Variation of Surface Water Quality at Bung Binh Thien Reservoir, An Giang Province, Vietnam Using Principal Component Analysis

Nguyen Thanh Giao, Truong Hoang Dan, and Huynh Thi Hong Nhien*

***Abstract*—This study was conducted to assess surface water quality at Bung Binh Thien reservoir, An Giang province, Vietnam. Sixty inhabitants living around the reservoir were interviewed to identify pollution sources. Nine water samples were collected in the dry and rainy seasons and then analyzed for eighteen variables (temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), turbidity (Turb), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), sulfate (SO_4^{2-}), chloride (Cl^-), ammonia (NH_4^+-N), nitrate (NO_3^--N), total nitrogen (TN), orthophosphate (PO_4^{3-}-P), total phosphorus (TP), and coliform). Principal component analysis (PCA) was used to identify the primary parameters influencing water quality. The results indicated that the major concerns for water quality in the reservoir were suspended solids, organic matters and fecal microbes. There were significant seasonal variations in water quality. While organic pollution was mainly observed in the dry season, the microbial problem was recorded in the rainy season. This pollution was associated with domestic wastes, agricultural production, livestock, and aquaculture. The PCA results also revealed that DO, BOD, COD, N-NH_4^+, N-NO_3^-, P-PO_4^{3-}, TP, Cl^-, and coliform greatly influenced water quality variations, thus requiring these parameters in the monitoring program. The local authority should apply proper measures to improve water quality in the reservoir, and inhabitants should not directly use water for their domestic activities without adequate treatment.**

***Index Terms*—An Giang, Bung Binh Thien, coliforms, organic matters, PCA, suspended solids.**

I. Introduction

Bung Binh Thien, a natural lake, is considered the largest lake in the Mekong Delta, Vietnam, with a total surface area of about 200 ha (dry season) and 800 ha (rainy season). It is surrounded by three communes (Nhon Hoi, Quoc Thai and Khanh Binh), An Phu district, An Giang province. The average size of the lake is 4 m in depth, 2900 m in length, and 430 m in width. The lake was connected to Binh Di and Hau rivers in the past. However, the Hau river has been disconnected from the lake due to sedimentation. Currently, local people use this water resource for domestic and agricultural activities. However, water quality in the lake is endangered by human activities such as the discharge of improperly-treated wastewater, ineffective management of solid wastes, and freely raising ducks and fish. At the local level, An Giang's People Committee issued the decision in 2016 to plan Bung Binh Thien Lake with the areas of 706.82 ha to become a place for conserving freshwater resources and flora and fauna and storing water for domestic and agricultural uses. In order to accomplish these goals, the status of lake water quality, pollution sources, and monitoring strategies need to be identified and established.

Nevertheless, interpretation of the monitoring data has not been completed effectively because of the lack of suitable methods to handle large and complex databases. To overcome this limitation, multivariate statistical methods have been widely applied [1], [2]. The application of these techniques can reduce data dimensions and interpret the analyzed environmental data with insignificant loss of information in the initial dataset [3]. Recently, water quality data has been explained using cluster analysis (CA) and principal component analysis (PCA). These techniques could help explain and correlate a large number of gauging locations and various water quality parameters [4]. Multivariate statistical techniques were successfully applied for explaining spatiotemporal water quality data in the Marikina river [2], Yeongsan Reservoir [1], and rivers from central Transylvania [3]. Additionally, they also support identifying water pollution sources [2], [5], designing sampling networks [6], and extracting the most crucial parameters for evaluating water quality variability [4]. Therefore, this study aims to apply multivariate statistical techniques to assess spatiotemporal variation of water quality in Bung Binh Thien reservoir and extract water quality parameters that are most representative of the lake. A future monitoring program at the lake can be optimized based on the obtained results.

