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WATER QUALITY ASSESSMENT OF SAIGON RIVER FOR PUBLIC WATER SUPPLY BASED ON WATER QUALITY INDEX

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Abstract. Water Quality Index (WQI) is a single dimensional number that aggregates information from many water quality parameters according to a defined method. WQI is accepted as an efficient tool for water quality management. In this study, WQI of Saigon river for public water supply was calculated from nine water quality parameters including pH, suspended solids (SS), dissolved oxygen (DO), chemical oxygen demand (COD), nitrite, ammonia, phosphate, total dissolved iron and total coliform based on water quality data obtained monthly from January 2016 to December 2019 at three sampling sites. The river water quality in terms of WQI was divided into 5 classes: class I, WQI = 90 to 100 (excellent); class II, WQI = 65 to 89 (good); class III, WQI = 35 to 64 (medium); class IV, WQI = 11 to 34 (poor), and class V, WQI = 1 to 10 (very bad). The method of inverse distance weighted (IDW) interpolation in geographic information system (GIS) was used to develop a map of river water quality. The results showed that most of WQI values belonged to class III (medium water quality with the WQIs of 35 - 64) and class IV (poor water quality with the WQIs of 11 - 34); and that a deteriorating trend was observed from upstream to downstream of Saigon river. Thus, the river water quality could not be used for public water supply.

Keywords: WQI, Saigon river, public water supply, water quality.

Classification numbers: 3.4.2, 3.8.1.

1. INTRODUCTION

The Saigon river plays an important role in Binh Duong province, Viet Nam. It flows from Dau Tieng dam to Binh Phuoc bridge with about 107 km long. The river is a water source mainly used for public water supply and irrigation. Besides, the river water is also utilized for industrial water supply, water transportation, drainage, or acts as a reservoir for wastewater [1].

Water quality index (WQI) aims at giving a single value to the water quality of a source on the basis of one or the other systems which translates the list of constituents and their concentrations present in a sample into a single value [2]. The formulation and use of such index have been strongly advocated by the agencies that are responsible for water supply and/or water pollution control. WQI serves as a convenient tool to examine trends, to highlight specific environmental conditions, and to help governmental decision-makers in evaluating the effectiveness of regulatory programs [2, 3]. WQI is commonly scaled from 0 (the worst water quality) to 100 (the best water quality). There are over 30 kinds of WQI being used in many parts of the world, such as the USA, Canada, Argentina, England, Scotland, India, Thailand, Malaysia, Zimbabwe, etc. [2, 4]. There are two categories of WQI, namely - general (multipurpose) use and specific use (such as public water supply, agriculture, and aquatic animal conservation).

In Viet Nam, WQI has been applied to several rivers such as Huong river in Thua Thien Hue province, Kien Giang river in Quang Binh province, Thach Han river in Quang Tri province [5], rivers and canals in Ho Chi Minh city [6], Hau river in Can Tho city [7], Thi Tinh river in Binh Duong province [8], Tien river in Tien Giang province [9], the upper part of Dong Nai river [10], etc. Among the WQI models, the model developed by Bhargava in 1983 is one of the simple models which is easily applied to water quality assessment for both general use and specific use [5, 8, 11]. Bhargava WQI model was proved to be more sensitive than a well-known WQI model developed by the United States – National Sanitation Foundation in reflection of water quality [5]. The Bahargava WQI model has been used to assess some surface water sources such as Euphrates river in Iraq for drinking and irrigation purposes [12, 13]; Netravathi river in South India for drinking purpose [14]; Polyphytos artificial lake and Aliakmon river in Greece for multipurpose use [15]; Huong, Thach Han, and Kien Giang rivers in Central Viet Nam [5] and Thi Tinh river in Southern Viet Nam [8] for multipurpose and specific uses (public water supply, irrigated agriculture, and aquatic life protection), etc.

In this paper, based on original Bhargava WQI model, we modified the selected parameters so that they are suitable for water quality of Saigon river, including i) turbidity and BOD (used in Bhargava model) are respectively replaced by SS and COD because the determination of COD is faster and more accurate than BOD, and turbidity is not specified in Vietnam national technical regulation on surface water quality; ii) addition of nitrite, ammonia, and phosphate to represent the nutrients, and iii) pH and total dissolved iron are also added in the WQI model because pH is an important parameter for surface water quality and iron concentrations are usually high in this river. The modified Bhagava WQI model was applied to assess Saigon river water quality for public water supply in the period from 2016 to 2019.

