Water Science & Technology

Water Science & Technology Vol 87 No 11, 2917 doi: 10.2166/wst.2023.151

Assessing water quality in the Dong Nai River (Vietnam): implications for sustainable management and pollution control

Tran Thi Thu Huong[a,*], Tran Anh Quan[a], Nguyen Thi Hong Hanh[b] and Nguyen Xuan Tong[c]

[a] Faculty of Environment, Hanoi University of Mining and Geology (HUMG), No.18, Vien Street, Duc Thang Ward, Bac Tu Liem District, Hanoi, Vietnam
[b] Faculty of Environment, Hanoi University of Natural Resources and Environment, No. 41 A Phu Dien Road, North-Tu Liem District, Hanoi, Vietnam
[c] Institute of Environmental Science, Engineering, and Management; Industrial University of Ho Chi MInh, Vietnam
*Corresponding author. E-mail: tranthithuhuong@humg.edu.vn

ABSTRACT

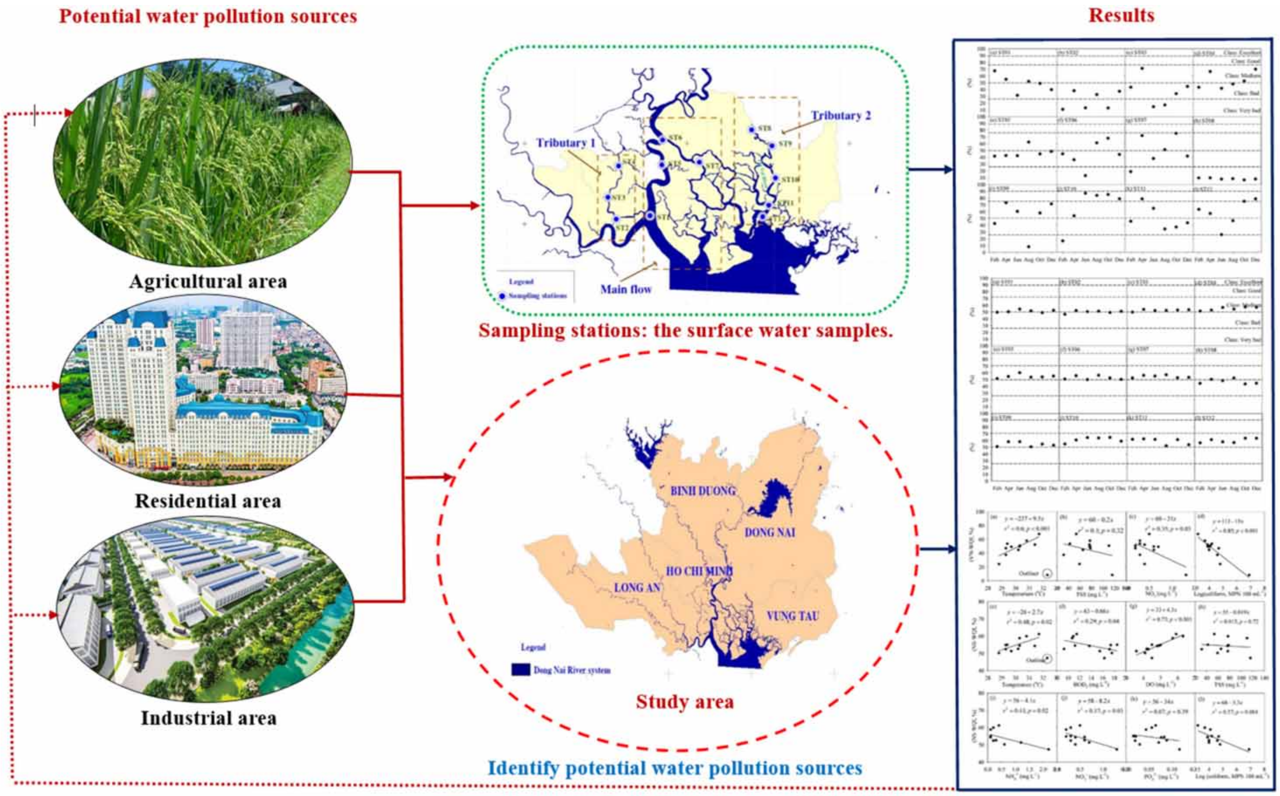
Dong Nai River provides essential water resources for millions of people across 11 provinces and cities in Vietnam. However, the different pollution sources such as household, farming, and industrial operations have caused the river water quality to deteriorate over the past decade. To gain a comprehensive understanding of the river's surface water quality, this study employed the water quality index (WQI) across 12 different sampling sites. In total,144 water samples with 11 parameters were analyzed in accordance with the Vietnamese standard 08:2015/MONRE. Results revealed a range of surface water quality, from poor to good according to the VN-WQI (Vietnamese standard), and a medium even bad level in some months according to the NS-WQI (American standard). The study also identified temperature, coliform, and dissolved oxygen (DO) as strong contributors to WQI values (VN_WQI standard). Principal component analysis/factor analysis was used to determine pollution sources, with the results highlighting agricultural and domestic activities as the main contributors to river pollution. In conclusion, this study underscores the importance of effective planning and management of infrastructure zoning and local activities to improve the river's surface water quality and surrounding areas, as well as safeguard the well-being of the millions who depend on it.

Key words: agricultural activities, domestic activities, Dong Nai River, infrastructure planning and management, water pollution, water quality index (WQI)

HIGHLIGHTS

- Surface water quality of the Dong Nai River varies from poor to good according to the VN-WQI and medium to bad according to the NS-WQI.
- Agricultural and domestic activities are the main contributors to river pollution according to the study's results.
- The study's findings could assist researchers and policymakers in taking comprehensive actions for sustainable water management.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is a vital component of ecosystems, providing sustenance for humans, animals, plants, and aquatic organisms (Sánchez *et al.* 2019). However, water resources around the world, including Vietnam, are facing significant pressure due to climate change, population growth, and human activities. This has led to a decline in water quality and a rise in pollution levels. Rivers are used as the main source of fresh water for different objectives worldwide, including domestic, industrial, agricultural, and conservation (Shi *et al.* 2017; Zhang *et al.* 2019; Belle *et al.* 2020). Regrettably, the quality of surface water sources has been seriously endangered by human activities and atmospheric pollutants. As a result, many countries consider water quality to be a sensitive and important issue (Şener *et al.* 2017; Kumar & Singh 2018). Systematic observation and assessment of water quality are crucial for controlling, managing, and safeguarding rivers against pollution and degradation, which is a sensitive and significant matter (Barakat *et al.* 2016).

