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Research Article

Contamination status of surface water from urban rivers and lakes in Hanoi, Vietnam: Pollution parameters and concentrations of selected elements

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ABSTRACT

Introduction: Surface water contamination is a concern in urban areas. However, comprehensive and updated studies on the pollution status of urban rivers and lakes in Vietnam are still relatively scarce. **Methods:** River and lake water samples were collected from Hanoi urban areas to determine the pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS) and concentrations of 15 elements. Elements were measured via inductively coupled plasma–mass spectrometry (ICP–MS). Statistical analysis was performed to elucidate the relationships between pollutants and samples. **Results:** The pH values in the lake water were greater than those in the river water. The differences in EC, TDS, TSS, and total element concentrations between the lake and river samples were not significant. The concentrations of Fe, Zn, Pb, Cu, Ni, Cr, and Sb were lower than the threshold values. However, concentrations of As and Hg can approach or even exceed acceptable limits in some locations. Significant correlations were found between several elements and basic parameters. **Conclusions:** The surface water of rivers and lakes in Hanoi has been contaminated at low to moderate levels in terms of pH, TSS, and some toxic elements. Further monitoring studies should be conducted to characterize the pollution status and ecological impacts of inorganic and organic toxicants in the Vietnamese aquatic environment.

Key words: Surface water, Pollution parameters, Toxic elements, Urbanization, Vietnam

INTRODUCTION

Water pollution is a global issue because of its adverse impacts on environmental and human health [1,2]. This problem is more critical in highly urbanized and industrialized areas of emerging and developing countries because substantial amounts of wastewater have not been adequately treated [3]. Frequent monitoring of water quality is essential in environmental management and pollution control. In addition to basic pollution parameters (e.g., pH, electrical conductivity–EC, total dissolved solids–TDS, and total suspended solids–TSS), the concentrations of chemical elements, especially heavy metals and toxic metalloids, have been frequently measured to evaluate water contamination status and ecological risk [4].

Some studies have investigated heavy metal concentrations in surface water samples in Vietnam, including coastal areas [5–8], rivers [9–11], reservoirs [11], and narrow waterways [11]. The release of toxic elements into water bodies through human activities such as mining and metal casting has also been reported in northern Vietnam [12,13]. Studies on surface water contamination with heavy metals in Vietnam are still relatively limited and have focused mainly on coastal areas. Information about the levels and distribution characteristics of toxic elements in the surface water of Vietnamese urban areas is still very scarce. Kikuchi et al. (2009) reported the concentrations of 7 elements (i.e., As, Cr, Cu, Mn, Ni, Pb, and Zn) and several basic parameters (i.e., pH, TSS, and total organic carbon) in water samples collected from the Nhue and To Lich Rivers between 2005 and 2006 [9]. Nguyen et al. (2020) investigated the levels of 8 elements (i.e., Al, B, Bi, Fe, Mn, Pb, Sr, and Zn) and pollution parameters (i.e., temperature, pH, dissolved oxygen, EC, and turbidity) in canal and river surface water samples collected during 2018–2019 from the Saigon River and its tributaries [10]. Previous studies on water pollution in Vietnam have analyzed only a limited number of toxic elements (e.g., 4 to 10 elements) in water samples, which may prevent comprehensive discussion.

In this study, the surface water quality of selected rivers and lakes in Hanoi urban areas was evaluated

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for basic pollution parameters (i.e., pH, EC, TDS, and TSS) and various element concentrations (i.e., Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Sn, and Zn). The National Technical Regulation on Surface Water Quality (QCVN 08:2023/BTNMT) has specified threshold limits for 11 elements, comprising As, Cd, Pb, Cr, Cu, Zn, Ni, Mn, Hg, Fe, and Sb. Our analyzed elements include these 11 elements and 4 additional elements, such as Al, Co, Mo, and Sn. To our knowledge, this is among the first studies reporting the concentrations of toxic elements such as Mo, Sn, and Sb in Vietnamese surface water. The whole dataset was assessed via statistical analysis to estimate potential relationships between the samples and the pollutants. Our results can provide several insights into the pollution status of the surface water environment in Vietnam, including (1) the concentrations and profiles of 15 elements in river and lake water from the most densely populated areas of Hanoi, (2) the degree of contamination evaluated by comparing measured element concentrations with threshold values, (3) the relationships between elements and basic parameters, (4) the relationships between water samples, and (5) potential pollution sources.

