Bioresources and Environment 2023, 1(2) 25-33.

Content list available at BioEnv

Bioresources and Environment

Journal homepage: www.bioenvuitm.com

Assessment of Metals Concentration from a Tropical River

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Received in March 23, 2023; Accepted in revised form May 31, 2023
Available online June 27, 2023

ABSTRACT. Water quality is a significant issue for humanity since water is a very precious natural resource. Pollution is caused by expanding population and the need to provide services and products relying on water. In this study, water samples were collected from the Jengka River, Pahang, Malaysia. Selected metal concentrations (Al, Fe, Cu, Zn) were determined to assess possible sources and estimate the health risks of metal exposure from river water. The metal concentrations were analysed using atomic absorption spectroscopy (AAS). Hierarchical cluster analysis (HCA) was employed to identify the possible sources of metal in water. The metal concentrations were found to be in the order of Al>Fe>Cu>Zn. The Metal Evaluation Index (MEI) suggests that the Jengka River is classified as high and medium metal levels according to the National Drinking Water Quality Standard (NDWSQ) and World Health Organization (WHO), respectively. HCA indicated that the metals came from both natural and anthropogenic sources. Children are more susceptible to non-cancer risk than adults based on health risk assessment (HRA). This study suggests that systematic monitoring of water quality indicators and a complete exposure assessment should be carried out.

Keywords: Metal, Surface water, Tropical river, Water quality

INTRODUCTION

Water is an essential component of all life on Earth and is considered the most crucial, nonrenewable resource on which a nation's socioeconomic development and sustainability are heavily dependent. Despite its significance, water is the least well-managed resource on Earth and is in great danger due to several anthropogenic activities like agriculture, industry, and urban development. Rapid and indiscriminate expansion of agricultural and industrial areas is regarded as the primary source of worldwide water pollution, especially in waterway environments, which are the final destination of effluents released by these activities (Proshad et al., 2021). Most industries introduce a variety of water pollutants, including heavy metals, through the discharge of untreated or inadequately treated effluents due to weaknesses in law enforcement and insufficient monitoring.

Due to their high persistence and potential to bioaccumulate in the food chain, heavy metals are a significant threat to the aquatic environment (Ali et al., 2019). The release of a considerable volume of untreated and partially treated industrial effluents continuously, together with other sources, raises heavy metal concentrations in water. This has a

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harmful impact on aquatic life, eventually disrupting normal ecosystem function (Kumar et al., 2019). Furthermore, heavy metals can penetrate the body, both via skin contact with polluted water and through the consumption of contaminated water and aquatic species (Saha and Paul, 2019). Thus, thoroughly evaluating surface water quality in terms of heavy metal contamination is crucial for environmental and human health protection alike.

Jengka River is in a suburban region in Jengka, Pahang, Malaysia. Jengka is also known for its palm oil plantations. The average daily temperature ranges between 24 and 35°C, and the annual rainfall is around 2000 mm. This river offers potable water and local fish supplies as they flow through agricultural regions, protected forests, and suburban development areas (Harith et al., 2021). Jengka River flows from the north of the Jengka region for about 40 km in length and merges with Pahang River at the southeast of Jengka near Chenor as one of the tributaries of the Pahang River. Studies in Argentina, China, India, and Bangladesh have found that urban and suburban waterways are often contaminated by heavy metals (Diaz et al., 2016; Zheng et al., 2017; Kumar et al., 2020; Proshad et al., 2021). Limited research has been reported on the Jengka River, so it is essential to determine the level of metal contamination in this riverine. This study determined selected metal concentrations and possible metal sources in the Jengka River. This study also assesses the potential health concerns for the residents.

METHODOLOGY

Sample Collection

Fifteen samples were collected from the Jengka River in Jengka, Pahang, Malaysia. During the hot days of October 2019, one sampling event was held. Wet days were excluded from sampling due to the risk of pollutant dilution. The samples were collected at the points labelled S1-S5 in Figure 1. In close proximity to the sampling locations are a rubber processing plant, two main residential areas (Felda Kampung Awah and Felda Sungai Nerek), and agricultural areas. The grab sampling technique was used to collect samples from the river's top surface (10 cm deep) to prevent data misinterpretation. Samples were collected from upstream to downstream at 500 m intervals between five sampling locations. Water samples were swiftly taken and put into 250 ml polyethylene (PE) bottles that had already been acid-washed. Before being transported to the laboratory, the water samples were acidified to a pH of 2 and stored in an icebox at 4° C until further analysis. A 0.45 µm pore size membrane filter was used to filter all samples before analysis. The concentrations of metals (Al, Fe, Cu, and Zn) in the filtered samples were then analysed using atomic absorption spectroscopy (AAS). In the spike recovery test, samples were spiked with the desired analytes. The rates of recovery varied from 83% to 112%.