The Water Quality Index (WQI) is a combined measure that integrates several measurements of water quality attributes into a solitary score, reflecting the overall quality of the river water at the research sites (Sarkar & Abbasi 2006; Neswiswi 2014; Ewaid 2017). The WQI provides a numerical scale that spans from 0 (lowest level) to 100 (highest level), enabling a quantitative representation of water quality. This enables monitoring of the changes in water quality over time for a river or specific section, or for different purposes of usage (Bhargava 1983). Additionally, different WQI models can be developed by each country for various purposes. Lately, several studies in Vietnam have focused on investigating the application of WQI models developed in India and Canada (Bhargava 1985). Furthermore, there have been suggestions in certain studies to utilize water quality indicators such as WQI-2 and WQI-4 to assess the water quality information pertaining to the Saigon River from 2003 to 2007 (Trinh 2008; Ho 2012). The Vietnam Environment Administration has officially released Decision No. 1460/QD-TCMT (12/11/2019), which is the national technical guidance for calculating and publishing Vietnam's water quality index (VN-WQI) standard. This decision aims to guarantee consistency in the computation of the WQI in Vietnam for water quality assessment.

The longest inland river in Vietnam is the Dong Nai River, which is a substantial body of water that begins the North of Lam Vien Plateau. The river has a basin that covers an area of 38,600 km² and flows through six provinces and Ho Chi Minh city, spanning a distance of 586 km. The basin of the Dong Nai River system includes 11 provinces and cities with a population of approximately 18 million, including seven provinces and cities that belong to the key economic region in the southern portion of Vietnam (Nien 2010b; Vietnam's Government 2013; Dong Nai's Decision 2014). An essential supply of water for industrial, agricultural, and domestic needs is provided by the river. The Dong Nai River receives wastewater from various sources, including industrial parks, hospitals, and urban areas, among others. Unfortunately, a significant number of these facilities discharge inadequately treated or untreated wastewater into the river, leading to water pollution. According to the Department of Natural Resources and Environment of Dong Nai province, the discharged wastewater contains many indicators that surpass the acceptable limits (Nien 2010a; Pham *et al.* 2017). Thus, it is essential to evaluate the water quality status of the Dong Nai River and identify potential hazards to reduce pollution in the future.

To achieve this goal, the researchers used the WQI and multivariate statistical techniques such as principal component analysis (PCA), correlation analysis, and factor analysis (FA) to assess the biological and chemical characteristics of the river. The study aimed to achieve the following three objectives:

(1) Assess the surface water quality;
(2) Identify the sources of pollution;
(3) Determine the relative significance of individual water quality parameters in the lower region of the Dong Nai River system.

2. EXPERIMENTAL DESIGN AND PROCEDURES

2.1. Experimental field

The study area is situated in Can Gio district, Ho Chi Minh City (Vietnam), in the downstream part of the Dong Nai River basin, within the geographical coordinates of 106°38′–107°11′E longitude and 10°20′–19°50′N latitude (Figure 1). The area is characterized by two different seasons with total rainfall ranging from 1,700 to 2,800 mm (dry and rainy). In the lower region, the Dong Nai River system is formed by the confluence of the Long Tau River and the Soai Rap River, along with two tributaries: the Vam Co River, corresponding to tributary #1, and the Thi Vai River, corresponding to tributary #2. The present research involved the surveying and sampling of 12 sites (ST) along the Dong Nai River, as shown in Figure 1.

Group 1 included three sampling sites, namely ST01, ST06, and ST12, located at the top of the two river tributaries. The remaining nine sites belonged to group 2, situated in the mainstream and downstream area of the two tributaries. Among these, ST1, ST2, ST07, and ST12 were positioned in residential areas; ST11, ST10, ST09, and ST05 were in industrial and residential areas; ST08 was near industrial and agricultural areas; ST06 was adjacent to a residential area, and ST03 and ST04 were in proximity to residential and agricultural areas. Furthermore, ST01, ST05, ST06, and ST07 sampling sites could potentially be affected by the flow from the upstream area of the two tributaries and the Saigon-Dong Nai River system.

2.2. Approaches for measuring and assessing water quality indicators

In 2017 and 2018, a total of 144 water samples were collected from 12 distinct locations within the Dong Nai River system for the purpose of sampling and analysis, with each location being measured in two seasons (i.e., rainy and dry) for 2 years, and replicates taken on three occasions. Various parameters were assessed from the water samples, including pH, dissolved oxygen (DO), turbidity, ammonium (NH_4^+), nitrate (NO_3^-), total suspended solids (TSS), phosphate (PO_4^{3-}), chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5), and coliform, in accordance with the Vietnamese standard 08:2015/MONRE: National Technical Regulation on surface water quality. The water temperature was also measured using a thermometer. The selection of the sampling sites was made by evaluating the characteristics of the area, the human communities residing there, and the boundary of the Dong Nai River area. The water samples were gathered under uniform conditions, avoiding sewage drains, and at a depth of 0.5 m below the water surface. Three samples of water were collected at each location, and then immediately placed into pre-cleaned glass bottles that were designed to block light. The bottles were then put into a cooler set at 5 °C, and conveyed to the laboratory for further examination.

