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KLANG RIVER WATER QUALITY ASSESSMENT AND ITS EFFECTS ON HUMAN HEALTH USING CHEMOMETRIC ANALYSIS

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Abstract

Introduction: *River water pollution has been a significant hazard to human health and is associated with severe health risks. This study evaluates water quality and heavy metal levels in the Klang River, analyzing their health risks through chemometric analysis.* ***Methods:*** *Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) was used to analyse the heavy metal contents in river water samples obtained from 9 sampling stations. Chemometric statistical techniques (principal component analysis (PCA) and hierarchical cluster analysis (HCA) are employed to identify the sources of physicochemical properties and heavy metals. The human health risk was evaluated using statistical analysis, apart from hazard quotient (HQ), hazard index (HI), and carcinogenic risk (CR).* ***Results and Discussion:*** *Results showed that the physicochemical parameters were within acceptable limits. The concentration of heavy metals was found to follow a decreasing order of As > Ni below permissible levels, except at P9 and P8. PCA and HCA showed important connections among parameters, emphasizing that COD, NH_3N, and TDS are key factors affecting Klang River water quality.* ***Conclusion:*** *The study assesses pollution risks in the Klang River, offering crucial insights for sustainable estuary management. It highlights significant changes in temperature, pH, TDS, BOD, DO, and NH_3N levels, along with specific trends in heavy metal concentrations. The Health Risk Assessment indicates acceptable HQ and Target Cancer Risk values. However, the study's limited sample sites and focused timeframe might hinder understanding long-term patterns and regional differences. Extended data collection and additional information are necessary to improve water quality management and protect public health*

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INTRODUCTION

Freshwater, essential for human survival, is scarce, with only about 3% available on the earth's surface (1). In Malaysia, surface water provides 99% of the water supply for domestic use, while groundwater accounts for only about 1% (2). Both natural and human activity can influence river water. The influence of land use patterns on physicochemical water quality measures might vary, potentially resulting in either favourable or negative outcomes. Land clearing, the disposal of animal waste, and other agricultural operations can potential can introduce sediment, nutrients, organic matter, heavy

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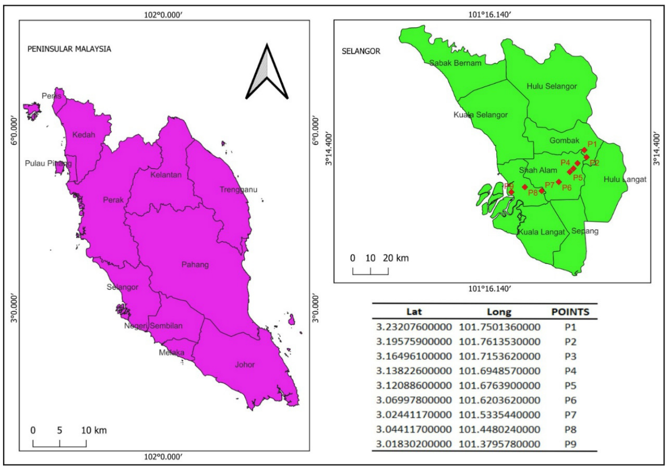
metals, and diseases into the surrounding environment via runoff or irrigation. Moreover, the increase in population and the accelerated process of urbanisation have resulted in heightened stress on the ecosystems and the aquatic environment. In an effort to meet the needs of an expanding population, industrial activities have been boosted, which has led to the release of pollutants and wastewater into the environment (3).

The Klang River continues to be essential for several purposes, including navigation, tourism, transit, and fishing (4). Yet rapid development, population growth, urbanization, and the growth of industrial, commercial, and agricultural activities have led to river water pollution, which is dangerous for the environment and poses a major risk to the health of all living things by reducing the water's quality and making it not suitable for human use (4-6). The increasing concentration of heavy metals in river water is a major worry since they are hazardous to human health. Extended exposure to heavy metals may cause low energy, affect the brain, lungs, liver, and kidneys' normal functions, and adversely affect the blood's composition. Furthermore, contact with these toxic metals can impair physical, neurological, and muscular abilities (7-8). Studies have also shown that anthropogenic and natural factors are responsible for the accumulation and spread of heavy metals in water, particularly arsenic (As) and nickel (Ni), which are predominantly released through Port Klang and can negatively affect the river water quality (4,9). The main routes of exposure to waterborne pollutants such as heavy metals typically include ingestion, dermal absorption, and inhalation. For the Klang River, possible ways individuals could be exposed include direct contact with polluted water during activities like swimming or fishing, drinking contaminated water or eating aquatic organisms, and breathing in pollutants from aerosols or vapours released by the water. Runoff, industrial discharges, and wastewater treatment effluents may contaminate river water, highlighting the need to identify human access sites and exposure routes. According to previous studies (10-11), the Department of Irrigation and Drainage Malaysia reported that the Klang River is the most contaminated river in the nation, citing an approximately annual disposal of 77,000 tons of waste. A comparable study conducted in 2016 revealed that the Klang River has been under severe threat for over a decade due to various pollution sources, encompassing industries such as chemical, food, and beverage, semiconductor, and electronics sectors (12). The fact that the river passes through heavily inhabited areas makes things more difficult, posing difficulties in gauging pollutant levels. Therefore, comprehensive plans must be implemented to guarantee that clean water will be available for both the current and future generations. As a preventive measure against the global spread of the pandemic induced by the coronavirus disease 2019 (Covid-19), Malaysia implemented a Movement Control Order (MCO) that prohibited movement, assembly, and international travel. Businesses, industries, government agencies, and educational institutions were ordered to close to limit the transmission of the said virus. One potential effect of the Covid-19 pandemic on the Klang River water quality is reduced industrial and commercial activity in the surrounding areas cleaning up the water (13). With fewer factories and businesses operating, there may have been a reduction in the discharge of pollutants and contaminants into the river. On the other hand, the pandemic could have also led to increased residential waste and domestic sewage being discharged into the river due to more people staying at home and potentially not following proper waste disposal practices (14). This could lead to critical water resources that have been impacted by environmental change. The lack of baseline information on heavy metal contamination immediately after the pandemic presents a significant problem (15).

