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Risks of Surface Water Pollution in Southern Vietnam

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Abstract

The study was carried out to assess surface water quality and ecological risks in water bodies in the southern region of Vietnam. The study used monitoring data at 58 locations, which were collected in March, May, June, July, August, October, November, and December of 2022, with 11 water quality parameters (temperature, pH, DO, TSS, BOD, COD, NH_4^+-N, NO_3^--N, Fe, Pb, and Cd). Comprehensive pollution index (CPI), ecological risk level, and multivariate statistical analysis methods were utilized. The values of CPI showed that the surface water quality was mildly polluted, moderately polluted, and severely polluted, accounting for 37.93, 46.93, and 15.52%, respectively. In particular, heavy pollution was concentrated in the water bodies of the Sai Gon and Vam Co Rivers. TSS, BOD, COD, NH_4^+-N, and Fe had a moderate to high level of risk, while water samples contaminated with NO_3^--N, Pb, and Cd had a level of risk from low to safe. High levels of risk were concentrated in the water bodies of the Sai Gon River and Vam Co River, typically BOD and COD. Based on the impact level, the positions were classified into five groups, with the locations on the Sai Gon River and Vam Co River (Groups 4 and 5) being affected by various waste sources in the inner city of Ho Chi Minh City. The PCA results presented three sources, such as discharge from residential areas, soil erosion, and agriculture, that have caused water quality fluctuations and increased the impact on the water quality of water bodies. Measures to protect water resources according to environmental protection laws must be implemented soon to minimize ecological risks from water-polluting sources.

Keywords: Cluster Analysis; Comprehensive Pollution Index; Ecological Risk; Water Quality.

1. Introduction

In recent years, freshwater ecosystems have faced serious threats from human activities such as industrial wastewater, agricultural activities, urban waste management problems, and increasing urbanization [1]. Freshwater shortages and quality deterioration have contributed to the extinction of biological communities and put undue pressure on the ecosystem, leading to ecosystem disturbance [2]. Typically, eutrophication causes the mass death of organisms [3, 4]. For example, the oxygen content in water bodies should be maintained in the range of 4.8–8.2 mg/L, which is considered suitable for the best growth of organisms [5], and therefore, DO levels below 3 mg/L would be harmful to aquatic life [6]. Some effects of heavy metals on fish and aquatic invertebrates include reduced growth, increased malformation, and a reduced survival rate of fish [7]. As a result, pollutants may disturb the ecological balance of water bodies. Therefore, water quality standards play an important role in local water quality management. For instance, Vietnam's surface water quality regulation has proposed maximum parameter limit values for different uses [8]. In addition, several other methods have also been developed and widely used based on water quality standards to assess the pollution level of a pollutant in a given water body. To be more specific, the Comprehensive Pollution Index (CPI)

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has been used in evaluating surface water quality [9, 10]. Moreover, risk assessment is essential to predicting potential risks to ensure effective prevention, control, and treatment [11]. The threat posed by pollutants to aquatic ecosystems can be estimated using a risk index (RQ) [12–14]. At the same time, it is important to determine the source and contribution of pollutants to the aquatic environment in order to address pollution appropriately and effectively. Therefore, multivariate analysis methods can be applied in combination with the analysis results to identify the water pollution sources [15, 16].

The southern region of Vietnam includes 21 provinces/cities with two major key economic regions: the southern key economic region and the Mekong Delta key economic region. However, with the rapid development of socio-economic development, the region's waste treatment system has not been invested in synchronously and treated following regulations, causing environmental pollution. Local pollution of organic matter, nutrients, and microorganisms in some South Vietnamese water bodies has also been recorded [17–19]. Currently, water quality characterization in the study area has been carried out; however, the potential ecological risk of the pollutants has not yet been assessed. Hence, the objectives of this study are (1) to evaluate the pollution status of water bodies using physicochemical parameters and the comprehensive pollution index (CPI), (2) to determine the ecological risk level of water bodies, and (3) to identify sources of water pollution causing ecological risks in the study area. The results provide information on the current status of risks due to water pollution, thereby showing the urgency of implementing solutions to protect water sources.

2. Research Methodology

2.1. Summary of the Study Area

The Dong Nai River system is one of the major river basins of Vietnam, with an area of about 37,885 km^2, including some main rivers such as the Vam Co River, the Thi Vai River, and the Saigon River. The Dong Nai River system flows through many provinces/cities in the southern region and is imperative in providing water for millions of people living in urban areas and concentrated industrial zones. Notably, this place concentrates on the provinces in the southern key economic region, the area with the most dynamic and strongest economic development in the country. Since then, the surface water has become a place to receive a large amount of waste from the process of socio-economic development. The Tien River is the lower left branch of the Mekong River, flowing from Cambodia into the Mekong Delta through the provinces of An Giang, Dong Thap, Tien Giang, Vinh Long, and Ben Tre. The Tien River is more than 234 km long and is a water source for daily life, production, agricultural irrigation, and aquaculture. At the same time, the Tien River is also a place to receive waste from industry and daily life, a part of urban solid waste, industrial and hazardous waste, and wastewater from agricultural production activities such as farming, livestock, and aquaculture. Besides, navigation activities and sand mining on rivers also affect surface water quality and aquatic life.

2.2. Water Sampling and Analysis

The study used surface water quality data in the southern region of Vietnam at 58 locations in the major rivers of the basins of the Dong Nai and Mekong River systems, including the Dong Nai River, Saigon River, Thi Vai River, Vam Co River, and Tien River. There were 20 monitoring stations (S1–S20) on the Dong Nai River flowing through Binh Duong, Binh Phuoc, Dong Nai, and Ho Chi Minh provinces/cities. On the Saigon River, 15 monitoring points (S21–S35) flowed through Binh Duong, Binh Phuoc, Ho Chi Minh City, and Tay Ninh provinces/cities. On the Thi Vai River, six monitoring positions (S36–S41) in the Ba Ria, Vung Tau, and Dong Nai provinces were evaluated. On the Vam Co River, 8 monitoring stations (S42–S49) flowed through Ho Chi Minh City and the two provinces of Long An and Tay Ninh. Nine monitoring stations (S50–S58) were set up on the Tien River in the provinces of An Giang, Tien Giang, Dong Thap, and Ben Tre.

The location of surface water monitoring stations in the southern region is shown in Figure 1. Surface water samples were collected eight times per year, including in March, May, June, July, August, October, November, and September 2022, for a total of 464 water samples. Each collected water sample was analyzed for 11 surface water quality parameters. In which, temperature, pH, and dissolved oxygen (DO) were measured directly in the field by a multi-parameter water quality meter (TOA-DKK WQC-24). The remaining parameters, including total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+-N), nitrate (NO_3^--N), iron (Fe), lead (Pb), and cadmium (Cd), were analyzed in the laboratory according to standard methods specified in Circular No. 10/2021/TT-BTNMT [20]. Concentrations of heavy metals, including Fe, Pb, and Cd, were determined by an atomic absorption spectrometer (AAS).

