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Effects of Covid–19 Pandemic on Surface Water Quality: A Case Study in Hong–Thai Binh River, Vietnam

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The Covid–19 epidemic that appeared and broke out from the end of 2019 until now has contributed to limiting human production and emissions. As a result, the quality of the global environment tends to be good, including the water environment. The impact of the Covid–19 epidemic on the water environment has been studied by us in the Hong–Thai Binh river of Vietnam. Data at 30 water monitoring points on the Hong–Thai Binh in the period of 2018 – 2021 were used to calculate water pollution indexes including: Comprehensive Polluted Index (CPI), Organic Pollution Index (OPI) and Trace Metal Pollution Index (TPI). The results show that the average values of all three indicators CPI, OPI, TPI on the Hong–Thai Binh river in the period of during the Covid–19 (from 2020 to 2021) were higher than their values before (from 2018 to 2019). This implies that the blockade and social distancing activities implemented during Vietnam's Covid–19 epidemic have disrupted production activities and reduced the amount of waste discharged into the Hong–Thai Binh river. As a result the river water quality has been improved. To protect the water quality of the Hong–Thai Binh river in particular and the quality of the water environment in general, measures to strictly control waste sources and transform the economy from linear to circular are recommended solutions for Vietnamese government in the post–Covid–19.

Key words: Covid–19 pademic, Hong–Thai Binh river, Vietnam, water pollution index, water quality

INTRODUCTION

Water pollution is currently a global environmental problem due to both natural and man–made causes (Vadde *et al*., 2018). Therefore, water quality monitoring activities are getting more attention by many countries around the world. The objective of the surface water quality assessment is to identify the sources of water pollution and to develop a sustainable water resource management strategy that ensures human well–being and socioeconomic development (Caroll *et al*., 2006). Using quality and pollution indexes to assess water quality has been applied by many countries and researchers such as: water quality index (WQI) (Cao *et al*., 2020), comprehensive polluted index (CPI) (Matta *et al*., 2017), organic pollution index (OPI) (Mezbour *et al*., 2018), trace metal pollution index (TPI) (Reza & Singh, 2010), eutrophication index (EI) (Liu *et al*., 2011) ... These indicators provides environment agencies and scientists information on water quality for improving water quality management. This is the basis for managers to take measures to protect, exploit and use water resources in a sustainable way.

In Vietnam, surface water quality tends to decline due to the rapid socioeconomic development. The water quality of most major river basins in Vietnam is degrading (MONRE, 2018). Recent studies have shown that surface water quality in many areas of Vietnam is polluted by various causes such as: the impact of industrialization (Cao *et al*, 2020; Hung *et al*., 2017), urbanization (Nguyen *et al*., 2021), the development of livestock farms (Ho *et al*., 2010, 2013; Son *et al*., 2021), agricultural cultivation (Kurosawa *et al*, 2006) and etc. This situation contributes to placing Vietnam in the group of countries at high risk of water shortage. According to estimates of the International Water Resources Association (IWRA), the average water use per capita of Vietnam is 9,560 m^3/person/year, lower than the global average of 10,000 m^3/person/year. To ensure the development of socio–economic activities in the coming time, Vietnam needs appropriate strategy to protect, exploit and use the national water resources sustainably.

The strongly emerging outbreak of the Covid–19 epidemic on a global scale has had severely adverse impacts on all economic and social activities of many countries. However, in that dire situation a rare bright spot was identified that the earth's environmental quality tends to be better. The Covid–19 epidemic has significantly reduced human production and emissions, specifically reducing greenhouse gas emissions about 81% from agricultural production and 13.7 billion tons of carbon converted from other production sectors (Bashir *et al*., 2021). A study by Khaled Elsid *et al*. (2021) has shown that the Covid–19 epidemic has contributed to the improvement of global air and water quality by reducing carbon and nitrogen emissions by up to 65% and limiting an amount of significant global wastewater and solid waste. In Vietnam, the Covid–19 epidemic appeared and broke out strongly in two years 2020 and 2021, going through 4 periods: phase 1 from January 23, 2020 to July 24, 2020; Phase 2 from July 25, 2020 to January 27,

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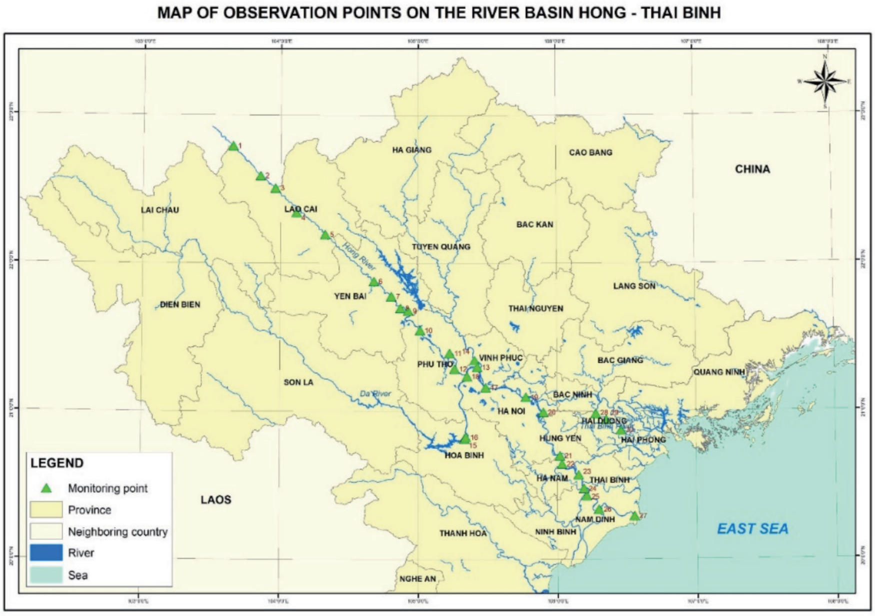

