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Long-Term Variation of Surface Water Quality at Bung Binh Thien, An Giang Province, Vietnam

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Abstract

This study uses the principal component analysis (PCA) to assess the variation of surface water quality in the Bung Binh Thien area (BBT), An Giang province. The samples of surface water quality were collected at three locations in BBT (BT1-BT3), with the frequencies of three times per year in March, June and September in the period from 2009 to 2020. The parameters of temperature, pH, total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), orthophosphate ($P\text{-}PO_4^{3-}$) and coliform were analysed for surface water quality assessment. The results showed that pH and temperature were within the allowable limits. The water quality at BBT was contaminated by organic matters, nutrients and coliform in which TSS and coliform were the most severe. The water quality in 2012 and 2017 was worse than the water quality in other years. PCA showed that the temperature, pH, TSS, DO, BOD, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, and coliform had significant influence on the surface water quality due to the potential pollution sources from domestic waste, livestock, aquaculture and agriculture.

1. Introduction

Bung Binh Thien (BBT) is known as one of the outstanding research sites in An Giang province, formed completely naturally. This is a natural freshwater ecosystem located in the upstream area of An Phu district, An Giang province. It is formed from a river section connecting Binh Di river with Hau river, due to the process of accretion over time at both ends. connected with two rivers to form a freshwater reservoir called BBT [1]. Therefore, this place will have low water level in the dry season and overflow in the rainy season because the water regime depends on the flow of water from the Mekong River [1]. This place is also known for its biodiversity, home to many aquatic species. According to [2-3], the BTT has 124 species of phytoplankton, 61 species of zooplankton, 18 species of large invertebrates, 111 species of fish. The site also includes six rare and precious species in the Red Book of Vietnam and one of them is Pangasius (*Notopterus notopterus*). In recent years, more and more people are living and implementing BBT-based livelihoods. People build raft villages, fish cages, bring tourism to other areas and freely fish. Bung Binh Thien has been mainly affected by natural and artificial sedimentation (agricultural farming), in addition to the influence of production and tourism activities [4]. The process of hydrological sedimentation is becoming more and more complicated. According to a study by [4], the water quality in Bung Binh Thien in the dry season of 2019 was assessed to be slightly polluted, especially BOD, COD, TSS, and Coliform exceed the allowable limit of the national technical regulation on

the surface water quality (QCVN 08-MT:2015/BTNMT) [5]. However, up until now, there is no long-term study on water quality fluctuations in Bung Binh Thien. Several previous studies [6-8] have used principal component analysis (PCA) to assess fluctuations of water quality and identify sources of pollution as well as criteria affecting water quality. This study was conducted to assess the water quality variation of BTT, An Phu district, An Giang province in the period 2009-2020. The results of the current study could contribute to providing important scientific information on the evolution of surface water quality in the study area, contributing to the planning of water use for people's living purposes and the conservation of biodiversity at BBT.

2. Materials and method

2.1. Water sampling and analysis

The research process collected samples at 3 locations in Bung Binh Thien namely BT1, BT2 and BT3 as seen from Table 1. At each sampling location, the frequency of monitoring samples was three times per year in March, June and September. This study used monitoring data collected from the Department of Natural Resources and Environment of An Giang province in the period from 2009 to 2020.

Table 1. Brief description of the sampling site

Sampling sites	Long	Lat	Location
BT1	1207451	533641	Hamlet 5, Khanh Binh Commune, An Phu District
BT2	1207408	534755	Hamlet 1, Quoc Thai Commune, An Phu District
BT3	1207971	536178	Hamlet 1, Quoc Thai Commune, An Phu District

The surface water monitoring data were collected at three locations with 10 indicators including temperature, pH, total suspended solids (TSS), dissolved oxygen (DO) biochemical oxygen demand (BOD), Chemical oxygen demand (COD), nitrate ($N\text{-}NO_3^-$), ammonium ($N\text{-}NH_4^+$), orthophosphate ($P\text{-}PO_4^{3-}$) and coliform were used to assess water quality. The parameters pH, temperature, DO were measure at the field while TSS, BOD, COD, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$ and coliform were collected, stored and analyzed according to standard methods [9]. The analytical methods of each indicator are listed in Table 2.

Table 2. Water quality parameters and sample analysis

No.	Variables	Unit	Analytical methods	QCVN, A1
1	Temp	^oC	pH Sensor pH31	-
2	pH	-	pH Sensor pH31	6.5 – 8.5
3	DO	mg/L	YSI 5000	≥6
4	TSS	mg/L	TCVN 6625:2000	20
5	COD	mg/L	TCVN 6491: 1999	10
6	BOD	mg/L	TCVN 6001-1:2008	4
7	$N\text{-}NH_4^+$	mg/L	TCVN 6179: 1996	0.3
8	$N\text{-}NO_3^-$	mg/L	TCVN 6180-1996	0.3
9	$P\text{-}PO_4^{3-}$	mg/L	SMEWW 4500-P.E:2012	0.1
10	Coliform	MPN/100mL	TCVN 6187-2:1996	2500

2.2. Data processing

In this study, individual parameters of surface water quality were assessed by comparing with those regulated in national technical regulation on surface water quality (QCVN 08-MT:2015/BTNMT, column A1). The overall water quality was assessed by water quality index (WQI) according to Decision 1460/QD-TCMT [10]. Table 3 presents the classification of surface water quality based on WQI. The difference in surface water quality values between years was performed using one-way ANOVA at the significant level of 5% using SPSS statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA). Principal component analysis (PCA) was used to identify the most influential indicators and predict the sources of water pollution. PCA analysis was performed using Primer 5 Windows software (PRIMER-E Ltd, Plymouth, UK) [11].