2. MATERIALS AND METHODS

2.1. Sampling

Three stations (abbreviated to SG1, SG2, and SG3) were selected for monthly sampling along the Saigon river (107 km long) from Dau Tieng dam to Binh Phuoc bridge (Figure 1), in the period from January 2016 to December 2019. At each sampling station, a composite water sample was taken by mixing two single samples collected at 2 points away from each riverbank; of which, the sampling depths were 50 cm and 100 cm. All samples were kept at 4 ^{o}C prior to analysis.

2.2. Analytical methods

pH, dissolved oxygen (DO), and suspended solids (SS) were in-situ measured by the water quality checker WQC 22A (TOA, Japan). Chemical oxygen demand (COD), nitrite (NO_2^-), ammonia (NH_4^+/NH_3), phosphate (PO_4^{3-}), total coliform, and total dissolved iron were analyzed in laboratory according to the standard methods for the examination of water and wastewater [16].

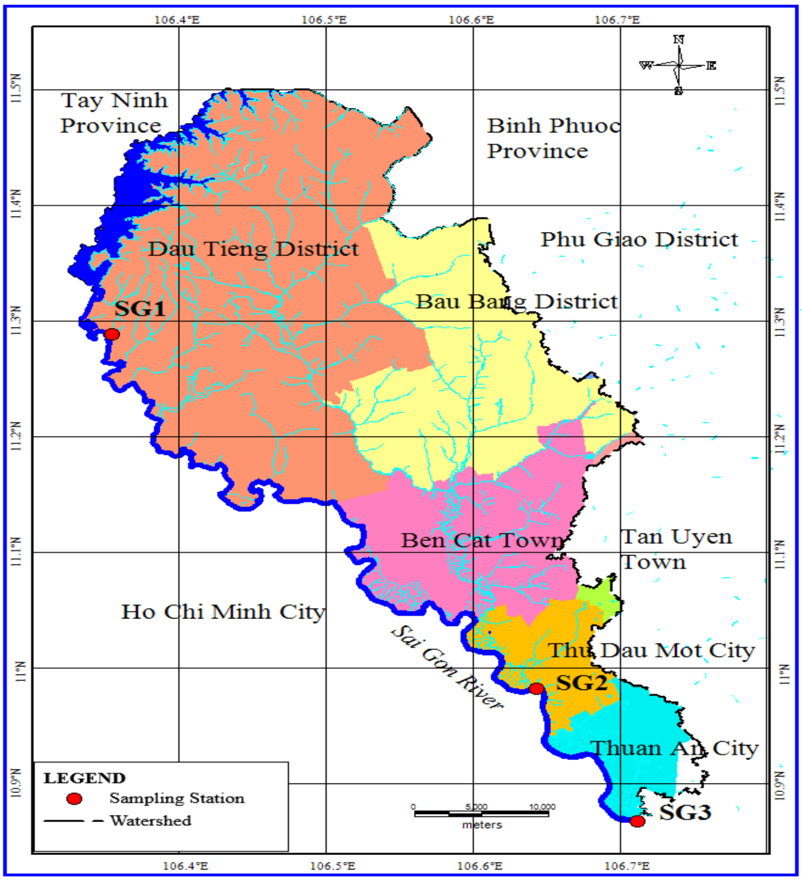

Figure 1. Sampling stations on Saigon river.

2.3. WQI calculation

WQI for public water supply was calculated from nine water quality parameters including pH, SS, DO, COD, nitrite, ammonia, phosphate, total dissolved iron and total coliform using the following formula [8, 11]:

$$WQI = \left[\prod_{i=1}^{n} F_i \right]^{1/n} \times 100$$

where n is the number of selected parameters (n = 9); F_i is the value of sensitivity function of parameter i describing the quality of parameter i and receiving the value between 0.01 (the worst quality) and 1 (the best one). It was defined as a basic linear graph of the sensitivity function of parameter i (Figure 2).