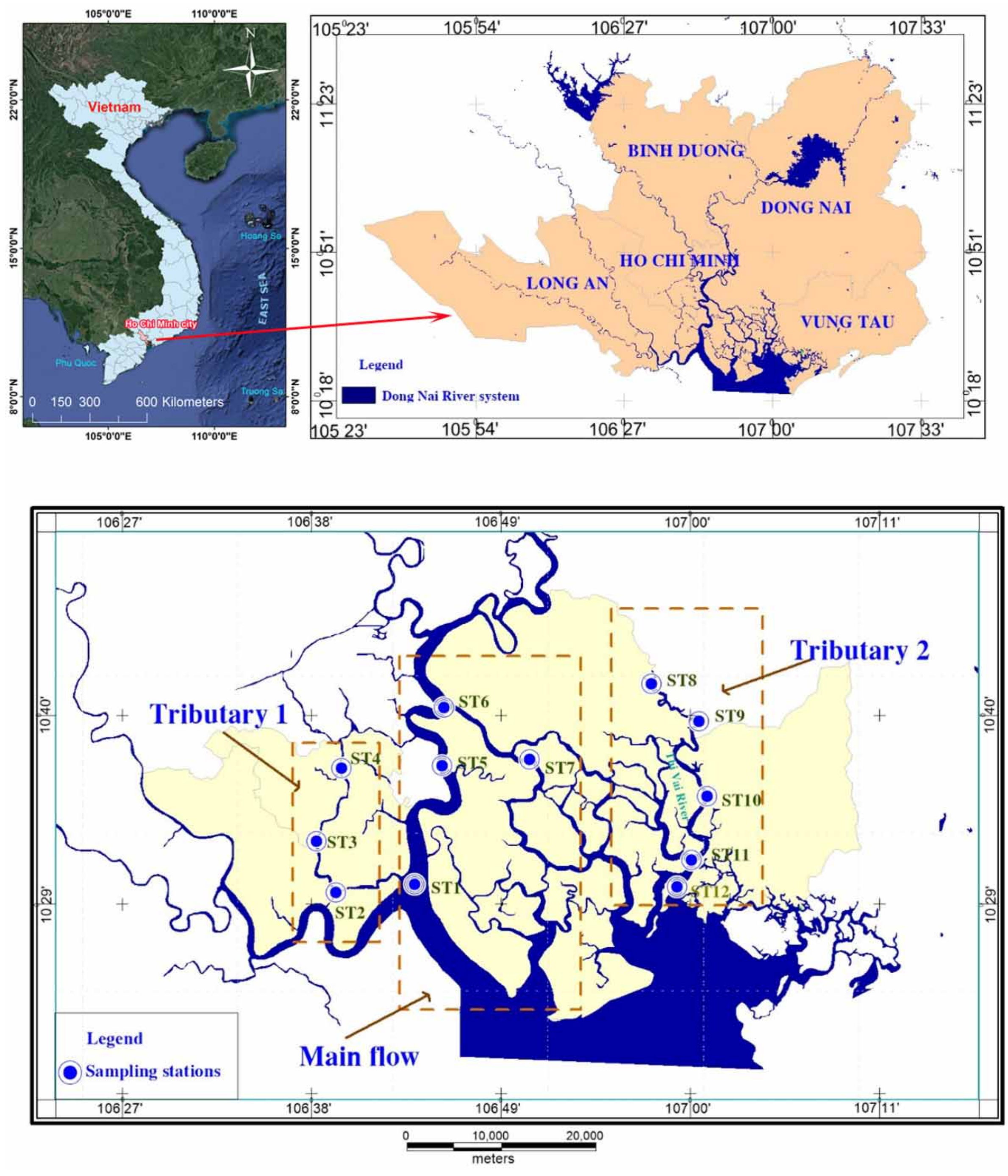


Figure 1 | The sampling site and study area map.

2.3. WQI calculation

The study continuously monitored 11 parameters of water quality, including temperature, pH, BOD_5, COD, DO, TSS, NH_4^+, NO_3^-, PO_4^{3-}, turbidity, and coliform, from 2017 to 2018. The collected data were converted to a general scale of 0–100 based on mathematical equations and transferred weights according to their importance to human health, as suggested by Kannel *et al.* (2007) and Sedeño-Díaz & López-López (2007). The values obtained indicated that the WQI is in the range of 0–100 with higher values reflect better quality of water. The NS-WQI standard classifies water quality into five categories (Brown *et al.* 1970; Noori *et al.* 2019):

(I) in the range of 0–25: very bad
(II) in the range of 25–50: bad
(III) in the range of 50–70: medium
(IV) in the range of 70–90: good
(V) in the range of 90–100: excellent.

Meanwhile, the VN-WQI standard categorizes water quality into six groups (MONRE 2011):

(I) in the range of <10: very heavy pollution
(II) in the range of 10–25: poor
(III) in the range of 26–50: bad
(IV) in the range of 51–75: medium
(V) in the range of 76–90: good
(VI) in the range of 91–100: very good

Thus, this study conducted multiple regression analysis to determine the correlation between parameters of water quality and WQI values. Furthermore, dominance analysis, based on the procedure proposed by Pissarra *et al.* (2019), was used to determine the relative importance of each water quality parameter. This study calculated the WQI values for the 11 parameters at 12 sites with a total of 144 samples (as described above) using the formula proposed by the National Sanitation Foundation of the United States (NSF) (Brown *et al.* 1970; Noori *et al.* 2019), as follows:

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \tag{1}$$

where n is the total of water quality parameters, C_i denotes the ith parameter after normalization, and P_i stands for the ith parameter's weight. Note that, weights will be assigned to all parameters and they are in the range of 1–4, and are determined based on their significance to water quality, as confirmed in previous studies (Koçer & Sevgili 2014; Deng *et al.* 2022; Rajkumar *et al.* 2022).

Another equation which was used to calculate the WQI for this study is based on the guideline in MONRE (2011) (VN-WQI standard), as described in the following equation:

$$\mathrm{WQI_{SI}} = \frac{q_i - q_{i+1}}{\mathrm{BP}_{i+1} - \mathrm{BP}_i}(\mathrm{BP}_{i+1} - C_p) + q_{i+1} \tag{2}$$

where BP_i is the acceptable minimum concentration level of the specified parameter value at the ith level; $\mathrm{BP}_{(i+1)}$ is the maximum allowable concentration of the specified parameter value at the $(i+1)$th level; q_i stands for WQI at the given ith level of BP_i; $q_{(i+1)}$ stands for WQI at the given $(i+1)$th level of $\mathrm{BP}_{(i+1)}$; C_p indicates the parameter value used in the calculation process.

2.4. Statistical analyses

In this study, the water quality of 11 parameters was analyzed in triplicate to ensure the accuracy and reliability of the data. The mean values $\pm$ SD were calculated at the 5% probability level ($p < 0.05$) to determine the central tendency and the variation in the data. Statistical analyses were conducted using two software packages: SPSS 20 and Sigmaplot 14. These software programs were used to determine the significance of the data, which is a critical step in statistical analysis. By using SPSS 20 and Sigmaplot 14, we were able to perform various statistical analyses, including regression analysis, correlation analysis, descriptive statistics, and analysis of variance (ANOVA). These statistical methods were used to test the hypotheses and to identify any significant dependencies between the parameters of water quality. Overall, the use of these statistical analysis methods ensured that the data were properly analyzed and that the results of the study were reliable and valid.

3. RESULTS AND DISCUSSIONS

3.1. WQI assessment

According to the VN-WQI standard, the quality of water in the Dong Nai River ranged from poor to good, as illustrated in Figures 2 and 3. Figure 2 illustrates the Dong Nai River water quality using the VN-WQI standard, which ranged from poor to good across different sites. According to the standard, ST10, ST11, and ST12 exhibited fluctuations at all months but reached good quality (80–90%) in some months, such as May and December for ST10, March and April for ST11, and from September to December for ST12. The water quality tended to increase at the ST10 site from February to October but remained poor (<20%) in January and February. The ST12 site also recorded bad quality (25–50%) in some months, including May, June, July, and August. Conversely, ST01, ST03, ST05, ST06, ST07, and ST09 only showed medium quality (10–70%) throughout the year. ST02 and ST08 recorded the worst water quality, with ST02 showing poor quality (10–30%) in several months, and bad quality (<50%) in the remaining months. ST08 had consistently poor and heavily polluted water due to organic pollution loads that reduced the river's self-cleaning capacity in the area. Overall, the results indicated that the water quality exhibited continuous fluctuations across all sampling sites.

The water quality at most sampling sites was found to be at a medium level throughout the year when compared to the NS-WQI standard, as shown in Figure 3. Specifically, ST01 and ST03 consistently exhibited medium-level water quality (around 50–55%), while ST02 showed bad-level water quality in the first 2 months of the year (ranging from 40 to 50%). Although the water quality at ST04 increased slightly from March to December (reaching 60%), it remained at a medium level (around 50%) in the first 2 months of the year (January and February). ST05 and ST09 showed similar water quality, with better water quality in the first few months of the year (over 60%) compared to the last few months (ranging from 50 to 60%).