Table 3. Values of WQI and water quality

WQI	Classification	Purposes of uses
91 - 100	Excellent	Use for domestic water supply purposes
76 - 90	Good	Use for domestic water supply purposes but need appropriate treatment measures
51 - 75	Average	Use for irrigation and other equivalent purposes
26 - 50	Poor	Use for navigation and other equivalent purposes
10 - 25	Heavily polluted	Water is heavily polluted, needs future treatment measures
< 10	Very heavily polluted	Poisoned water, need to take measures to overcome and treat

3. Results and discussion

3.1. Evolution of surface water quality in Bung Binh Thien from 2009 to 2020

The average temperature value over time at the monitoring area ranges from 27.93±1.55 ^{o}C to 32.67±0.74 ^{o}C (Figure 1). The average temperature at the time of observation has the difference and the difference is statistically significant ($p<0.05$). The result of [12] showed that the temperature in the Mekong river basins widely fluctuates in the range of 19.9 ^{o}C-32.2 ^{o}C. Temperature fluctuation of the BBT study area is within the tolerant range of aquatic organisms [12]. The mean temperature in June of the year is usually higher and different than the rest of the years. This difference may be due to seasons.

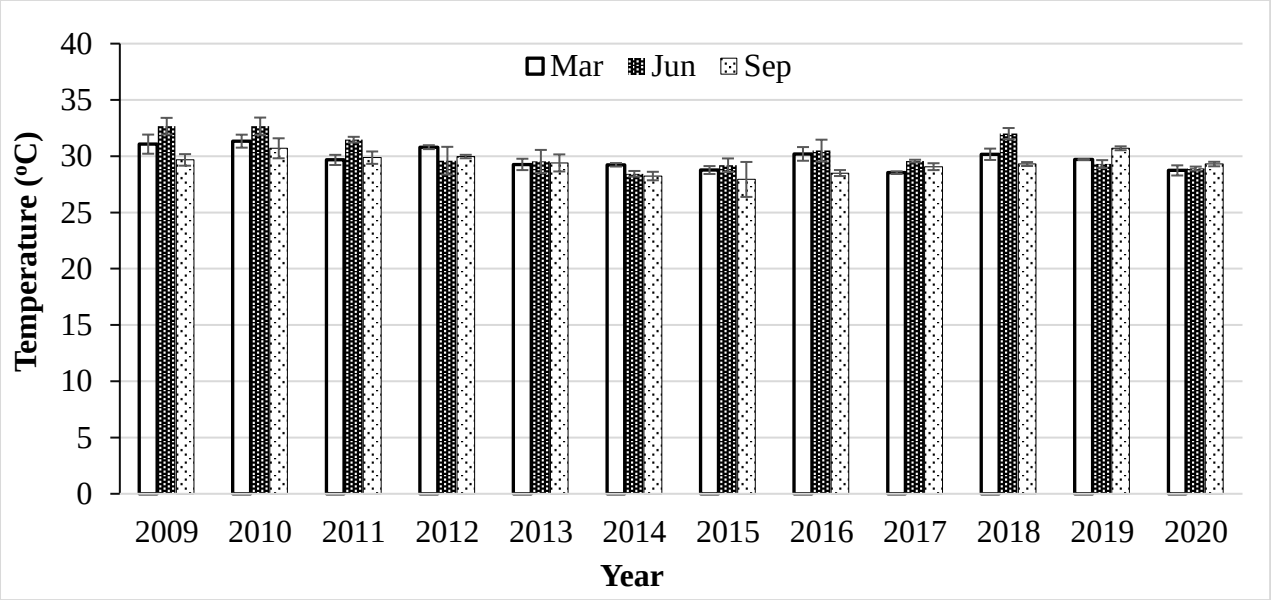

Figure 1. Long-term variation of temperature at BBT during 2009-2020

The pH value fluctuated in the study area over time from 6.5±0.45 to 8.49±0.17 (Figure 2). There is a difference in pH in the study area and at the same time there is a difference in terms of statistical significance ($p<0.05$). The pH value had no sign of exceeding the permissible limit of the column A1 of QCVN 08-MT:2015/BTNMT. The pH value is one of the environmental factors that have a great influence directly and indirectly on aquatic life such as growth, survival rate, reproduction and nutrition [13]. The water environment at BBT has a pH value of almost neutral, which ensures the normal growth and development of aquatic species.