Fig. 1. Location of water monitoring points on the Hong-Thai Binh river of Vietnam. Source: Northern Environmental Monitoring Center of Vietnam, 2022.

2021; Phase 3 from January 28 to April 26, 2021; Phase 4 from April 27, 2021 to now. Vietnam's total number of Covid–19 cases as of April 2022 is 10.6 million with 43,004 deaths (GSO, 2022). Like the general situation of the world, Vietnam's socio–economic activities are affected by the Covid–19 epidemic. This may contribute to the improvement of the surface water quality. This study was conducted to test the hypothesis that water quality in Hong–Thai Binh rivers of Vietnam during the Covid–19 epidemic period was improved compared to the pre–epidemic period by the blockade order and social distancing. Water pollution indexes including CPI, OPI and TPI were calculated and compared for two periods before the Covid–19 epidemic (in 2018 and 2019) and during the Covid–19 epidemic (in 2020 and 2021) to compare and evaluate.

STUDY AREAS AND RESEARCH METHODS

Study area

The Hong–Thai Binh river basin is an inter–country river basin that flows through China, Laos, and Vietnam with a total area of about 169,000 km^2. The area of the Hong–Thai Binh river basin in Vietnam's territory has an area of about 17,000 km^2. The Hong river in Vietnam's territory has a length of 328 km, making it the second longest river in Vietnam after the Mekong river. The Hong river has mainly mountainous terrain, strongly dissected with 70% of its area at an altitude of >500 m. Meanwhile, Thai Binh river is located entirely in the territory of Vietnam, with a length of about 100 km, the terrain is mainly hilly with an altitude of 50–150 m (accounting for 60%). The main flow direction of Hong–Thai Binh river is from Northwest to Southeast along the slope of Vietnam's topography (MONRE, 2018).

The Hong–Thai Binh river flows through one of the most dynamic socio–economic development areas of Vietnam, so it is affected by agricultural, industrial and people's activities. As of 2020, the population in the region was about 22.92 million people (accounting for 23.4% of the population of Vietnam), the average economic growth rate of the region in the period 2010–2020 reached 11.42% with an average growth rate of industrial production of 11.91% per year. The whole region had a total of 152 industrial zones built (the highest in the Vietnam), of which 92 industrial zones had been put into operation. Agricultural production is a long–standing traditional activity with a total cultivated area of about 790 ha (MOPI, 2020). The agricultural production area of the region consumes 30–40% of the total amount of chemical fertilizers used in Vietnam annually. Thus, it can be seen that the Hong–Thai Binh river of Vietnam has been under great pressure from socioeconomic development activities.

Water monitoring points on Hong–Thai Binh rivers in Vietnam

In this study, we used monitoring data at 30 water monitoring points on the Hong–Thai Binh river which are distributed in 8 northern provinces of Vietnam, including: Lao Cai (5 points), Yen Bai (4 points), Phu Tho (4 points), Hoa Binh (3 points), Hanoi (4 points), Ha Nam (3 points), Nam Dinh (4 points) and Hai Duong (3 points) (see Fig. 1). Some basic information of water monitoring is presented in Table 1.

Water quality monitoring data

Surface water quality monitoring data at 30 monitoring points on the Hong–Thai Binh river in the period 2018–2021 were collected from the Northern Environmental Monitoring Center of Vietnam. Average values of water quality parameters (see Table 2) at mon-