Metal Evaluation Index (MEI)

Edet and Offiong (2002) have suggested that overall water quality in terms of metals can be predicted using the metal evaluation index (MEI) and computed using Equation 1:

$$MEI = Mc / MAC \quad (1)$$

Mc denotes the metal concentration, and *MAC* signifies the maximum allowable metal concentration. The maximum permissible limits for Al, Fe, Cu, and Zn are 0.2, 0.3, 1.0, and 3.0 mg/l, respectively (NDWQS, 2021). The MAC for Al is 0.2 mg/l, and for Cu is 2.0 mg/l (WHO, 2011). There are no maximum permissible limits for Fe and Zn (WHO, 2011). The MEI can be classified as low (< 10), medium (10 -20), or high (> 20).

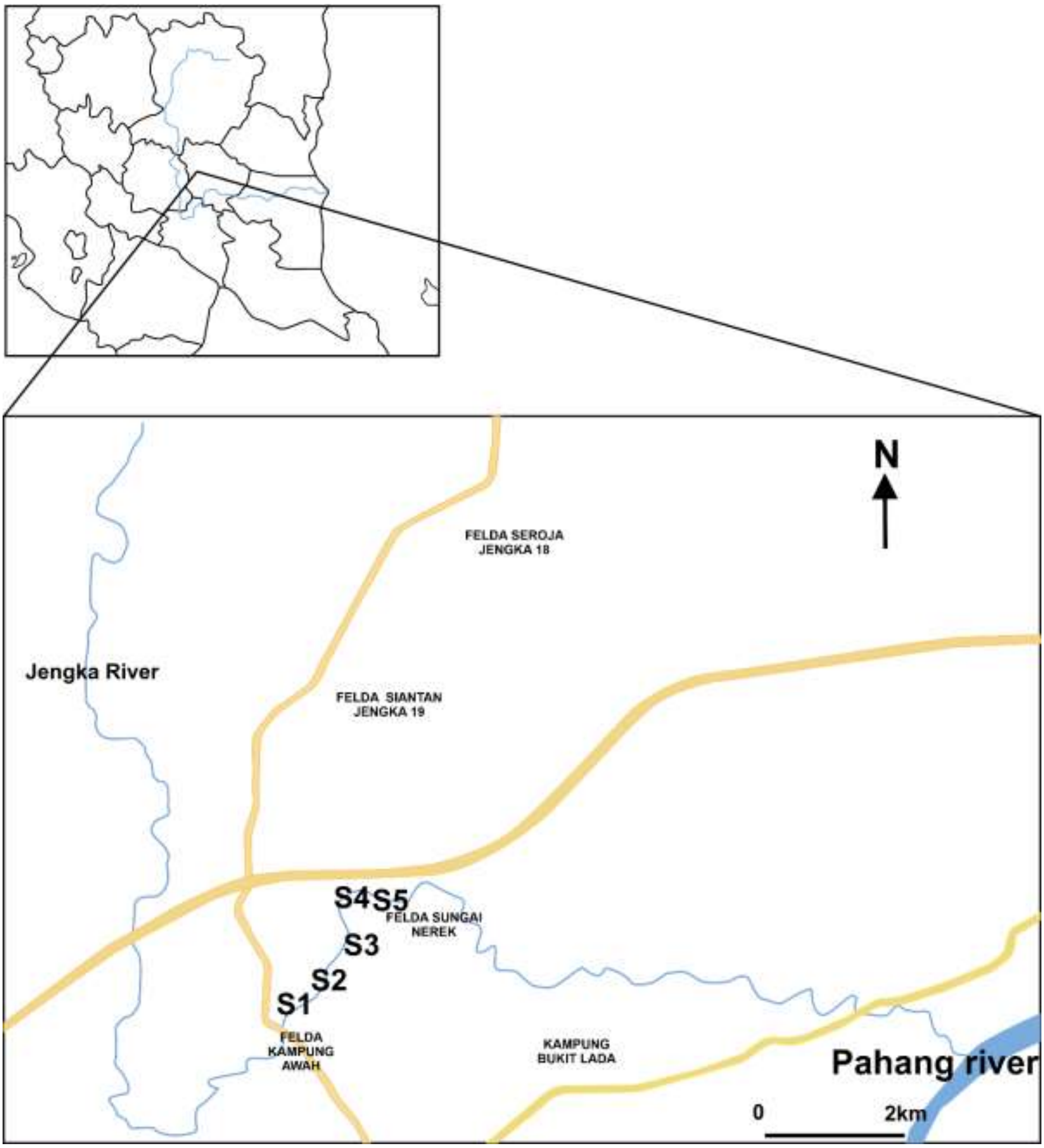

Figure 1. Location of Jengka River and sampling locations.