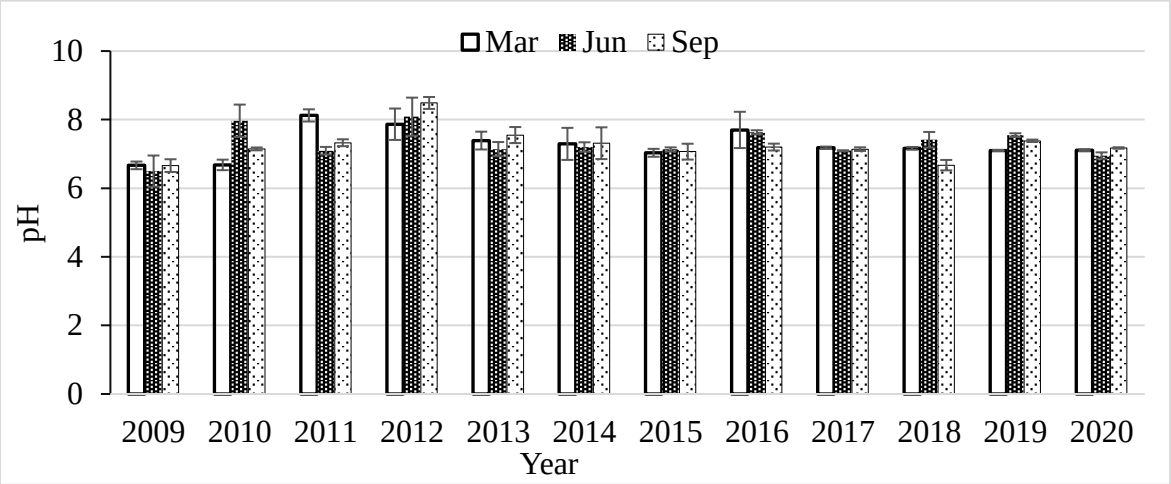

Figure 2. Long-term variation of pH at BBT during 2009-2020

According to the monitoring results, the average DO value ranges from 3.12±0.65 mg/L to 9.04±0.69 mg/L (Figure 3). Most of the observed values are lower than the permissible limit of the column A1 (DO≥6 mg/L) for aquatic life conservation (QCVN 08-MT:2015/BTNMT). DO values 2011, 2012 and 2014 satisfy the requirements of surface water quality standard. The reason for the low dissolved oxygen situation can be attributed to the increasing appearance of rafts, fish cages and mooring boats. Former study by [14] reported that water sources in the basins of main tributaries and rivers of Hau river route receive wastes from agricultural production, livestock wastewater and biological wastewater leading to low DO. Dissolved oxygen in water depends on metabolic processes to maintain energy for growth, reproduction, and reproduction for algae-rich microorganisms through photosynthesis [15]. Low DO could result in negative effects on aquatic organisms [12].

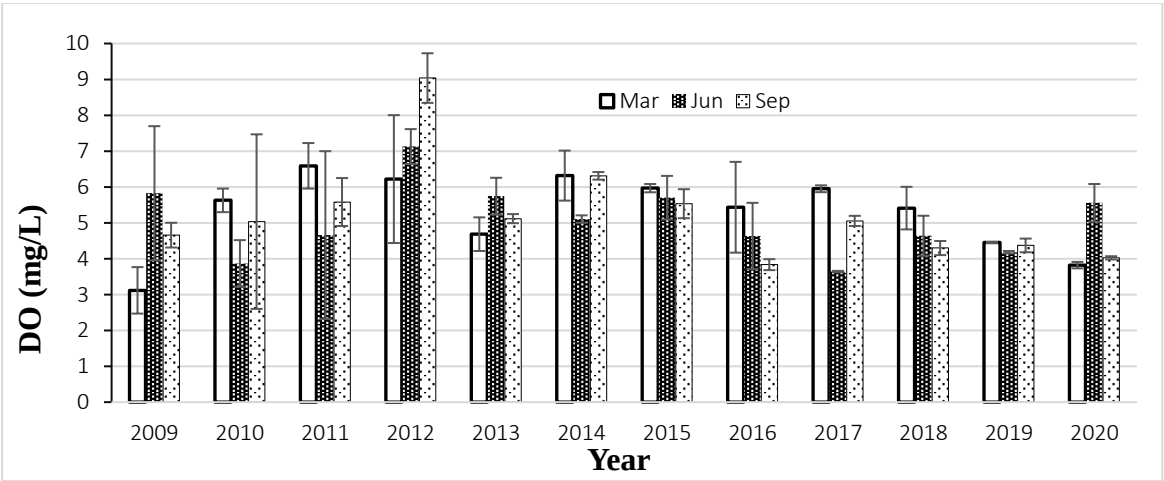

Figure 3. Long-term variation of DO at BBT during 2009-2020

Total suspended solids (TSS) values ranged from 8.67±2.08 mg/L to 120±27.51 mg/L (Figure 4). TSS values almost all exceed the allowable limit in column A1 of QCVN 08-MT:2015/BTNMT (20 mg/L). High TSS values appeared in 2015 (120±27.51 mg/L) was 6 times higher than the allowable threshold and TSS in 2010 (83.33±116.69 mg/L) was 4 times higher than the threshold. From 2016 to 2020, the TSS values showed signs of stabilizing but is still higher than the allowable limit. The causes of high TSS in the BBT can be attributed to erosion, silt, storm water runoff, and other activities [7]. This is a sign of concern because high TSS can be harmful to aquatic animals, hinder the photosynthesis of algae, make the water unusable for drinking and other domestic needs [13]. In addition, in water with high TSS, it is expensive to treat water supply, contains many harmful agents such as bacteria, chemicals from pesticides, heavy metals [12].