This study aims to evaluate and examine the concentrations of physicochemical properties, including total dissolved solids (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammoniacal nitrogen (NH_3N), pH, temperature, and heavy metals (arsenic and nickel). This paper also aims to ascertain how heavy metals along with water quality interact using chemometric analysis and evaluate the potential health risks to humans by calculating hazard quotient (HQ), hazard index (HI), and carcinogenic risk (CR). In addition, this study could provide a reference for future research on heavy metal contamination and update the data on heavy metal exposure that affects water quality.

METHODS

Klang River (Figure 1) holds great importance in Peninsular Malaysia as it meanders across Kuala Lumpur and the Klang Valley, ultimately discharging into the Straits of Malacca. Its length and catchment area are approximately 120 km and 1288 km^2, respectively (16). It comprises 11 primary tributaries, including Sungai Gombak, Sungai Batu, Sungai Penchala, and Sungai Ampang. Rapid urbanisation and human activities in the residential areas along the river have adversely affected the health of the Klang River. The current research focuses on this region due to its location in the most urbanised and densely populated area, home to over 4.4 million individuals and constitutes approximately 16% of the total national population residing in the vicinity of this area (17). The data collection was conducted at nine points along the Klang River, which was selected based on habitat suitability and sub-water catchments, as detailed in Table 1.



Lat	Long	POINTS
3.23207600000	101.7501360000	P1
3.19575900000	101.7613530000	P2
3.16496100000	101.7153620000	P3
3.13822600000	101.6948570000	P4
3.12088600000	101.6763900000	P5
3.06997800000	101.6203620000	P6
3.02441170000	101.5335440000	P7
3.04411700000	101.4480240000	P8
3.01830200000	101.3795780000	P9

Figure 1. The Location Map of Sampling Points

Table 1. Sampling stations along the Klang River

Points	Latitude	Longitude	Designation	Sites
P1	3.232076	101.750136	Urban	Jalan Kolam Air, Taman Desa Melawati
P2	3.195759	101.761353	Urban area	Ampang Jaya
P3	3.164961	101.715362	Urban area	Kampung Baru
P4	3.138226	101.69485	Urban area	Masjid Jamek
P5	3.120886	101.67639	Urban area	Mid Valley City
P6	3.069978	101.620362	Urban, industrial area	Jalan Kampung Lembah Kinrara, Puchong
P7	3.028046	101.533544	Urban, industrial area	Taman Sri Muda
P8	3.044117	101.448024	Urban area	Klang Town
P9	3.018302	101.379578	Industrial area	Bandar Sultan Suleiman, Port Klang

There were nine sampling points along the Klang River, P1 through P6 at the upstream, and P7 through P9 at the downstream, resulting in 27 water samples collected in November 2021 (Table 1; Figure 1). Water sampling, sample preservation, in situ measurements, and laboratory tests were carried out following the guidelines established by the American Public Health Association (APHA) (18), examining water and wastewater. The sampling bottles were thoroughly rinsed three times with sample water in preparation for sample collection. The water samples were collected at depths up to 1 meter. To ensure the quality of the samples and minimise the activity and metabolism of aquatic organisms, all water samples were kept in a coolant box containing dry ice and immediately transported to the lab for further analysis. Various parameters were measured, including physical parameters, pH, temperature, dissolved oxygen (DO), and total dissolved solids (TDS) using the YSI Multiprobe (Model 6600-M) was used to measure in situ parameters with prior laboratory calibration before its deployment in the field. Chemical parameters, such as ammoniacal nitrogen (NH_3N), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and heavy metals, including arsenic (As) and nickel (Ni), were measured in the laboratory following the APHA (18) standard method.

