Recommending Surface Water Quality Monitoring for the Nature Reserve Using Multivariate Statistical Methods

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Abstract

Lung Ngoc Hoang Nature Reserve has a crucial role in conserving and protecting the natural ecosystem and biodiversity in the Mekong Delta, Vietnam, and the local communities also receive great benefits from aquatic resources in this nature reserve. This study was conducted to assess water quality in the Lung Ngoc Hoang Nature Reserve and to provide important information for the monitoring program using multivariate statistical methods. Water samples were collected bimonthly from fifteen locations belonging to five functional zones of the nature reserve (i.e., buffer zone, main canal, administrative and service zone, ecological restoration zone, and strictly protected zone). The physiochemical properties of water samples were measured, including temperature, pH, electrical conductivity (EC), total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), sulfate (SO_4^{2-}), iron (Fe^{2+}), and aluminum (Al^{3+}). The results showed that the levels of TSS, COD, and Fe^{2+} exceeded the Vietnamese standard on surface water quality, and the DO level was also far below the standard. Besides, the concentrations of TN, TP, and Al^{3+} in the nature reserve area showed the risk of eutrophication and negative effects on aquatic organisms. Problems of water quality were observed in the main canal and the administrative and service zones more than in the other zones. Cluster analysis (CA) suggested a reduction in the number of monitoring frequencies and locations to four months (i.e., January, April, July, and September) and twelve locations, respectively. This reduction allows for a decrease in the effort and cost of the monitoring program with adequate information to evaluate water quality. Moreover, principal component analysis (PCA) identified five principal components, which could explain 80.98% of the total variance of the initial dataset. Potential pollution sources were also recognized based on PCA, including the nature properties of sulfate-acid soils, livestock, fertilizer, and domestic activities. The findings of this study can enhance our understanding of water quality in the nature reserve area and the effectiveness of future monitoring programs.

Keywords: Water Quality; Lung Ngoc Hoang Nature Reserve; Organic Pollution; Cluster Analysis; Nutrients.

1. Introduction

Due to the degradation of biodiversity, a lot of nature reserves have been established in Vietnam in order to protect important species in nature. Lung Ngoc Hoang Nature Reserve is one of the crucial biodiversity and habitat conservation areas of the Mekong Delta [1, 2]. It is a substantial wetland area stretching from the west of the Hau River to the Ca Mau peninsula in Phung Hiep district, Hau Giang province. The total land area of the nature reserve is 2800 ha, with a buffer zone of 8836 ha. It is divided into three main subdivisions: a strictly protected zone (1015 ha), an ecological restoration zone (937.11 ha), and an administrative and service zone (846.92 ha). Lung Ngoc Hoang Nature Reserve has an important role in protecting the unspoiled melaleuca forest wetland ecosystem and diverse native plant and animal

species. It is home to about 206 animal species and 330 flora species [3, 4]. Some species in the Red Book of Vietnam are found in this area, such as hairy-nosed otters, cobras, and box turtles. In addition to the biodiversity benefits, Lung Ngoc Hoang Nature Reserve also brings economic benefits to the surrounding communities through abundant shrimp and fish resources. According to the fire prevention policy of Lung Ngoc Hoang Nature Reserve, a sluice gate will be closed to store water inside the canals at the end of the rainy season and remain during the dry season. Due to the lack of water circulation and the degradation of organic matter, the water in the Nature Reserve changed to a black color [5]. This water quality deterioration has significantly influenced the indigenous habitats and species in this area, especially Melaleuca [5]. Moreover, surface water in this province also has problems with high concentrations of organic matter, nutrients, coliform, and iron [6–8]. According to Quang & Giao (2023), the enrichment of organic matter and nutrients in surface water in Hau Giang province was determined by the composition of the phytoplankton species [9]. This has resulted in the risk of high contaminant concentrations in the canals of the natural reserve. Therefore, it is necessary to conduct regular monitoring programs to evaluate water quality and promptly propose solutions to protect the biodiversity of the natural reserve.

Regional or national monitoring programs on water quality are conducted annually and create a large dataset with many parameters, locations, and monitoring frequencies. This has caused difficulties in storage as well as consuming a lot of money and effort. Moreover, the traditional method to evaluate environmental quality is unable to exploit the large amount of original data thoroughly, thus failing to provide comprehensive water quality status [10–13]. Multivariate statistical analyses, such as principal component analysis (PCA) and cluster analysis (CA), are of great interest in the field of water quality assessment. PCA is considered a dimension-reduction technique [13]. In other words, the original variables will be reduced into a few new variables, which are defined as principal components (PCs). Despite the smaller amounts of PCs, these are able to ensure the representation of the original data and also determine potential pollution sources [6, 13]. In addition to PCA, CA is widely applied to classify the monitoring sites into simplified clusters based on the similarities within the cluster and also the differences between clusters [13, 14]. These multivariate statistical techniques have successfully supported water quality monitoring and management. For example, based on the results of PCA, anthropogenic activities, such as wastewater from the city and fertilizer industry and agricultural runoff, were pollution sources in the Gorai River, Bangladesh [14]. According to Giao (2020), the number of monitoring points could be diminished to 26 from 42, which has helped to reduce about 32% of the monitoring costs [6]. To the best of our knowledge, there is no available study on water quality at the Lung Ngoc Hoang Nature Reserve applying multivariate statistical analysis. In the context of global water scarcity and the impact of climate change, it is required to perform proper analysis methods to fully understand water quality status, especially in the natural reserve areas. Therefore, the objective of this study was to evaluate surface water quality using PCA and CA methods and to provide important information for developing the monitoring programs at the Lung Ngoc Hoang Nature Reserve.