Health Risk Analysis

Surface water containing metals can penetrate the human body through oral and skin contact. Health risk assessment (HRA) models can estimate whether oral ingestion or skin contact will be non-carcinogenic. Equations 2 and 3 were used to calculate the average daily dose (*ADD*) to assess the daily effects of heavy metal exposure in water on human health. The hazard quotient (*HQ*) was estimated using *ADD* to quantify non-cancer effects (Equation 4). In Equation 5, the hazard index (*HI*) was calculated by aggregating the *HQ*s.

$$ADDoral = (Cwater \times IR \times ED \times EF) / (BW \times AT) \quad (2)$$

$$ADDdermal = (Cwater \times SA \times AF \times ABF \times ED \times EF) / (BW \times AT) \quad (3)$$

$$HQ = ADD / RfD \quad (4)$$

$$HI = \sum HQ \quad (5)$$

Cwater represents the metal concentration in water samples, while *IR* denotes the ingestion rate (2 L/day); *ED* signifies exposure duration (24 years for adults; 6 years for children); *EF* indicates the exposure frequency (365 days/year); *BW* means the body weight (62.65 kg adults, 15 kg children); *AT* implies the averaging time (8760 days adults, 2190 children); *SA* represents the surface area of skin contact (5700 cm^2/event adults, 2800 cm^2/event children); *AF* signifies the skin adherence factor (0.07 mg/cm^2 adults, 0.2 mg/cm^2 children); *ABF* designates the skin absorption factor (0.001); and *RfD* defines as the reference dose (oral: Fe and Zn is 0.3 mg/kg/day; dermal: Fe 0.045, Cu 0.012, and Zn 0.06 mg/kg/day) (Azmi et al., 2009; USEPA, 2002).

Statistical Analyses

All data were explored using the IBM Statistical Package for Social Sciences (Version 21). Because the data were normally distributed, Pearson's correlation was used to validate the link between the metals. Metal concentrations were classified using hierarchical cluster analysis (HCA) based on comparable possible contamination sources.

RESULTS AND DISCUSSION

Metal Concentrations in Jengka River

The descriptive statistics for metal concentrations in the Jengka River are shown in Table 1. The mean concentration of metals is determined in the order of Al (4.008 mg/l) > Fe (1.01 mg/l) > Cu (0.02 mg/l) > Zn (0.018 mg/l). Cu has a high coefficient of variation (CV) value of 35%. Metals with a high CV value could come from anthropogenic sources (Guo et al. 2012). In Jengka River, Al had the highest concentration of all four metals. This result contradicts previous findings by Sulaiman et al. (2022), which reported that iron (Fe) is the highest concentration in the tributaries of the Jengka River, namely the Jempul and Weh rivers. Nevertheless, Fe concentrations have also been found to be high in this study. Perhaps it is worth noting that Al and Fe are the most abundant elements in the Earth's crust. Fe and Al concentrations are higher than the limit concentrations set by NDWQS (2021) and WHO (2011). Cu and Zn, however, showed concentrations lower than the permissible values.

Table 1. Statistics of metal concentrations from Jengka River (mg/l)

	Min	Max	Mean	SD	CV	WHO[a]	NDWQS[b]
Al	3.840	4.480	4.008	0.261	6.48%	0.20	0.20
Fe	0.980	1.050	1.011	0.032	2.97%	-	0.30
Cu	0.010	0.030	0.020	0.007	35%	2.00	1.00
Zn	0.017	0.019	0.018	0.0005	2.77%	-	3.00

[a]Based on WHO (2011) maximum acceptable concentration, [b]Based on National Drinking Water Quality Standard (NDWSQ, 2021)

Table 2 shows the correlation coefficient between metal concentrations in Jengka River water at confidence levels of p<0.01 and p<0.05. Fe-Al, Al-Cu, and Fe-Zn showed a strong positive link (r>0.750). However, Al-Zn and Cu-Zn had a weak correlation (r<0.460). HCA for Al, Cu, Fe, and Zn concentrations from the Jengka River show two distinct clusters (Figure 2). Group 1 (G1) consists of Cu, Zn, and Fe, and Group 2 (G2) comprises Al, which suggests two potential metal concentration sources. Metal in G1 comes from anthropogenic and natural sources, while metal in G2 derives from natural sources. Metal in G1 could have originated from agricultural activities along the river via surface runoff (Che Nadzir et al., 2019; Razali et al., 2021).