The water samples were taken to the laboratory for analysis, where the samples underwent filtration with a pore membrane size of 0.45 mm Whatman brand to obtain the final elute. The elute was then treated with 3 mL of 69% nitric acid (HNO_3) to avoid adsorption and crystallisation of trace elements, which may affect further analysis. The water samples were stored in cool and dark containers at a temperature of 4°C and transported to the laboratory for analysis (19-20). The laboratory used the standard APHA method (18) (APHA 3125B) to analyse the water samples. The samples were digested in an acidic solution containing nitric acid (HNO_3), and heavy metals (As and Ni), were detected using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), which was calibrated in accordance with the guidance provided by the manufacturer. To ensure analytical reliability, the analyses were conducted in triplicate, and the results were expressed as a 95% confidence interval of the mean in mg/L.

Quality control (QC) and quality assurance (QA) were implemented during the sampling process to ensure accurate analytical performance of the measurements. Laboratory glassware was thoroughly cleaned with phosphate-free soap, rinsed with distilled water, and soaked in 10% of HNO_3 for 24 hours. Field measurement instruments were calibrated before sampling, and pre-cleaned sampling containers were used. Three replicate samples were taken at each sampling point. The instrumental limit of detection (LOD) for heavy metals in water samples was determined to be 0.001 µg/L. Certified reference materials (CRMs) were used to establish accuracy, and standard reference solutions alongside known concentrations of heavy metals were employed for evaluating measurement precision (21-22). Control samples were analysed after every batch of nine samples to verify analysis accuracy, with recovery rates falling within the acceptable range of 80 to 120%. The concentrations of As and Ni were recorded in µg/L based on fresh weight, with the average concentration of each element utilized for subsequent interpretation at a 95% reproducibility confidence level. Heavy metal analyses were carried out at a certified private laboratory.

The primary pathway for exposure through water is consumption (ingestion), calculated using equation 1. The study compares the reference doses and chronic daily intake (CDI) for the studied elements using US Environmental Protection Agency (USEPA) standards for both children (as a sensitive group) as well as adults (as the general population), as shown in Table 2.

Table 2. Health Risk Assessment Parameters in Adults and Children

Parameter	Unit	Child	Adult
Exposure Frequency (EF)	day/year	365	365
Body Weight (BW)	kg	15	70
Ingestion Rate (IR) or Daily Intake (DI)	L/day	1.8	2.2
Exposure Duration (ED)	years	6	70
Skin surface area (SA)	6ycm^2	5700	5700
Exposure Time (ET)	hours/day	1	0.58
Conversion Factor (CF)	kg/mg	10^{-6}	10^{-6}
Averaging Time (AT)	day(s)	365 × 6	365 × 70
Adherence Factor (AF)	Mg.cm^2	0.07	0.07

The International Agency for Research on Cancer (IARC) Chemical Pollutant Carcinogenic Classification System (CPCCS) has classified heavy metals, such as As and Ni, as carcinogenic or possible carcinogens (23).

CDI_{ing} = (EC x IR x EF x ED) / (BW x AT) …Equation 1

where CDI is expressed as chronic daily intake through ingestion pathways (CDI_{ing}) (mg.kg^{-1}day^{-1}), EC is exposure concentration, EC = 365 days year^{-1}, and IR represents the daily ingestion rate (L.day^{-1}), with average consumption rates for Malaysian children and adults set at 1.8 and 2.2 per day, respectively. ED signifies the duration of human exposure, which is 6 years for children and 70 years for adults. The body weight (BW) for children and the adult groups is 15 and 70 kg, respectively. AT denotes the average time of human exposure, calculated as AT = 365 × 6 for children and AT = 365 × 70 for adults.

The potential risks of non-carcinogenic effects resulting from exposure to heavy metals were assessed by comparing the estimated levels of contaminants ingested with the reference dose (RfD) set by the USEPA. The RfD values for ingesting As and Ni are 0.00003 and 0.02, respectively. The hazard quotient (HQ) and hazard index (HI) were used to evaluate the toxicity potential of daily average intake compared to reference dose via ingestion pathways using Equations 2 and 3. If the HQ and HI values exceed 1, it indicates a high risk to human health (24-25).

$HQ_{ing} = (CDI_{ing}) / (RfD_{ing})$…………Equation 2

$HI = SHQ_i$…………………………Equation 3

The RfD, also known as the oral reference dose (µg kg^{-1}day^{-1}), denotes the daily exposure threshold the human population can endure throughout their lifetime without notable risks of adverse effects. Furthermore, HI (Hazard Index) was computed to assess the cumulative non-carcinogenic risks from various exposure routes. The lifetime cancer risk (LCR) of heavy metals is evaluated by equation 4. The carcinogenic risk represents the increased probability of cancer caused by chemical exposure (26-27). Cancer slope factor (CSF) values for ingestion of As and Ni are 0.0015 and 0.00366 mg/kg/day (28-29).

LCR = CDI X CSF...................Equation 4

The data underwent statistical analysis using the SPSS version 21.0 (SPSS, USA). Mean values and standard deviations of metal concentrations in the river water were computed. Pearson's correlation matrix was employed to assess how well the variance of each constituent is explained by its relationship with others. To best characterize the heavy metals, box and whisker plots, hierarchical correlation analysis (HCA), and principal component analysis (PCA) were utilized to categorize metals based on their potential pollution sources. The correlations between heavy metals were analysed using Pearson's correlation coefficients.