2. Material and Methods

2.1. Water Sampling and Analysis

The water samples were collected in five different functional zones of the Lung Ngoc Hoang Nature Reserve, as illustrated in Figure 1. These are the main canal (KC), buffer zone (VD), administrative and service zone (DV), ecological restoration zone (ST), and strictly protected zone (NN). A total of 15 sampling points comprises 3 in KC (KC01, KC02, and KC03), 2 in VD (VD01 and VD02), 3 in DV (DV01, DV02, and DV03), 3 in ST (ST01, ST02, and ST03), and 4 in NN (NN01, NN02, NN03, and NN04).
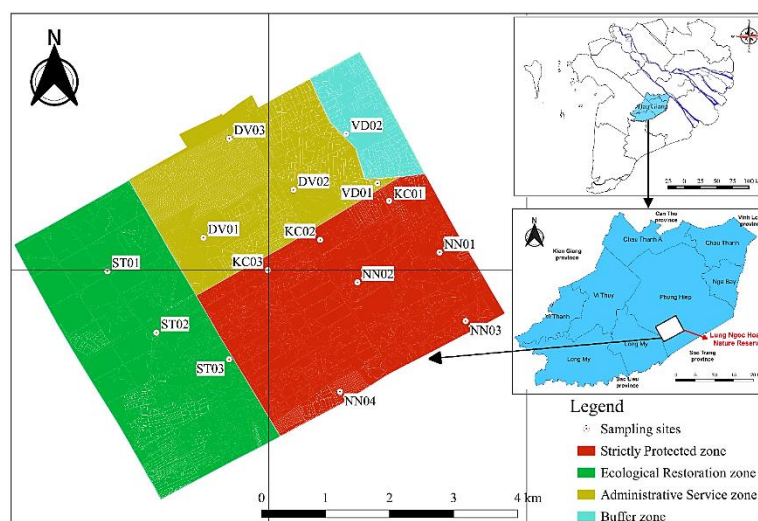

Figure 1. Map of the sampling locations in the Lung Ngoc Hoang Nature Reserve

Water samples were collected three times in the rainy season (May, July, and September 2019) and three times in the dry season (November 2019, January, and April 2020). In order to ensure representativeness and homogeneity, water samples at each sampling point were collected three times and then mixed to create a composite sample. The mixed water samples were stored in polyethylene bottles and transported to a laboratory for further analysis. In this study, twelve physiochemical parameters were measured to assess water quality, including temperature, pH, electrical conductivity (EC), total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphate (TP), sulfate (SO_4^{2-}), iron (Fe^{2+}), and aluminum (Al^{3+}). pH, temperature, EC, and DO were recorded on-site using a handheld pH meter (ADWA AD-12), an EC meter (HM Digital COM100), and a DO/temperature meter (GONDO 7031 DO meter). The remaining parameters were analyzed in the laboratory according to the standard methods [15], presented in Table 1. One liter of water sample was passed through a filter paper that was then dried at 105°C to a constant weight. TSS was the total dry matter of solids remaining on the filter paper. The titration was used to analyze COD. Total nitrogen and phosphorus were estimated based on the Kjeldahl and ascorbic acid methods, respectively. Cations (Al^{3+} and Fe^{2+}) were determined by the eriochrome cyanine method and atomic absorption spectrophotometer, respectively. Based on the turbidimetric method, sulfate anions react with barium cations to form barium sulfate, which is measured at 420 nm. Regarding quality assurance and quality control, standard methods of APHA were selected to analyze the water samples. The handheld meters were calibrated with buffer solutions before measuring the samples on-site.

Table 1. Methods of analysis of water quality parameters

No.	Parameters	Unit	Analytical methods
1	Temperature (T)	ºC	SMEWW 2550B:2017
2	pH	-	Measure directly with the Adwa AD12 pH meter in the field
3	Electrical conductivity (EC)	mS/cm	Measure directly with EC/TDS COM100 meter in the field
4	Dissolved oxygen (DO)	mg/L	Measure directly DO/temperature GONDO 7031 meter in the field
5	Total suspended solids (TSS)	mg/L	SMEWW 2540D:2012.
6	Chemical oxygen demand (COD)	mg/L	SMEWW 5220C:2012.
7	Biological oxygen demand (BOD)	mg/L	Improved Winkler method
8	Total nitrogen (TN)	mg/L	Kjeldahl method
9	Total phosphorus (TP)	mg/L	Ascorbic acid method, APHA 1998.
10	Aluminium (Al^{3+})	mg/L	Eriochrome cyanine method
11	Iron (Fe^{2+})	mg/L	Atomic absorption spectrophotometer
12	Sulfate (SO_4^{2-})	mg/L	Turbidimetric method

2.2. Data Analysis

The values of water quality parameters were compared with the Vietnamese regulation on surface water quality (QCVN 08-MT:2015/BTNMT), column A1 [16]. One-way analysis of variance (One-Way ANOVA) and Duncan's calculation at a 5% significance level were used to compare the difference in surface water quality between functional zones of the Lung Ngoc Hoang Nature Reserve. This analysis was processed using the IBM SPSS Statistics 20 statistical software for Windows [17]. Multivariate statistical analysis methods, namely PCA and CA, were conducted using Primer V5.2 for Windows license software (PRIMER-E Ltd., Plymouth, UK). For PCA, Varimax was selected for the axis rotation method.