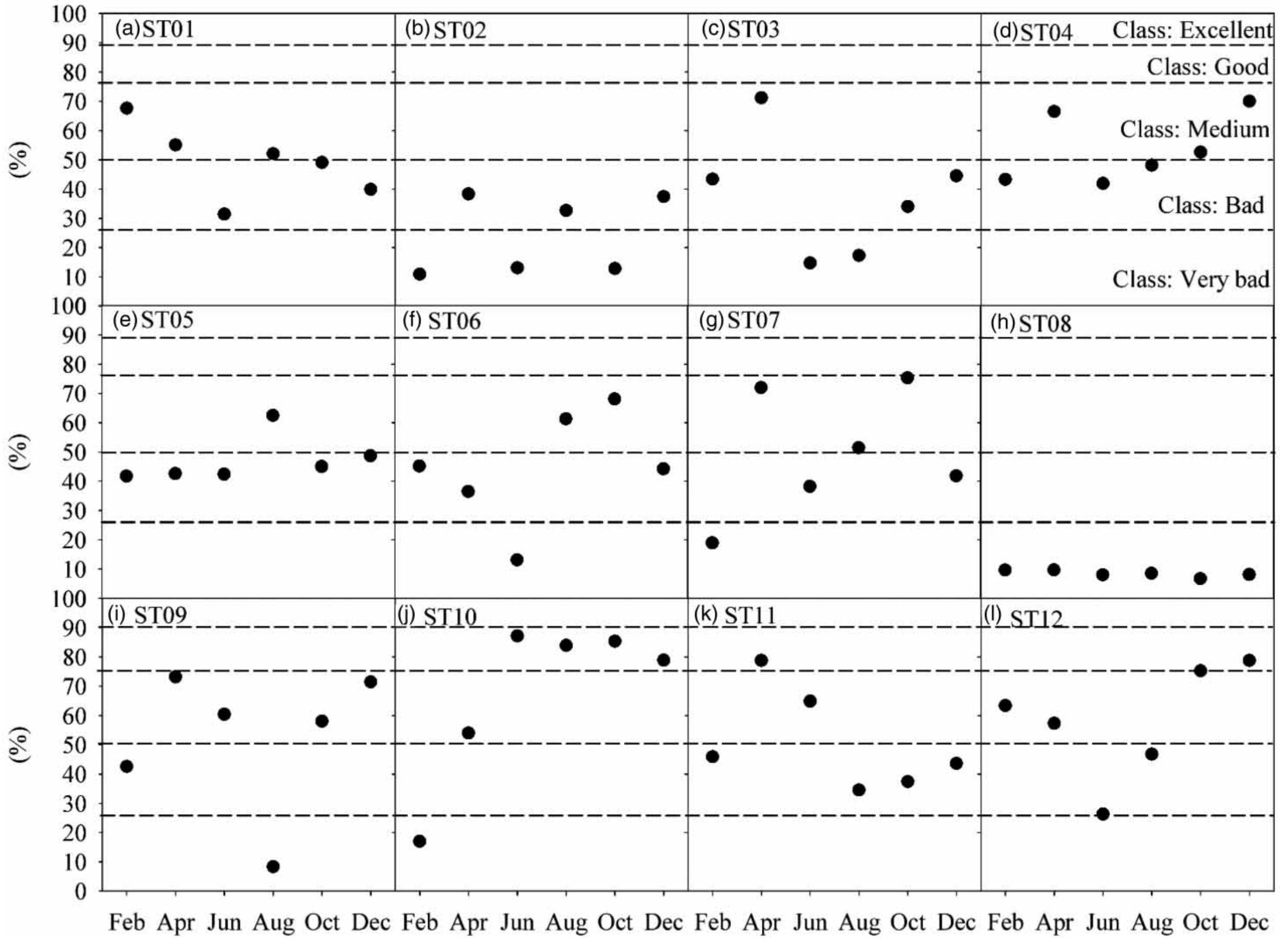


Figure 2 | Assessment results of water quality using the VN-WQI index and its classification categories.