II. Materials and Methods

A. Investigation of Pollution Sources

Sixty people living in three communes Nhon Hoi, Quoc Thai and Khanh Binh, in the vicinity of Bung Binh Thien reservoir, were interviewed using structured questionnaires. Demographic information like name, age, gender, and education levels was collected. The current situation of waste generation and management and the change in water quality at Bung Binh Thien over the last five to ten years according to interviewees' perspectives were also gathered.

B. Method for Collection and Analysis of Water Samples

Bung Binh Thien reservoir is subjected to various pollution sources from solid and liquid wastes. Waste treatment facilities are unavailable for pollution sources. Water quality characterization was determined by physical, chemical and biological parameters. Temperature (^oC), pH,

Manuscript received December 28, 2021; revised January 27, 2022; accepted June 7, 2022.

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doi: 10.18178/ijesd.2023.14.1.1412

electrical conductivity (EC, µS/cm), total dissolved solids (TDS, mg/L), total suspended solids (TSS, mg/L), depth (H, m) and turbidity (NTU) are physical variables. The chemical variables are dissolved oxygen (DO, mg/L), biological oxygen demand (BOD, mg/L), chemical oxygen demand (COD, mg/L), sulfate (SO_4^{2-}, mg/L), chloride (Cl^-, mg/L) ammonium (NH_4^+-N, mg/L), nitrate (NO_3^--N, mg/L), total nitrogen (TN, mg/L), orthophosphate (PO_4^{3-}-P, mg/L), and total phosphorus (TP, mg/L). Coliform (MPN/100mL) is a biological indicator for the occurrence of fecal materials in the study area. These water quality parameters were selected based on the literature review [1], [2], [4] and the potential sources of water pollution (domestic wastewater, aquaculture, agriculture, etc.) at the Bung Binh Thien reservoir. The eight water samples (designated VT1-VT8) were collected inside the lake, and one sample (denoted VT9) was collected in the Binh Di River directly connected to the lake. Sample sites are demonstrated in Fig. 1. The samples were collected in the dry season (12 January 2019) and rainy season (12 October 2019). Temperature, EC, TDS, DO, and depth were measured at the field using handheld meters. The other parameters of water quality analysis and quality control were performed using Standard Methods for the Examination of Water and Wastewater [7].

Fig. 1. Sampling locations at Bung Binh Thien reservoir.

C. Data Analysis

Data of water quality were presented as Mean±SD. Positive or negative correlation coefficients indicate the two water variables are proportional relation or inverse relation, respectively [3]. The mean values of samples were the inputs for Pr

incipal Component Analysis (PCA). PCA has been extensively used in multivariate analysis to extract important information from the original dataset [1]-[3]. PCA reduces initial data variables that contribute insignificantly to data variation while creating a group of new variables called principal components or primary factors (PCs or PFs). These PCs are not interconnected and appear in descending order of importance. The important factor to consider is the eigenvalue coefficient which measures the significance of the components. The larger the coefficient, the greater the contribution it could make to explain the variation of the original dataset. Varimax was widely used as a rotation method, and each of the original data variables will be associated with one component. Each component represents only a small set of variables [3]. The correlation between the main components and the initial data variables was indicated by loadings [3]. In this study, PCA was performed using Primer 5.2 for Windows (PRIMER-E Ltd, Plymouth, UK).

Water Quality Index (WQI) was calculated based on Equation 1 which is based on Decision No. 879/QD-TCMT of the Vietnam National Administration [8].

$$WQI = \frac{WQI_{pH}}{100} \times \left[\frac{1}{5}\sum_{a=1}^{5} WQI_a \times \frac{1}{2}\sum_{a=1}^{2} WQI_b \times WQI_c\right]^{\frac{1}{3}} \quad (1)$$

where, WQI_a is WQI calculated for DO, BOD_5, COD, NH_4^+-N, PO_4^{3-}-P; WQI_b is WQI calculated for TSS and turbidity; WQI_c is calculated for total coliform; and WQI_{pH} is WQI calculated for pH. where, the $WQI_{a,b,c}$ values are calculated by formula 2, except for the DO parameter which is calculated by formula 3.