Table 1. Description of sampling location in Hong–Thai Binh river, in Vietnam

Sampling locations			Locations	
No	Name	Province	Longtitude	Latitude
1	Lung Po	Lao Cai	22^{0}47’28,5	103^{0}39’10,3
2	Ban Vuoc Boder gate	Lao Cai	22^{0}35’25,8	103^{0}51’11,9
3	Nam Thi	Lao Cai	22^{0}18’26,8	103^{0}09’28,9
4	Pho Lu Bridge	Lao Cai	22^{0}20’32,9”	104^{0}06’58,7”
5	Bao Ha	Lao Cai	22^{0}11’38,5”	104^{0}19’29,6”
6	Mau A	Yen Bai	21^{0}52’40,83”	104^{0}40’43,16”
7	Quy Mong	Yen Bai	21^{0}46’39,2”	104^{0}48’16,7”
8	Yen Bai Bridge	Yen Bai	21^{0}41’46,5”	104^{0}52’18,2”
9	Van Phu	Yen Bai	21^{0}40’48,8”	104^{0}55’37,1”
10	Ha Hoa	Phu Tho	21^{0}32’50,4”	105^{0}00’50,0”
11	Me Market	Phu Tho	21^{0}32’48,1”	105^{0}13’20,2”
12	Phong Chau Bridge	Phu Tho	21^{0}17’12,8”	105^{0}15’41,4”
13	South Industrical Zone of Viet Tri City	Phu Tho	21^{0}17’51,1”	105^{0}25’30,2”
14	Duc Bac	Hoa Binh	21^{0}20’36,8”	105^{0}24’23,7”
15	Hoa Binh hydropower plants	Hoa Binh	20^{0}48’49,8”	105^{0}19’52,2”
16	Hoa Binh Bridge	Hoa Binh	20^{0}49’29,7”	105^{0}20’26,7”
17	Duong Lam	Ha Noi	21^{0}09’35,4”	105^{0}29’8,8”
18	Trung Ha Bridge	Ha Noi	22^{0}42’51,1”	106^{0}52’30,2”
19	Chem Village	Ha Noi	21^{0}05’41,1”	105^{0}46’32,0”
20	Thanh Tri Bridge	Ha Noi	20^{0}59’32,85”	105^{0}54’3,38”
21	Moc Bac	Ha Nam	20^{0}42’29,1”	106^{0}45’24,08”
22	Yen Lenh Bridge	Ha Nam	20^{0}42’13,1”	106^{0}45’24,08”
23	Nhu Trac water pump station	Ha Nam	20^{0}39’23,1”	106^{0}52’32,08”
24	Huu Bi water pump station	Nam Dinh	20^{0}28’41,6”	106^{0}11’26,4”
25	Confluence of Red River and Dao River	Nam Dinh	20^{0}25’39,2”	106^{0}12’38,6”
26	Confluence of Red River and Ninh Co River	Nam Dinh	20^{0}20’5,1”	106^{0}17’48,2”
27	Ba Lat Gate	Nam Dinh	20^{0}17’22,0”	106^{0}33’10,3”
28	Cam Van	Hai Duong	20^{0}58’58,3”	106^{0}16’45,5”
29	Phu Luong Bridge	Hải Dương	20^{0}56’37,4”	106^{0}21’11,8”
30	Hop Duc	Hải Dương	20^{0}52’14,4”	106^{0}27’33,2”

Source: Northern Environmental Monitoring Center of Vietnam, 2022

Table 2. Monitoring parameters of surface water on the Hong–Thai Binh river of Vietnam

No	Parameter	Units	Analytical methods	Average±SD
1	pH	–	ISO 10523:2008	7.76±0.10
2	Turbidity	TNU	ISO 7027: 1999	41.1±20.05
3	TSS	mg/L	SMEWW 2540B:2012	57±27.16
4	DO	mg/L	ISO 5814:1990	6.33±0.27
5	BOD	mg/L	SMEWW 5210B:2012	4±0.85
6	COD	mg/L	SMEWW 5220C:2012	9±1.55
7	NH_4^+	mg/L	ISO 7150–1:1984	0.17±0.11
8	NO_3^-	mg/L	SMEWW 4500–NO_3^-.F:2012	0.82±0.18
9	NO_2^-	mg/L	SMEWW 4500.NO_2^-.B:2012	0.043±0.035
10	Fe	mg/L	EPA method 6020 A	0.6734±0.2534
11	Pb	mg/L	EPA method 7000	0.0043±0.0013

Source: Northern Environmental Monitoring Center of Vietnam, 2022
SD=standard deviation

Table 3. Rating scale for CPI, OPI and TPI

CPI*		OPI**		TPI***	
Scores	Pollution level	Scores	Pollution level	Scores	Pollution level
0 – 0.2	Clean	< 0	Excellent	0 – 1	None polluted
0.21 – 0.40	Sub clean	0 – 1	Good	> 1	Polluted
0.41 – 1.00	Slightly polluted	1 – 4	Polluted		
1.01 – 2.00	Medium polluted	4 – 5	Heavily polluted		
≥ 2.01	Heavily polluted				

Source: * Matta *et al*., 2017; ** Mezbour *et al*., 2018; *** Reza & Singh, 2010

itoring points were used to calculate pollution indices such as: Comprehensive Polluted Index (CPI), Organic Pollution Index (OPI) and Trace Metal Pollution Index (TPI) at the times of before (2018 – 2019) and during Covid–19 outbreak (2020 – 2021) in Vietnam.

Water Pollution Indices

The water pollution indices have been calculated to assess the change in water quality of the Hong–Thai Binh river, including CPI, OPI and TPI.

* *Comprehensive Polluted Index (CPI)*:

CPI is used to assess the pollution level of a water body based on water quality parameters (Matta *et al*., 2017). The formula for calculating CPI is as follows:

$$CPI = \frac{1}{n}\sum_{i=1}^{n} PIi \quad (1) \qquad PI_i = \frac{Ci}{Si} \quad (2)$$

Where: n–number of water monitoring parameters; PI_i – Pollution index of the i^{th} parameter is calculated by the formula 2. In formula 2, C_i is the concentration of parameter i in the water body; S_i is allowable limit of parameter i specified in national technical regulations on surface water quality. CPI is rated on a scale, which is described in Table 3.