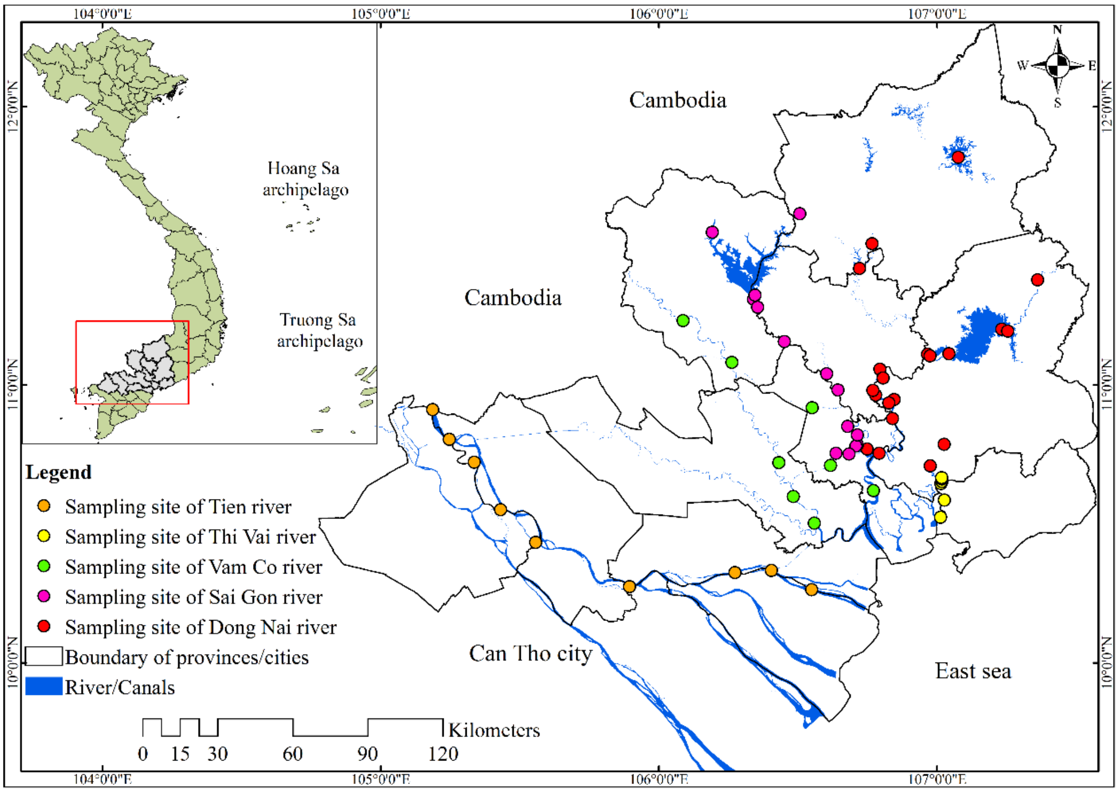

Figure 1. Location of water sampling in the Southern region of Vietnam

2.3. Data Processing

The values of water quality parameters in water bodies were compared with the allowable limit values according to the National Technical Regulations for assessment of surface water quality (QCVN 08-MT:2015/BTNMT, column A1- used for domestic water supply, aquatic flora and fauna conservation and other purposes) [8]. In addition, One-way ANOVA analysis was also applied to identify different water bodies. The Comprehensive Pollution Index (CPI) was used to assess the overall pollution level of a particular water body using monitored environmental parameters [21]. In this study, CPI was applied to assess the pollution level at each specific monitoring location, as well as the pollution status in major rivers in the South area of Vietnam based on eight parameters of TSS, BOD, COD, NH_4^+-N, NO_3^--N, Fe, Pb and Cd. CPI was calculated according to the previous studies [9, 21]:

$$CPI = \frac{1}{n}\sum_{i=1}^{n} PI_i = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_i} \tag{1}$$

where: n is the number of monitored parameters, PI_i is the i^{th} pollution index, C_i is the measured concentration of i^{th} parameter in water (mg/L), and S_i is the limit value of the parameters in the QCVN 08-MT:2015/BTNMT, column A1. The CPI value is classified into 5 pollution levels, including (1) CPI > 2.01, heavy pollution; (2) 1.01< CPI<2.00, medium pollution; (3) 0.41<CPI<1.00, slight pollution; (4) 0.21<CPI<0.40, pretty clean; and (5) 0<CPI< 0.20, clean [21].

In this study, ecological risk assessment was performed on 8 surface water pollutants, including TSS, BOD COD, NH_4^+-N, NO_3^--N, Fe, Pb and Cd. The ecological risk assessment of surface water pollutants to aquatic organisms was carried out using a combination of impact level (RQ) and pollution frequency (F). In which, RQ was calculated according to the formula [22]:

$$RQ_i = \frac{MEC_i}{PNEC_i} \tag{2}$$

MEC_i is the measured concentration of the i^{th} pollutant in water (mg/L), and $PNEC_i$ is the predicted unaffected concentration of the i^{th} pollutant (mg/L). In this study, the predicted concentrations without the influence of physical parameters were obtained from QCVN 08-MT:2015/BNTMT, column A1. The PNEC values of TSS, BOD, COD, NH_4^+-N and NO_3^--N, Fe, Pb and Cd were 20, 4, 10, 0.3, 2, 0.5, 0.02 and 0.005 mg/L, respectively. RQ and the frequency are divided into four and three levels, respectively [22]. The matrix of ecological risk levels is shown in Table 1.

Table 1. Ecological risk matrix based on frequency and impact

RQ-F	No (RQ ≤ 1)	Low (1 < RQ < 2)	Moderate (2 ≤ RQ < 3)	High (RQ ≥ 3)
Frequent (F > 70%)	Safe	Moderate	High	High
Moderate (30% < F < 70%)	Safe	Low	Moderate	High
Infrequent (< 30%)	Safe	Low	Low	Moderate

Based on the level of impact of pollutants, Cluster Analysis (CA) was conducted to provide information on monitoring locations with similar impact levels. Ward's method and Euclidean distance were used to group impact levels at 58 study sites. CA results were presented as dendrograms, visually reflecting the results obtained [6, 10, 16]. Furthermore, Principal Component Analysis (PCA) was also applied with a similar dataset in cluster analysis to determine the influence of pollution sources in the water bodies. The PCA results generated principal components (PCs) with a decreasing contribution to explaining variation and correlations of water quality parameters with PCs identified through the loading factor. More specifically, PCs with eigenvalues greater than 1 help retain the important information of the original data, which is a major contributor to the overall variability of the data [2, 9, 10]. The Statgraphics software Centurion XVI (Statgraphics Technologies Inc., The Plains, Virginia) was used for CA and PCA analysis.