$$WQI_{SI} = \frac{q_i - q_{i+1}}{BP_{i+1} - BP_i} \times \left(BP_{i+1} - C_p\right) + q_{i+1} \quad (2)$$

$$WQI_{DO} = \frac{q_{i+1} - q_i}{BP_{i+1} - BP_i} \times \left(C_p - BP_i\right) + q_i \quad (3)$$

BP_i, BP_{i+1}, q_i, and q_{i+1} are the values specified by the Vietnam Environment Administration (2011) [8]. C_p is the value of the observed parameter to be included in the calculation.

III. Results and Discussion

A. Sources of Pollution Generation in Bung Binh Thien

The interview results showed that most participants work as hired laborers and seasonal workers, local traders, and farmers yielding rice and fruit trees, accounting for 30.00, 28.33, and 11.67%, respectively. The ratio of people growing vegetables, livestock, and aquaculture accounted for 5% to 10%. In addition, 3.33% of the total has the main income from the government subsidy. The activities of the inhabitants around Bung Binh Thien reservoir could cause adverse effects on the surface water quality. Several sources of water pollution in the reservoir are illustrated in Fig. 2. Domestic wastewater showed the greatest impact on the water quality by 24.18% because there is no sewage collection system in the survey area. Wastewater from cultivation contributed 23.08% to water pollution, while solid waste management contributed 20.88%. Wastes from aquaculture and livestock processes together contributed about 6.59%. According to the interview, Binh Di River and dead aquatic plants inside the Bung Binh Thien reservoir contributed to the pollution problem by 18.68% (Fig. 2).

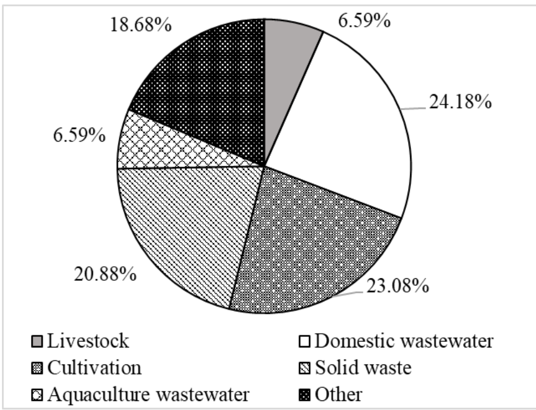

Fig. 2. The sources contribution (%) affected water environment.

Different perspectives on the changes in water quality in the last 5 to 10 years are presented in Fig. 3. The total percentage of interviewees recognizing the slight to heavy deterioration of water was 76.7%. Meanwhile, the remaining (23.3%) answered that water quality has remained unchanged. Households in the latter group are using water directly from Bung Binh Thien for their daily activity because they cannot afford tap water. However, they sometimes had problems with odor and opaqueness of this water source.

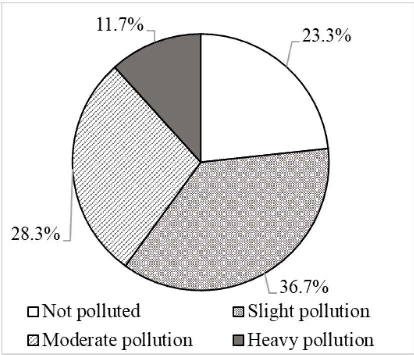

Fig. 3. Perception of local inhabitants on water quality in Bung Binh Thien.

B. Variations in Water Quality in Bung Binh Thien Reservoir

Spatiotemporal variations in physical water quality parameters are presented in Fig. 4.