MATERIALS AND METHODS

The sampling activities were conducted in September 2024 from five rivers and five lakes in urban areas of Hanoi, including the Red River (R-R), Kim Nguu River (R-KN), Lu River (R-L), Set River (R-S), Lich River (R-TL), Hoan Kiem Lake (L-HK), Bay Mau Lake (L-BM), Giang Vo Lake (L-GV), Xa Dan Lake (L-XD), and West Lake (L-W). The five rivers investigated in this study play the most important roles in the sewer system of Hanoi urban areas because of their elevated lengths, flow rates, and wastewater loads. Moreover, the five lakes are located in the most densely populated areas of five inner-city districts in Hanoi, including Hoan Kiem, Hai Ba Trung, Ba Dinh, Dong Da, and Tay Ho Districts. The river water flows of R-R, R-TL, R-KN, R-S, and R-L were 228×10^6, 290×10^3, 139×10^3, 60×10^3, and 50×10^3 m^3/day, respectively. A map showing the sampling locations is provided in Figure 1. The sampling time was chosen as the end of the rainy season in Hanoi to estimate the overall effects of rain on water quality. The average ambient temperature during the sampling campaign ranged from 26 to 31 °C. The surface water samples (up to a depth of 30 cm) were collected via stainless steel buckets. The sampling depth of 30 cm was selected according to the Vietnam Standard TCVN 6663-6:2018 (Water quality – Sampling – Part 6: Guidance on the sampling of rivers and streams). One pooled sample of approximately 1.5 L was obtained by mixing five subsamples (300 mL) collected from five points along the river or around the lake. The samples were transferred into 1.5-L polyethylene terephthalate (PET) bottles and immediately transported to a laboratory in a cool box. Approximately 150 mL portions of the water samples were taken to measure basic pollution parameters. The remaining portions were acidified with a nitric acid solution (1:1) to pH < 2 and frozen at –30 °C until further analysis.

The basic pollution parameters measured in the water samples included pH, EC (μS/cm), TDS (mg/L), and TSS (mg/L). The pH, EC, and TDS values were measured via an EZ-9908 portable tester (Total Meter, Taiwan) at room temperature. For TSS determination, a 100 mL water sample was vacuum filtered through a preweighed glass fiber filter (Whatman GF/B, 47 mm diameter, 1 μm pore size). After filtration, the filter plus solid particles were dried overnight at 100 °C, kept in a dry cabinet for 30 min, and weighed. The TSS concentrations were calculated as the increased mass of the filter (mg) divided by the water volume (L).

For elemental analysis, the water samples were treated according to the United States Environmental Protection Agency (US EPA) Method 6020B (Inductively Coupled Plasma–Mass Spectrometry). The filtered water sample (50 mL) was transferred into a 50-mL volumetric flask, 2 mL of nitric acid solution (1:1), 1 mL of hydrochloric acid solution (1:1), and 0.2 mL of hydrogen peroxide solution (30%) were added, and the mixture was thoroughly mixed before analysis. All chemicals were of analytical grade and purchased from Merck KGaA, Germany. The concentrations of the elements were measured via a 7850 ICP–MS system (Agilent Technologies). The ICP–MS instrument parameters were as follows: radio-frequency power, 1600 W; Ar plasma flow, 15 L/min; Ar make-up gas flow, 0.9 L/min; He carrier gas flow, 5 mL/min; nebulizer gas flow, 0.83 L/min; sampling depth, 10 mm; analysis time, 100–500 ms; and sample uptake rate, 0.12 rps. A total of 15 elements were determined, including Al (m/z = 27), As (m/z = 75), Cd (m/z = 111), Co (m/z = 59), Cr (m/z = 52), Cu (m/z = 63), Fe (m/z = 56), Hg (m/z = 201), Mn (m/z = 55), Mo (m/z = 95), Ni (m/z = 60), Pb (m/z = 208), Sb (m/z = 121), Sn (m/z = 118), and Zn (m/z = 66). Concentrations lower than the method detection limits were denoted as <MDL.

The dataset of pollution parameters and element concentrations in the water samples was subjected to statistical analysis via Microsoft Excel and Minitab® 19 statistical software.