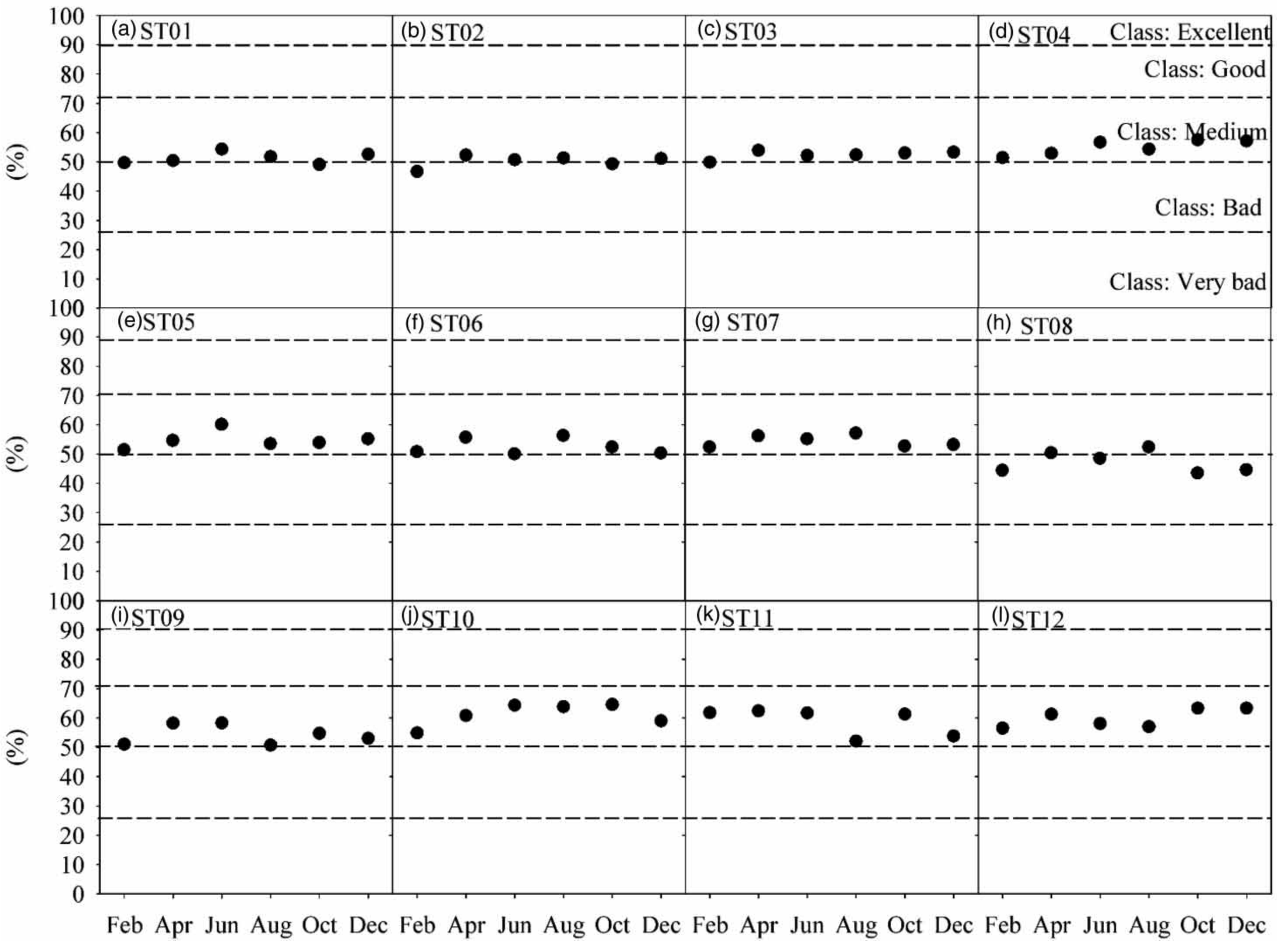


Figure 3 | Assessment results of water quality using the NS-WQI index and NFS standard classification categories.

ST06 and ST07 had medium-level water quality throughout the year (ranging from 50 to 60%). The water quality at ST09 to ST12 tended to be good (ranging from 50 to 67%, mostly over 60%) according to NS-WQI standards. However, the water quality at position 08 was only at a medium level (ranging from 50 to 55%) and even bad in some months (January, February, May, June, and September to December).

The results of the current study on surface water quality assessment using the WQI value in the Dong Nai River, Vietnam, are consistent with those of previous research (Namugize & Jewitt 2018; Díaz-Casallas *et al.* 2019; Pissarra *et al.* 2019). Namugize & Jewitt (2018) discovered that the WQI value of the Mungeni River (South Africa) varied over time, with a decrease in water quality from the upper to lower regions. Similarly, in the Luanhe River (North China), medium water quality was prevalent at 75.3%, with the remaining water quality levels being very good, good, and poor, accounting for 0.4, 19.6, and 4.7%, respectively. No sampling site was classified as very bad (Tian *et al.* 2019). Furthermore, Díaz-Casallas *et al.* (2019) reported that the water quality of the Bogota River (Colombia) achieved only 43% medium, 32% acceptable, and 24% poor, with only 1% being classified as very bad and no site reaching good water quality.

Comparatively, the Dong Nai River's water quality was found to be inferior to that of the entire Yamuna River section in India (Maneesh Jaiswal *et al.* 2019). The Beheshtabad River's water quality in Iran did not undergo significant modifications during the experimental stage and only achieved medium and good WQI values (Fathi *et al.* 2018). Eight locations in two major rivers in Odisha exhibited suitable water quality for drinking purposes, with only one location requiring precautions due to poor water quality (Rath *et al.* 2019). A river in southeastern Nigeria demonstrated good to very good water quality at almost all surveyed sites, although discharge activities required monitoring and control (Donald & Blessing 2019). In contrast, the Shatt Al-Arab River's water quality was mostly classified as medium based on WQI values, with poor water quality observed in Al-Ribat, Al-Khandaq, Al-Khora, and Al-Ashar. Furthermore, the Nag River (Dutta *et al.* 2018) and the Carahá River in Lages (Brazil) (Quinatto *et al.* 2019) exhibited poor water quality, likely caused by agricultural and human activities.

3.2. Relationship between WQIs and water quality parameters

In this study, the dominance analysis was selected using the stepwise elimination method and compared to both VN-WQI and NS-WQI standards. The analysis results are calculated as shown in Table 1.

Table 1 presents the water quality parameters that were selected using the stepwise elimination method and compared both VN-WQI and NS-WQI standards. The chosen parameters for evaluating water quality at the sampling sites were temperature, TSS, NO_3^-, PO_4^{3-}, coliform, BOD_5, DO, and NH_4^+. These parameters were deemed the most effective, as illustrated in Table 1. The dominance analysis in Table 1 revealed that, according to the VN-WQI standard, coliform was the most influential factor among all water quality parameters. It contributed significantly to the linear regression model, followed by TSS, temperature, and NO_3^-. Similarly, based on the NS-WQI standard, DO was the most dominant factor among all water quality parameters, followed by coliform, TSS, BOD_5, NH_4^+, NO_3^-, temperature, and PO_4^{3-}.

As mentioned earlier, ST01 and ST03 consistently had moderate water quality levels, whereas ST02 had poor water quality during the first 2 months of the year, but there was a slight improvement from March to December. ST04 had a similar pattern to ST02, with slightly increased water quality from March to December, but still at a moderate level during January and February. ST05 and ST09 had comparable water quality, with better quality during the first few months of the year but a decline in the last few months. ST06 and ST07 had moderate water quality throughout the year. ST09–ST12 generally had good water quality according to NS-WQI standards, but ST08 had only moderate water quality and poor quality during some months.

Throughout the year, most sampling sites exhibited medium-level water quality (around 50–55%) even bad level in some months (lower than 50%) compared to the NS-WQI standard. The outcomes indicate a significant association between temperature and coliform, as per the VN-WQI standard, as illustrated in Figure 4 with a p-value of less than 0.001. Conversely, based on the NS-WQI standard, only DO displays a positive correlation, while the other indicators exhibit either weak or negative correlation. Our initial findings are reinforced by further examinations conducted on WQI value. For instance, a study carried out on the Kinta River in Malaysia demonstrated that DO displayed a strong correlation with WQI values, whereas pH and TSS had a feeble correlation (Gazzaz *et al.* 2013). Similarly, Kumar & Dua (2009) discovered that in the Ravi River in India, the WQI value was influenced by the DO factor, and as the DO level rose, water clarity improved. This is in agreement with the findings of Verma *et al.* (2019), which also reported a significant correlation between DO and WQI value in surface water environments. However, in contrast, the water quality of the Ubogo and Egini Rivers in Nigeria, as per the WQI value, displayed a negative correlation with DO and BOD (Ejoh *et al.* 2018). Moreover, Pham

Table 1 | Stepwise elimination (SE) for the multiple regression of WQIs with water quality parameters and dominance analysis (DA)

	VN-WQI				**NS-WQI**			
	SE		**DA**		**SE**		**DA**	
Parameters	**Estimate**	**Prob > |t|**	**pr([a])**	**Ranking**	**Estimate**	**Prob > |t|**	**pr([a])**	**Ranking**
Temperature	**4.90**	**0.001**	0.4798	3	**0.63**	**0.004**	0.4369	7
pH	0.00	0.606			0.00	0.291		
BOD_5	0.00	0.503			**− 0.15**	**<0.001**	−0.5238	4
COD	0.00	0.531			0.00	0.935		
DO	0.00	0.361			**2.63**	**<0.001**	0.8616	1
TSS	**− 0.19**	**<0.001**	−0.6046	2	**− 0.03**	**<0.001**	−0.6746	3
NH_4^+	0.00	0.246			**0.87**	**0.003**	0.4586	5
NO_3^-	**− 11.04**	**0.014**	−0.3604	4	**− 2.14**	**0.003**	−0.4539	6
PO_4^-	**0.00**	**0.145**			**− 16.47**	**0.016**	−0.3734	8
Turbidity	0.00	0.692			0.00	0.322		
Log(coliform)	**− 13.33**	**<0.001**	−0.771	1	**− 1.96**	**<0.001**	−0.8105	2

[a]Partial correlation.