The water temperature in the study sites slightly varied between the two seasons, ranging from 28.07±0-30.03±0°C (dry season) and 28.57±0-31.6±0°C (rainy season). There was an insignificant difference between the internal and external areas of the reservoir. The temperature changes in the study area depend on the weather, reservoir depth, water exchange, and flow velocity [9]. The turbidity values measured in the rainy season were significantly higher than in the dry season, ranging from 3.27±0.3-130.67±0 NTU. The higher turbidity in the rainy season was caused by higher suspended solids [10] and resulted from runoff and overflow in the rainy season [11]. pH values were neutral, ranging from 7.55±0.025-7.85±0.006 in the dry season and from 7.42±0.00-7.85±0.006 in the rainy season. Compared to previous studies in Bung Binh Thien, the pH values in this study were higher [12]. The TSS content in the dry season ranged from 44±1.00-53.33±0.577 mg/L, which was lower than in the rainy season (44.67±0.577-79.67±2.517 mg/L). TSS depends on organic matters, soil, and silt, and it is also directly correlated to turbidity in water. High TSS could increase temperature and reduce dissolved oxygen in water [13], [14]. EC values fluctuated mildly between the two surveying periods and the sampling locations. The values of EC in the dry season (123.70±0.06-137.37±0.15 µS/cm) were higher than those in the rainy season (129.20±0.02-135.7±0 µS/cm). The EC values were unfavorable for large fish and invertebrates in freshwater. TDS in the dry season (61.80±0.265-68.57±0.462 mg/L) was higher than in the rainy season (64.77±0.058-71.27±0.404 mg/L), which was almost proportional to the EC [15]. The main sources contributing to higher TDS may be agricultural flows and domestic discharges from the human activities living around the reservoir. In general, there was no significant change between the above parameters, except for TSS and turbidity. The fluctuation of TSS and turbidity is due to rainwater and other overflow runoff.

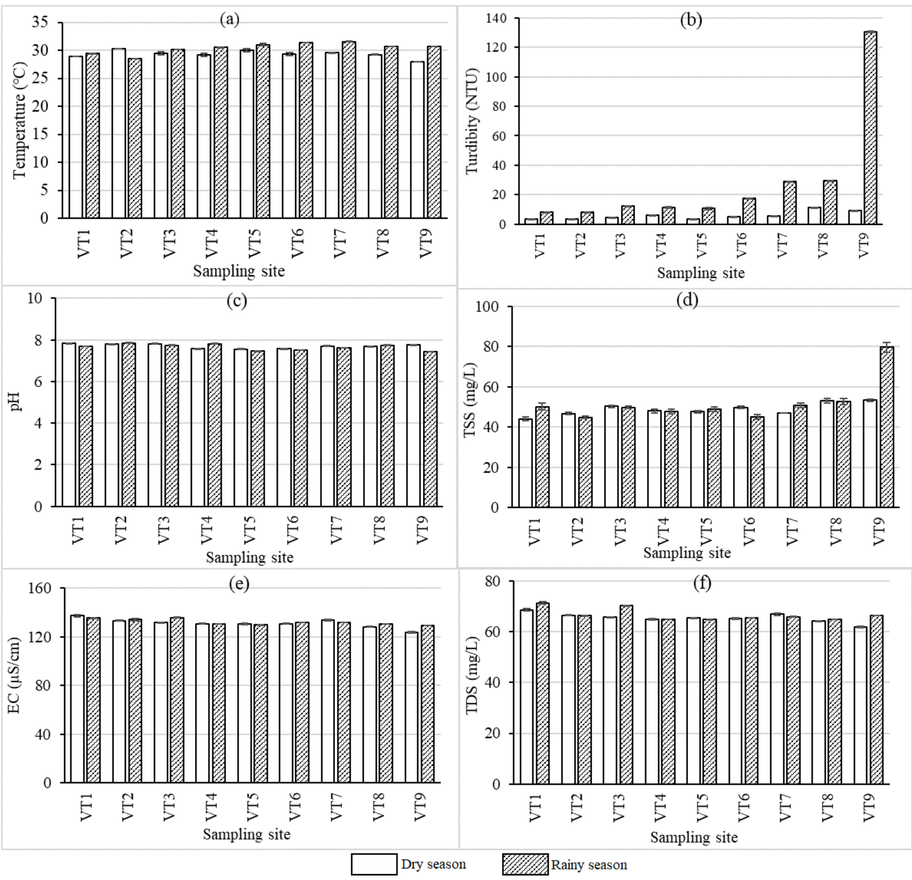

Fig. 4. Physical water quality parameters at Bung Binh Thien reservoir.