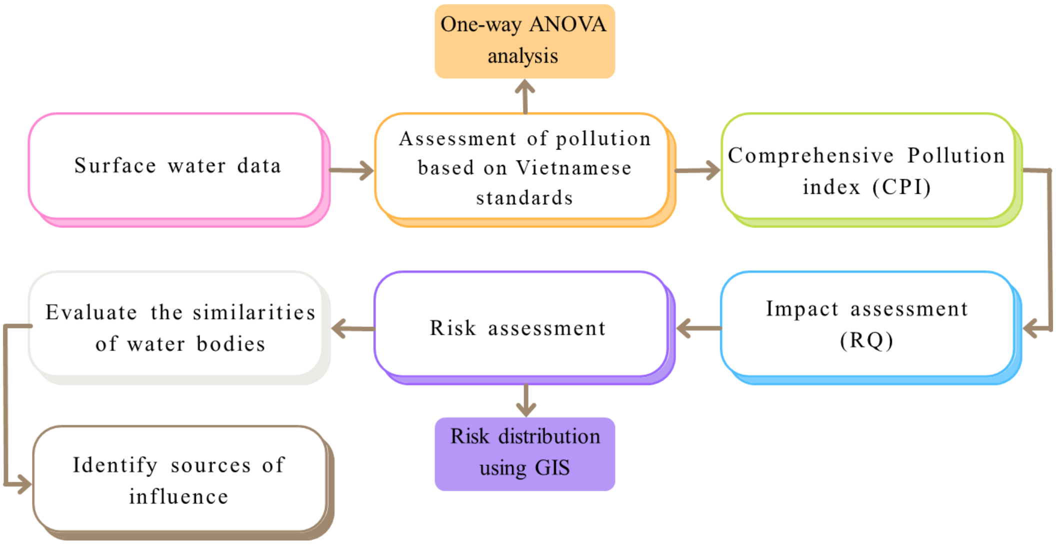

Figure 2. Summary of the research method

3. Results and Discussion

3.1. Surface Water Quality in the Studied Water Bodies

The water pH was weakly alkaline, ranging from 6.78 to 7.44 in the water bodies (Table 2). Table 2 illustrates that TSS, BOD, COD, NH_4^+-N and Fe in most water bodies exceeded the allowable limits of QCVN 08-MT:2015/BTNMT, column A1 [8]. Moreover, the DO content in water does not meet the minimum value specified in QCVN 08-MT:2015/BTNMT, leading to negative effects on the processes taking place in the water. Nevertheless, DO content in Thi Vai River water has improved significantly compared to the previous period [23]. With regard to the content of TSS, the highest TSS was detected in the Tien River, with an average of 56.38±46.86 mg/L, exceeding the allowable limit 2.82 times, significantly different from the rest of the river basins ($p<0.05$). The cause of TSS on the Tien River is high because the Tien River contains a lot of suspended solids due to riverbank erosion, overflowing rainwater carrying organic matter, sand mining, transportation, and the presence of phytoplankton. TSS content has an effect on the adsorption of pollutants. For example, P adsorption capacity increases with increasing SS concentration [24].

BOD and COD values were the highest in the water bodies of Sai Gon and Vam Co rivers, exceeding the allowable limits from 2.70-2.94 times and 2.32-2.42 times, respectively. In addition, the NH_4^+- N content in the Sai Gon River and Vam Co River water bodies is also recorded to be significantly higher than the remaining water bodies. Statistical analysis results also showed that the concentrations of these pollutants in the Sai Gon River and Vam Co River significantly differed from other rivers ($p<0.05$). A previous study by Tuyet et al. (2019) [25] also recorded high nutrient content in the water bodies of Ho Chi Minh City. This could be explained by incomplete nitrification due to the lack of oxygen in the water [26]. For heavy metals, the median concentrations of Pb and Cd met the regulated levels and suitable for the growth of aquatic species, whereas the median concentrations of Fe exceeded the regulated level. The highest Fe concentration was found in Vam Co River, averaged at 3.11±2.09 mg/L (6.22 times higher) and significantly different from the other 4 river basins ($p<0.05$). High Fe values in the water might be related to high erosion processes as well as industrial activities in the area [27]. In addition, Fe pollution could reduce the diversity and abundance of invertebrates and fish species [27, 28].

Table 2. Mean values of water quality parameters in the studied water bodies

Parameter	Unit	Dong Nai river	Sai Gon river	Thi Vai river	Vam Co river	Tien river	QCVN 08 - MT:2015/BTNMT
Temp.	°C	29.52±1.03[c]	29.88±1.08[b]	30.46±1.31[a]	30.14±0.81[ab]	30.07±0.82[b]	-
pH	-	7.05±0.35[b]	6.80±0.36[c]	7.44±0.29[a]	6.78±0.33[c]	7.42±0.27[a]	6-8.5
DO	mg/L	**5.70±1.22[a]**	**3.5±2.28[c]**	**5.92±0.79[a]**	**2.53±1.21[d]**	**5.19±1.19[b]**	≥6
TSS	mg/L	**29.36±26.39[cd]**	**39.50±46.35[bc]**	17.79±5.88[d]	**50.29±55.39[ab]**	**56.38±46.86[a]**	20
BOD	mg/L	3.64±1.58[b]	**11.75±14.85[a]**	**4.02±0.91[b]**	**10.83±8.07[a]**	3.43±1.51[b]	4
COD	mg/L	**10.49±3.86[b]**	**23.20±24.44[a]**	**13.42±2.67[b]**	**24.17±14.51[a]**	**10.18±3.6[b]**	10
NH_4^+-N	mg/L	0.19±0.24[c]	**2.69±4.95[a]**	0.14±0.05[c]	**1.51±2.00[b]**	0.15±0.11[c]	0.3
NO_3^--N	mg/L	0.69±0.34[a]	0.55±0.59[ab]	0.59±0.39[ab]	0.60±0.52[ab]	0.47±0.24[b]	2
Fe	mg/L	**1.57±1.19[c]**	**1.9±2.22[c]**	**0.51±0.16[d]**	**3.11±2.09[a]**	**2.46±2.02[b]**	0.5
Pb	mg/L	0.0022±0.0026[cd]	0.0027±0.0027[bc]	0.0014±0.0007[d]	0.0034±0.0036[b]	0.0050±0.0053[a]	0.02
Cd	mg/L	0.00022±0.0001[a]	0.00023±0.0002[a]	0.0002±0.00002[a]	0.00024±0.0001[a]	0.00023±0.0001[a]	0.005

Note: [a], [b] in the same row, the difference is not statistically significant (p>0.05) and vice versa.