Note: The bold type shows the significant differences and contributed significantly to the linear regression model.

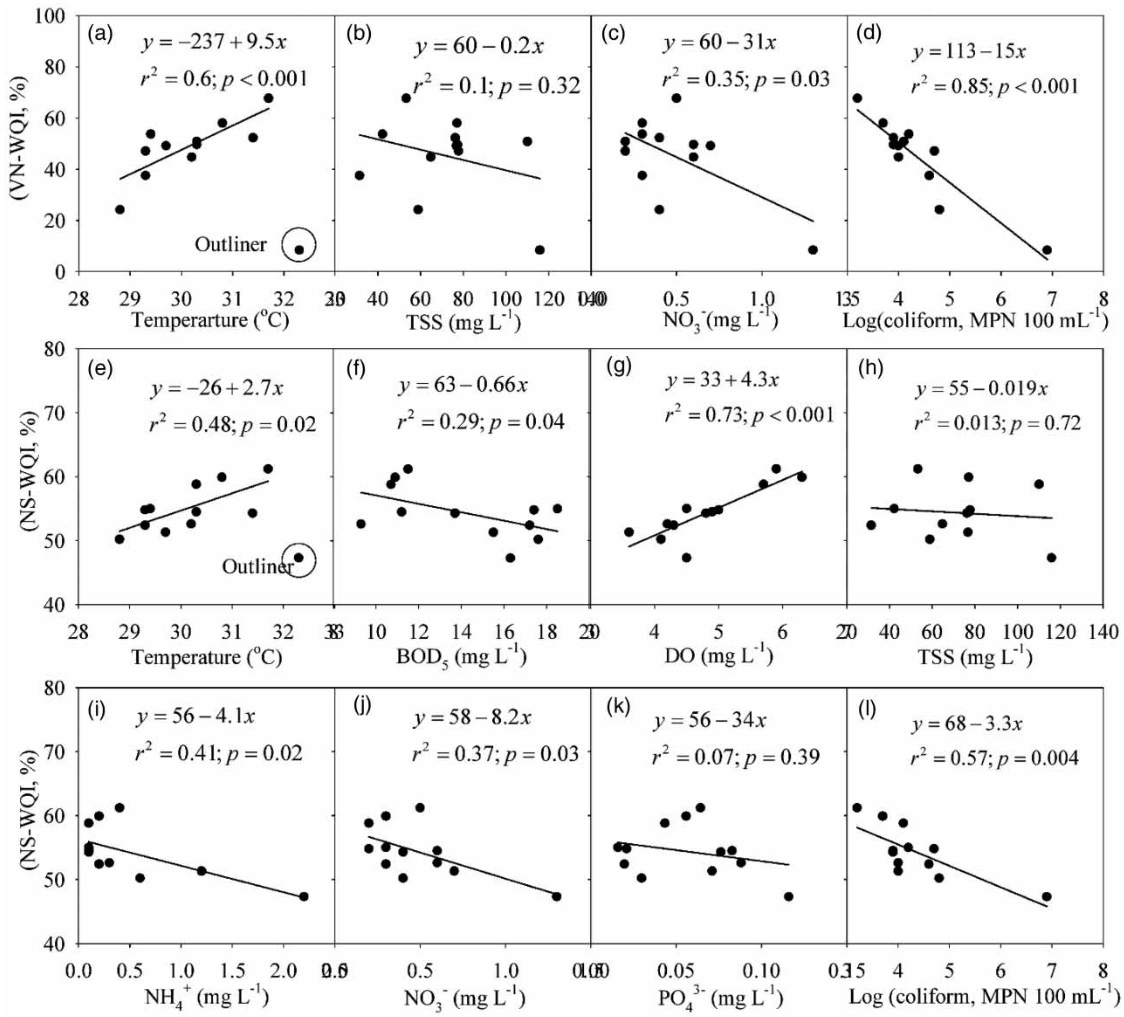


Figure 4 | The relationship between WQIs and important parameters of water quality identified by dominance analysis.

et al. (2017) observed either no or weak correlation between WQI and COD, BOD, and NH_4^+-N concentrations during the rainy season in the Dong Nai River sub-basin in Vietnam. DO and pH parameters are not strongly related to the WQI value since they meet the VN-WQI standard.

3.3. Principal component/factor analysis

To identify the primary water quality parameters and assess the causes of water pollution in the research area, this study employed a PCA/FA method. The significance of factors was determined by the eigenvalue, with a value equal to or greater than 1.0 considered as meaningful, as shown in Table 2. The absolute load values of the primary components were divided into three categories based on their magnitudes: strong (values > 0.75), medium (values between 0.75 and 0.50), and weak (values between 0.50 and 0.30), as stated by Everitt & Hothorn (2011). The PCA results, including loading values, eigenvalues, total variance, and cumulative variance, are presented in Table 2. It is important to mention that the loading values acquired through the PCA/FA encompassed 11 water quality parameters and the varimax factor (VF).

In this study, four VF components were analyzed using PCA, which accounted for 78.32% of the total variance. Consistent with previous statistical analyses, these results helped identify the source of water quality pollution. VF1 components accounted for 30% of the total variance, with a substantial loading of NO_3^-. This finding indicates that a mobile pollutant source, likely from decaying organic matter in agricultural areas, significantly contributes to the pollution in this river (Nien

Table 2 | PCA results of this study based on 11 water quality parameters

	Principle component			
Parameters	**VF1**	**VF2**	**VF3**	**VF4**
Temperature	0.59	−0.23	0.09	0.67
pH	−0.36	0.43	0.64	0.15
BOD_5	− 0.53	0.69	−0.07	0.41
COD	− 0.60	0.67	−0.22	0.19
DO	0.00	−0.38	**0.75**	0.23
TSS	0.56	0.45	0.57	−0.11
NH_4^+	0.38	0.37	−0.38	0.15
NO_3^-	**0.78**	0.07	−0.34	−0.17
PO_4^-	0.63	−0.06	−0.13	0.58
Turbidity	0.64	0.50	0.41	−0.32
Log(coliform)	0.56	0.61	−0.14	−0.05
Eigenvalue	3.30	2.27	1.81	1.23
% total variance	30.00	20.64	16.48	11.20
Cumulative percentage variance	30.00	50.65	67.13	78.33

Note: The bold type presents values that are greater than 0.75, while underlined type presents values that are greater than 0.5 but less than 0.75.