3. Results and Discussion

3.1. Surface Water Quality Assessment in the Lung Ngoc Hoang Nature Reserve

The results of the physiochemical water quality parameters in the five functional zones of the nature reserve are shown in Figure 2. The average temperature between areas in the nature reserve was insignificantly different, ranging from 30.13±2.1 to 31.03±1.19°C. The administrative and service zone had the highest temperature with 31.03±1.19°C, and the strictly protected zone had the lowest temperature with 30.13±2.1°C. In addition, there was no statistically significant difference between functional zones (p>0.05). Temperature is an important factor for biological and physicochemical processes in aquatic environments and significantly affects aquaculture production [18]. The average water temperature in the study area is still within the tolerance limit of aquatic organisms and suitable for the growth of microorganisms [19]. The temperature recorded on the rivers and canals in Hau Giang province ranged from 28 to 29°C [6]. In general, there is no significant difference in water temperature in the Hau River and Hau Giang River compared with the study area [7, 20].
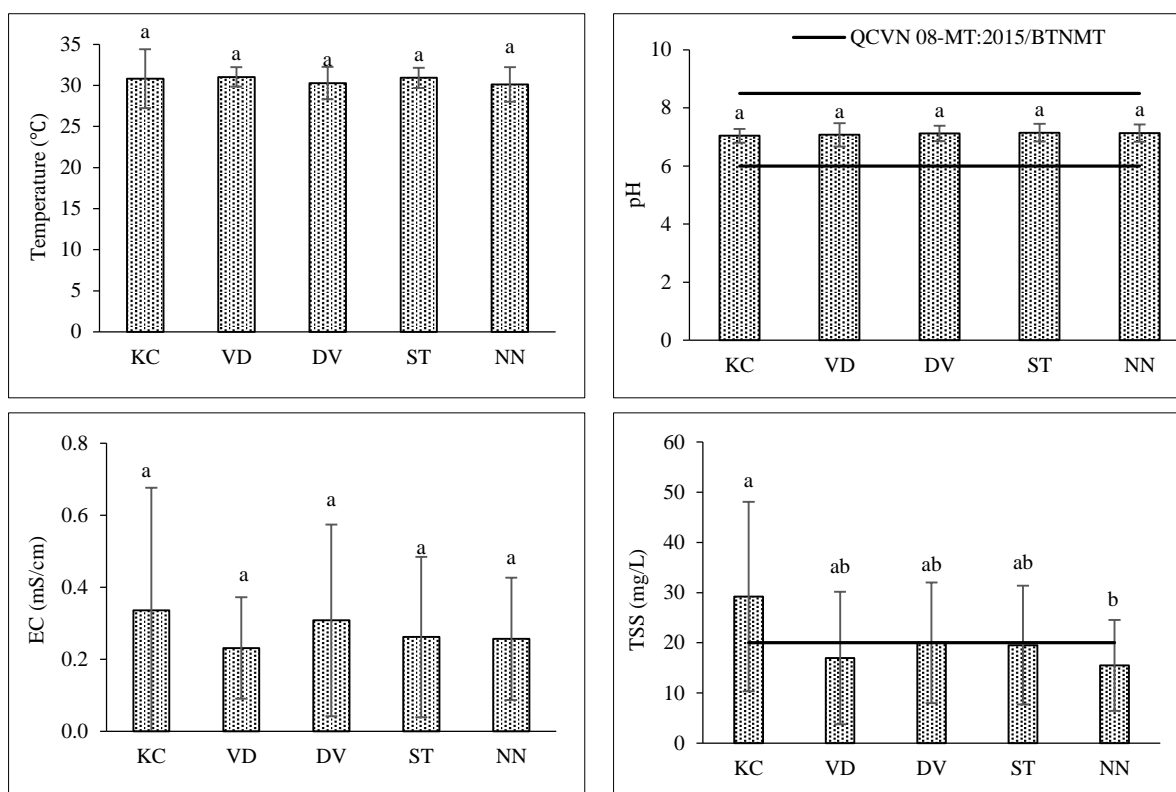
Figure 2. Physical parameters at functional zones of the Lung Ngoc Hoang Nature Reserve

pH is one of the crucial environmental factors influencing the growth of aquatic organisms. The pH values were marginally varied between functional zones, ranging from 7.04 ± 0.24 to 7.15 ± 0.31. This range was within the permissible limits of QCVN 08-MT:2015/BTNMT, column A1 (6 – 8.5) [16]. In addition, there is no statistically significant difference in pH between the functional zones ($p > 0.05$). It is consistent with previous studies on pH variation in Hau Giang province [6, 8, 9]. pH of surface water is generally varied from 6.64 to 7.34 [6, 8, 9]. This pH range can ensure the metabolism and biochemical reactions in the water environment take place normally and do not harm living organisms in water [20].