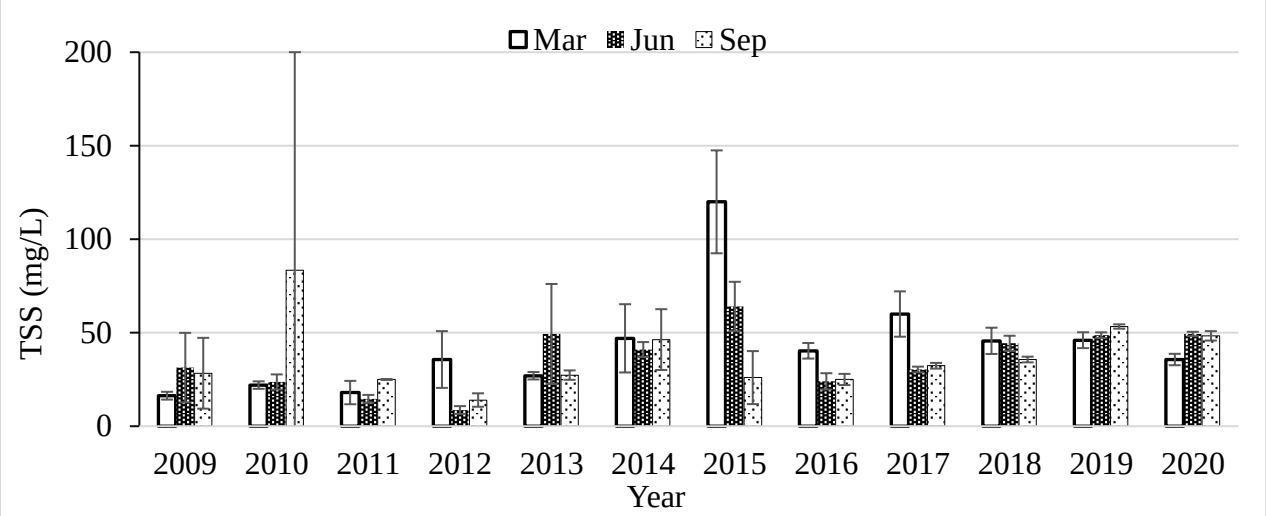

Figure 4. Long-term variation of TSS at BBT during 2009-2020

The COD parameter has been measured since 2015. COD values ranged from 10±1 mg/L to 32±2 mg/L (Figure 5). The monitoring results showed that the COD in the BBT study area was higher than the allowable threshold for column A1 of QCVN 08-MT:2015/BTNMT. COD values are usually low in June. Water contaminated by high COD could result in low dissolved oxygen in water. The cause of high COD can come from agriculture, aquaculture, tourism, and domestic activities. High COD can be harmful to organisms living in BBT.

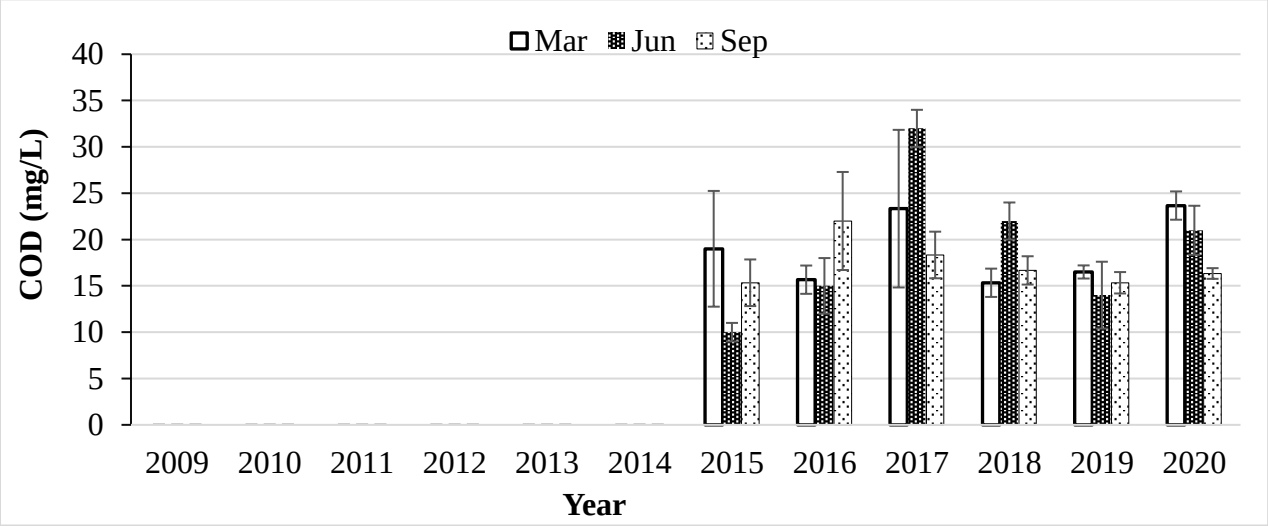

Figure 5. Long-term variation of COD at BBT during 2009-2020

Figure 6 shows the average BOD value fluctuations at BBT during the period 2009-2020. The monitoring results showed that the BOD value ranged from 3.67±1.15 mg/L to 24.67±2.08 mg/L (Figure 6). The mean BOD values in June in 2010 (3.67±1.15 mg/L) were within the limit of QCVN 08-MT:2015/BTNMT, column A1 while the mean values of BOD in the remaining months were all over the allowable threshold. The monitoring results of the BOD indicator was also consistent with the COD and DO results in this study.