2010b; Vietnam's Government 2013; Dong Nai's Decision 2014). This is in line with the findings of Pham *et al.* (2017), who suggest that agricultural sewage is the primary source of pollution due to high fertilizer use in the tributaries (Pham *et al.* 2017). The medium loading was observed for temperature, BOD_5, COD, TSS, PO_4^{3-}, turbidity, and coliform, while pH, DO, and NH_4^+ showed weak loading. The oxidation of nitrogenous materials in water can decrease DO concentration, leading to continuous depletion and microbial depletion, which promotes water pollution (Venkatramanan *et al.* 2014).

The present study utilized PCA/FA to identify key water quality parameters in the Dong Nai River and assess pollution sources. VF1 components, accounting for 30% of total variance, showed a large loading for NO_3^- parameter, indicating organic matter decay from agricultural areas as a significant pollutant source. VF2 components, accounting for 20.64% of the total variance, showed medium loadings for BOD_5, COD, turbidity, and coliform parameters, indicating pollution from agricultural areas and domestic wastewater. VF3 components, accounting for 16.48% of the total variance, had a large loading for DO, indicating pollution due to nitrogenous material oxidation. VF4 components, accounting for 11.2% of total variance, showed medium loadings for temperature and PO_4^{3-} and weak loadings for other parameters, suggesting pollution from multiple sources. These findings are consistent with previous studies, confirming the impact of human activities and natural processes on water quality. A previous study by Nguyen *et al.* (2019) has shown that organochlorine pesticides (OCPs) could come from residential and agricultural areas and are one of the causes contributing to pollution and deterioration in the quality of the receiving water, which is the Dong Nai River (Pham *et al.* 2017; Nguyen *et al.* 2019) . Because some substances in the plant-protection chemical group (OCPs) such as DDTs are still illegally used in Vietnam as an effective tool to kill mosquitoes against malaria, kill termites against damage to houses and warehouses. Although, according to the Stockholm Convention, DDTs have been banned since 1972. In addition, agricultural wastewater containing chemicals such as pesticides, stimulants, fertilizers also contributes to river water pollution, making the water quality deterioration (Pham *et al.* 2017). The present study found that ST02 and ST08 have bad water quality according to both standards (VN-WQI and NS-WQI standard), in which ST08 was near industrial and agricultural areas and ST02 was positioned in residential areas. These results once again confirm that the geographical location, infrastructure, and human activities in daily life as well as in production have a great influence on the river water quality. Therefore, the usefulness of WQI and PCA/FA in analyzing complex water quality data and identifying pollution sources/factors is highlighted, providing valuable insights into water quality management, and facilitating effective measures for improving the Dong Nai River system's water quality.

4. CONCLUSIONS

To summarize, this study assessed the water quality of the Dongnai River using two WQIs, VN-WQI and NS-WQI. The results showed that the water quality varied from 'poor' to 'good' based on the VN-WQI and achieved a medium or bad level across all sampling sites according to the NS-WQI. The study identified human activities, agricultural practices, and industrial production as significant pollution sources impacting the river's surface water quality. Therefore, the implementation of appropriate management strategies, such as urbanization plans, agricultural practices, and industrial production, is crucial for improving the river water quality and the surrounding areas. These measures are essential to protect the sustainability of the region's ecosystem and public health. Overall, this study provides valuable insights into the water quality management of the Dongnai River and can guide policymakers in implementing effective measures to enhance water quality in the area.

AUTHORS CONTRIBUTIONS

T.T.H.T. wrote the original draft, wrote, reviewed, and edited the article; T.T.H.T. and T.X.N did database analysis and software analysis. All authors investigated the study, collected samples, and analyzed the methodology. All authors have read and agreed to the published version of the manuscript.

FUNDING STATEMENT

No funding was obtained for this study.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Barakat, A., El Baghdadi, M., Rais, J., Aghezzaf, B. & & Slassi, M. 2016 Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. *International Soil and Water Conservation Research* **4** (4), 284–292.

Belle, G., Fossey, A. & Esterhuizen, L. 2020 Use of multiple indicators to assess the pollution condition of urban streams: a case study of Bloemspruit, Free State Province, South Africa. *Water and Environment Journal* **34** (1), 93–105.

Bhargava, D. S. 1983 Use of water quality index for river classification and zoning of Ganga River. *Environmental Pollution Series B, Chemical and Physical* **6** (1), 51–67.

Bhargava, D. S. 1985 Water quality variations and control technology of Yamuna river. *Environmental Pollution Series A, Ecological and Biological* **37** (4), 355–376.

Brown, R. M., McClelland, N. I., Deininger, R. A. & Tozer, R. G. 1970 A water quality index-do we dare. *Water and Sewage Works* **117** (10), 339–343.

Deng, L., Chen, K., Liu, Z., Wu, B., Chen, Z. & He, S. 2022 Spatiotemporal variation evaluation of water quality in middle and lower Han River, China. *Scientific Reports* **12** (1), 14125.

Díaz-Casallas, D. M., Castro-Fernández, M. F., Bocos, E., Montenegro-Marin, C. E. & González Crespo, R. 2019 2008–2017 Bogota river water quality assessment based on the water quality index. *Sustainability* **11** (6), 1668.

Donald, A. E. & Blessing, U. A. 2019 Index approach to water quality assessment of a south eastern Nigerian river. *International Journal of Fisheries and Aquatic Studies* **7** (1), 153–159.

Dong Nai's Decision. 2014 *Decision No. 2230/QD-UBND Dated July 21, 2014 on Approval of Investment Project for Landscape Improvement and Urban Development Along Dong Nai River (in Vietnamese)*.

Dutta, S., Dwivedi, A. & Suresh Kumar, M. 2018 Use of water quality index and multivariate statistical techniques for the assessment of spatial variations in water quality of a small river. *Environmental Monitoring and Assessment* **190**, 1–17.

Ejoh, A. S., Unuakpa, B. A., Ibadin, F. H. & Edeki, S. O. 2018 Dataset on the assessment of water quality and water quality index of Ubogo and Egini rivers, Udu LGA, Delta State Nigeria. *Data in Brief* **19**, 1716–1726.

Everitt, B. & Hothorn, T. 2011 *An Introduction to Applied Multivariate Analysis with R*. Springer Science & Business Media.

Ewaid, S. H. 2017 Water quality evaluation of Al-Gharraf river by two water quality indices. *Applied Water Science* **7** (7), 3759–3765.

Fathi, E., Zamani-Ahmadmahmoodi, R. & Zare-Bidaki, R. 2018 Water quality evaluation using water quality index and multivariate methods, Beheshtabad River, Iran. *Applied Water Science* **8**, 1–6.

Gazzaz, N. M., Yusoff, M. K., Juahir, H., Ramli, M. F. & Aris, A. Z. 2013 Water quality assessment and analysis of spatial patterns and temporal trends. *Water Environment Research* **85** (8), 751–767.