The EC values in the zones ranged from 0.23 ± 0.14 to 0.34 ± 0.34 mS/cm. The highest and lowest EC values were found in the main canal and the buffer zone, respectively. The main canals in the nature reserve could be affected by high salinity water from the canal outside, namely the Hau Giang 3 canal. Moreover, due to the properties of acidic soil in the nature reserve, the enrichment of iron, aluminum, and manganese salts can be released into water bodies [15]. There is no significant difference in EC between functional zones ($p > 0.05$). It is recommended that EC values in surface water should not exceed 1.5 mS/cm [14]. In Ca Mau province, the EC values were far higher than in this study, with an average of 12 ± 3.3 mS/cm in the wet season and 34.78 ± 0.47 mS/cm in the dry season [21]. In the Bzura River, Poland, EC values ranged from 0.27 to 1.3 mS/cm [12]. Higher values of EC in Malian River, China, were reported from 1.03 to 27.8 mS/cm because of natural weathering processes and industrial and sewage wastes [11].

TSS analyzed in the Lung Ngoc Hoang Nature Reserve ranged from 15.48 ± 9.05 to 29.22 ± 18.9 mg/L, falling into the buffer zone and main canal, respectively. Herein, high TSS in the main canal can be related to the domestic and navigation activities of the community in the nature reserve. The concentration of TSS in the strictly protected zone and the main canal is a statistically significant difference ($p < 0.05$), which is not different from the remaining zones. The average TSS concentrations in the administrative and service zone (20 ± 12.02 mg/L) and the main canal (29.22 ± 18.9 mg/L) exceeded the QCVN 08-MT:2015/BTNMT column A1 (20 mg/L) [16]. Previous studies revealed that TSS in surface water in Hau Giang province varied from 23.6 to 101.8 mg/L [6, 9], which is associated with navigation and domestic activities along the rivers. Moreover, TSS in the nature reverse is generally lower than in other regions, such as Can Tho (48.70 ± 6.67 mg/L) and Soc Trang (95.79 ± 8.45 mg/L) [8].

The results of the analysis of organic matter parameters in the functional zones of the nature reserve are shown in Figure 3. Oxygen is one of the most important environmental parameters that directly affect the growth of aquatic organisms and the production of aquatic products through metabolism and environmental conditions [20]. The average DO concentration in the study area is very low, ranging from 1.95 ± 0.83 - 3.37 ± 2.32 mg/L. The DO level in the nature reserve areas was much lower than the standard QCVN 08-MT:2015/BTNMT (DO $\geq$ 6 mg/L) [16]. Moreover, there is a statistically significant difference in DO levels of the main canal, buffer zone and administrative service zones($p < 0.05$). It can be seen that low DO in the main canal and administrative and service zone is because various human activities occur in these areas and wastes from these activities are also discharged into water bodies. In addition, a low DO level