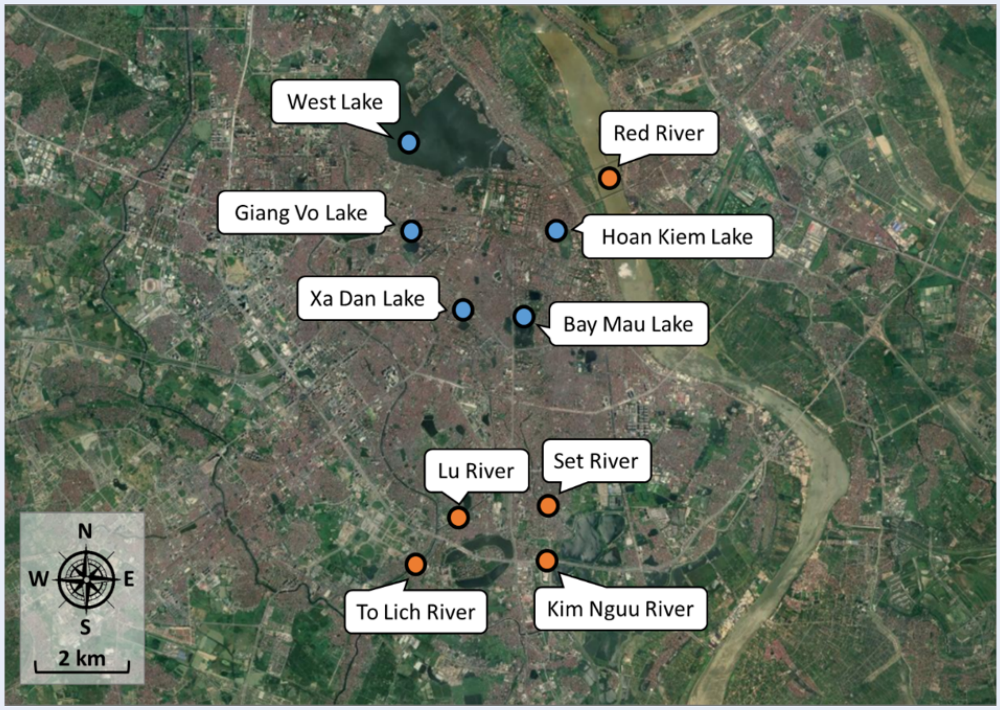

Figure 1: Map of the sampling locations in the Hanoi urban rivers and lakes.

RESULTS

The pollution parameters of our water samples are presented in Figure 2. The pH values ranged from 7.20 to 9.77 (average 8.16), with higher values measured in the lake water (average 8.91, range 7.71–9.77) than in the river water (average 7.40, range 7.20–7.63). The EC and TDS values ranged from 114 to 842 (average of 422) μS/cm and 57 to 421 (average of 211) mg/L, respectively. The EC and TDS values of the river water were generally higher than those of the lake water. The TSS concentrations ranged from 18.5 to 75.4 (average 38.6) mg/L. Except for the pH values, the differences in the EC, TDS, and TSS parameters between the lake and river samples were not statistically significant (Mann–Whitney U test, > 0.05).

The total elemental concentrations of the water samples ranged from 92.8 to 658 (average 369) μg/L. The concentrations of elements in the river water (average 500, range 394–658 μg/L) were higher than those in the lake water (average 237, range 92.8–587 μg/L). However, the difference in total elemental levels between the two groups was not statistically significant (> 0.05), probably due to considerable variation and relatively small sample sizes. The concentrations of individual elements decreased in the following order: Mn (average 108, range 23.9–307), Fe (102, <MDL–309), Al (86.5, 39.8–163), Zn (60.1, <MDL–324), As (4.43, 1.26–10.6), Pb (2.76, <MDL–15.6), Cu (1.81, <MDL–8.29), Hg (1.45, <MDL–4.38), Ni (0.689, <MDL–1.81), Cr (0.549, 0.135–1.32), Mo (0.531, 0.333–0.902), Sb (0.388, 0.144–0.828), Co (0.209, 0.079–0.380), Sn (0.078, <MDL–0.784), and Cd (0.039, <MDL–0.155) μg/L (Figure 3).