Ho, P. N. 2012 Total water quality index using weighting factors and standardized into a parameter. *Environment Asia* **5** (2), 63–69.
Jaiswal, M., Hussain, J., Gupta, S. K., Nasr, M. & Nema, A. K. 2019 Comprehensive evaluation of water quality status for entire stretch of Yamuna River, India. *Environmental Monitoring and Assessment* **191**, 1–17.
Kannel, P. R., Lee, S., Lee, Y. S., Kanel, S. R. & Khan, S. P. 2007 Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment. *Environmental Monitoring and Assessment* **132**, 93–110.
Koçer, M. A. T. & Sevgili, H. 2014 Parameters selection for water quality index in the assessment of the environmental impacts of land-based trout farms. *Ecological Indicators* **36**, 672–681.
Kumar, A. & Dua, A. 2009 Water quality index for assessment of water quality of river Ravi at Madhopur (India). *Global Journal of Environmental Sciences* **8** (1), 49–57.
Kumar, B. & Singh, U. K. 2018 Source apportionment of heavy metals and their ecological risk in a tropical river basin system. *Environmental Science and Pollution Research* **25** (25), 25443–25457.
MONRE 2011 *Sổ tay hướng dẫn tính toán chỉ số chất lượng nước (in Vietnamese)*. Ministry of Natural Resources and Environment of Vietnam.
Namugize, J. N. & Jewitt, G. P. W. 2018 Sensitivity analysis for water quality monitoring frequency in the application of a water quality index for the uMngeni River and its tributaries, KwaZulu-Natal, South Africa. *Water SA* **44** (4), 516–527.
Neswiswi, A. B. 2014 *Development of Water Quality Index (WQI) for the Jukskei River Catchment*. University of the Witwatersrand, Faculty of Engineering and the Built, Johannesburg.
Nguyen, T. X., Nguyen, B. T., Tran, H. T. T., Mai, H., Duong, T. T. & Bach, Q. V. 2019 Seasonal, spatial variation, and potential sources of organochlorine pesticides in water and sediment in the lower reaches of the Dong Nai River system in Vietnam. *Archives of Environmental Contamination and Toxicology* **77**, 514–526.
Nien, N. T. 2010a *Integrated Management of Water Resources in Dong Nai River Basin – an Urgent Requirement. Master Thesis and Presentation at the Dialogue on Water Resources Degradation in the River Basin (in Vietnamese)*.
Nien, N. T. 2010b Integrated management of water resources in Dong Nai river basin – an urgent requirement (in Vietnamese). In: *Presentation at the Dialogue on Water Resources Degradation in the River Basin*.
Noori, R., Berndtsson, R., Hosseinzadeh, M., Adamowski, J. F. & Abyaneh, M. R. 2019 A critical review on the application of the national sanitation foundation water quality index. *Environmental Pollution* **244**, 575–587.
Pham, H., Rahman, M. M., Nguyen, N. C., Le Vo, P., Van Le, T. & Ngo, H. 2017 Assessment of surface water quality using the water quality index and multivariate statistical techniques–A case study: the upper part of Dong Nai river basin, Vietnam. *Journal of Water Sustainability* **7** (4), 225–245.
Pissarra, T. C. T., Valera, C. A., Costa, R. C. A., Siqueira, H. E., Martins Filho, M. V., Reuter Foundation, Sanches Fernandes, L. F., Pacheco, F. A. L. & Pacheco, F. A. L. 2019 A regression model of stream water quality based on interactions between landscape composition and riparian buffer width in small catchments. *Water* **11** (9), 1757.
Quinatto, J., Zambelli, N. L. D. N., Souza, D. H., Rafaeli Neto, S. L. R., Cardoso, J. T. & Skoronski, E. 2019 Using the pollutant load concept to assess water quality in an urban river: the case of Carahá River (Lages, Brazil). *Revista Ambiente & Água* **14**, 1–11.
Rajkumar, H., Naik, P. K. & Rishi, M. S. 2022 A comprehensive water quality index based on analytical hierarchy process. *Ecological Indicators* **145**, 109582.
Rath, H. S., Das, M. & Dash, U. N. 2019 Determination of water quality index for Brahmani River in terms of physico-chemical parameters for suitability of drinking purpose. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)* **8** (6), 613–620.
Sánchez, J. A., Velasco, M. J. F., Belmonte, U. L. J. & Manzano, A. F. 2019 The worldwide research trends on water ecosystem services. *Ecological Indicators* **99**, 310–323.
Sarkar, C. & Abbasi, S. A. 2006 QUALIDEX–a new software for generating water quality indices. *Environmental Monitoring and Assessment* **119**, 201–231.
Sedeño-Díaz, J. E. & López-López, E. 2007 Water quality in the Río Lerma, Mexico: an overview of the last quarter of the twentieth century. *Water Resources Management* **21**, 1797–1812.
Şener, Ş., Şener, E. & Davraz, A. 2017 Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). *Science of the Total Environment* **584**, 131–144.
Shi, P., Zhang, Y., Li, Z., Li, P. & Xu, G. 2017 Influence of land use and land cover patterns on seasonal water quality at multi-spatial scales. *Catena* **151**, 182–190.
Tian, Y., Jiang, Y., Liu, Q., Dong, M., Xu, D., Liu, Y. & Xu, X. 2019 Using a water quality index to assess the water quality of the upper and middle streams of the Luanhe River, northern China. *Science of the Total Environment* **667**, 142–151.
Trinh, L. 2008 *Nghiên cứu phân vùng chất lượng nước theo các chỉ số chất lượng nước (WQI) và đánh giá khả năng sử dụng các nguồn nước sông, kênh rạch ở vùng TP.* Ho Chi Minh Department of Science and Technology, Hồ Chí Minh. (in Vietnamese).
Venkatramanan, S., Chung, S. Y., Lee, S. Y. & Park, N. 2014 Assessment of river water quality via environmentric multivariate statistical tools and water quality index: a case study of Nakdong River Basin, Korea. *Carpathian Journal of Earth and Environmental Sciences* **9** (2), 125–132.
Verma, R. K., Murthy, S., Tiwary, R. K. & Verma, S. 2019 Development of simplified WQIs for assessment of spatial and temporal variations of surface water quality in upper Damodar river basin, eastern India. *Applied Water Science* **9**, 1–15.

Vietnam's Government. 2013 *Directive Dispatch of the Prime Minister on 2 About Dong Nai 6 and 6A Power Projects. Official Letter No. 7958/VPCP-KTN Issued on September 23, 2013 by the Office of the Government (in Vietnamese)*.

Zhang, J., Li, S., Dong, R., Jiang, C. & Ni, M. 2019 Influences of land use metrics at multi-spatial scales on seasonal water quality: a case study of river systems in the Three Gorges Reservoir Area, China. *Journal of Cleaner Production* **206**, 76–85.

First received 25 March 2023; accepted in revised form 5 May 2023. Available online 17 May 2023