is also a sign of organic contamination due to the high oxygen demand of microorganisms to degrade contaminants [22]. According to Giao (2020), DO levels in Hau Giang province varied from 3.2 to 5.2 mg/L of in-field canals and 4.6 to 4.7 mg/L in Hau River [6]. Another study in Hau Giang province also showed that DO level was in the range of 2.48 to 4.68 mg/L [9]. The average DO levels in Can Tho city and Soc Trang province were 5.68±0.16 and 3.11±0.64 mg/L, respectively [8]. In addition to DO, another parameter to determine the level of organic pollution is BOD. As presented in Figure 3, BOD levels in the study area ranged from 3.36±1.53 to 4.06±1.46 mg/L, and there is no statistically significant difference between the functional zones (p>0.05). The lowest and highest BOD fell into the ecological restoration zone and the buffer zone, respectively. Moreover, only the buffer zone exceeded the allowable limit of QCVN 08-MT:2015/BTNMT, column A1 (4 mg/L) [16] because it is seriously influenced by agriculture and domestic activities. The results in this study are lower than those in Hau Giang province (9.02–1.23 mg/L) and Bac Lieu province (13.6 – 192.19 mg/L) [7, 23]. The COD concentration recorded in the nature reserve is very high, ranging from 32.10±17.92 to 43.85±24.76 mg/L. It is noted that the COD levels at all zones were greater than the allowable limit of QCVN 08-MT:2015/BTNMT, column A1, from 3.2 to 4.1 times. There is no statistically significant difference in COD level between functional zones (p>0.05). COD level in this study is generally higher than in other regions: from 12.58 to 27.76 mg/L of Can Tho, Hau Giang and Soc Trang [8] and from 13.50 to 21.50 mg/L of Hau Giang province [9]. It implies that inorganic and organic pollution is a major problem for the water systems in the nature reserve. Many studies have demonstrated that elevated COD levels are associated with the accumulation of organic pollutants originating from agricultural and domestic activities [24, 25].
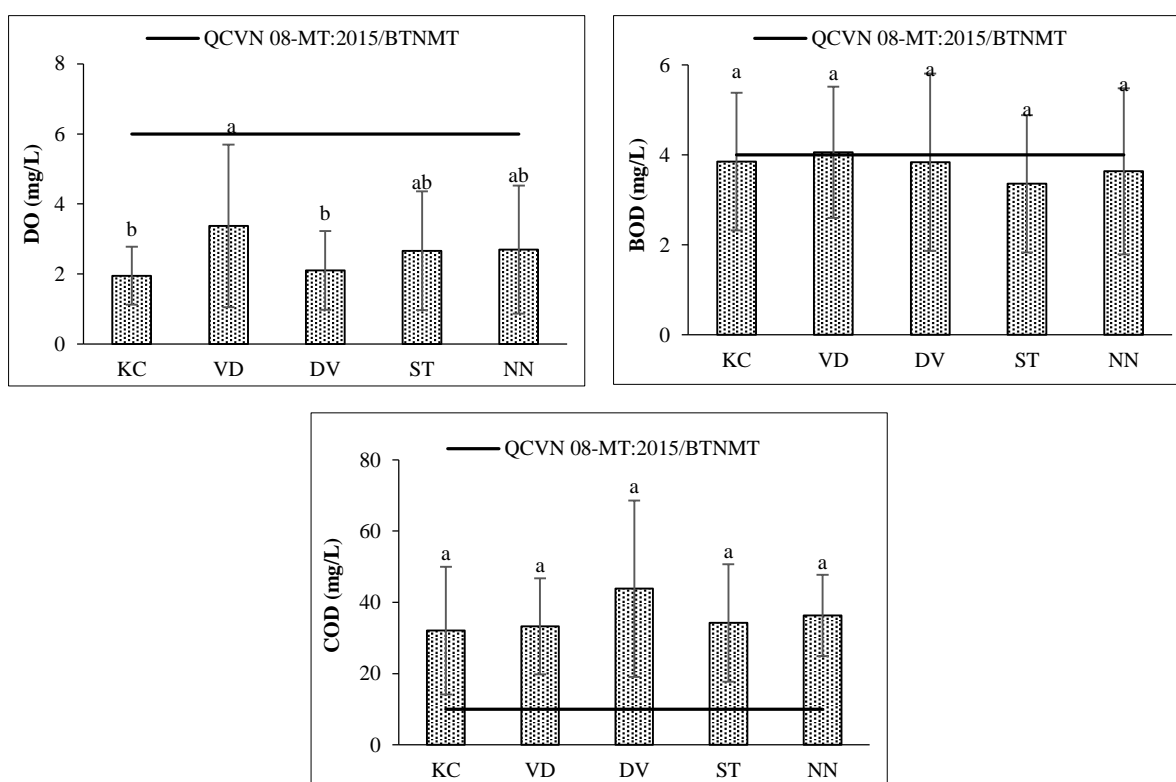
Figure 3. Organic matter parameters at functional zones of the Lung Ngoc Hoang Nature Reserve

The concentration of total nitrogen and total phosphorus in functional zones of the nature reserve is shown in Figure 4. Total nitrogen concentration is not significantly different between functional zones (p>0.05), ranging from 1.36±0.68 – 1.8±1.22 mg/L. The total nitrogen in the main canal was reported to be the highest because it is strongly affected by the agricultural and livestock activities of the residents along the canal. In the rainy season, water runoff carries excess fertilizer residue to the canals, thus causing high concentrations of total nitrogen in the study area [20]. The lowest total nitrogen was in the strictly protected zone of 1.36±0.68 mg/L because it is less susceptible to human impact. It is suggested that the level of total nitrogen in water bodies should be less than 1.5 mg/L in order to avoid eutrophication [26]. Total nitrogen in the study area was relatively lower than in Hau River, Vietnam (1.59–2.44 mg/L) [27] and in Malian River, China (0.43–73.60 mg/L) [11]. The enrichment of nitrogen in the Malian River was related to waste from livestock activities [11]. As shown in Figure 4, total phosphorus in the nature reserve ranged from 0.21±0.09 – 0.26±0.11 mg/L, and there is no significant difference in total phosphorus between functional zones (p>0.05). Both total nitrogen and total phosphorus have not been regulated in the Vietnam standard QCVN 08-MT:2015/BTNMT. According to Amic and Tadic, once the total phosphorus concentration is greater than 0.1 mg/L, eutrophication is likely to occur [28]. Thus, water bodies in the study have the risk of eutrophication, which in turn influences aquatic life in the nature reserve. In the Malian River, the total phosphorus varied from 0.03 to 0.16 mg/L due to domestic and livestock activities [11].
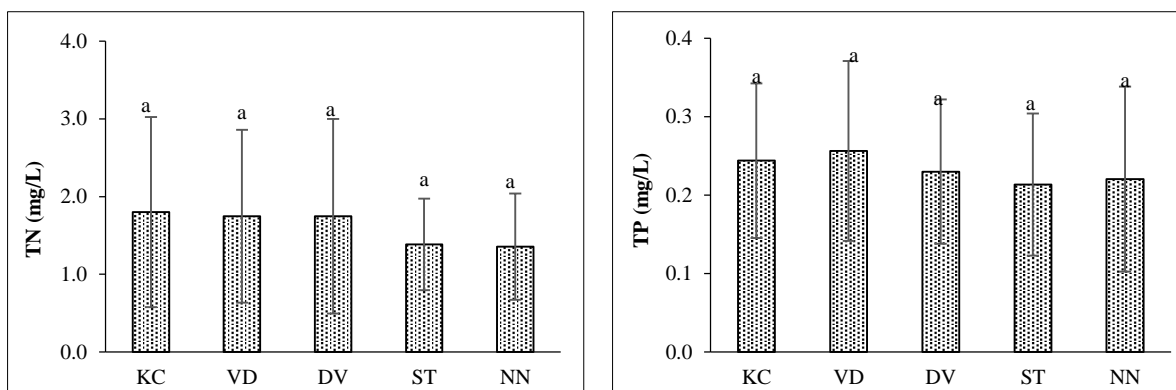
Figure 4. Nutrient parameters at functional zones of the Lung Ngoc Hoang Nature Reserve