RESULTS

Fundamental statistical measures for the studied Klang River water quality parameters and heavy metals, along with the guideline values, were given in Table 3.

Table 3. Physicochemical Parameters, As and Ni Concentration in Klang River

Point	Temp (°C)	pH	DO (mg/L)	TDS (mg/L)	BOD (mg/L)	COD (mg/L)	NH_3N (mg/L)	As (mg/L)	Ni (mg/L)
1	28.1	6.8	6.56	31.8	12.0	12.0	<0.01	0.003	<0.001
2	28.0	6.8	6.89	61.1	12.0	12.0	0.62	0.010	<0.001
3	27.4	6.8	6.71	117.2	20.0	20.0	1.20	0.026	<0.001
4	26.9	6.7	5.94	169.0	6.0	23.0	1.70	0.015	<0.001
5	27.3	6.7	6.22	167.2	6.0	22.0	1.72	0.015	<0.001
6	27.5	6.8	6.58	188.3	4.0	20.0	2.12	0.018	<0.001
7	28.0	6.6	5.22	176.5	6.0	22.0	1.66	0.016	0.001
8	29.7	6.6	5.45	9.18	6.0	29.0	1.36	0.046	0.002
9	27.9	6.7	6.28	153.5	11.0	11.0 a a	1.80	0.072	0.001
Mean ± SD	27.9 ± 0.8	6.7 ± 0.1	6.2 ± 0.6	119.3 ± 68.1	9.2 ± 5.0	19.0 ± 6.1	1.5 ± 0.5	0.025 ± 0.021	0.0004 ± 0.001
Range	26.9–29.7	6.6–6.8	5.22–6.89	9.18–188.3	4.0–20.0	11.0–29.0	<0.01– 2.12	0.003–0.072	<0.001–0.002
NWQS	NA	6.50–9.00	5.0–7.0	1.00	6.00	10.00	0.1–0.3	0.003	0.05
p value[a]	0.070	0.010*	0.026*	0.860	0.516	0.597	0.456	0.035*	0.007*

NWQS = National Water Quality Standard; NA = values not available

[a]independent t-test used to determine the mean differences between samplings points

**significant difference at p-value < 0.05*

Seven parameters, including dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), temperature, pH, ammoniacal nitrogen (NH_3N), and total dissolved solids (TDS), were examined in order to determine the Klang River's water quality. In the present study, the temperature recorded ranged between 26.9°C (P4) and 29.7°C (P8), and they are within the recommended range of the National Water Quality of Malaysia (NWQS). The recorded temperature showed a higher level in the urban areas, and a lower temperature was recorded in the natural vegetation areas (P4). There is no significant difference in temperature for nine sampling points along the river.

pH level in the study area ranges between 6.6 and 6.8 (Table 3), which is within the permissible limit of Class I of NWQS. The pH measurement within the Klang River exhibits a favorable alkalinity level. The statistical analysis showed a significant difference ($p = 0.010$) in pH level between the nine sampling points. The value of TDS in the river water ranged from 9.18 to 188.3 mg/L, with the highest values observed at P3, P4, P5, P6, P7, and P9 of the study area which is located at the busiest location in Kuala Lumpur, and Selangor with the concentration of 117.2 mg/L, 169.0 mg/L, 167.2 mg/L, 188.3 mg/L, and 176.5 mg/L, respectively. The statistical analysis indicates no significant difference observed among the sampling points ($p > 0.05$, $p = 0.860$).

The COD concentration at Klang River was recorded between 11.0 to 29.0 mg/L (Table 3) and classified as Class I and II of NWQS. The statistical analysis shows that there is no significant difference between COD and sampling points ($p > 0.05$, $p = 0.597$). The BOD concentration of the river water ranged from 4 mg/L to 20 mg/L (Table 3). The statistical analysis shows no significant difference between BOD and sampling points ($p > 0.05$, $p = 0.516$). The measured concentrations of DO in Klang River were found in the range of 5.22 to 6.89 mg/L (Table 3). At each study site, DO concentrations were within the NWQS and can be classified in Class I and II. The statistical analysis shows a significant difference between DO and sampling points ($p > 0.05$, $p = 0.026$). The ammoniacal nitrogen ranged from 0.01 at P1 and 2.12 mg/L at P6 (Table 3). In accordance with the NWQS, the ammoniacal nitrogen concentration in this study was elevated with low concentration upstream and higher concentration downstream of the river, which fall into Class II and IV. The statistical analysis shows no significant difference between ammoniacal nitrogen with sampling points ($p > 0.05$, $p = 0.456$).

Table 3 presents the descriptive statistics of two heavy metals, namely, As and Ni, that were analysed in the river water samples collected from nine different locations along the Klang River. The analytical procedures for heavy metals analysis (As and Ni) were evaluated for recovery, and the results are presented in Table 4.

