb ($r = 0.89$). The results suggest that Factor 1 may have a mix of natural and anthropogenic contributions. Natural factors such as weathering of rocks and water–rock interaction could result in Cr (Khan et al. 2013).

Table 4 Factor loading for metal after varimax rotation using principal component analysis

	Factor 1	Factor 2
Cr	**0.88**	− 0.28
Pb	**0.89**	0.25
Zn	− 0.05	**0.98**
Eigenvalues	1.59	1.10
Variability (%)	53.11	36.73
Cumulative (%)	53.11	89.85

Factor in bold shows a strong factor loading

The correlation test proved that these metals are linked, meaning that they had similar origins and chemical behaviour. Apart from that, anthropogenic factors such as the brass and copper used as fitting materials in the pipeline system may contribute to Cr concentration (Tam and Elefsiniotis 2009; Karim 2011). Another possible contributor for Cr and Pb was road runoff that flows over into the water resource (Boyacioglu and Boyacioglu 2011), in this case, the Pahang River. This argument is supported by Rashid et al. (2018), as which agriculture and logging are typical economic activities along the Pahang River, so main roads are built nearby. Although leaded fuel has been banned since the late 1990s in Malaysia, Pb traces can still be found (Sulaiman et al. 2020).

The second factor (Factor 2) showed strong positive loading of Zn with 36.73% of the total variance. As mentioned, the conventionally treated drinking water supplied to Jengka comes from the Pahang River. Therefore, an anthropogenic origin such as agricultural activities may be one of the sources for the high Zn concentration in the river water. Intensive agriculture has deposited a significant amount of metals in the soil, which is then washed into the river by soil erosion and

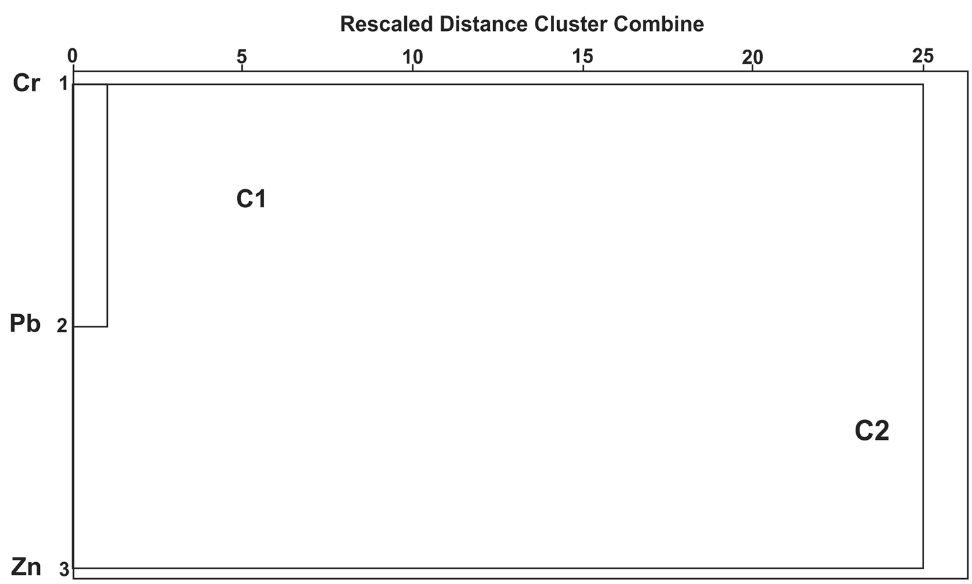

Fig. 3 Dendrogram of cluster analysis for metal concentration in drinking water

surface runoff (Razali et al. 2021). Therefore, surface runoff from agricultural areas along the Pahang River perhaps contributes to Zn composition. Previous studies have suggested that Zn in drinking water comes from sources contaminated with fertilizers and fungicides applied in agriculture (Poyraz and Taspinar 2014; Sulaiman et al. 2016; Mishra et al. 2021).

Conclusion

This study found that the metal concentrations in drinking water were in the order of Zn > Pb > Cr > Cd. The concentrations of metals were below the permissible level set by WHO and MMOH, except for Pb. HQ values for all metals are still below the unity level (HQ < 1), indicating a low potential of non-carcinogenic effects to adults and children. Similarly, LCR values lower than unity (LCR < 1) for Pb and Cr exposure suggest low cancer risk to the population. Nonetheless, children are exposed to a higher risk of metals exposure via drinking water compared to adults. The PCA, CA, and correlation analyses suggest that all metals were possibly originating from two different groups of sources. This study has provided more information on the HRA of metal exposure and potential sources of contamination in drinking water to the Jengka population in general. A comprehensive monitoring study is still required, specifically to develop an accurate risk assessment. Ensuring safe drinking water access requires awareness amongst this population. In the future, the awareness level could be assessed via a knowledge, attitude, and practice (KAP) assessment. Perhaps, the output from this study may assist the authorities in enhancing the management of drinking water quality.

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Author contributions FRS and NM planned the study. FRS analysed the data and wrote the manuscript. NM collected the sample and analysed the sample. AZA verified, reviewed, and edited the manuscript. All authors have approved the final version of the manuscript.

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Data availability Data are available upon request to the corresponding author (fazrul@uitm.edu.my).

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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