* *Organic Pollution Index (OPI)*:

OPI is used to assess the level of organic pollution of a water body based on the monitoring results of four water quality parameters including: chemical oxygen demand (COD), dissolved oxygen (DO), dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP) (Mezbour *et al*., 2018). However, because the water monitoring program of the Hong–Thai Binh river did not monitor the PO_4^{3-} parameter, the formula for calculating OPI was calculated as formula 3.

$$\mathbf{OPI} = \frac{COD}{COD s} + \frac{DIN}{DIN s} + \frac{DO}{DO s} \quad (3)$$

Where: COD, DO and DIN are concentrations of water quality parameters measured in water body. COD*s*, DO*s* and DIN*s* are the limit thresholds of the parameters specified in the Vietnamese national technical regulation on surface water quality. The DIN and DIN*s* values are calculated as the sum of the concentrations of nitrate, nitrite and ammonium in the water body and in the Vietnamese national technical regulation on surface water quality, respectively. The OPI rating scale is described in Table 3.

* *Trace Metal Pollution Index (TPI)*

TPI is used to assess contamination of trace heavy metals in the aquatic environment (Reza & Singh, 2010). The formulas for calculating this index are as follows:

$$Q_i = \frac{Ti}{Xi} \quad (4) \qquad K = 1/\sum_{i=1}^{n} \frac{1}{Xi} \quad (5) \qquad W_i = \frac{K}{Xi} \quad (6)$$

$$\mathbf{TPI} = \sum_{i=1}^{n} \mathbf{QiWi} / \sum_{i=1}^{n} \mathbf{Wi} \quad (7)$$

Where: K is the proportinality constant; Xi is the limit for the concentration of i^{th} trace metal in the; Wi is the mass ratio of the i^{th} trace metal; Qi is the quality index of the i^{th} trace metal; Ti is the concentration of the i^{th} trace metal in aqueous medium; n is the total number of trace metals observed. In this study, TPI was calculated based on the average concentration of Fe and Pb. These are the two trace metals observed in the program on water quality monitoring of the Hong–Thai Binh river. The TPI rating scale is shown in Table 3.

Data analysis

Pearson analysis is used to determine the correlation between the concentration of pollution parameters in the water environment. T–test is used to test the difference in water pollution levels between the two periods of before and during Covid–19.

RESULTS AND DISCUSSIONS

Concentration of water monitoring parameters in the Hong–Thai Binh river

The average concentrations of water quality parameters in the Hong–Thai Binh river before and during the Covid–19 pandemic are presented in Table 4. It can be seen that the water quality of the Hong–Thai Binh river in both periods was generally good when only TSS parameter exceeded the allowable threshold of QCVN08:2015/BTNMT –A2– the Vietnam national technical regulation on surface water quality (MONRE, 2015), all other parameters had the average concentrations within the allowable thresholds of the standards. The average concentration of water quality parameters during the Covid–19 pandemic tended to decrease as compared to the previous period, except for nitrate and nitrite parameters. The differences in the average concentrations of pH, DO, TSS, NO_3^-, Pb, and Fe parameters at the two periods, before and during the Covid–19 pan-

Table 4. Average concentrations of water monitoring parameters of the Hong–Thai Binh rivers in the two period of before and during the Covid–19 pandemic

Parameter	Unit	Before Covid–19 period (2018–2019)		During Covid–19 period (2020–2021)		difference between two periods	QCVN–08:2015/ MONRE Column A2
		Average	SD	Average	SD	P–Value	
pH		7.84	0.13	7.73	0.11	0.000091***	6.0 – 8.5
Tubidity	NTU	44.24	22.15	39.41	21.52	0.144832	–
DO	mg/L	6.52	0.27	6.24	0.28	0.000000***	≥ 5
TSS	mg/L	68	31.62	49	26.36	0.000083***	30
COD	mg/L	9.27	1.88	9.11	1.67	0.621029	15
BOD_5	mg/L	3.92	1.00	4.08	1.00	0.426359	6
NH_4^+	mg/L	0.20	0.21	0.15	0.05	0.093629	0.3
NO_3^-	mg/L	0.78	0.16	0.85	0.20	0.002402*	5
NO_2^-	mg/L	0.042	0.030	0.045	0.044	0.360026	0.05
Pb	mg/L	0.0051	0.0020	0.0036	0.0011	0.000012***	0.02
Fe	mg/L	0.8591	0.3439	0.5446	0.2519	0.000006***	1

SD=standard deviation; (*), (**) and (***) indicates level of significance at P–value 0.05, 0.01 and 0.001
QCVN–08:2015/MONRE–Column A2=Vietnamese national technical regulation on surface water quality

Table 5. Correlation matrix of water parameters in Hong–Thai Binh river of Vietnam

	pH	Turbidity	DO	TSS	COD	BOD_5	NH_4^+	NO_3^-	NO_2^-	Fe	Pb
pH	1										
Turbidity	**0.81**	1									
DO	**0.60**	**0.51**	1								
TSS	**0.76**	**0.93**	0.40	1							
COD	–0.16	0.19	–0.08	0.12	1						
BOD_5	–0.14	0.19	–0.07	0.11	**0.97**	1					
$NH4^+$	–0.08	–0.16	–0.07	–0.23	0.20	0.28	1				
NO_3^-	0.42	**0.68**	0.10	**0.60**	0.08	0.14	–0.16	1			
NO_2^-	–0.23	–0.25	–0.31	–0.38	0.21	0.24	**0.53**	–0.01	1		
Fe	**0.53**	**0.78**	0.19	**0.81**	0.40	0.38	–0.05	0.46	–0.15	1	
Pb	**0.62**	**0.84**	0.48	**0.83**	0.20	0.19	–0.20	**0.55**	–0.35	**0.83**	1

demic, were statistically significant.