Table 4. Percentage Recovery of Heavy Metals in River Water Analysis by ICP-MS

Heavy Metal	Spike Concentration (mg/L)	Spike Recovery (%)	Recovery Limit (%)
As	0.075	89.0	80.0–120
Ni	0.075	84.7	80.0–120

Table 5. Correlation Analysis Between Physicochemical Properties And Heavy Metals Concentration

r	Temp	pH	TDS	BOD	COD	NH_3N	DO	As	Ni
Temp	1								
pH	-0.152	1							
TDS	-0.611	-0.080	1						
BOD	0.170	-0.240	-0.369	1					
COD	-0.136	-0.627	0.118	0.066	1				
NH_3N	-0.510	-0.267	0.733*	-0.359	0.110	1			
DO	-0.100	-0.935**	-0.183	-0.408	-0.684*	-0.250	1		
As	0.017	-0.385	0.059	-0.120	0.089	0.494	-0.209	1	
Ni	0.560	-0.793*	-0.199	0.161	0.242	0.129	-0.647	0.650	1

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

The recovery of these procedures for metal analysis in river water samples was found to fall within the range of 80% to 120% for all heavy metals (30). The concentration of heavy metals in the Klang River followed a decreasing order of As > Ni. As there were higher concentrations downstream than upstream. The As concentration varies from 0.003 to 0.072 mg/L. Maximum As concentration (0.072 mg/L) was observed at P8. In the study area, all the river water quality samples are reported to have As concentration within the acceptable limits of NWQS, except at the P9. The statistical analysis shows a significant difference between As concentration with sampling points ($p > 0.05$, $p = 0.035$). NWQS has recommended an acceptable limit of 0.9 mg/L of Ni in surface water. The statistical analysis shows a significant difference between Ni concentration and sampling points ($p > 0.05$, $p = 0.07$). The highest concentration of Ni, at 0.002 mg/L, is observed at P8. This increase in Ni concentration in specific areas could be attributed to human activities such as sewage discharge phosphate fertilizers and pesticides.

Table 6 presents the Pearson correlation matrix of various parameters and heavy metals, with the associated p-values indicating the significance level of the correlation matrix and the strength of correlations among the heavy metals.

Table 6. Health Risk Assessment of Heavy Metals Exposure Through River Water Consumption Among Adults and Children

Risk	**Male Adult**		**Female Adult**		**Children**	
Non-carcinogenic	**CDI (mg/kg/day)**	**HQ**	**CDI (mg/kg/day)**	**HQ**	**CDI (mg/kg/day)**	**HQ**
As	8.07×10^{-4}	2.69×10^{-1}	7.87×10^{-4}	2.62×10^{-1}	1.30×10^{-3}	4.33×10^{-1}
Ni	1.29×10^{-5}	6.46×10^{-4}	1.26×10^{-5}	6.30×10^{-4}	2.08×10^{-5}	1.04×10^{-3}
HI (ΣHQ)		2.70×10^{-1}		2.63×10^{-1}		4.34×10^{-1}
Carcinogenic	**LCR (mg/kg/day)**	**TCR**	**LCR (mg/kg/day)**	**TCR**	**LCR (mg/kg/day)**	**TCR**
As	1.21×10^{-6}	1.21×10^{-6}	1.18×10^{-6}	1.23×10^{-6}	1.95×10^{-6}	1.96×10^{-5}
Ni	4.72×10^{-9}		5.00×10^{-8}		8.00×10^{-8}	

The study has shown a significant positive correlation between TDS and NH_3N, suggesting that TDS and NH_3N may have common sources of input into the river system. For example, the river's agricultural runoff, industrial discharges, and urban pollution can contribute to the river's TDS and ammoniacal nitrogen levels (31-32). The pH level has a negative correlation with both DO and Ni. This suggests that Lower pH levels indicate more acidic conditions in the water. In acidic environments, oxygen solubility decreases, leading to lower DO concentrations. This decrease in DO can negatively impact aquatic organisms, as they require oxygen for respiration. Similarly, acidic conditions may also affect the solubility and mobility of certain metals, such as Ni, leading to decreased concentrations of dissolved Ni in the water (33-34). The study also showed a weak correlation between COD and DO ($r = -0.035$, $p < 0.05$) (Table 5). The negative correlation between COD and DO suggests that as COD levels increase, DO levels tend to decrease. This correlation indicates that higher levels of COD indicate greater organic pollution in the water. Organic matter present in the water consumes oxygen during decomposition by aerobic bacteria. As a result, elevated levels of COD can lead to increased oxygen demand, leading to lower DO concentrations in the water (35-37).

Health risk assessment (HRA) of As and Ni was observed via the two main exposure pathways: water ingestion and dermal absorption through the skin. Table 6 shows the results of the Hazard Quotient (HQ) for both routes of exposure, ingestion, and dermal route of studied heavy metals for adults and children. The results showed that the HQ value for all non-carcinogenic metals in both adults and children was below the threshold reference value of 1 which USEPA recommends.