DISCUSSION

The contamination status of the water samples was evaluated by comparing our measured values with guideline values proposed by the National Technical Regulation on Surface Water Quality (QCVN 08:2023/BTNMT) (Table 1). Accordingly, water quality can be classified into four levels: level A (good quality), B (medium quality), C (bad quality), and D (very bad). Seven of the ten samples had pH values within the acceptable range of 6.5–8.5. Three lake water samples (i.e., L-HK, L-GV, and L-W) presented relatively high alkalinity, with pH values ranging from 9.01–9.77. High pH values of 8.2–10.5 were documented for the Hoan Kiem Lake water, with an increasing trend of pH over time [14,15]. A previous study reported a pH > 8.5 in 8/10 water samples collected from West Lake [16]. The higher pH values recorded in some lakes are likely attributed to intensive algae

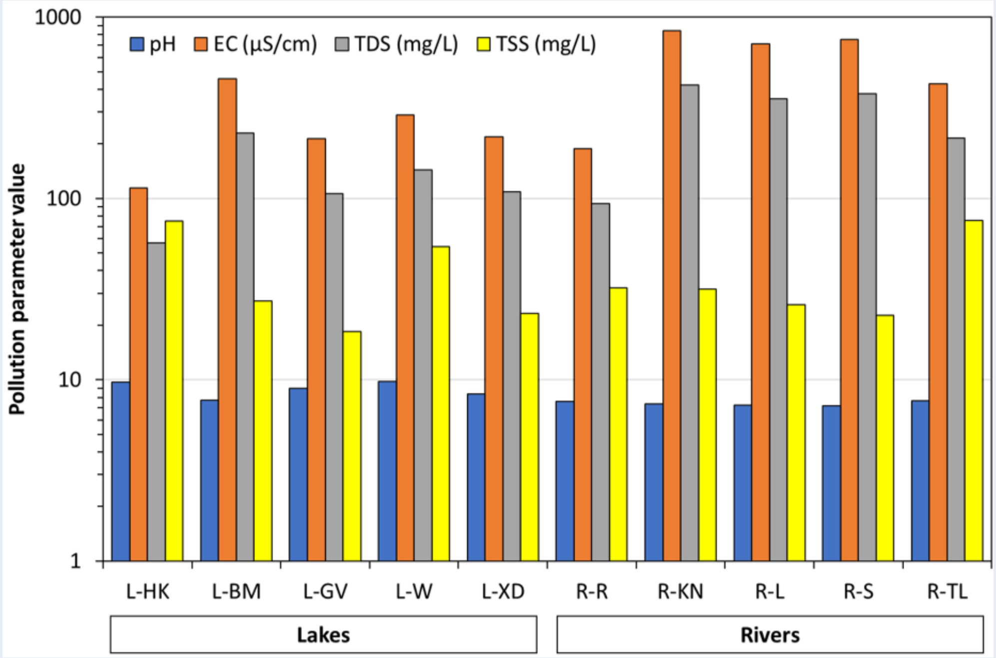

Figure 2: Pollution parameters of surface water samples from lakes and rivers in Hanoi