The results of the correlation analysis of quality parameters in the water environment of the Hong–Thai Binh river show that there were 3 parameters that were closely related to other parameters, including pH, turbidity, and TSS. In which, the pH parameter was the dominant parameter and affected the concentrations of most of the other parameters in the environment (see Table 5). Turbidity and TSS were the two physical parameters with significant variations according to the flow regime in most river systems of Vietnam (Cao *et al.*, 2020).

Evaluation of water pollution indicators of the Hong-Thai Binh river

* *Comprehensive Polluted Index (CPI)*

In the period of before the Covid–19 epidemic, the CPI of the Hong–Thai Binh river reached 0.67 and 0.52 for the rainy season and the dry season, respectively (the whole year average of 0.62). Of which, up to 86.67% (26 in 30 monitoring points) had the CPI values within the range of 0.41–1.00, corresponding to slightly polluted water level; only 4 in 30 water monitoring points (13.33%) had a CPI in the range of 0.21–0.40, corresponding to a fairly clean water quality.

Besides, the period of during Covid–19 epidemic, the CPI in the Hong–Thai Binh river decreased to 0.57 in the rainy season, 0.45 in the dry season, and 0.51 in the whole year. In which, 25/30 water monitoring points (83.33%) had the water quality classified as slightly polluted (0.41<CPI<1.00) and the remaining 5/30 water quality monitoring points (16.67%) had quality water as sub clean (0.21<CPI<0.40).

CPI values in the water of the Hong–Thai Binh river in the period of Covid–19 tended to decrease as compared to their values in the period before the Covid–19 epidemic. Most of the average CPI values of the water monitoring stations in the pre–Covid–19 period were all higher than those during the Covid–19 epidemic (Figure

Table 6. Comparison of CPI, OPI and TPI of Hong–Thai Binh river between before and during Covid–19 period pandemic

Time	Pollution Index	Before Covid–19 Period		During Covid –19 Period		Two period difference
		Ave	*SD*	*Ave*	*SD*	*P–value*
Rainy season	CPI	0.67	0.18	0.57	0.18	0.023888*
	OPI	1.68	1.46	0.70	0.43	0.000277***
	TPI	0.1094	0.867	0.0921	0.0563	0.024488*
Dry season	CPI	0.52	0.26	0.45	0.12	0.098102
	OPI	1.09	2.11	1.01	1.12	0.809104
	TPI	0.0707	0.0626	0.0930	0.0665	0.000000***
All year	CPI	0.62	0.17	0.51	0.11	0.000058***
	OPI	1.48	1.39	0.87	0.73	0.000152***
	TPI	0.0965	0.0759	0.0926	0.612	0.395804

SD=standard deviation; (*), (**), (***) indicates level of significance at P–value is 0.05, 0.01 and 0.001

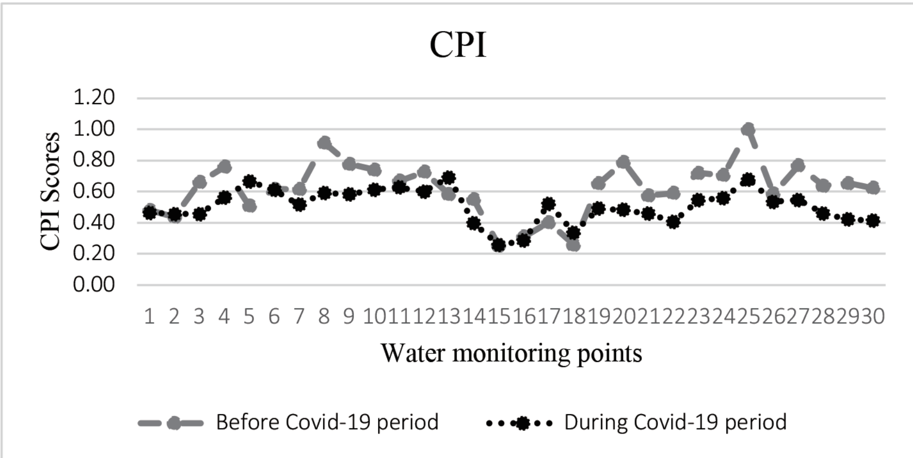

Fig. 2. Comparison of CPI values on the Hong–Thai Binh river in the tow periods of before and during Covid–19 pandemic.

2). This change was not statistically significant in the dry season (P–*value*=0.098102) but was statistically significant in the rainy season and the whole year (P–*value* were 0.023888 and 0.000058, respectively).

** Organic Pollution Index (OPI)*

The OPI value in the Hong–Thai Binh river water were 1.68 and 1.09 in the rainy season and the dry season, respectively (1.48 for the whole year) in the period 2018–2019 (before Covid–19). With this result, there were 50% of the monitoring points (15/30 monitoring points) with good water quality (0<OPI<1), 46.67% of the monitoring points (14/30 monitoring points) at polluted level (1<OPI<4); and only 3.33% of the monitoring points (1/30 monitoring points) classified as heavy polluted (OPI>4).