The concentrations of SO_4^{2-}, Fe^{2+} and Al^{3+} in the Lung Ngoc Hoang Nature Reserve are shown in Figure 5. The results showed that the average SO_4^{2-} values in five functional zones were insignificantly different ($p>0.05$), ranging from 27.47 ± 12.12 to 30.52 ± 16.45 mg/L. In addition, the SO_4^{2-} concentration in the study area was much higher than that in Dong Thap ($18.04 - 28.65$ mg/L) [29]. In Gorai River, Bangladesh, the average concentration of SO_4^{2-} was 12.73 ± 4.68 and 7.88 ± 1.03 mg/L in the rainy and dry seasons, respectively [14]. In addition to anthropogenic impacts, the acid sulfate soil in the nature reverse is also responsible for the enrichment of SO_4^{2-}, Fe^{2+} and Al^{3+} [9]. The administrative and service zone has the highest Fe^{2+} and Al^{3+} concentrations with values of 0.78 ± 0.46 mg/L and 0.70 ± 0.76 mg/L, respectively. Meanwhile, the lowest Fe^{2+} and Al^{3+} concentrations were found in the strictly protected zone, with values of 0.46 ± 0.3 mg/L and 0.4 ± 0.39 mg/L, respectively. The Fe^{2+} concentration in the study area is relatively lower than in Bac Lieu province ($0.11 - 4.84$ mg/L) and Soc Trang ($0.30 - 3.75$ mg/L) [23, 30]. The concentration of Fe^{2+} in all functional zones exceeded the standard (0.5 mg/L) except for the strictly protected zone. The Al^{3+} concentration in the functional zones of the nature reserve has no statistically significant difference with each other ($p>0.05$). The concentration of Fe^{2+} and Al^{3+} in the administrative and service zone is the highest, possibly because this is the main operating area of the conservation area management board and has many constructions, so the bare land occupies a large area. When it rains, it is easy to wash alum into the canals, so the Fe^{2+} and Al^{3+} concentration in this area always reaches the highest value compared to the remaining zones. High concentrations of Al^{3+} would reduce the number of fish and amphibians due to the reaction of aluminum ions with proteins in the gills and embryos of frogs and also affect birds and other animals that eat fish [31].
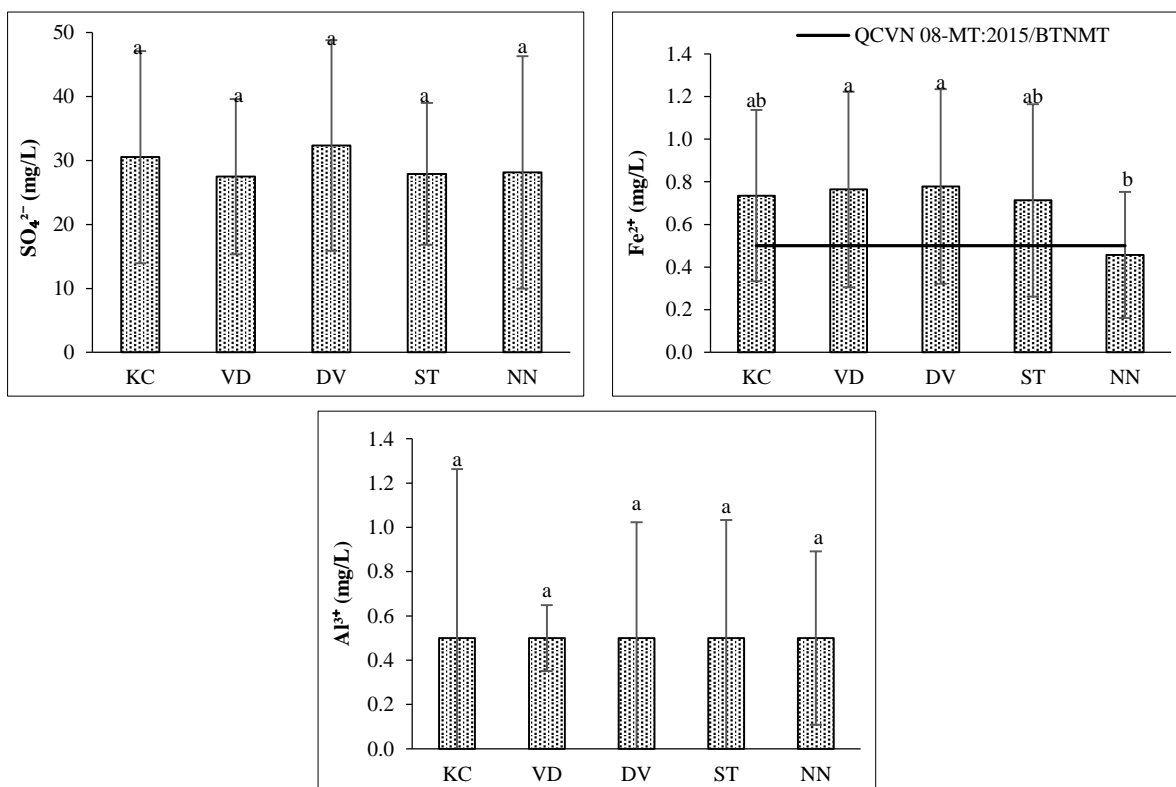