3.2. Classification of Surface Water Quality Using a Comprehensive Pollution Index

CPI values ranged from 0.51-11.66, representing slight to heavy pollution. The levels of slight pollution were identified at 22 locations (accounting for 37.93%), with these locations mainly concentrated in the water bodies of Thi Vai and Dong Nai rivers (Figure 3). While the medium polluted water quality was identified at 27 locations (made up about 46.55%), including the locations of Dong Nai, Sai Gon, Vam Co, and Tien rivers (Figure 3). The heavy pollution level was concentrated at the locations of Sai Gon River and Vam Co River, which made up about 15.52% (Figure 3). These locations are in the inner city of Ho Chi Minh City, affected by a large amount of wastewater from densely populated residential areas and scattered production facilities. In addition, the single pollution indices of TSS, BOD, COD, NH_4^+-N and Fe at these locations were high, all greater than 1, indicating that the water quality was seriously polluted [9, 10]. In general, the water bodies of the Sai Gon and Vam Co rivers were highly polluted, while moderate water pollution was found in the Tien River.

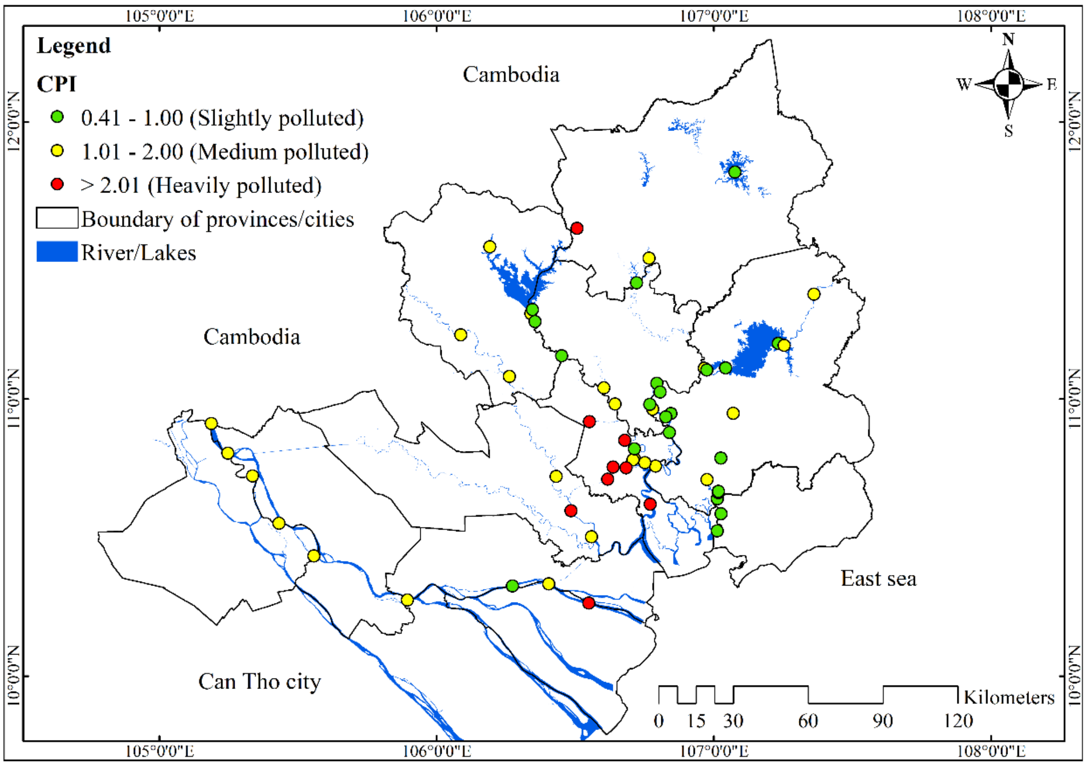

Figure 3. Distributions of CPI values in the study areas

3.3. Risk Assessment for Contaminants in Water

The RQ values of pollutants in the study area are mainly divided into four levels; however, the study only focuses on analyzing areas with medium and high ecological risks (Figure 4). The RQ has shown a high level of ecological risk to aquatic organisms in the water bodies of the Southern part of Vietnam, mainly causing BOD, COD, NH_4^+-N, TSS and Fe.