Dissolved oxygen concentration in the dry season (5.33±0.03-9.17±0.03 mg/L) was dramatically higher than in the rainy season (4.65±0.01-4.86±0 mg/L). This result is consistent with the temperature measurement that the warmer temperature may reduce oxygen dissolved in water [16], [17]. In addition, the reduction of DO in the rainy season may be owing to the reduction of photosynthesis and increased respiration of aquatic plants [18]. However, the current DO in the reservoir would not harm aquatic life (> 3.0 mg/L) [19]. The BOD concentration ranged from 10± 0-11.67±0.577 mg/L (dry season) and 8±0-10.667±0.577 mg/L (wet sesason). The concentration of COD in the dry and wet seasons varied from 15±0-17.67±0.56 mg/L and 12±0-16.67±0.56 mg/L, respectively. The BOD and COD concentrations tended to decrease gradually during the rainy season. This result is consistent with previous studies in the study area [20] and the Hau river [21], [22].

Ammonium and nitrate were low and ranged from 0.0±0.00 to 0.62±0.002 mg/L and 0.0±0.013 to 0.13 ±0.002 mg/L, respectively. It was observed that ammonium and nitrate were lowest in the dry season and highest in the rainy season. pH value in the study area could increase the toxicity of ammonia in the water [23]. Total nitrogen in the dry season was not detected at all sampling locations, and the failure to detect TN could be due to the uptake of aquatic phytoplankton plants. However, TN in the rainy season was detected to be relatively high, ranging from 1.49±0.16 to 3.08±0.14 mg/L. Eutrophication could occur in the reservoir during the rainy season since TN of greater than 1.7, contributing to the organic pollution from activities and water runoff from agricultural areas [24]. Orthophosphate concentrations in the dry and wet seasons were almost undetectable, except for VT9 (outside reservoir) in both seasons and VT7 in the rainy season. Total phosphorus (TP) concentration in the dry and rainy seasons varied from 3.09±0.006-9.2±0.132 mg/L and 1.3±0.00-4.83±0.012 mg/L, respectively. Eutrophication could occur in the reservoir when TP is greater than 0.1 mg/L [25]. The chloride concentration recorded in the dry season ranged from 7.23±0.00 to 8.44±0.00 mg/L and in the rainy season ranged from 9.69±0.41 to 12.33±0.40 mg/L. The concentration of SO_4^{2-} ranged from 1.04±0.0-2.25±0.04 mg/L in the dry season and 4.84±0.02-6.0±0.04 mg/L in the rainy season. The concentration of Cl^- and SO_4^{2-} in the rainy season was significantly higher than that of the dry season, indicating seasonal variation of these two species. In addition, human activities also influence Cl^- and SO_4^{2-} [4]. Coliform in the rainy season (2300±0-24,000±0 MPN/100mL) was 1.05-2.59 times higher than that in the dry season (2300±173.21-9300±0.0 MPN/100mL). An increase in coliform density during the rainy season may limit the usage of this water source for daily demands. In summary, organic pollution was recorded mainly during the dry season, while coliform, nutrients and ions were significantly high in the rainy season.