Figure 5. SO_4^{2-}, Fe^{2+} and Al^{3+} parameters at functional zones of the Lung Ngoc Hoang Nature Reserve

3.2. Recommendations for Monitoring Frequency and Location in the Lung Ngoc Hoang Nature Reserve

As mentioned in the previous section, the water quality monitoring program in the nature reserve was conducted six times per year. CA has grouped monitoring periods with high similarities in water quality into a cluster, as illustrated in Figure 6. A total of six monitoring periods were classified into four clusters at an Euclidean distance of five. Clusters II, III, and IV consist of July, January, and April, respectively. Cluster II represents the middle months of the rainy season, while clusters III and IV represent the middle and late months of the dry season, respectively. Meanwhile, cluster I includes three months (i.e., May, September, and November), representing the months of the rainy season and the beginning of the dry season. Only one month can be selected to evaluate water quality in cluster I. Therefore, January, April, July, and September were selected, representing the water quality in the study area.
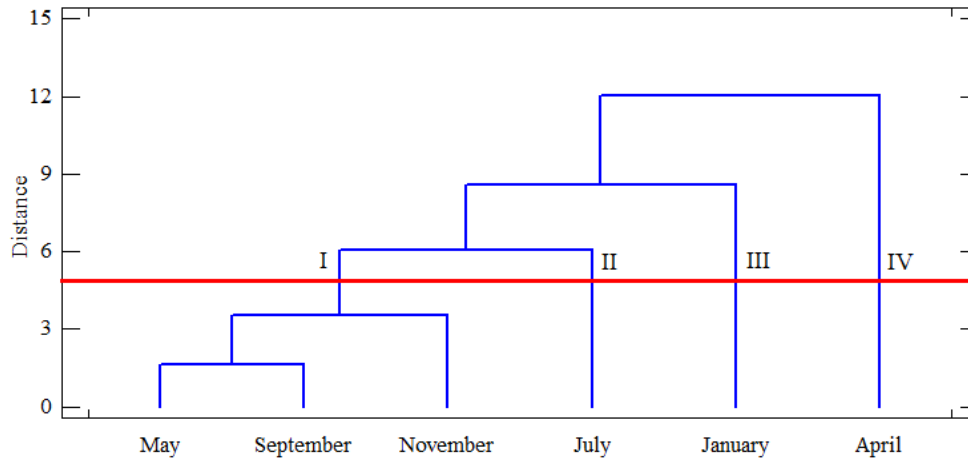

Figure 6. Frequency of water quality monitoring of the Lung Ngoc Hoang Nature Reserve

The CA method divided fifteen monitoring locations into five clusters based on their similarities in water quality, as shown in Figure 7. Cluster 5 includes three locations, ST01, NN02, and NN04 (which account for 20% of the total sampling sites), which are located in the strictly protected zone. Therefore, the water quality in this area was better than in other areas.
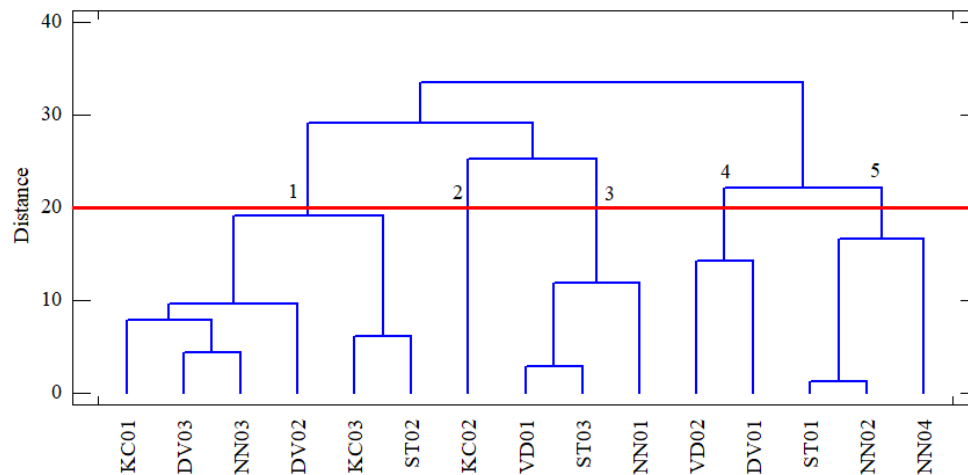

Figure 7. Clustering water quality monitoring locations of the Lung Ngoc Hoang Nature Reserve

Cluster 1 includes six positions (i.e., ST02, KC01, KC03, DV02, DV03, and NN03), with about 40% of the total sampling sites. Four locations in this cluster belong to the administrative service zone and main canal. As a result, this cluster shows signs of high organic pollution because this is an area with a large population concentration and agricultural activities. Cluster 2 has only one location, KC02 (6.67%), which is located in the main canal in the nature reserve. There were three locations in cluster 3, including VD01, ST03, and NN01 (which made up 20%). These locations are mainly located in the buffer zone, administrative service zone, and ecological restoration zone. Cluster 4 was formed by two locations, VD02 and DV01 (13.33%). These two locations were recorded in areas affected by residential areas. Based on the results of CA, the number of sampling locations could be reduced by maintaining only one sampling location per zone in each cluster. Thus, three locations (KC01, DV02, and NN02 or KC03, DV03, and NN04) might not need to be monitored in the next sampling periods.