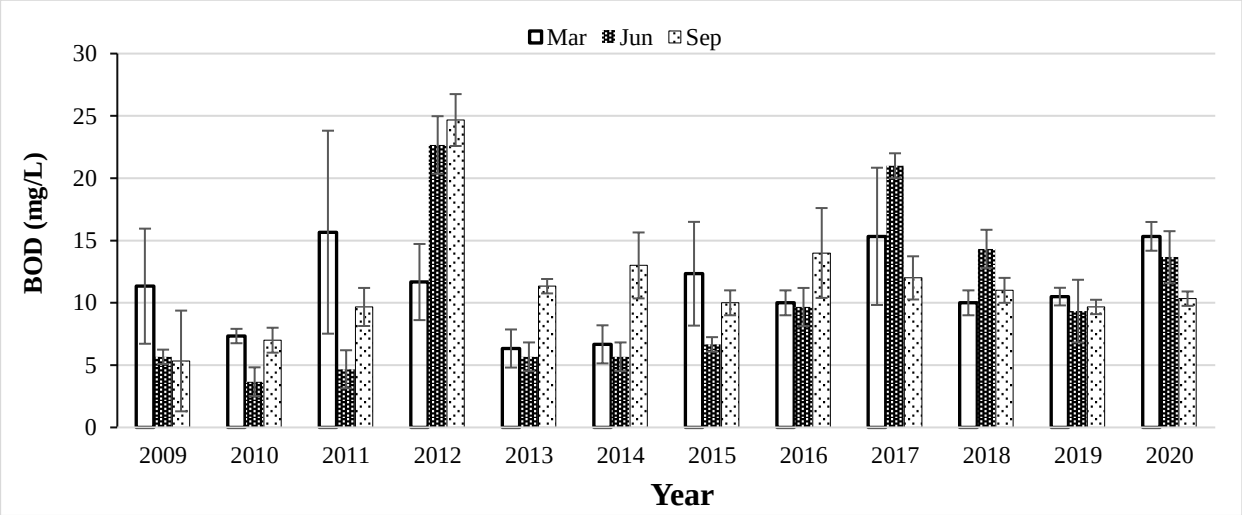

Figure 6. Long-term variation of BOD at BBT during 2009-2020

Nitrate ($N\text{-}NO_3^-$) values ranged from 0 mg/L to 0.8±0.19 mg/L (Figure 7). Most of the nitrate results were within the allowable limit of column A1 of QCVN 08-MT:2015/BTNMT (2 mg/L). However, nitrate concentrations in 2011 and 2012 both exceeded the permitted threshold of the standard. These were also the two years where nitrate concentrations were significant higher than the other years. High nitrate values can affect the growth of organisms and cause water poisoning affecting surface water quality.

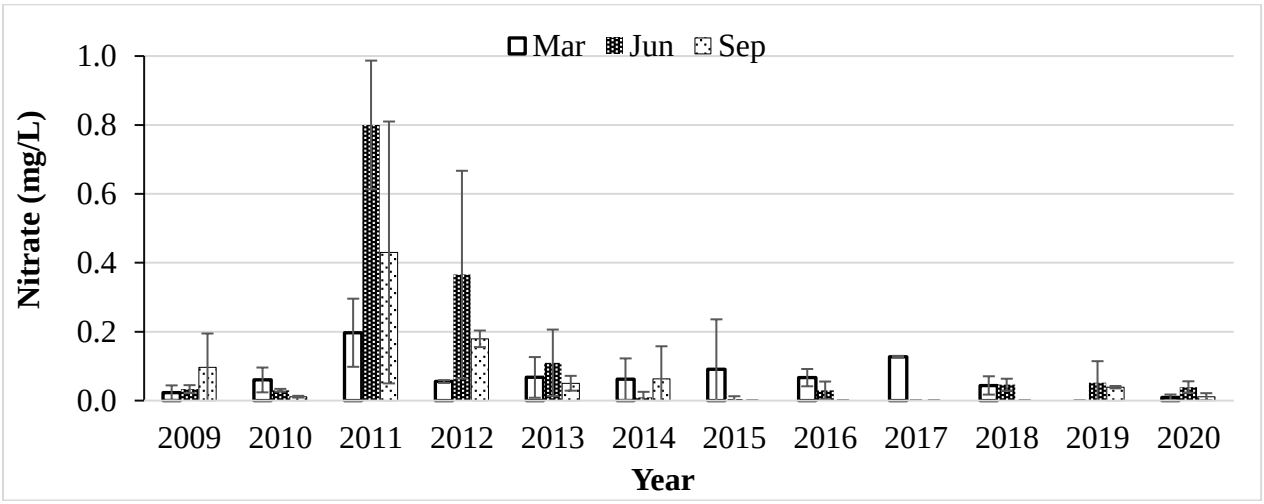

Figure 7. Long-term variation of nitrate at BBT during 2009-2020

Figure 8 showed the value of $P\text{-}PO_4^{3-}$ at BBT in the period 2009-2020, ranging from 0 mg/L to 0.22±0.22 mg/L, with a statistically significant difference ($p<0.05$). There were six monitoring results that exceeded the allowable threshold, the rest are within the allowable limit of column A1 of QCVN 08-MT:2015/BTNMT. Both high nitrate and orthophosphate can be traced back to agricultural activities, which makes Bung Binh Thien highly susceptible to eutrophication [1].