A Target Cancer Risk (TCR) value of less than 10^{-6} was deemed acceptable, while those falling between 10^{-6} and 10^{-4} were generally acceptable, and values exceeding 10^{-4} were regarded as unacceptable (38). The TCR values for male adults (1.21×10^{-6}), female adults (1.23×10^{-6}), and children (1.96×10^{-5}) fell within the generally accepted range for carcinogenic risk. In contrast to other pathways, ingestion is a critical route of exposure since heavy metals in water cannot be eliminated, even when treated at a water treatment facility (39). The release of As and Ni into the water can occur under certain environmental conditions, such as changes in pH, redox potential, or organic matter decomposition rates (40). Once in the water, As and Ni can become bioavailable and enter the food chain, potentially accumulating in aquatic organisms and posing risks to human health through consuming contaminated fish or water. Moreover, the presence of As and Ni in water bodies can lead to long-term contamination, affecting ecosystems and biodiversity. Therefore, understanding the behaviour of As and Ni in sediment-water systems is crucial for assessing their potential impacts on human health and the environment (38).

The hierarchical cluster analysis (HCA) showed that P1 had a high BOD level compared to other points, while the other parameters tended to be lower. P8 had a lower TDS than the other points, while P6 deviated from the others mainly due to its high BOD levels. These findings support previous research that showed a strong relationship between TDS, BOD, and COD due to their corresponding cluster structures (41). A study also reported that clustering of river water quality based on different physicochemical characteristics, such as BOD, showed very high positive loading values on the same factor (2).

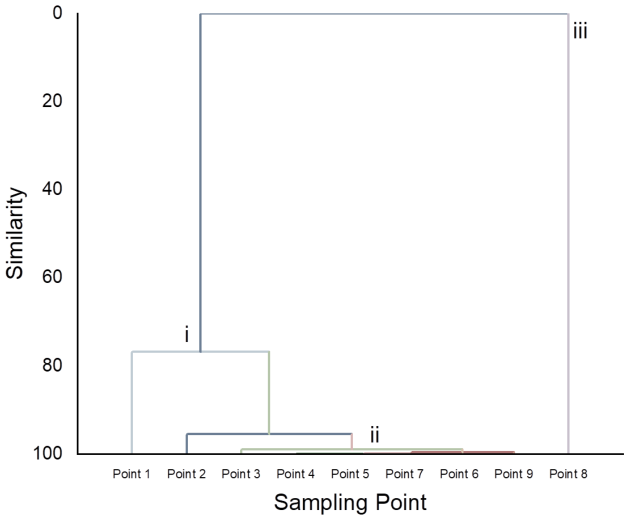


Figure 2. HCA of Klang River Water Samples

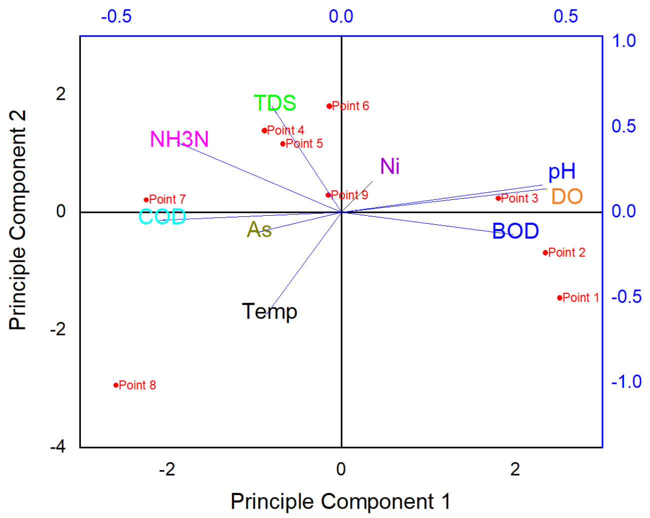


Figure 3. PCA of Klang River Water Samples

The study utilised Principal Component Analysis (PCA) to determine the main contributors to the physicochemical properties and heavy metals content in water samples collected from various points along the Klang River. Figure 3 shows that positive coefficients were detected for physicochemical properties like BOD, DO, pH, and Ni on the horizontal axis of principal component 1 (PC 1). In contrast, negative coefficients were observed for COD, NH_3N, TDS, and heavy metals As. This suggests that COD, NH_3N, and TDS were the primary factors responsible for the contamination of Klang River water quality.

Principal component 2 (PC 2) was assessed using a dataset of all sampling points, and positive coefficients were found for temperature, BOD, COD, and As, while negative coefficients were found for NH_3N, TDS, pH, DO, and Ni. These results suggest a negative correlation among the interpretation of data for NH_3N, TDS, pH, DO, and Ni, as there was no linear relationship between the observed values. The data points were assessed using their maximum score value and coefficient length, enabling the determination of relative locations solely from the plot. A similar study was conducted in Uttar Pradesh, where PCA was used to assess water quality in the Ganga River, and it was found that organic loads (COD, BOD, NH_3N, TDS), inorganic nutrients (As, Ni), and biological contaminants were responsible for water quality deterioration (42).