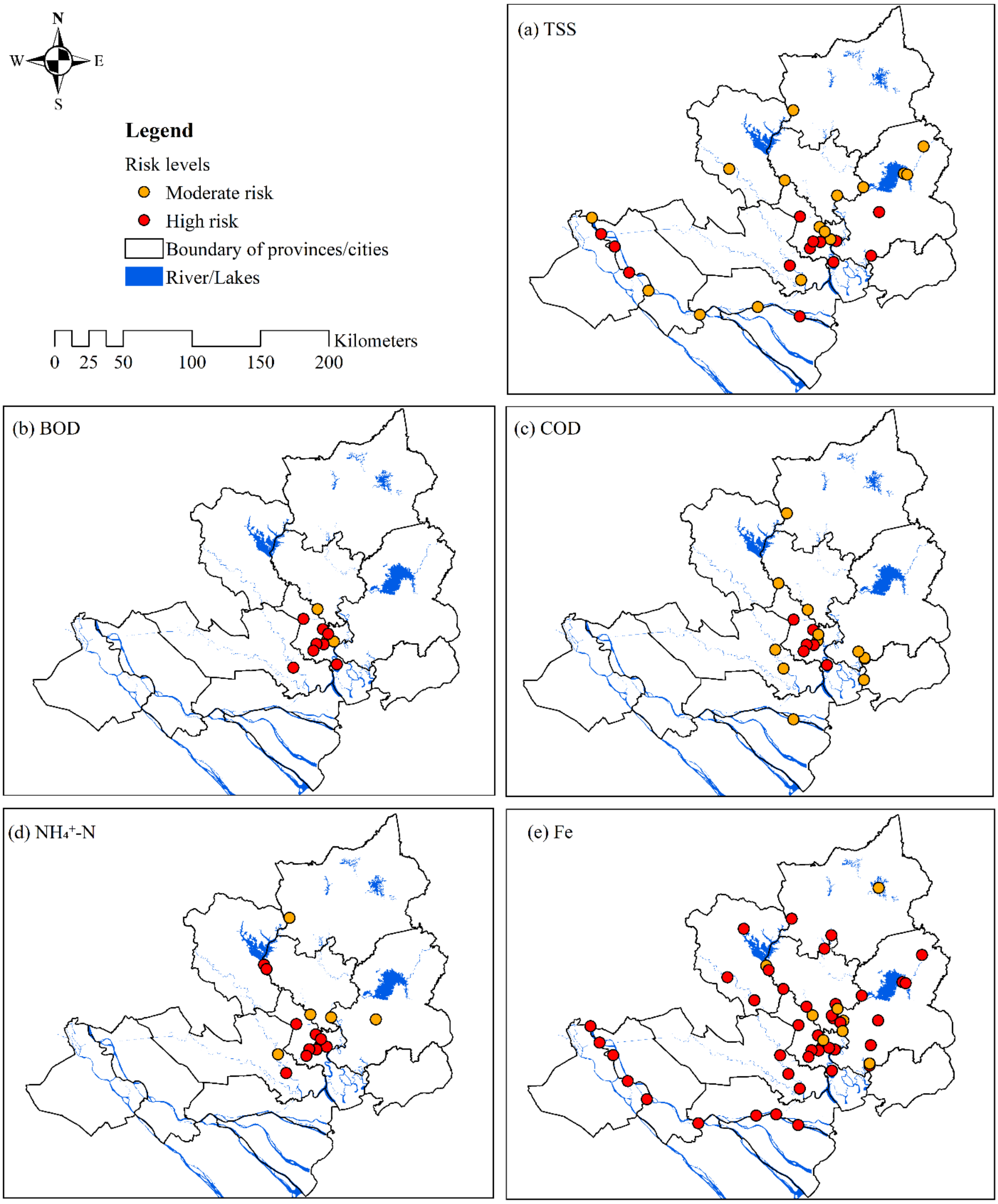

Figure 4. The single ecological risk index (RQ_i) at each monitoring location

For the TSS, medium and high risks were recorded at 16 sites and 13 sites, respectively, accounting for 27.6% and 22.4% (Figure 4-a). In which, the medium ecological risk was concentrated in the locations of the Sai Gon River, while the high risk was identified in the Vam Co River and the upstream part of the Tien River. High TSS concentrations affect light transmission and aquatic life [9]. According to Renitasari et al. (2021) [29], TSS has negative impacts on biological life through five mechanisms: (1) TSS directly abrades the gills of aquatic animals; (2) TSS obstructs fish gills or other respiratory membranes; (3) TSS inhibits growth or suffocates eggs due to lack of oxygen in the water; (4) TSS disrupts foraging, including foraging and food selection; and (5) stress aquatic organisms. With regard to the BOD, RQ_{BOD} has medium and high ecological risks at 12 locations (20.7%), which were determined in the Sai Gon and Vam Co Rivers. Similarly, 18 sites (31.0%) reflected medium and high levels of ecological risk posed by COD content in water. Organic pollution and a high degree of ecological risk to aquatic organisms occur on a large scale in the study area. BOD and COD directly affect the amount of dissolved oxygen; the higher the concentration of these substances, the lower the amount of dissolved oxygen, leading to the death of aquatic organisms [5, 30].

Regarding the NH_4^+-N, the medium risk level accounted for 8.6% and was distributed mainly in the Dong Nai River, equivalent to 5 out of 58 monitoring locations. Meanwhile, locations on the Sai Gon and Vam Co rivers were determined to have a high-risk level, accounting for 20.7%. NH_4^+-N is present in surface water mainly due to artificial activities such as waste treatment, landfill operations, over-fertilization or improper fertilizer management practices [31]. Nevertheless, this study did not record an ecological risk to NO_3^--N concentrations in the Sai Gon River, which indicates that the pollutant from agricultural activities is low. This observation was also noted in the previous study by Grizzetti et al. (2012) [32]. The RQ value of Fe was mainly characterized by high ecological risk in the studied water bodies (Figure 4-e). More than 70% of the total locations were identified as high ecological risk; these locations are widely distributed throughout the study areas. Fe has both direct and indirect effects on aquatic ecosystems, as it affects aquatic species by interfering with their normal metabolism and osmotic regulation [7, 33]. High concentrations of Fe negatively affect the behaviour, reproduction, survival and diversity of aquatic animals [33]. In addition, Fe was found to increase turbidity, reduce primary yield, suffocate invertebrates and precipitate iron that clog and damage gills, causing impaired respiratory function in aquatic organisms [34]. The analysis results show that the Pb and Cd content in the water has not significantly affected aquatic life in this area.

3.4. Clustering Impact Level of Monitoring Locations

The input data of cluster analysis included impact assessment values at 58 study sites. The similarity between the impact groups was divided into five groups (Figure 5).