Along with nitrate, orthophosphate values were high in 2011 and 2012, which may also be the two most likely years for eutrophication.

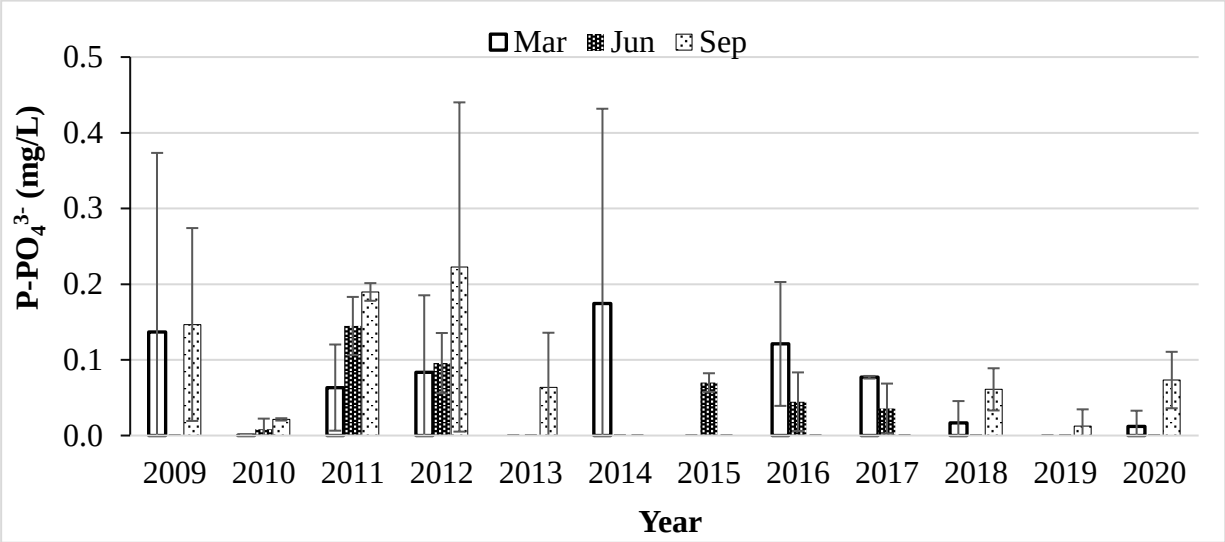

Figure 8. Long-term variation of $P\text{-}PO_4^{3-}$ at BBT during 2009-2020

Ammonium ($N\text{-}NH_4^+$) started collected since 2016, ranged from 0 mg/L to 0.39±0.17 mg/L as seen from Figure 9. The year of 2016 and 2017 were two years when $N\text{-}NH_4^+$ values were within the allowable threshold. During the years 2018, 2019 and 2020, $N\text{-}NH_4^+$ exceeded the allowable limit according to column A1 of QCVN 08-MT:2015/BTNMT. The monitoring results showed that the $N\text{-}NH_4^+$ value is increasing over the years, the lowest in 2016 and the highest in 2020. $N\text{-}NH_4^+$ in 2020 reached the highest value. According to the study of [16], $N\text{-}NH_4^+$ originated from agricultural and aquaculture activities. High $N\text{-}NH_4^+$ indicated that the BBT study area was experiencing nutrient contamination. The causes could be from agricultural activities, excessive use of organic fertilizers, along with pesticides and large-scale cattle rearing activities of people living near the study area thereby affecting TSS in the area [17-18].