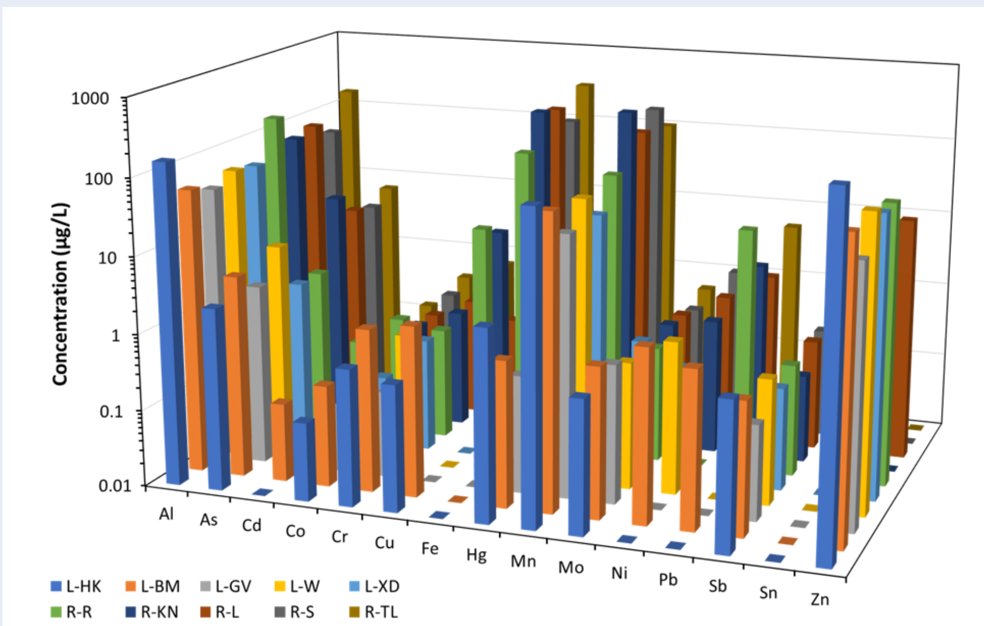

Figure 3: Concentrations of selected elements in surface water samples from lakes and rivers in Hanoi

growth, which consumes carbon dioxide during photosynthesis and increases the pH[17]. The TSS concentrations in the river water were lower than the critical value of 100 mg/L, indicating good or medium quality. Moreover, all the lake water samples had TSS values higher than 15 mg/L, implying bad or very bad conditions. The TSS concentrations that exceeded the acceptable limits were also previously reported for water in Hoan Kiem Lake[15] and West Lake[16]. The EC (114–842 μS/cm) and TDS (57–421 mg/L) values of our water samples were within the ranges documented for the Red River downstream water samples (EC 2.07–1028 μS/cm; TDS 1.44–3160 mg/L)[18]. The TSS/TDS ratios were higher in the lake water (average 0.441, range 0.119–1.319) than in the river water (average 0.180, range 0.060–0.351), implying differences in hydrological properties and material transportation and distribution processes between rivers and lakes.

The concentrations of selected elements, such as Fe, Zn, Cu, Ni, Cr, Pb, Sb, and Cd, in our water samples were lower than the threshold values of 500, 500, 100, 100, 50, 20, 20, and 5 μg/L proposed by Regulation QCVN 08:2023/BTNMT. The Mn, As, and Hg concentrations exceeded the acceptable limits of 100, 10, and 1 μg/L in the 4, 1, and 5 water samples, respectively. There was no significant difference between the element concentrations measured in our study and those reported by Kikuchi et al. (2009)[9] for water samples collected from the Nhue River and the To Lich River in Hanoi between 2005 and 2006, except for a remarkable decrease in the Cr and Ni concentrations over the last two decades. The current element concentrations in Hanoi water samples were in line with those measured in surface water from the Sai Gon River in Ho Chi Minh City[10] and three water bodies (i.e., reservoirs, rivers, and narrow waterways) in Khanh Hoa Province[11].

Spearman correlation analysis was performed to assess potential relationships between pollutants. The TDS and EC values were strongly correlated (Spearman ρ = 1.000) with the EC/TDS ratio of 2.0. The pH values were negatively correlated with the EC and TDS values (ρ = −0.685, = 0.029). This finding contrasts with the results reported by Maphanga et al. (2024) for water in the Kaap River, South Africa, which revealed a positive correlation between pH and EC[19]. The pH values were positively correlated with Zn (ρ = 0.742, = 0.014) and negatively correlated with Co, Fe, and Mn (ρ = −0.663 to −0.756, = 0.011 to 0.037). A negative correlation between pH and metals such as Co, Fe, and Mn indicated that the solubilities of these metals would be greater at low pH values. An inverse correlation between pH and two metals, Fe and Mn, was found in groundwater in Ibadan, Nigeria[20]. The concentrations of Zn also exhibited a significant correlation with pH values at some locations in the Kaap River, South Africa; however, the correlation direction was not consistent across locations[19]. The TDS and EC values were negatively correlated with Zn (ρ = −0.644, = 0.044) and positively correlated with Mn, Ni, and As (ρ = 0.648 to 0.718, = 0.019 to 0.043). Zou et al. (2024) reported a significant correlation between the EC values and concentrations of Ni (ρ = 0.60) and Zn (ρ = 0.40) in estuarine water from the Yangtze River, China[21]. The TSS levels were positively associated with the concentrations of Al (ρ = 0.806, = 0.005) and Sb (ρ = 0.733, = 0.016), suggesting the distribution of these metals in water-suspended particulates. We measured metal concentrations in the dissolved phase plus particles < 1 μm, and Herngren et al. (2005) reported that the majority of some elements, including Al, can be found in runoff water particles with sizes ranging from 0.45–75 μm[22]. The significant correlations between elements are presented in Figure 4. The highest positive correlation coefficient (ρ = 0.887, = 0.001) was observed for Pb and Cu. A noteworthy relationship between these two metals has also been reported for surface water from other locations in Vietnam, such as Thai Binh, Nam Dinh, and Khanh Hoa Provinces[8,11], suggesting that their anthropogenic sources, such as combustion emission, vehicle exhaust, domestic wastewater, and industrial activities, are similar. Pb was also correlated with Co, Cd, Al, and Fe, whereas Cu was correlated with Al, Cd, and Co; Co was correlated with Fe, Pb, Cu, Cd, and Al; and Fe was correlated with Co, Pb, Mn, and As. These correlations imply the similarity in emission sources and the environmental behavior and fate of the elements. A significant negative correlation was found between Zn and Fe (ρ = −0.887, = 0.002). We expected that pH may play an important role in the relationship between Zn and Fe because this parameter had opposite effects on Zn (positive correlation) and Fe (negative correlation). However, this relationship has not been fully explained, and additional investigations with larger sample sizes and more water parameters are needed.