Table 2. Pearson correlation of metal from Jengka River

	Al	Fe	Cu	Zn
Al	1.000	0.751**	0.791**	0.453
Fe		1.000	0.611*	0.779**
Cu			1.000	0.328
Zn				1.000

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed)

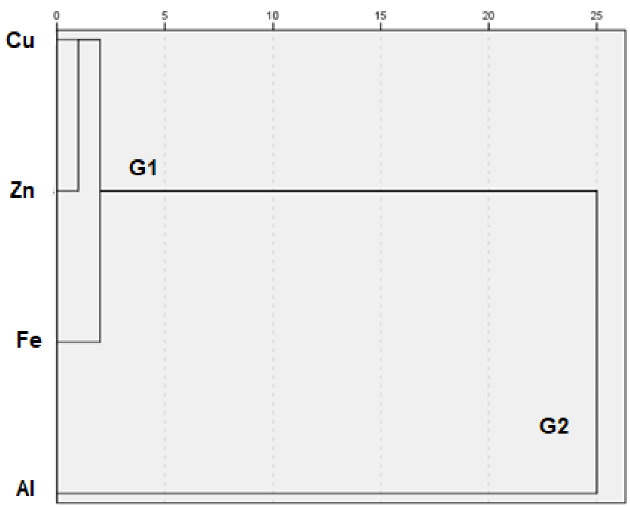

Figure 2. Cluster analysis for metals in Jengka River

MEI

The metal evaluation index (MEI) can be applied to assess the metal content of water. The MEI describes overall water quality in terms of the amount of metal present. MEI values for Al, Cu, Fe, and Zn are estimated based on NDWQS (2021) and WHO (2011) permissible limits (Table 3). Based on WHO's limits, the MEI value was classified as low for Cu but medium for Al. The MEI in the Jengka River was low in terms of Fe, Cu, and Zn and medium for Al if based on the NDWQS. Generally, metal pollution levels in the Jengka River were medium according to the WHO but slightly higher if based on the NDWQS.

Table 3. Metal evaluation index of Jengka River

	Al	Fe	Cu	Zn	MEI	Classification
WHO[a]	20.04	-	0.01	-	20.05	Medium
NDWSQ[b]	20.04	3.36	0.02	0.006	23.43	High

[a]Based on WHO (2011) maximum acceptable concentration, [b]Based on National Drinking Water Quality Standard (NDWSQ, 2021)

Potential Health Risk

Table 4 presents the average daily dose (ADD) of Cu, Fe, and Zn from ingestion and skin contact in children and adults. Children's ADD for metals is higher than for adults via oral exposure to water. Dermal contact with water is another potential metal exposure pathway. Metals can be absorbed in a variety of ways through skin contact, including swimming, bathing, and fishing. However, the ADD values for skin contact are less than for oral exposure.

The HQ approach is commonly used to quantify metals' potential non-carcinogenic adverse effects. Humans may suffer health consequences (non-cancer risk) if the HQ value exceeds 1 (HQ > 1) (USEPA 2011). Adult and child ingestion poses a greater non-cancer risk than dermal contact (Table 4). Nonetheless, adults and children may have a lower non-cancer risk, as the HQ values were below unity.

The overall impact of exposed metals is defined as the hazard index (HI). Figure 3 demonstrates the HI values from dermal contact and ingestion exposure for children and adults. Children have higher HI values than adults, indicating that they are at a higher risk of non-cancer disease. According to Qu et al. (2012), children are exposed to more metals per unit of body weight because they have a lower body mass than adults. Although the HI values did not exceed unity, there was still a potential non-carcinogenic risk of all metals for child and adult health in the long term. If the metal concentration increases and the exposure time increases, the HQ and HI values may increase.