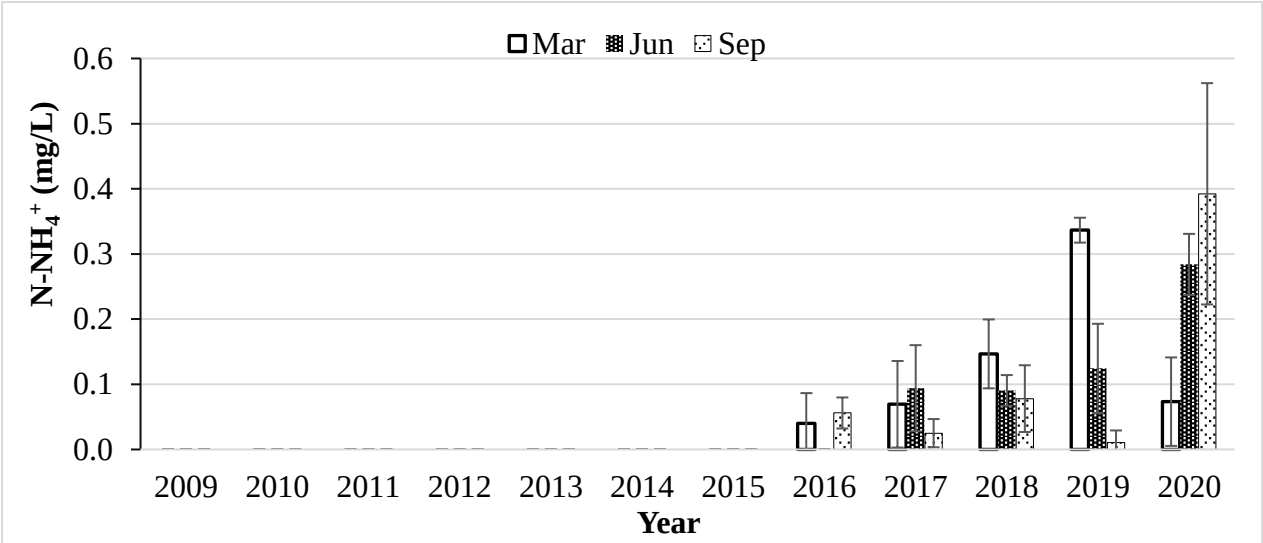

Figure 9. Long-term variation of $N\text{-}NH_4^+$ at BBT during 2009-2020

The fluctuation of coliform values was showed in Figure 10. The highest coliform value recorded was 46333.33±27153.88 MPN/100mL, while the lowest coliform value was only 2.83±1.59 MPN/100mL. The highest and lowest coliform values were both found in 2017. Coliform in 2011 was within the allowable limits according to column A1 of QCVN 08-MT:2015/BTNMT while coliform in the remaining years all exceeded the threshold.

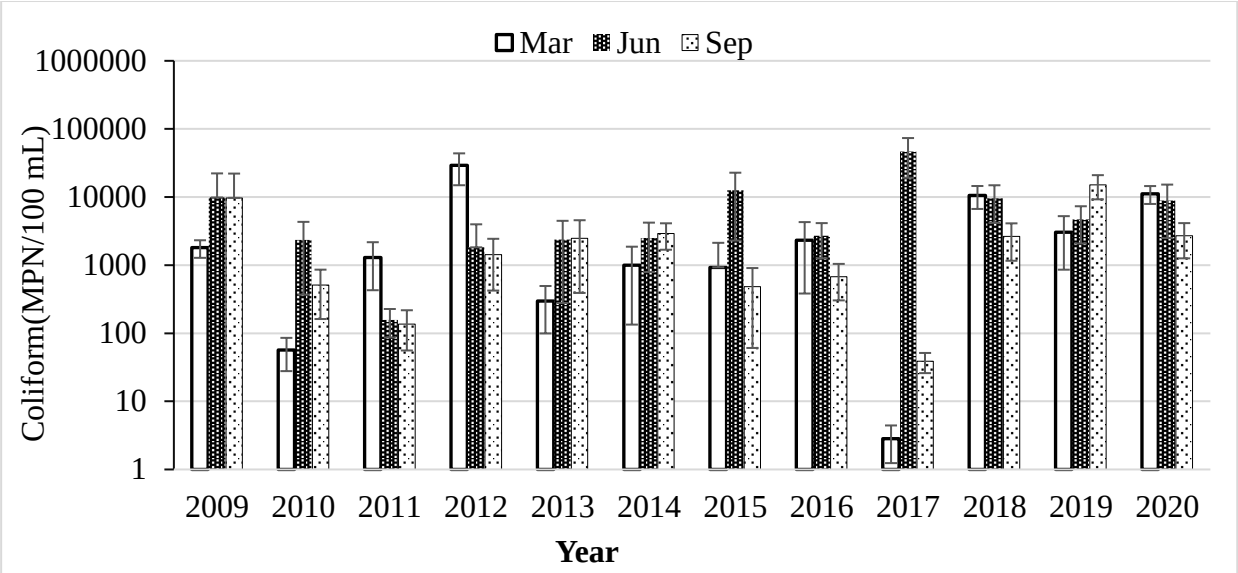

Figure 10. Long-term variation of coliform at BBT during 2009-2020

3.2. Overall quality of surface water at BBT during 2009-2020

The evolution of water quality has strong fluctuations between the years in the period of 2009-2020 in Bung Binh Thien. The water quality index ranged from 23 to 91 as seen from Figure 11. WQI in 2012 was the lowest (WQI=23), classified at the heavily polluted level. In 2017, WQI was classified at poor level (WQI=28). WQI in 2016 was very good and water quality at this year was the highest among the years. The water quality in 2016 was suitable for the purpose of using water for daily life. The remaining years, the overall water quality was classified from moderate to good with WQI ranging from 56 to 78.