The contamination profiles of the water samples were subjected to hierarchical cluster analysis (Figure 5). On the basis of their similarity in terms of pollution patterns, the samples were classified into three groups: L-HK, L-GV, L-XD, L-W, R-R, R-KN, R-L, R-S, and L-BM, R-TL. The four lakes (except Bay Mau Lake) showed a similar trend to that of the Red River. Three rivers, the Kim Nguu River, Lu River, and Set River,

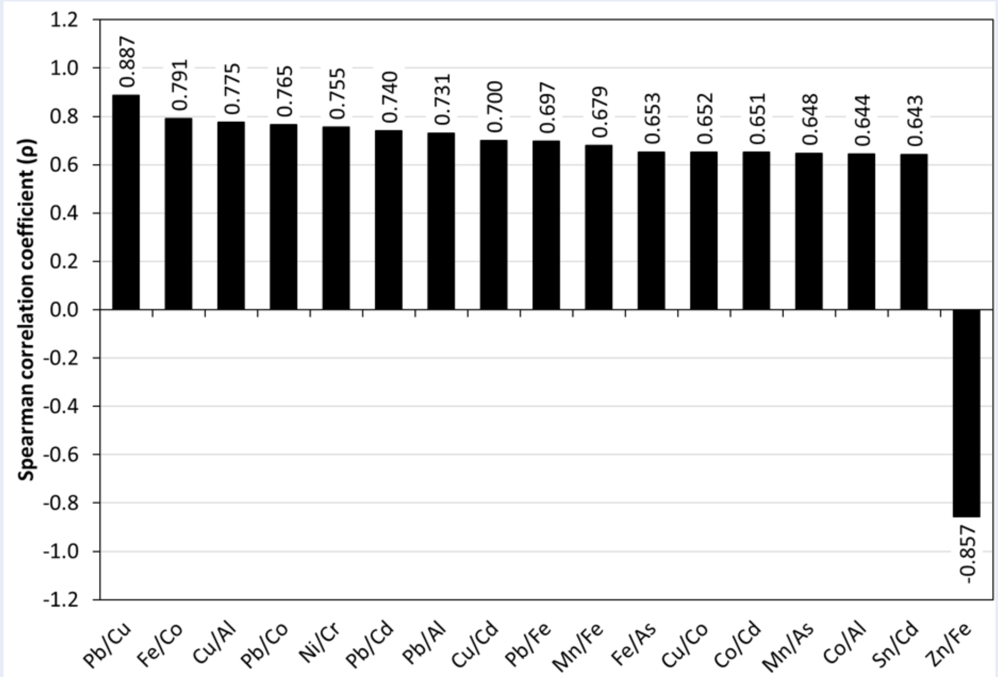

Figure 4: **Spearman correlation analysis of element concentrations in surface water samples from lakes and rivers in Hanoi**