Table 4. Average daily dose (ADD) and hazard quotient (HQ) for adults and children exposure via oral intake and skin contact

	Adults			Children		
ADD	Cu	Fe	Zn	Cu	Fe	Zn
Dermal	1.14×10^{-10}	1.27×10^{-10}	6.67×10^{-9}	6.72×10^{-10}	7.46×10^{-10}	3.91×10^{-8}
Oral	5.74×10^{-4}	6.38×10^{-4}	3.34×10^{-2}	1.20×10^{-3}	1.33×10^{-3}	6.98×10^{-2}
HQ	Cu	Fe	Zn	Cu	Fe	Zn
Dermal	9.55×10^{-9}	2.83×10^{-9}	1.11×10^{-7}	5.60×10^{-8}	1.65×10^{-8}	6.52×10^{-7}
Oral	-	2.12×10^{-3}	1.11×10^{-1}	-	4.44×10^{-3}	2.32×10^{-1}

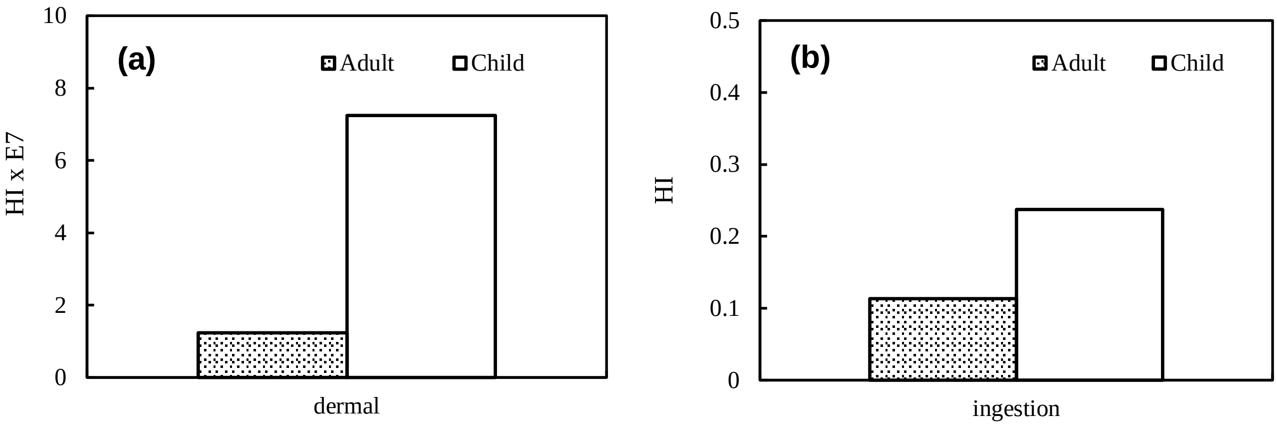

Figure 3. Hazard index of metal exposure via dermal contact and ingestion

CONCLUSION

Metal concentrations in the Jengka River followed the Al > Fe > Cu > Zn trend. Using hierarchical cluster analysis, anthropogenic (primarily agricultural) and natural metal origins were identified. MEI scores indicated medium- to high-level metal contamination. Based on the findings, there was a low non-cancer risk to children and adults via ingestion and skin contact. Nevertheless, children have a higher non-carcinogenic risk than adults. Although the risk is low, there is a potential for an increase in metal concentrations in the river water, which could increase the risk. River water should be free of excess concentrations of metals because it is used for numerous purposes. Comprehensive monitoring is required for water quality indicators, including temperature, COD, pH, and other metal elements such as Cr, Pb, and Mn. A thorough health risk assessment may be necessary because the local population is at risk for non-cancer and cancer diseases.

ACKNOWLEDGMENTS

The authors would like to thank UiTM Cawangan Pahang for providing the necessary research facilities. Special thanks also go to Mr. Nik Mohd Zamani Nik Ismail for the assistance with the AAS analysis.

AUTHOR CONTRIBUTIONS

Fazrul Razman Sulaiman, **Noorzamzarina Sulaiman** and **Nur Izzah Izzana Mazlan**: planned the study. **Nur Izzah Izzana Mazlan**: collected and analysed the samples. **Fazrul Razman Sulaiman**: analysed the data and drafted the manuscript. **Noorzamzarina Sulaiman**: reviewed, edited, and verified the manuscript. All authors have endorsed the manuscript upon submission.

FUNDINGS

Not available.

DATA AVAILABILITY

Data is available upon request to the author.

COMPETING INTEREST

The authors declare that there are no competing interests.

COMPLIANCE WITH ETHICAL STANDARDS

Not applicable.

SUPPLEMENTARY MATERIAL

Not applicable.

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