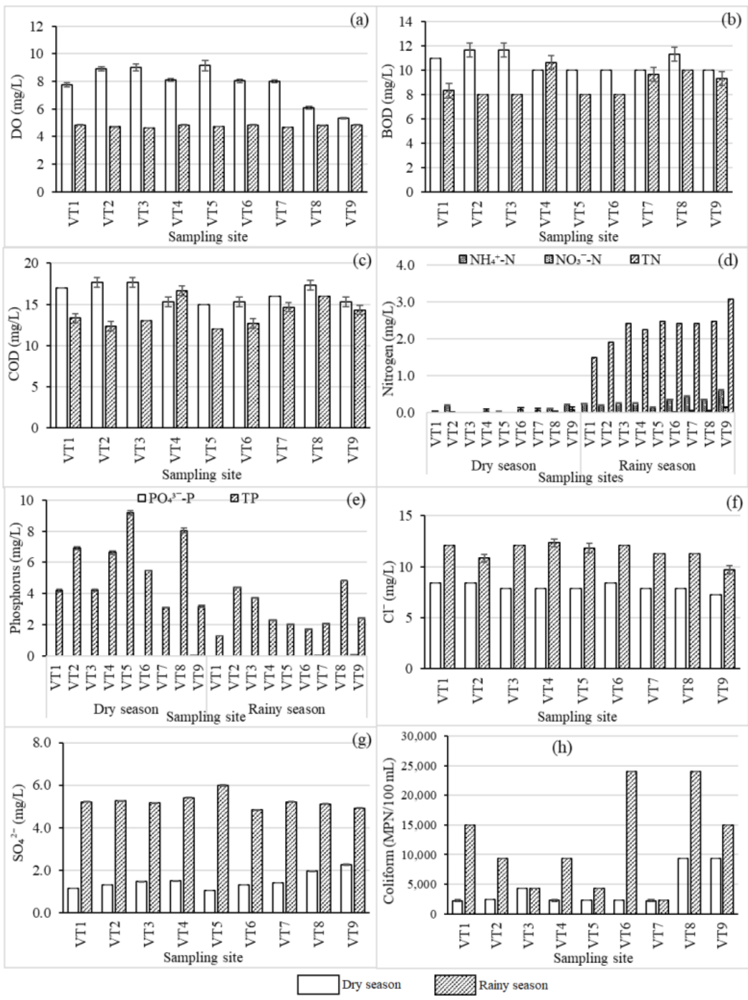

Fig. 5. Chemical and biological water quality parameters at Bung Binh Thien reservoir.

C. Factors Leading to Changes in Water Quality

As shown in Table I, five PCs could explain 95.1% and 91.7% of water quality variations in the dry and rainy seasons, respectively. The PC with the highest Eigenvalues is the most important, and the Eigenvalues coefficient of 1.0 or higher is considered significant [26], [27]. According to Liu et al. (2003) [28], the correlation coefficient (loading) is called high if the absolute value is > 0.75, moderate if the absolute value is between 0.75 and 0.50, and the correlation coefficient is considered weak if the absolute value is in the range of 0.50-0.30.

In the dry season, PC1 explained 52.7% and was poorly correlated with EC, TDS, TSS, SO_4^{2-}, and coliform; that is, PC1 composition originates from natural processes and high solid waste-containing sources. In addition, it may be affected by other water bodies [27]. PC2 explained 20.2% of water quality variation and correlated with pH, BOD and COD with moderate loadings of -0.486, -0.514 and -0.524, respectively. PC3 explained that 11.5% of the water variation was mainly contributed by pH (-0.333) and TP (0.683). PC4 only explained the variation of water quality by 6.3 % by NH_4^+-N (0.605), temperature (-0.304), DO (0.302), PO_4^{3-}-P (0.308). The eigenvalues coefficient of PC5 was 0.7 <1, only explaining 4.4% of the data variability. However, this PC5 highly correlated with Cl^- (-0.685) and relatively related with the occurrence of NH_4^+-N (-0.307) and NO_3^--N (-0.474).