In the period of 2020–2021, the OPI value in the Hong–Thai Binh river water reached 0.70 in the rainy season, 1.01 in the dry season and 0.87 in the whole year. There was 30% (9/30 monitoring points) of the monitoring points classified as polluted (1<OPI<4), while the remaining 70% (21/30 monitoring points) was good water quality (0<OPI<1). In general, these values of OPI were lower than those of the period before the Covid–19 epidemic. Similarly CPI, the differences of OPI were statistically significant in the rainy season (P–*value*=0.000277) and the whole year (P–*value*= 0.000152).

The comparison of the OPI values of the monitoring points in the two periods showed that most of the OPI at the monitoring points in the period of before Covid–19 had a higher mean value than their average value in the period of during Covid–19 pandemic (see Fig. 3).

** Trace metal pollution index (TPI)*

The TPI calculation results show that the average TPI value in the water of the Hong–Thai Binh river was 0.0965 (0.1094 in the rainy season and 0.0707 in the dry season) in the period of before covid–19. The TPI score tended to decrease during Covid–19 pandemic when it reached an average value of 0.0926 (0.0921 in the rainy season and 0.0930 in the dry season). With this value, the water of the Hong–Thai Binh river was not contaminated by trace metals, 100% of the monitoring points

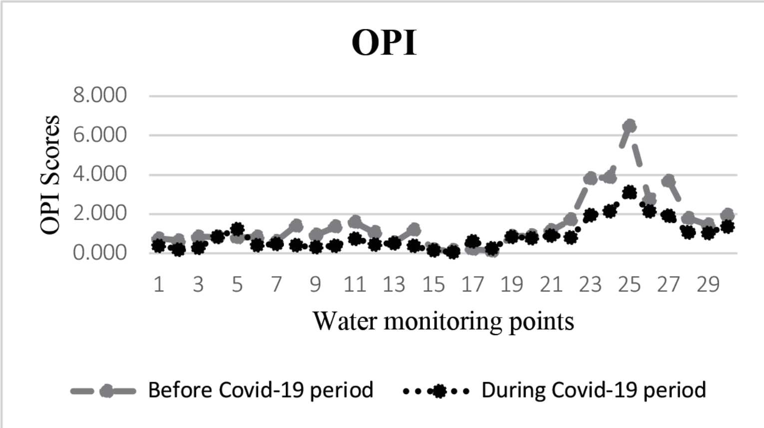

Fig. 3. Comparison of OPI values on the Hong–Thai Binh river in the tow periods of before and during Covid–19 pandemic.

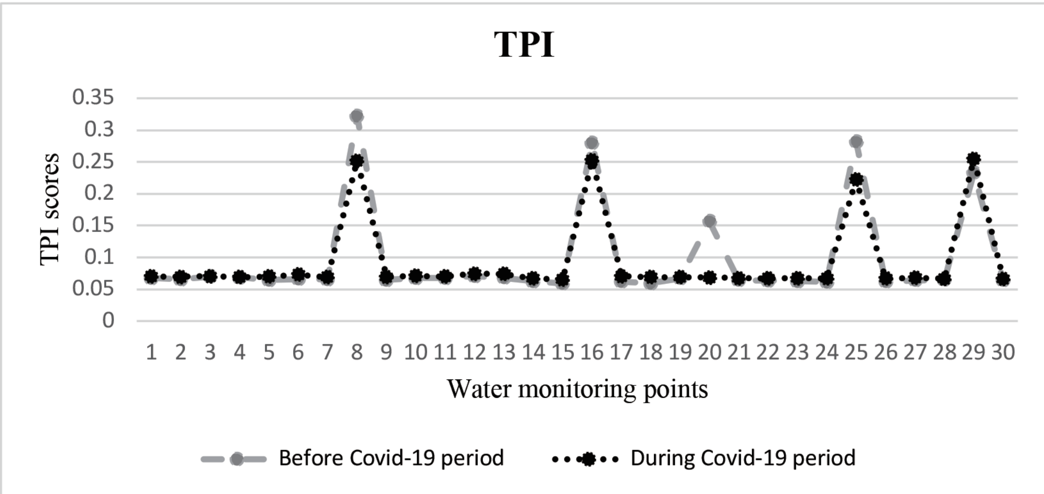

Fig. 4. Comparison of TPI values on the Hong–Thai Binh river in the tow periods of before and during Covid–19 pandemi.

had TPI<1 in both periods, before and during Covid–19 epidemic. The difference in TPI score between the two periods was statistically significant in the rainy season (P–*value*=0.024488) and the dry season (P–*value*=0.000000), but overall, there was no difference in terms of the whole year statistics (P–*value*=0.395804). The comparison of TPI values at the two periods of the studied water monitoring points showed that most of the TPI monitoring points did not change significantly. However, at monitoring points of 8, 16, 20 and 25, the TPI values changed markedly. Specifically, the average value of TPI at the monitoring points in the period of during Covid–19 epidemic decreased significantly as compared to their average value in the pre–Covid–19 period (see Fig. 4).