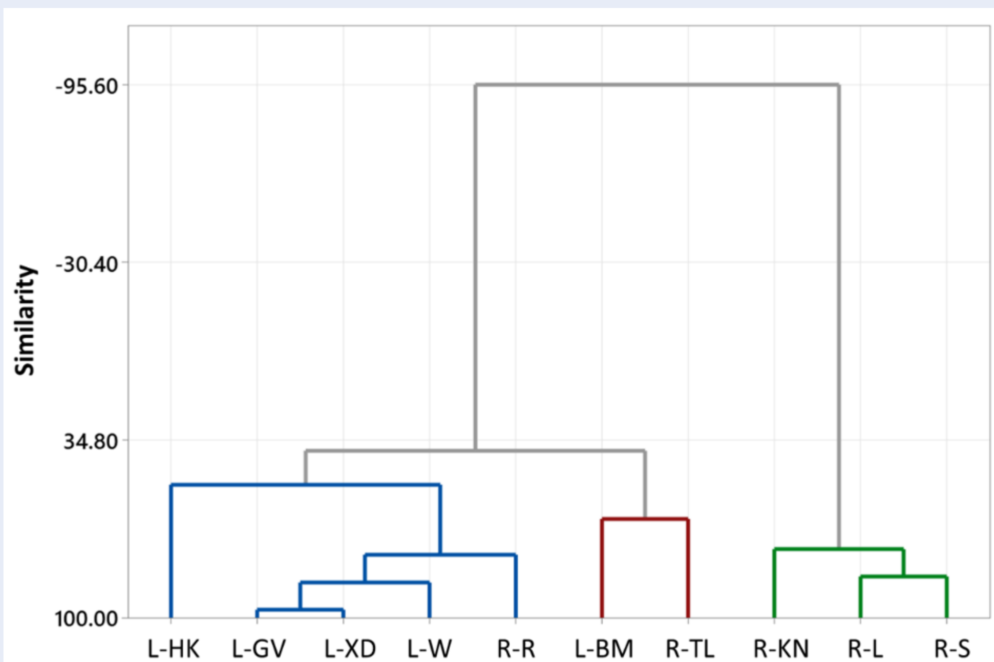

Figure 5: **Hierarchical cluster analysis of contamination profiles of surface water samples from lakes and rivers in Hanoi**

Table 1: Comparison of the pollution parameters of the water samples in this study and the guideline values proposed by the National Technical Regulation on Surface Water Quality (QCVN 08:2023/BTNMT)

Parameters	Measured values in water samples	Guideline values of QCVN 08:2023/BT-NMT
pH	7.00–9.77	6.0–8.5 (sufficient river and lake water quality)
EC (µS/cm)	114–842	Not specified
TDS (mg/L)	57–421	Not specified
TSS (mg/L)	18.5–75.4	≤ 100 (sufficient river water quality) ≤ 15 (sufficient lake water quality)
Al (µg/L)	39.8–163	Not specified
As (µg/L)	1.26–10.6	10
Cd (µg/L)	<MDL – 0.155	5
Co (µg/L)	0.079–0.380	Not specified
Cr (µg/L)	0.135–1.32	50
Cu (µg/L)	<MDL – 8.29	100
Fe (µg/L)	<MDL – 309	500
Hg (µg/L)	<MDL – 4.38	1
Mn (µg/L)	23.9–307	100
Mo (µg/L)	0.333–0.902	Not specified
Ni (µg/L)	<MDL – 1.81	100
Pb (µg/L)	<MDL – 15.6	20
Sb (µg/L)	0.144–0.828	20
Sn (µg/L)	<MDL – 0.784	Not specified
Zn (µg/L)	<MDL – 324	500

may share pollution sources and hydrological conditions. Lake Bay Mau and the To Lich River presented unique pollution profiles. Our previous studies revealed that sediment contamination with organic pollutants such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and brominated flame retardants in the To Lich River presented different seasonal trends than those in other inner-city rivers in Hanoi, such as the Kim Nguu River, Lu River, and Set River, probably because of its relatively high wastewater flow and significant sediment resuspension and bed load processes[23,24].