TABLE I: THE RESULTS OF PCA IN THE DRY AND RAINY SEASON

Variable	Dry season					Rainy season				
	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4	PC5
Temp	-0.291	0.076	0.131	-0.304	0.174	-0.189	0.313	0.305	0.029	-0.232
Turbidity	0.286	-0.077	0.173	-0.421	-0.173	-0.347	-0.179	-0.021	-0.017	0.045
pH	-0.017	-0.486	-0.333	0.033	0.152	0.22	0.105	-0.348	-0.395	0.006
DO	-0.29	0.066	0.123	0.302	0.216	-0.108	0.154	-0.326	0.513	0.074
EC	-0.319	-0.08	-0.19	-0.13	-0.081	0.256	-0.369	-0.187	-0.113	-0.006
TDS	-0.321	-0.091	-0.175	-0.128	-0.043	0.152	-0.466	-0.168	0.038	0.242
TSS	0.3	-0.041	0.22	-0.164	0.061	-0.323	-0.209	-0.034	-0.029	0.145
BOD	-0.083	-0.514	0.169	0.012	-0.044	-0.164	0.382	-0.269	-0.196	0.351
COD	-0.089	-0.524	0.053	-0.11	-0.081	-0.136	0.359	-0.363	-0.178	0.3
NH_4^+-N	0.211	-0.216	0.039	0.605	-0.307	-0.34	-0.11	-0.13	-0.038	0.035
NO_3^--N	0.196	0.278	-0.347	-0.132	-0.474	-0.358	-0.126	-0.062	-0.028	-0.026
PO_4^{3-}-P	0.287	0.004	-0.268	0.308	0.158	-0.316	-0.182	0.09	-0.13	0.244
Cl^-	-0.269	-0.07	-0.007	-0.011	-0.685	0.278	0.216	0	0.222	0.143
SO_4^{2-}	0.328	-0.128	-0.031	-0.152	-0.02	0.151	0.203	0.388	-0.064	0.27
TN	-	-	-	-	-	-0.303	0.083	0.224	-0.11	-0.187
TP	-0.063	0.077	0.683	0.163	-0.174	0.023	0.052	-0.187	-0.503	-0.515
Coliform	0.301	-0.202	0.134	-0.189	0.068	-0.097	0.071	-0.382	0.397	-0.437
Eigenvalues	8.44	3.23	1.85	1	0.7	7.31	2.66	2.4	1.91	1.31
% Variation	52.7	20.2	11.5	6.3	4.4	43	16	14	11	8
Cum.% Variation	52.7	72.9	84.5	90.7	95.1	43	58.6	72.8	84	91.7

In the rainy season, PC1 explained 43% of the data variability, with a weak correlation with turbidity (-0.347), TSS (-0.323), NO_3^--N (-0.358), PO_4^{3-}-P (-0.316) and TN (-0.303). PC2 explained 16% variability in the water quality, contributing by temperature (0.313), EC (-0.369), TDS (-0.466), BOD (0.382) and COD (0.359). PC3 explained 14% of the variability, weakly contributed by temperature (0.305), pH (-0.348), DO (-0.363), SO_4^{2-} (0.388) and coliform (-0.382). The correlation of SO_4^{2-} and pH also indicated that water quality tended to acidify. This factor can be explained by the impact of household waste containing detergents and livestock waste because coliform is closely related to the pollutant indicated by feces [26]. PC4 explained 11% of data fluctuation, showing weak relation to DO (0.513), TP (-0.503) and coliform (0.397). This PC has been shown to reduce organic pollution during the rainy season. PC5 was contributed by BOD (0.351), TP (-0.515) and coliform (-0.437) and explained 8% of the data variation. BOD, TP and coliform could be from the sources of agricultural and livestock activities [29], [30].

The sources of water pollution in Bung Binh Thien reservoir in the dry season were closely related to pH, organic matters (BOD, COD), nutrients (NH_4^+-N, NO_3^--N, PO_4^{3-}-P and TP), and Cl^-. These parameters could be originated from domestic wastewater, husbandry, solid wastes, aquaculture and agricultural activities. However, during the rainy season, the water pollution was related to physicochemical processes (turbidity, TDS, DO) such as erosion, water exchange, aquatic life activities, etc.), overflow from agricultural and domestic activities (TP), especially livestock activities (coliform).