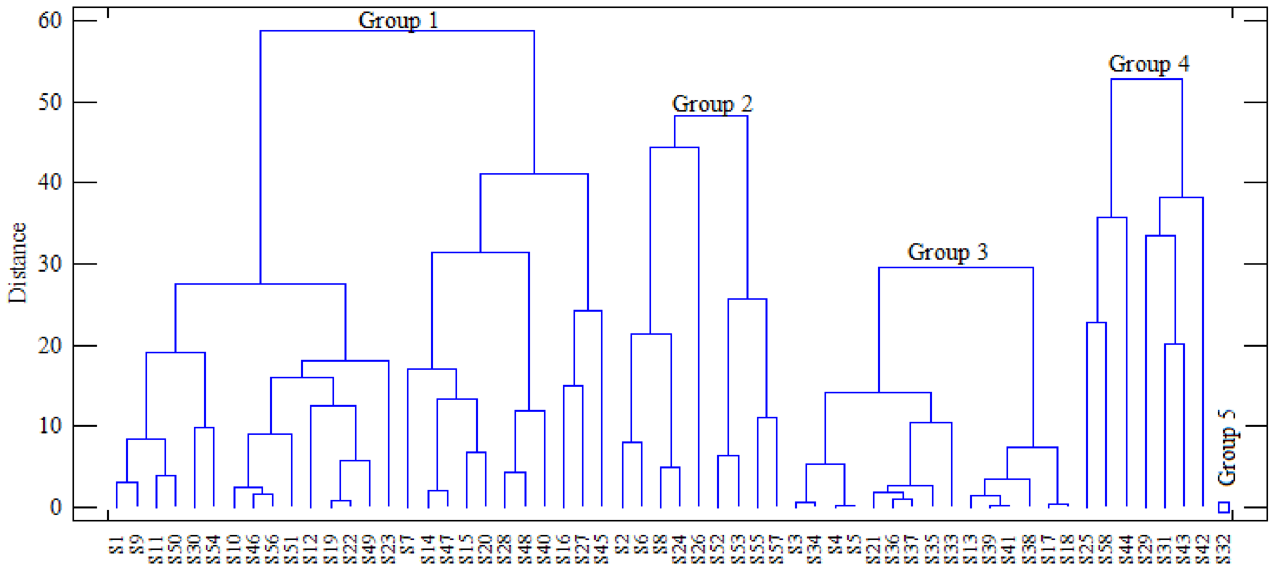

Figure 5. Clustering impact levels of monitoring locations

Group 1 included many monitoring sites with 26 locations, accounting for 44.83% of the total number of locations, and these monitoring locations belonged to the Dong Nai (near Tri An reservoir), Sai Gon, Vam Co, and Tien Rivers. The sites in Group 1 represented the places where the wastewater was received from in the inner city of Ho Chi Minh City. Therefore, the concentrations of organic and nutritional pollutants in the water were very high, posing a particularly serious ecological risk to aquatic organisms. Group 2 included locations in the Tien River, the upstream Sai Gon River, and some scattered sites in the Dong Nai River. These monitoring sites represented about 15.52% (9 out of 58 locations). Group 3 was mostly concentrated on monitoring sites in the Thi Vai (6 locations) and Dong Nai Rivers (6 locations), which had better water quality and lower impact levels than Groups 1, 2, 4 and 5. Group 4 contained monitoring locations belonging to the Tien, Vam Co, and Sai Gon Rivers. Location S32 (Group 5) completely differed from the remaining site groups. Group 5 had the highest impact on aquatic life, mainly caused by NH_4^+-N. In addition, the impact level of Group 4 was related to the presence of Fe. Groups 4 and 5 were the most contaminated sampling sites, posing the greatest potential risk to aquatic ecosystems. Meanwhile, Group 1, Group 2, and Group 3 did not clearly indicate the impact of a specific parameter. The average values of the impact indicators of each Group are shown in Table 3.

Table 3. The mean value of ecological risk in identified groups

RQ Parameters	Group 1	Group 2	Group 3	Group 4	Group 5
TSS	3.76	2.92	1.59	9.70	15.05
BOD	2.02	1.81	1.38	6.46	23.75
COD	2.02	1.74	1.71	5.19	17.10
NH_4^+-N	2.98	2.87	1.25	16.04	88.67
NO_3^--N	0.64	0.60	0.42	0.58	0.50
Fe	6.95	6.04	3.48	19.85	12.52
Pb	0.44	0.66	0.12	0.56	0.45
Cd	0.05	0.20	0.04	0.09	0.13

3.5. Key Sources Influencing Water Associated Ecological Risk

The PCA results showed that 3 components (PCs) explained 79.01% of the total variation in surface water quality data (Table 4). Meanwhile, components with eigenvalues less than 1 were eliminated because they do not play an important role in water quality changes [10, 31, 35]. Table 4 given indicates the parameters' loading factor in three components to identify sources influencing the impact levels. The first principal component (PC1) accounted for 43.93% of the total variance, with a weakly positive load with TSS (0.39), BOD (0.49), COD (0.50), and NH_4^+-N (0.47). According to the ecological risk analysis and similarities of the sites, this may represent organic pollution found especially in residential areas around Sai Gon and Vam Co Rivers, which focused on many human activities. As a result, this component represented organic and nutrient contamination derived primarily from anthropogenic sources, such as domestic, agricultural, and industrial waste [10, 36]. Furthermore, these wastes would likely increase suspended particles, typically TSS [9, 37].

Table 4. Key sources influencing water quality

Parameters	PC1	PC2	PC3
TSS	0.39	0.42	-0.16
BOD	0.49	-0.28	-0.04
COD	0.50	-0.24	-0.07
NH_4^+-N	0.47	-0.32	-0.02
NO_3^--N	0.07	-0.07	0.57
Fe	0.29	0.52	-0.17
Pb	0.17	0.56	0.28
Cd	0.12	0.01	0.73
Eigenvalue	3.51	1.56	1.25
Percent of Variance	43.93	19.51	15.57
Cumulative Percentage	43.93	63.44	79.01

The second principal component (PC2) explained 19.51% of the total variance, showing a weak positive load with TSS (0.42) and a moderate one with Fe (0.52) and Pb (0.56), and therefore, it is representative of heavy metal pollution. Accordingly, this PC could represent soil erosion processes, which can wash away a large amount of inorganic and organic components in the soil. Although the concentration of Pb is relatively low in surface waters, its presence constitutes a significant ecological risk to aquatic ecosystems. Many studies have documented that Pb can originate from urban runoff, agricultural runoff, chemical and electronic manufacturing, fertilizer production, and oil and cement production [35, 38]. The third principal component (PC3), which explains 15.57% of the total variance, contained a moderate positive load for NO_3^--N (0.57), a strong positive with Cd (0.73), indicating that nutrients from agricultural runoff contributed to nitrate formation [36, 39]. In addition, waste sources such as domestic wastewater and other nitrogenous wastes are also involved in forming NO_3^--N [40]. According to the analysis results, sources of surface water pollution can be both natural and artificial. Natural sources such as stormwater runoff, soil nature, and erosion. Artificial sources are mainly affected by wastewater discharge from domestic, industrial, and agricultural activities (livestock, aquaculture, and farming). The results reflect that many sources of impacts cause deterioration of surface water quality, leading to many adverse risks to the aquatic ecosystem in this area.

4. Conclusion

The results showed that total suspended solid, organic, and nutrient pollution was the highest in the Sai Gon and Vam Co rivers. The CPI ranged from slight to heavy pollution, specifically slight pollution (Dong Nai and Thi Vai Rivers), moderate pollution (Tien River), and heavy pollution (Sai Gon and Vam Co Rivers). The risk assessment indicates that TSS, BOD, COD, NH_4^+-N, and Fe contributed moderate to high ecological risks, whereas the remaining water parameters had low ecological risk to safety. The location in the Sai Gon River mainly distributes high ecological risks from BOD, COD, and NH_4^+-N parameters. TSS and Fe were found widely throughout the study sites. CA results classified 58 locations into five groups. There were three principal components that played an imperative role in explaining changes in surface water quality in the study area. Each component represents a different source; specifically, domestic wastewater, soil erosion, and agriculture are the three most influential factors. From the aforementioned results, it is proposed that water quality management should focus on organic and Fe pollution to minimize risks to aquatic organisms.