Pollution level and solutions to improve water quality of the Hong–Thai Binh river

Level of water pollution in Hong–Thai Binh river

Through the assessment of water pollution indices, it can be seen that the overall water quality of the Hong–Thai Binh river was slightly polluted with 86.67% before Covid–19 and 83.33% during Covid–19 of the monitoring points having CPI values ranges between 0.41 and 1.00. Regarding organic matter pollution, 30% to 50% of monitoring points, for the period of before and during the Covid–19 pandemic, respectively, were contaminated with OPI values greater than 1. However, the water of the Hong–Thai Binh river was not contaminated by trace metals as 100% of the water monitoring points had TPI values smaller than 1.0 in both periods of before and during Covid–19 in Vietnam.

Water pollution of the Hong–Thai Binh river is an inevitable consequence of the socio–economic development processes in the northern region of Vietnam. This is an area with a dense population and rapid economic development in the country in the recent period (MONRE, 2020). However, it is clear that there was a change in the water quality of the Hong–Thai Binh river between the two periods of before and during Covid–19 pandemic in Vietnam. Specifically, during the Covid–19 period, most of the concentrations of pollution parameters in the water decreased significantly. All three indices of CPI, OPI and TPI, at 30 water monitoring points on the Hong–Thai Binh river, decreased in value, or in other words, the water quality was improved during the Covid–19 period. This is not a surprising result since in the Covid–19 period in Vietnam many blockade and social distancing activities were established to prevent the pandemic. This process slowed down socioeconomic activities and reduced the sources of discharge into the river, which improved the river water quality. This statement has also been shown by a number of studies on the impact of the Covid–19 epidemic on environmental quality in the world (Bashir *et al.*, 2021; Iriarte *et al.*, 2021).

Solutions to improve the water quality of Hong–Thai Binh river

The marked improvement of the water quality of the Hong–Thai Binh river during the Covid–19 period in Vietnam has once again confirmed the negative impact of wastes from socio–economic activities on water quality of river basins in Vietnam (MONRE, 2020). A proper control of waste sources after the end of the Covid–19 epidemic is an important task to improve the water quality of the Hong–Thai Binh river in particular and other river basins of Vietnam in general. To do this, the Vietnamese government needs to tighten the Law on Environmental Protection and prohibit illegal discharges into the water environment. Furthermore, the development of a green–oriented economy is a long–term solution that Vietnam should pursue towards the goal of sustainable development. In which, the key solution is to change the mindset of manufacturers to transform the economy from linear to circular, especially in developing countries where linear economies are dominant (Bodegom *et al.*, 2019; Boon & Anuga, 2020). Circular economy is a production and consumption model that focuses on sharing, renting, refurbishing, reusing, recycling existing products and materials and minimizing waste generation (Bahn–Walkowiak *et al.*, 2019), thereby, contributing to minimizing the pressure from socio–economic activities to the quality of the water environment in particular and the quality of environmental components in general.

CONCLUSION

The water quality of the Hong–Thai Binh river in Vietnam was lightly polluted when 86.67% and 83.33% of water monitoring points have CPI fluctuating between 0.41 and 1.00 (lightly pollution level); 50% and 30% of monitoring points had OPI >1.0 (pollution level), for the periods before and during the Covid–19 pandemic, respectively. However, the water quality of the Hong–Thai Binh river is currently not contaminated with trace metals when 100% of water monitoring points have TPI<1.0 (None Pollution). The water quality of the Hong–Thai Binh river during the Covid–19 epidemic period was better than the before Covid–19 period when the average concentration of pollution parameters and three pollution indexes of CPI, OPI and TPI at most monitoring points tend to decrease. The blockade and social distancing measures have slowed down socioeconomic development activities in the study area and reduced discharges into the Hong–Thai Binh river. As a result, river water quality is improved than before. The change in water quality also indicates that the waste treatment of factories near Hong–Thai Binh river before the Covid–19 epidemic has not met the environment requirements, causing significant pollution. In order to improve the water quality of the Hong–Thai Binh river in the near future, measures to control waste sources after the end of the Covid–19 epidemic should be prioritized. Besides, developing a green economy and gradually transforming the economy from linear to circular should be considered as a solution and a strategy in long–term of Vietnam to limit water pollution.

AUTHOR CONTRIBUTIONS

Cao Truong SON: Idea development, Study design, Methodology, Wrote original manuscript, Review and Editing; Nguyen xuan HOA: Idea development, Wrote original manuscript, Review and editing; Vo Thi Thu HOAI: Data collection, Study design, Wrote original manuscript and Editing; Le Thi Thu HUONG: Writing–Review, Data analysis and editing; Luong Duc ANH: Review and Editing; Doan Thanh THUY: Data collection and Data analysis; Dinh Thi Hai VAN: Review, Editing and Supervision; Mitsuyasu YABE: Conceptualization, Visualization, Review, Editing and Supervision.