DISCUSSION

River water temperature induces noteworthy environmental effects on the aquatic ecosystem (43). Previous research found that the urban areas along the Klang River experienced the highest temperatures, followed by cultivated land, with natural vegetation areas recording the lowest temperatures (44). This is like the current study where the highest temperatures were shown at P1, P2, P7, and P8, located in the city centre of Kuala Lumpur and Selangor.

pH significantly influences biological activity and various properties of water bodies, as well as the activity of organisms and the efficacy of toxic substances within the aquatic environment. This is because organisms can survive only within a particular pH range (pH 7-9), and pH directly influences the solubility and accessibility of essential nutrients required by aquatic organisms (31). The pH of a water body can be influenced by various factors, including the presence of plant growth and organic substances in the water (45). As these substances decompose, they emit carbon dioxide, which reacts with water, forming carbonic acid. Although this acid is relatively mild, an excess of it can result in a decrease in pH.

Total Dissolved Solids (TDS) quantifies the quantity of substances dissolved in a water sample, encompassing dissolved minerals and organic matter, with the potential inclusion of contaminants (46). This is due to the increasing human activities from the upstream to the downstream of Klang River (47) and classified under Class I of NWQS. The increase in concentration could be attributed to a reduction in the flowing discharge and the illegal disposal of pollutants into the river at certain stations, mirroring the findings in the Tigris River within Baghdad City (48). The comparison of the average value with the standard value indicates a minor variation, with the field value being below the standard value (NWQS). Therefore, the river water is deemed suitable for common purposes.

Chemical oxygen demand (COD) quantifies the amount of dissolved and suspended organic substances in water by measuring the oxygen needed for their oxidation. This renders COD valuable as an indicator of organic pollution in surface water (49). The highest reading was recorded at P8, which encompasses commercial and residential areas of Klang Town. This suggests that the ongoing activities in this area involve a substantial presence of organic pollutants, resulting in an elevation of the COD concentration at that sampling point. Nevertheless, the concentration is within the limits of NWQS and falls under Class II. A low COD concentration generally signifies minimal pollution, whereas an elevated COD concentration indicates a heightened degree of water pollution within the studied area (50).

Biochemical oxygen demand (BOD) quantifies the oxygen necessary for aerobic bacteria and microorganisms to convert organic substances into stable inorganic forms through oxidation within a water body (51). The highest recorded readings are observed at P3 (20 mg/L) in Kampung Baru, Kuala Lumpur. This area is distinguished by its densely populated commercial and residential spaces featuring non-uniform building footprints (52). In regions with inadequate sanitation infrastructure, untreated sewage could contaminate water bodies, introducing harmful bacteria and pathogens. This situation is especially prevalent in rural communities that do not have access to modern sewage facilities. Studies conducted in the Mediterranean and Black Seas in the past have shown the impact of both household and industrial wastewater discharge on the concentrations of BOD in rivers (53-54). A significant quantity of diverse organic matter was found in the river in the research region, as shown by the COD level being noticeably greater than the BOD level (55). The BOD content fell between Class II and V according to NWQS, requiring significant treatment and irrigation.

Dissolved Oxygen (DO) refers to oxygen dissolved in water molecules state, and DO is vital for all aquatic life. Both elevated and decreased DO concentrations can lead to deteriorating water quality and disruption of aquatic ecosystems due to pollution from organic matter and reducing substances (56). The observed lowest DO concentration in P7 could be caused by stagnant water in the area, which promotes the accumulation of organic matter, such as dead plants and algae, which undergo decomposition by bacteria. This decomposition process consumes oxygen, reducing DO levels in the water (57-59). As a result, low DO concentrations can lead to decreased oxygen availability, potentially impacting aquatic organisms and overall water quality in the river. As per previous findings, DO concentration was influenced by organic and inorganic substances resulting from land uses and human activities in Klang River (60). This is similar to the current study, where the primary factor behind the diminished levels of DO concentration at nine sampling points along the Klang River could be the discharge of effluent from both commercial and residential areas generated in the vicinity of the river.

The microbial breakdown of nitrogenous organic matter is a crucial source for generating ammoniacal nitrogen (NH_3N) within rivers. These compounds enter the environment via various sources, including by-products from sewage decomposition. Aqueous ammonia concentrations exceeding 0.2 mg/L could threaten numerous aquatic organisms (61). Ammoniacal nitrogen is a critical environmental and public health concern worldwide (62), and it was observed at nearly all sampling points in the study area. The highest ammoniacal nitrogen was reported at P6, located at an urban residential and industrial area at the heart of Puchong, Selangor. Urbanization could alter natural hydrological processes, such as increased impervious surfaces and stormwater runoff, which can carry pollutants, including ammonia, into the river. Previous research highlights that predominant water pollutants, such as ammoniacal nitrogen, are notably discharged from non-point sources in Malaysia (63). According to NWQS, Class IV water is not suitable for water intake. By improving the quality, more water could be sustainably abstracted from the downstream stretches of the river basins. The pollution problems at the downstream reaches compel the water industry to source water from the upstream areas and relatively less polluted river basins (63).