Toxic elements such as heavy metals and some metalloids in the water environment can be associated with natural processes and anthropogenic sources (e.g., domestic wastewater, agricultural and industrial production, and leachates from waste processing activities)[25]. Correlations between elements have been widely used to evaluate their emission sources[9,10,26,27]. The significant associations between Pb, Cu, and Cd observed in our water samples were in good agreement with those reported in the Winongo River (Indonesia), implying the presence of anthropogenic sources such as domestic waste disposal and traffic-related sources (e.g., fuel combustion, vehicular emission, and tire abrasion) in urban areas[26,27]. Industrial wastewater can also contribute to river pollution in Hanoi[9]. Fe and Al are considered indicators of natural sources such as erosion from earth crust materials, and these two metals are positively correlated in water and sediment samples from the Winongo River[27]. However, we did not find a significant correlation between Fe and Al in our water samples. Moreover, Fe was correlated with other heavy metals (e.g., Pb, Co, and Mn), whereas Al was highly associated with Pb, Cu, and Co. These results indicated that the sources of Fe and Al in our water samples were likely anthropogenic rather than natural.

The negative correlation between Fe and Zn in our samples has not been fully explained. The emission sources of Zn are relatively complicated (e.g., vehicle emission, surface runoff, sewage sludge, industrial wastewater, and geogenic input), and more potent tools (e.g., isotopic analysis of ^{66}Zn) should be applied to elucidate the source distribution profiles of this element [28]. Our results suggest the need for an effective monitoring scheme for water pollution in Vietnamese urban areas, which can provide updated information about spatiotemporal trends and potential emission sources of toxic substances. Several management and policy limitations should be addressed and resolved to improve the surface water quality in Hanoi urban areas, including (1) strengthening analysis and monitoring capacity for relevant laboratories; (2) fulfilling the database of water contamination status; (3) applying advanced data processing techniques in pollution mapping and source appointment; and (4) completing policy and environmental guidelines for the protection of water quality and ecosystem health.

CONCLUSIONS

This study comprehensively evaluated the pollution status of surface water in the lakes and rivers of Hanoi urban areas through updated monitoring results of basic water quality parameters (i.e., pH, EC, TDS, and TSS) and concentrations of 15 elements (i.e., Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Sn, and Zn). Generally, the surface water samples in this study were contaminated at low to moderate levels according to the National Technical Regulation on Surface Water Quality (QCVN 08:2023/BTNMT), except for Mn, As, and Hg concentrations, which exceeded the acceptable limits in some water samples. There was no significant difference between the element concentrations measured in our study and those previously reported for water samples collected from the Nhue River and the To Lich River in Hanoi between 2005 and 2006, suggesting relatively stable emission patterns. The element concentrations measured in the Hanoi water samples were in line with those measured in surface water from other areas, such as the Sai Gon River in Ho Chi Minh City and water bodies in Khanh Hoa Province. Relatively high pH values have been measured in some lakes, implying intensive algae growth and eutrophication. There was no statistically significant difference in the EC, TDS, TSS, or elemental concentrations between the lake and river water samples. We also found several correlations between basic pollution parameters and elements; some relationships need further confirmation. Additional comprehensive and detailed monitoring studies should be performed to characterize the contamination status, emission sources, and ecological risks of toxic elements and hazardous substances in Vietnamese aquatic environments. The distribution characteristics of toxic elements in the water bodies of Hanoi should be investigated by determining element concentrations in not only dissolved phases but also suspended particles and sediments. An effective monitoring and risk assessment system should be developed for water pollution control and mitigation in Vietnam, especially in highly urbanized and industrialized areas.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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ABBREVIATIONS

EC: Electrical conductivity
ICP–MS: Inductively coupled plasma–mass spectrometry
TDS: Total dissolved solids
TSS: Total suspended solids
US EPA: United States Environmental Protection Agency

AUTHOR'S CONTRIBUTIONS

Hoang Quoc Anh and Nguyen Thi Anh Huong conceptualized the research methodology. Hoang Quoc Anh supervised the investigation and wrote the original draft. Tran Hoang Giang, Dinh Viet Chien, Trinh Hai Minh, Kieu Thi Huyen, Nguyen The Hieu, Nguyen Xuan Thao, Nguyen Thi Duyen, To Hong Anh, Nguyen Huy Duong, Nguyen Duc Hieu, Nguyen Le Thuy Hien, Luu Mai Anh, and Dinh Hoang Anh conducted the experiments. All the authors discussed and edited the manuscript.

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