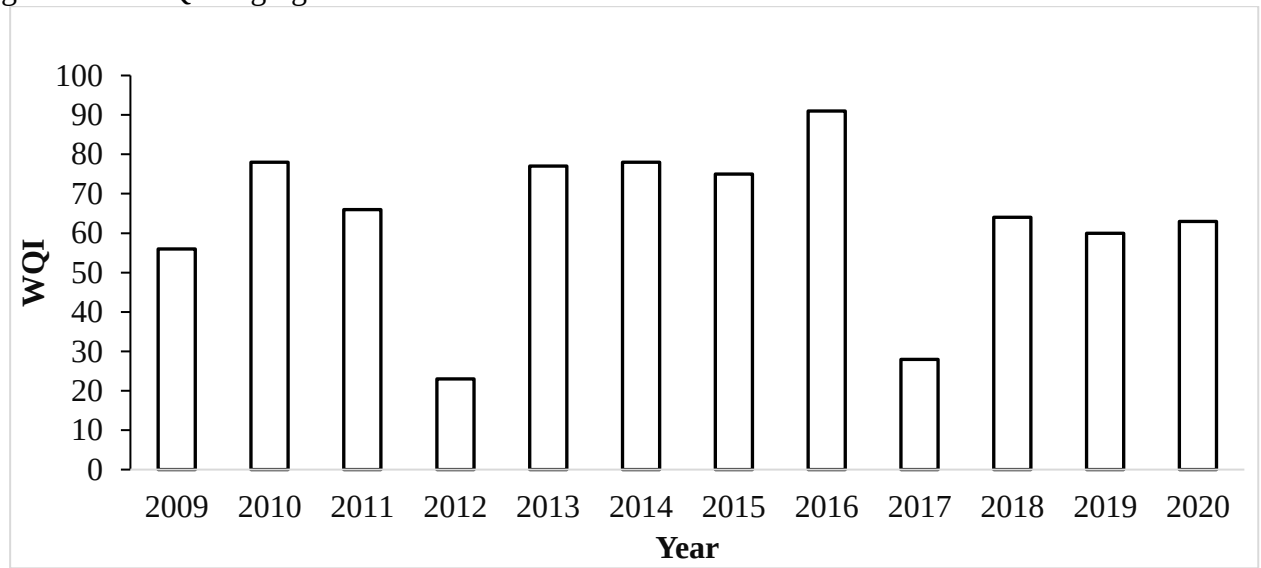

Figure 11. Overall water quality at BBT during 2009-2020

3.3. Key variables influencing water quality during 2009-2020

The analysis results showed that there were four main factors explaining 73.1% of water quality variation in the study area in the period 2009-2020 as seen from Table 4. PC1 explained the changes of DO (-0.366) and pH (-0.303) at a weak correlation, N-NO_3^- (-0.619) and P-PO_4^{3-} (-0.526) at the average correlation. PC2 explained the variation of temperature (0.317), pH (-0.465) and BOD (-0.707). PC3 was weakly correlated with DO (-0.484) and P-PO_4^{3-} (-0.395) and moderately correlated with coliform (0.743). PC4 was moderately correlated with TSS (0.568), temperature (-0.630) and weakly correlated with DO (0.348) and P-PO_4^{3-} (0.334). From the PCA results, it was shown that the parameters of temperature, pH, TSS, DO, BOD, N-NO_3^-, P-PO_4^{3-}, and coliform all affect the surface water quality of Bung Binh Thien. The causes of water pollution at Bung Binh Thien could be from natural and artificial factors.

Table 4. Key variables influencing surface water quality at BBT during 2009-2020

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
T	-0.110	**0.317**	-0.025	**-0.630**	**-0.543**	**0.373**	-0.232	-0.053
pH	**-0.303**	**-0.465**	0.013	-0.084	**-0.570**	**-0.586**	0.113	0.059
DO	**-0.366**	-0.110	**-0.484**	**0.348**	-0.207	**0.513**	**0.395**	0.192
TSS	0.295	0.291	-0.225	**0.568**	**-0.430**	-0.141	**-0.495**	0.065
BOD	0.000	**-0.707**	0.076	0.028	0.065	**0.383**	**-0.585**	-0.015
NO_3^-	**-0.619**	0.241	-0.011	-0.026	0.292	-0.171	**-0.386**	**0.543**
PO_4^{3-}	**-0.526**	0.165	**0.395**	**0.334**	-0.056	0.079	-0.070	**-0.644**
Coliform	0.123	0.024	**0.743**	0.198	-0.245	0.231	0.189	**0.493**
Eigen.	1.78	1.51	1.38	1.18	0.84	0.65	0.40	0.27
%Var	22.3	18.9	17.2	14.7	10.5	8.1	5.0	3.4
Cum.%Var	22.3	41.2	58.4	73.1	83.5	91.6	96.6	100.0

4. Conclusion

The results showed that surface water quality at Bung Binh Thien in the period 2009-2020 was contaminated by organic matters, nutrients and coliform. The mean values of pH and temperature were within the allowable limits of technical regulations on surface water quality. TSS and coliform were the two indicators with the most severe pollution monitoring results. Overall water quality was classified from moderate to good level except for the year 2012 and 2017. The main parameters influenced on surface water quality at BBT were temperature, pH, TSS, DO, BOD, N-NO_3^-, P-PO_4^{3-}, and coliform. Four potential water polluting sources were identified at the study area. Future study should focus on investigating concrete polluting sources to propose appropriate solutions for better water quality management.

Acknowledgement

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Nomenclature

Abbreviations	Description
Temp	Temperature
pH	pH
DO	Dissolved oxygen
TSS	Total suspended solid
COD	Chemical oxygen demand

BOD	Biological oxygen demand
$N\text{-}NH_4^+$	Ammonium
$N\text{-}NO_3^-$	Nitrate
$P\text{-}PO_4^{3-}$	Orthophosphate
Coliform	Coliform density
WQI	Water quality index

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