In the context of the Klang River, focusing on arsenic (As) and nickel (Ni) analysis is crucial for several reasons. Both heavy metals are known for their toxicity and persistence in the environment, posing significant health risks to humans and aquatic organisms. Given the Klang River’s status as an industrial hub, pollution from industrial activities such as metal processing and chemical production is a primary concern, leading to the release of As and Ni-containing substances into the river (64). Additionally, historical pollution and improper waste disposal practices have contributed to elevated levels of heavy metals in the river (65). As and Ni in the Klang River poses health risks and has adverse effects on the aquatic ecosystem, including bioaccumulation in fish and potential ecosystem disruption (64). Therefore, analyzing As and Ni levels in the Klang River is essential for assessing pollution levels, understanding associated risks, and guiding effective management strategies to improve water quality and protect human health and the environment as exists in diverse inorganic and organic compounds with varying toxicity levels, which mirror the physicochemical properties of As across different valence states (66). Similar results were observed in the Klang River, where concentrations exceeded the maximum limit of NWQS due to the rapid development along the Klang River, which could pose a risk to human health due to its non-biodegradable nature (4, 67). It is assumed that Ni is an essential element for some plants and animals. The current study also found that the overall mean concentration of Ni in the Klang River was below the guideline values set by the NWQS at all sampling points in both upstream and downstream areas. However, high concentrations of Ni were found in the downstream area where most agriculture and industrial activities occur. Previous studies have also reported high levels of Ni in the river water of Port Klang, an industrial area, which is related to anthropogenic pollution (68).

The findings indicated that the risk of being exposed to As and Ni through daily consumption of water from the Klang River was within the acceptable level of consumption for all the metals studied. The Hazard Index (HI) for all categories of adult males and females and children was below 1. Children who are more likely to encounter water and engage in hand-to-mouth oral ingestion are particularly vulnerable to both carcinogenic and non-carcinogenic risks (65). The yearly total health index for children exposed to heavy metals through ingestion of the river water was significantly higher than that of adults. Both HQ values and HI for ingestion and dermal routes are below the maximum acceptable value established by the USEPA guidelines, which are less than one, representing an unlikely risk of adverse health effects of As and Ni to the residents along the Klang River, whether through oral or dermal exposure.

Hierarchical cluster analysis (HCA) is a multivariate technique that groups objects based on their properties. Regarding water quality variables, HCA measures the degree of similarity between them using Euclidean distance and determines the joining rule using Ward’s approach. The use of HCA demonstrates that the water samples from Klang River could be grouped into three clusters based on their similarities (Figure 2). These clusters share similar characteristics and have a common water source in the Klang River linkage. It was discovered that only three sampling points needed to be monitored instead of the original nine locations without affecting the findings.

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CONCLUSION

The water quality evaluation of the Klang River using basic statistical methods and recommended values uncovered significant results. The temperature at the sample stations met the National Water Quality Standards (NWQS), with urban regions showing greater levels and natural vegetation areas showing lower levels. The pH values were within acceptable ranges, displaying a notable variation across sample locations. TDS concentrations were higher in the sampling point located at the urban area in Kuala Lumpur and Selangor. In contrast, COD and BOD concentrations were within Class I and II of NWQS with no significant difference between BOD with sampling points. The DO levels satisfied the NWQS standards but varied significantly across sample locations. Ammoniacal nitrogen levels fluctuated across the river, showing no notable distinctions between sampling points. Distinct patterns of heavy metal concentrations, particularly As and Ni, were seen throughout the river. Significant variations were found across sampling points for As, but no significant changes were reported for Ni. Correlation analysis showed connections between several parameters and heavy metals, suggesting possible shared sources and environmental influences. The Health Risk Assessment (HRA) indicated that the Hazard Quotient (HQ) and Target Cancer Risk (TCR) values were within acceptable limits for both adults and children. Hierarchical cluster analysis (HCA) and principal component analysis (PCA) were used to analyse the clustering and variables affecting water quality and heavy metal concentration in the Klang River ecosystem, emphasising the impact of physicochemical features and pollution sources. The results provide useful insights into the water quality dynamics and possible dangers in the Klang River, highlighting the need of continuous monitoring and management measures for environmental conservation and public health protection.

Meanwhile, the study focuses on a specific period, which may not capture long-term trends or seasonal variations in heavy metal pollution. A more extended data collection period could provide a more comprehensive understanding of the Klang River’s dynamics. Based on the findings, this study has limited its sampling locations to specific areas along the Klang River, which could affect the representativeness of the finding and may not account for variations in heavy metal concentrations throughout the entire length of the Klang River. It also suggested including complementary data such as information on the source of heavy metal pollution and the ecological impacts on the river ecosystem, where this study primarily focuses on heavy metal concentration and their potential health risks. Cooperation from the government and policymakers to address and strengthen related to water quality should be improved.

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