5. Declarations

5.1. Author Contributions

Conceptualization, N.T.G. and T.H.D.; methodology, N.T.G. and T.H.D.; software, N.T.G. and T.H.D.; validation, N.T.G.; formal analysis, N.T.G. and T.H.D.; investigation, N.T.G.; data curation, N.T.G. and T.H.D.; writing—original draft preparation, N.T.G.; writing—review and editing, N.T.G. and T.H.D.; visualization, N.T.G. and T.H.D.; supervision, N.T.G. and T.H.D.; project administration, N.T.G. and T.H.D.; funding acquisition, N.T.G. and T.H.D. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgements

The authors sincerely thank the Southern Environmental Monitoring Centre for providing monitoring data. The opinions of the scientific analysis of the data in this article are the authors' personal opinions and do not represent the opinions of the data provider.

5.5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Amoatey, P., & Baawain, M. S. (2019). Effects of pollution on freshwater aquatic organisms. Water Environment Research, 91(10), 1272–1287. doi:10.1002/wer.1221.

[2] Kumar, A., Mishra, S., Taxak, A. K., Pandey, R., & Yu, Z. G. (2020). Nature rejuvenation: Long-term (1989–2016) vs short-term memory approach based appraisal of water quality of the upper part of Ganga River, India. Environmental Technology and Innovation, 20, 101164. doi:10.1016/j.eti.2020.101164.

[3] Sidabutar, T., Srimariana, E. S., Cappenberg, H. A. W., & Wouthuyzen, S. (2022). Harmful algal bloom of the three selected coastal bays in Indonesia. IOP Conference Series: Earth and Environmental Science, 1119(1), 12035. doi:10.1088/1755-1315/1119/1/012035.

[4] Mishra, P., Naik, S., Babu, P. V., Pradhan, U., Begum, M., Kaviarasan, T., Vashi, A., Bandyopadhyay, D., Ezhilarasan, P., Panda, U. S., & Murthy, M. V. R. (2022). Algal bloom, hypoxia, and mass fish kill events in the backwaters of Puducherry, Southeast coast of India. Oceanologia, 64(2), 396–403. doi:10.1016/j.oceano.2021.11.003.

[5] Sarda, P., & Sadgir, P. (2015). Assessment of multi parameters of water quality in surface water bodies-a review. International Journal for Research in Applied Science & Engineering Technology, 3(8), 331-336.

[6] Iwegbue, C. M. A., Faran, T. K., Iniaghe, P. O., Ikpefan, J. O., Tesi, G. O., Nwajei, G. E., & Martincigh, B. S. (2023). Water quality of Bomadi Creek in the Niger Delta of Nigeria: assessment of some physicochemical properties, metal concentrations, and water quality index. Applied Water Science, 13(2), 36. doi:10.1007/s13201-022-01804-2.

[7] Khayatzadeh, J., & Abbasi, E. (2010, April). The effects of heavy metals on aquatic animals. The 1st International Applied Geological Congress, 26-28 April, 210, Department of Geology, Islamic Azad University–Mashad Branch, Mashhad, Iran.

[8] QCVN 08-MT:2015/BTNMT. (2008). National technical regulation on surface water quality. Ministry of Natural Resources and Environment, Hanoi, Vietnam.

[9] Islam, M. S., Nakagawa, K., Abdullah-Al-mamun, M., Khan, A. S., Goni, M. A., & Berndtsson, R. (2022). Spatial Distribution and Source Identification of Water Quality Parameters of an Industrial Seaport Riverbank Area in Bangladesh. Water (Switzerland), 14(9), 1356. doi:10.3390/w14091356.

[10] Yang, Y., Huang, X., Wu, X., Liu, C., Zhao, S., & Zhu, X. (2022). The spatiotemporal variations characteristic and pollution evaluation of water quality in Qujiang River, China. Applied Water Science, 13(2), 32. doi:10.1007/s13201-022-01829-7.

[11] Wang, Z., Luo, P., Zha, X., Xu, C., Kang, S., Zhou, M., Nover, D., & Wang, Y. (2022). Overview assessment of risk evaluation and treatment technologies for heavy metal pollution of water and soil. Journal of Cleaner Production, 379, 134043. doi:10.1016/j.jclepro.2022.134043.

[12] Hanif, H., Waseem, A., Kali, S., Qureshi, N. A., Majid, M., Iqbal, M., Ur-Rehman, T., Tahir, M., Yousaf, S., Iqbal, M. M., Khan, I. A., & Zafar, M. I. (2020). Environmental risk assessment of diclofenac residues in surface waters and wastewater: a hidden global threat to aquatic ecosystem. Environmental Monitoring and Assessment, 192(4), 204. doi:10.1007/s10661-020-8151-3.

[13] Nieto-Juárez, J. I., Torres-Palma, R. A., Botero-Coy, A. M., & Hernández, F. (2021). Pharmaceuticals and environmental risk assessment in municipal wastewater treatment plants and rivers from Peru. Environment International, 155, 106674. doi:10.1016/j.envint.2021.106674.

[14] Xu, H., Liu, Y., Xu, X., Lan, H., Qi, W., Wang, D., Liu, H., & Qu, J. (2022). Spatiotemporal variation and risk assessment of phthalate acid esters (PAEs) in surface water of the Yangtze River Basin, China. Science of the Total Environment, 836, 155677. doi:10.1016/j.scitotenv.2022.155677.

[15] Zhang, Z. M., Zhang, F., Du, J. L., & Chen, D. C. (2022). Surface Water Quality Assessment and Contamination Source Identification Using Multivariate Statistical Techniques: A Case Study of the Nanxi River in the Taihu Watershed, China. Water (Switzerland), 14(5), 778. doi:10.3390/w14050778.

[16] Desa, M. S. M., Sulaiman, M. A., & Rajan, S. (2023). Water Quality Assessment and Characterization of Rivers in Pasir Gudang, Johor via Multivariate Statistical Techniques. Pertanika Journal of Science and Technology, 31(1), 495–510. doi:10.47836/pjst.31.1.29.

[17] Thi Thu Huong, T., Quan, T. A., Hanh, N. T. H., & Tong, N. X. (2023). Assessing water quality in the Dong Nai River (Vietnam): implications for sustainable management and pollution control. Water Science and Technology, 87(11), 2917-2929. doi:10.2166/wst.2023.151.

[18] Dung, T. D., Quan, N. Q., Hue, N. T. T., & Luan, P. (2021). Evaluation of water quality of La Buong River by multivariate statistical method in space and time. Journal of Meteorology and Hydrology, 731, 36-53.

[19] Trinh, N. N., Thinh, N. H. D., Thu, N. T. Q., Phuong, P. T. D., Thoa, L. T. K., & Van, C. T. (2022). Application of WQI index to assess the current state of surface water quality of Bao Dinh River flowing through Tan An city. Journal of Meteorology and Hydrology, 744, 28-38.