D. Assessing Water Quality Using WQI Index

The Vietnam Environment Administration (2011) [8] uses the WQI to evaluate water quality. The WQI ranged from 0 to 100, dividing water quality into five levels. Level 1 (100>*WQI*>91) is good water quality that could be used for water supply purposes. Level 2 (90>*WQI*>76) is also used for domestic water supply, but suitable treatment measures are required. Level 3 is for irrigation and other similar purposes (75>*WQI*>51). Level 4 (50>*WQI*>26) is the water suitable for transport and equivalent purposes, while Level 5 (25>*WQI*>0) is considered to be heavily polluted water that proper treatment measures are urgently needed.

In Bung Binh Thien reservoir, the WQI index ranged from 57-88 in the dry season and 11-79 in the rainy season. During the dry season, water quality in the study site was classified as clean (Level 2) that is suitable for supplying domestic water with the requirements of appropriate measures. This is excepted for VT8 and VT9 sites of Level 3 (Fig.6). In the rainy season, water quality became more polluted under Level 3 with WQI ranging from 57-79 (at locations VT2, VT3, VT4, VT5, and VT7) and Level 5 with WQI ranging from 11-18 (at locations VT1, VT6, VT8, VT9). The main cause of the change in water quality between the two seasons was the presence of organic matter (low DO, high TSS, and COD) and high microorganisms (coliform). This showed that people should restrict water use in Bung Binh Thien in the rainy season. The level of water pollution in Bung Binh Thien is consistent with the perception of people about the slightly polluted water quality. Both seasons showed that the WQI outside the Bung Binh Thien was lower than the inside. This was also consistent with the perception of local people that water flowing from upstream was also one of the pollution sources.

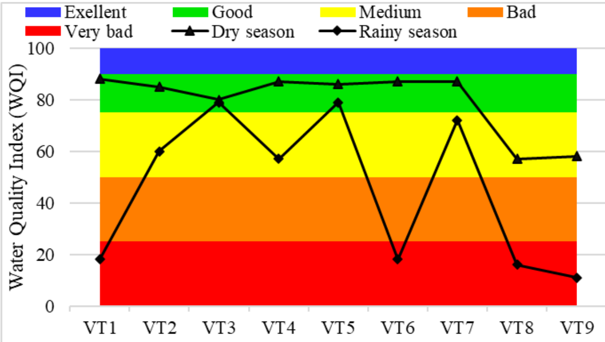

Fig. 6. Classification of water quality using WQI index.

IV. Conclusion

Water quality in Bung Binh Thien was assessed at the level of organic pollution and microorganisms (coliform). Significant seasonal variation has been observed in water quality, especially for coliforms. The main sources of pollution could be domestic wastes (sewage and solid waste), agricultural production, livestock, and aquaculture. Binh Di River greatly contributed to water pollution in the study area. Residents living in Bung Binh Thien have the right perception of the change in water quality. The parameters including pH, BOD, COD, N-NH_4^+, N-NO_3^-, P-PO_4^{3-}, TP and Cl^- significantly resulted in water quality variation in the dry season. Meanwhile, the variability of water was mainly caused by turbidity, DO, TP, and coliform in the wet season. Thus, water quality monitoring should consider the water quality parameters that resulted in the change in water quality in both seasons. There is a need to raise environmental protection awareness among the inhabitants living around Bung Binh Thien reservoir through educating and strictly implementing environmental protection laws.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

N.T.G, T.H.D and H.T.H.N, Conceptualization; N.T.G and T.H.D, Methodology; N.T.G and T.H.D, Validation; N.T.G and T.H.D, Investigation; N.T.G and T.H.D, Resources; N.T.G, Data curation; N.T.G, T.H.D, H.T.H.N, Writing-original draft preparation; N.T.G, Writing-review and editing, Supervision, Project administration; H.T.H.N, Software, Formal analysis, Visualization.

All authors had approved the final version.

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