3.3. Potential Pollution Sources of Water Quality in The Nature Reserve

PCA was conducted to provide a better understanding of the relationship between water quality monitoring parameters and also to figure out the potential sources of pollution. Components are considered principal components (PCs) once their eigenvalues are larger than 1 [13]. Table 2 presents the results of PCA, including five PCs and their corresponding loading factors for water quality parameters. An absolute value of the loading factor reveals a weak (0.3-0.50), moderate (0.50-0.75), and strong (>0.75) correlation to each PC [13]. As given in Table 2, five PCs could explain 80.98% of the total variance in the original data. PC1 had a weak correlation with EC, TSS, DO, TN, Fe^{2+}, and Al^{3+}, which could explain 29.06% of the total variance. Only DO showed a negative correlation in this PC. PC1 denotes the impacts of both natural and anthropogenic activities. Rainwater runoff can carry a large amount of soil, sand, dust, and fertilizer residues into the canal, causing a high TSS concentration in the water and reducing the DO level in the water. The nature properties of sulfate acid soil in the nature reserve also contribute to the enrichment of Fe^{2+} and Al^{3+} and high EC. PC2 explained 18.98% of the total variance, with a weakly negative correlation with BOD, COD, and SO_4^{2-} and a positive correlation with temperature. Moreover, a moderately negative correlation between pH and PC2 was recorded. PC2 could reflect the influence of organic pollutants on water quality as a result of manure poultry from livestock activities. pH and SO_4^{2-} could be related to the sulfate-acid soil properties in this area. PC3 explained 12.98% of the total variance, and it had a negatively moderate correlation with temperature and a weak correlation with DO. Temperature has a significant influence on the solubility of oxygen. Moreover, PC3 had a positively weak correlation with total phosphorus, which implies the effect of domestic wastewater and the residue of phosphorus-containing fertilizer in water bodies. PC4 and PC5 explained 10.50 and 9.46% of the total variance, respectively. PC4 had a weakly negative correlation with TSS and a positive correlation with BOD and TN. This PC also had a moderately positive correlation with total phosphorus. Thus, it can share the same pollution sources as PC3. PC5 had a moderately negative correlation with COD and a positive correlation with BOD. Moreover, these two PCs also represent the problems of nutrient and organic matter pollution associated with domestic activities, agriculture, and livestock production in the nature reserve.

Table 2. Methods of analysis of water quality parameters

Variables	PC1	PC2	PC3	PC4	PC5
Temperature	-0.07	0.30	-0.57	0.16	-0.39
pH	-0.24	-0.53	-0.18	-0.11	-0.06
EC	0.33	-0.26	0.03	0.02	-0.12
TSS	0.42	-0.05	-0.10	-0.37	0.14
DO	-0.34	-0.25	-0.36	0.17	0.16
BOD	0.04	-0.33	-0.27	0.41	0.52
COD	-0.08	-0.35	0.20	0.26	-0.67
SO_4^{2-}	0.22	-0.47	0.27	-0.05	0.00
TN	0.37	-0.02	-0.23	0.39	-0.17
TP	0.15	0.20	0.41	0.59	0.14
Fe^{2+}	0.39	0.01	-0.22	0.13	0.03
Al^{3+}	0.41	-0.07	-0.23	-0.19	-0.11
Eigenvalues	3.49	2.28	1.56	1.26	1.14
% Variation	29.06	18.98	12.98	10.50	9.46
% Cum. Variation	29.06	48.04	61.02	71.51	80.98

4. Conclusion

In this study, water quality in the Lung Ngoc Hoang Nature Reserve was evaluated using multivariate statistical methods, namely PCA and CA. The results indicated that water quality in the nature reserve is facing problems of organic (DO, COD), nutrient (TN, TP), and inorganic (Al^{3+}, Fe^{2+}) pollution. It was even worse in some areas, such as the main canal and the administrative and service zones, where the activities of the local people greatly impacted surface water quality. The results of CA based on the similarities in water quality characteristics suggest having only four monitoring times and twelve locations in the next monitoring program. Furthermore, 5PCs obtained from the PCA method could explain 80.98% of the total variance. In addition, the results of PCA also determined that natural factors (e.g., sulfate-acid soils) and anthropogenic activities (e.g., livestock, fertilizer, domestic wastewater) are potential sources of water pollution. This present study evaluated the status of water quality in the Lung Ngoc Hoang Nature Reserve, which helps managers take proper actions to protect water quality as well as biodiversity and the natural ecosystem. Moreover, multivariate statistical analysis methods are also recommended for further studies to extract important information for the monitoring programs.

5. Declarations

5.1. Author Contributions

5.2. Data Availability Statement

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

5.3. Funding

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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