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REFERENCES

Bashir, A., Kola, Y. K., Pankaj, K., Vinod, K., Kyung, S. C., Krishna, K. Y., Akanksha, Y., El–Denglawey, A., Marina, M. S. C. P., Cao, T. S., Santhana, K., Nadeem, A. K. 2021. A review on mechanistic understanding of the COVID–19 pandemic and its impact on sustainable agri–food system and agroecosystem decarbonization nexus. *Journal of Cleaner production*, **381**: 128451

Boon, E. K., Anuga, S. W. 2020. Circular economy and its relevance for improving food and nutrition security in sub–saharan Africa: the case of Ghana. *Mater. Circ. Econ*, **2**: 5

Cao, T. S., Nguyen, T. H. G., Trieu, P. T., Nguyen, H. N., Nguyen, T. L., Vo, H. C. 2020. Assessment of Cau river water quality assessment using a combination of water quality and pollution indices. *Journal of Water quality Supply: Research and Technology–Aqua*, **69**(2): 160–172

Carroll, S. P., Dawes, L., Hargreaves, M. & Goonetilleke, A. 2006. *Water Quality Profile of an Urbanising Catchment–Ningi Creek Catchment. Technical Report*. School of Urban Development, Queensland University of Technology, Caboolture Shire Council, QLD, Australia, pp. 1–93

General Statistics Office (GSO) of Vietnam. 2022. *Statistics on the Covid–19 epidemic*. Hanoi, Vietnam

Ho, T. L. T., Cao, T. S., Tran, T. L., Kurosawa, K., & Egashira, K. 2010. Assessment of surface and groundwater quality in pig–raising villages of Haiduong province in Vietnam. *Journal of the Faculty of Agriculture, Kyushu University*, **55**(1): 123–130

Ho, T. L. T., Cao, T. S., Luong, D. A., Vu, D. T., Kurosawa, K., & Egashira, K. 2013. Evaluation of Water Pollution Caused by

Different Pig–Farming Systems in Hungyen Province of Vietnam. *J. Fac. Agr., Kyushu Univ*, **58**(1): 159–165

Hung, P., Rahman, M. M., Nguyen, C. N., Phu, L. V., Trung, L. V., Huu, H. N. 2017. Assessment of surface water quality using the water quality index and multivariate statistical techbiques – A case study: the upper part of Dongnai river basin, Vietnam. *Journal of water sustainability*, **7**(4): 225–245

Iriarte, A., Y´ anez, P., Villalobos, P., Huenchuleo, C., Rebolledo–Leiva, R. 2021. Carbon footprint of southern hemisphere fruit exported to Europe: the case of Chilean apple to the UK. *J. Clean. Prod*. **293**: 126118

Khaled, E., Valentina, O., Enas, T. S., Tabbi, W., Mohammad, A. 2021. Effects of covid–19 on the environment: An overview on air, wastewater, and solid waste. *Journal of environmetal management*, **292**: 112694

Kurosawa, K., N. H. Do, H. T. Nguyen, T. L. T. Ho, T. L. H. Tran, T. C. Nguyen and K. Egashira. 2006. Temporal and spatial variations of inorganic nitrogen levels in surface and ground water around Ha Noi, Viet Nam. *Communications in Soil Science and Plant Analysis*, **37**: 403–415

Liu, S., Lou, S., Kuang, C., Huang, W., Chen, W., Zhang, J. & Zhong, G. 2011. Water quality assessment by pollution–index method in the coastal waters of Hebei Province in western Bohai Sea, China. *Mar. Pollut. Bull*, **62**: 2220–2229

Matta, G., Kumar, A., Uniyal, D. P., Singh, P., Kumar, A., Dhingra, G. K., Ajendra, K., Naik, P. K. & Shrivastva, N. G. 2017. Temporal assessment using WQI of River Henwal, a Tributary of River Ganga in Himalayan Region. *Int. J. Environ. Rehabil. Conserv*, **8**(1): 187–204

Mezbour, R., Reggam, A., Maazi, M. C. & Houhamdi, M. 2018. Evaluation of organic pollution index and the bacteriological uality of the water of the Lake of birds (ELTarf East–Algerian). *J. Mater. Environ. Sci*, **9**(3): 971–979

MOPI–Ministry of Planning and Investment of Vietnam. 2020. *Statistics of Vietnam's industrial zones*. Hanoi, Vietnam.

MONRE–Ministry of Natural resources and Environment in Vietnam. 2010. *The National Environmental Report 2020: Environmental overview*. Ministry of Natural Resources and Environment

MONRE–Ministry of Natural resources and Environment in Vietnam. 2018. *The National Environmental Report 2018: Water Quality in River Basins*. Ministry of Natural Resources and Environment

Nguyen, T. T. H., Dinh, T. D., Ho, T. T. H., Trinh, Q. H., Nguyen, N. T. 2021. Water quality assessment and eutrophic classification of Hanoi lakes using different indices. *Vietnam journal of agriculture sciences*, **4**(4): 1229–1240

Son, T. C., Ha, P. T., Huong, T. T. L., Hoa, P. K. B., Giang, T. H. N., Lam, T. N., Binh, T. N., Anh, D. L. 2021. Impacts of effluent from different livestock farm types (pig, cow, and poultry) on surrounding water quality: a comprehensive assessment using individual parameter evaluation method and water quality indices. *Journal of Environmental Science and Pollution research*, **28**: 50302–50315

Reza, R. & Singh, G. 2010. Heavy metal contamination and its indexing approach for river water. *Int. J. Environ. Sci. Technol*, **7**: 785–792

Vadde, K. K., Jianjun, W., Long, C., Tianma, Y., Alan, J. & Raju, S. 2018. Assessment of water quality and identification of pollution rick locations in Tiaoxi river (Taihu watershed), China. *Water*, **10**: 183