[20] Circular No. 10/2021/TT-BTNMT. (2021). Circular Technical regulations on environmental monitoring and management of environmental quality monitoring information and data. Ministry of Natural Resources and Environment, Hanoi, Vietnam.

[21] Son, C. T., Giang, N. T. H., Thao, T. P., Nui, N. H., Lam, N. T., & Cong, V. H. (2020). Assessment of Cau River water quality assessment using a combination of water quality and pollution indices. Journal of Water Supply: Research and Technology - AQUA, 69(2), 160–172. doi:10.2166/aqua.2020.122.

[22] Wan Mohtar, W. H. M., Abdul Maulud, K. N., Muhammad, N. S., Sharil, S., & Yaseen, Z. M. (2019). Spatial and temporal risk quotient based river assessment for water resources management. Environmental Pollution, 248, 133–144. doi:10.1016/j.envpol.2019.02.011.

[23] Lorenz, M., Nguyen, H. Q., Le, T. D. H., Zeunert, S., Dang, D. H., Le, Q. D., Le, H., & Meon, G. (2021). Discovering water quality changes and patterns of the endangered thi vai estuary in southern Vietnam through trend and multivariate analysis. Water (Switzerland), 13(10), 1330. doi:10.3390/w13101330.

[24] Nguyen, T. T. N., Némery, J., Gratiot, N., Garnier, J., Strady, E., Tran, V. Q., Nguyen, A. T., Nguyen, T. N. T., Golliet, C., & Aimé, J. (2019). Phosphorus adsorption/desorption processes in the tropical Saigon River estuary (Southern Vietnam) impacted by a megacity. Estuarine, Coastal and Shelf Science, 227, 106321. doi:10.1016/j.ecss.2019.106321.

[25] Nguyen, T. T. N., Némery, J., Gratiot, N., Strady, E., Tran, V. Q., Nguyen, A. T., Aimé, J., & Peyne, A. (2019). Nutrient dynamics and eutrophication assessment in the tropical river system of Saigon – Dongnai (southern Vietnam). Science of the Total Environment, 653, 370–383. doi:10.1016/j.scitotenv.2018.10.319.

[26] Wehrheim, C., Lübken, M., Stolpe, H., & Wichern, M. (2023). Identifying Key Influences on Surface Water Quality in Freshwater Areas of the Vietnamese Mekong Delta from 2018 to 2020. Water (Switzerland), 15(7), 1295. doi:10.3390/w15071295.

[27] Costa-Böddeker, S., Hoelzmann, P., Thuyên, L. X., Huy, H. D., Nguyen, H. A., Richter, O., & Schwalb, A. (2017). Ecological risk assessment of a coastal zone in Southern Vietnam: Spatial distribution and content of heavy metals in water and surface sediments of the Thi Vai Estuary and Can Gio Mangrove Forest. Marine Pollution Bulletin, 114(2), 1141–1151. doi:10.1016/j.marpolbul.2016.10.046.

[28] Milazzo, A. D. D., Silva, A. C. M., Oliveira, D. A. F. de, & Cruz, M. J. M. da. (2014). The influence of seasonality (dry and rainy) on the bioavailability and bioconcentration of metals in an estuarine zone. Estuarine, Coastal and Shelf Science, 149, 143–150. doi:10.1016/j.ecss.2014.08.013.

[29] Renitasari, D. P., Kurniawan, A., & Kurniaji, A. (2021). Blood glucose of tilapia fish Oreochromis Mossambica as a water bio indicator in the downstream of Brantas waters, East Java. AACL Bioflux, 14(4), 2040–2049.

[30] Bhateria, R., & Jain, D. (2016). Water quality assessment of lake water: a review. Sustainable Water Resources Management, 2(2), 161–173. doi:10.1007/s40899-015-0014-7.

[31] Gaur, N., Sarkar, A., Dutta, D., Gogoi, B. J., Dubey, R., & Dwivedi, S. K. (2022). Evaluation of water quality index and geochemical characteristics of surfacewater from Tawang India. Scientific Reports, 12(1), 11698. doi:10.1038/s41598-022-14760-3.

[32] Grizzetti, B., Bouraoui, F., & Aloe, A. (2012). Changes of nitrogen and phosphorus loads to European seas. Global Change Biology, 18(2), 769–782. doi:10.1111/j.1365-2486.2011.02576.x.

[33] Edokpayi, J. N., Odiyo, J. O., Popoola, O. E., & Msagati, T. A. M. (2016). Assessment of trace metals contamination of surface water and sediment: A case study of Mvudi River, South Africa. Sustainability (Switzerland), 8(2), 135. doi:10.3390/su8020135.

[34] Cadmus, P., Brinkman, S. F., & May, M. K. (2018). Chronic Toxicity of Ferric Iron for North American Aquatic Organisms: Derivation of a Chronic Water Quality Criterion Using Single Species and Mesocosm Data. Archives of Environmental Contamination and Toxicology, 74(4), 605–615. doi:10.1007/s00244-018-0505-2.

[35] Choudhury, T. R., Islam, T., Md Towfiqul Islam, A. R., Hasanuzzaman, M., Idris, A. M., Rahman, M. S., Alam, E., & Chowdhury, A. M. S. (2022). Multi-media compartments for assessing ecological and health risks from concurrent exposure to multiple contaminants on Bhola Island, Bangladesh. Emerging Contaminants, 8, 134–150. doi:10.1016/j.emcon.2022.03.001.

[36] Zhang, Y., Li, F., Zhang, Q., Li, J., & Liu, Q. (2014). Tracing nitrate pollution sources and transformation in surface- and ground-waters using environmental isotopes. Science of the Total Environment, 490, 213–222. doi:10.1016/j.scitotenv.2014.05.004.

[37] Ngatia, M., Kithiia, S. M., & Voda, M. (2023). Effects of Anthropogenic Activities on Water Quality within Ngong River Sub-Catchment, Nairobi, Kenya. Water (Switzerland), 15(4), 660. doi:10.3390/w15040660.

[38] Ali, M. M., Islam, M. S., Islam, A. R. M. T., Bhuyan, M. S., Ahmed, A. S. S., Rahman, M. Z., & Rahman, M. M. (2022). Toxic metal pollution and ecological risk assessment in water and sediment at ship breaking sites in the Bay of Bengal Coast, Bangladesh. Marine Pollution Bulletin, 175. doi:10.1016/j.marpolbul.2021.113274.

[39] Bijay-Singh, & Craswell, E. (2021). Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. SN Applied Sciences, 3(4), 518. doi:10.1007/s42452-021-04521-8.

[40] Yen, T. P., & Rohasliney, H. (2013). Status of water quality subject to sand mining in the Kelantan River, Kelantan. Tropical Life Sciences Research, 24(1), 19.