WQI receives the value between 1 (the worst water quality) and 100 (the best water quality).

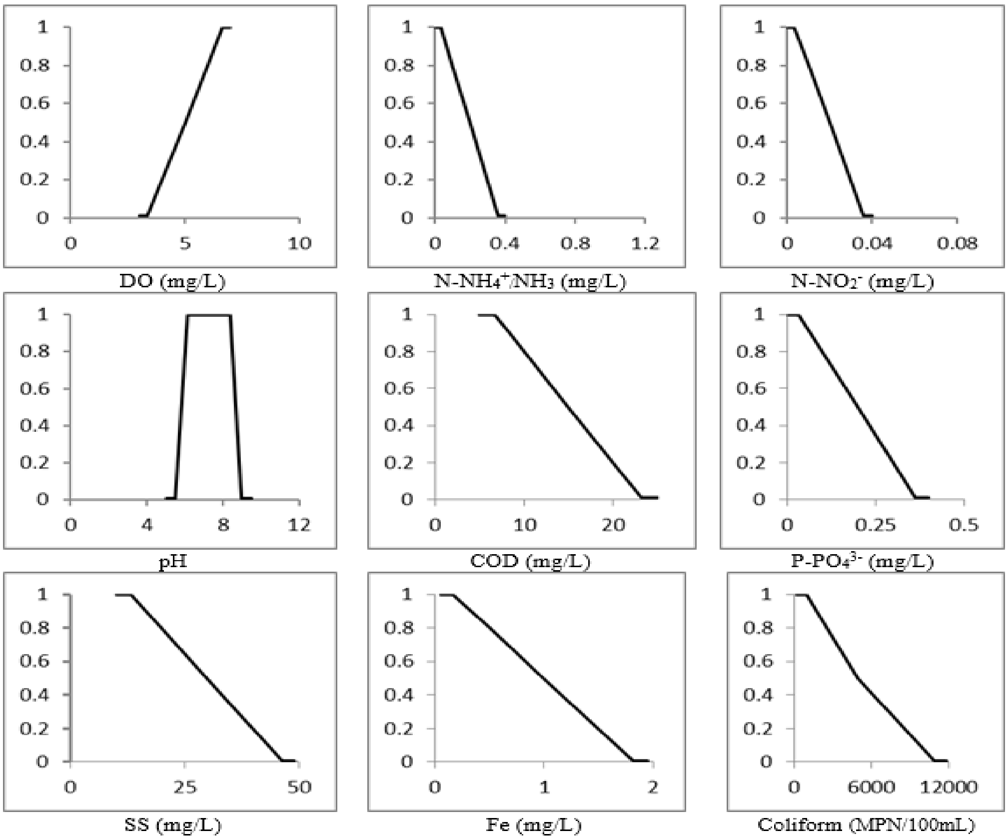

Figure 2. Sensitivity functions versus water quality parameters [8].

2.4. Water quality assessment and map

Saigon river water quality was divided into 5 classes as presented in Table 1 [8, 11]. According to this classification, a water source is good for public water supply when its WQIs belong to Class I and II [11].

Table 1. Water quality classification and interpretation based on WQI.

Class/Level	WQI	Interpretation	Color
I	90 ÷ 100	Excellent	Blue
II	65 ÷ 89	Good	Green
III	35 ÷ 64	Medium	Yellow
IV	11 ÷ 34	Poor	Orange
V	1 ÷ 10	Very bad	Red

The method of inverse distance weighted (IDW) interpolation in geographic information system (GIS) was used to develop the map of river water quality based on the WQI scale [17].

2.5. Statistical analysis and box-and-whisker plot

A box-and-whisker plot was used for illustration of spatial (sampling stations) and temporal (months of the year) variation of the river water quality.

Two-way analysis of variance (two-way ANOVA) was used to assess the effects of sampling station and month factors on the river water quality variation [18].

3. RESULTS AND DISCUSSION

3.1. Spatial and temporal variation of the river water quality

WQIs at the sampling stations (SG1 – SG3) in Saigon river from January 2016 to December 2019 are shown in Figure 3. Table 2 presents the results of two-way ANOVA.

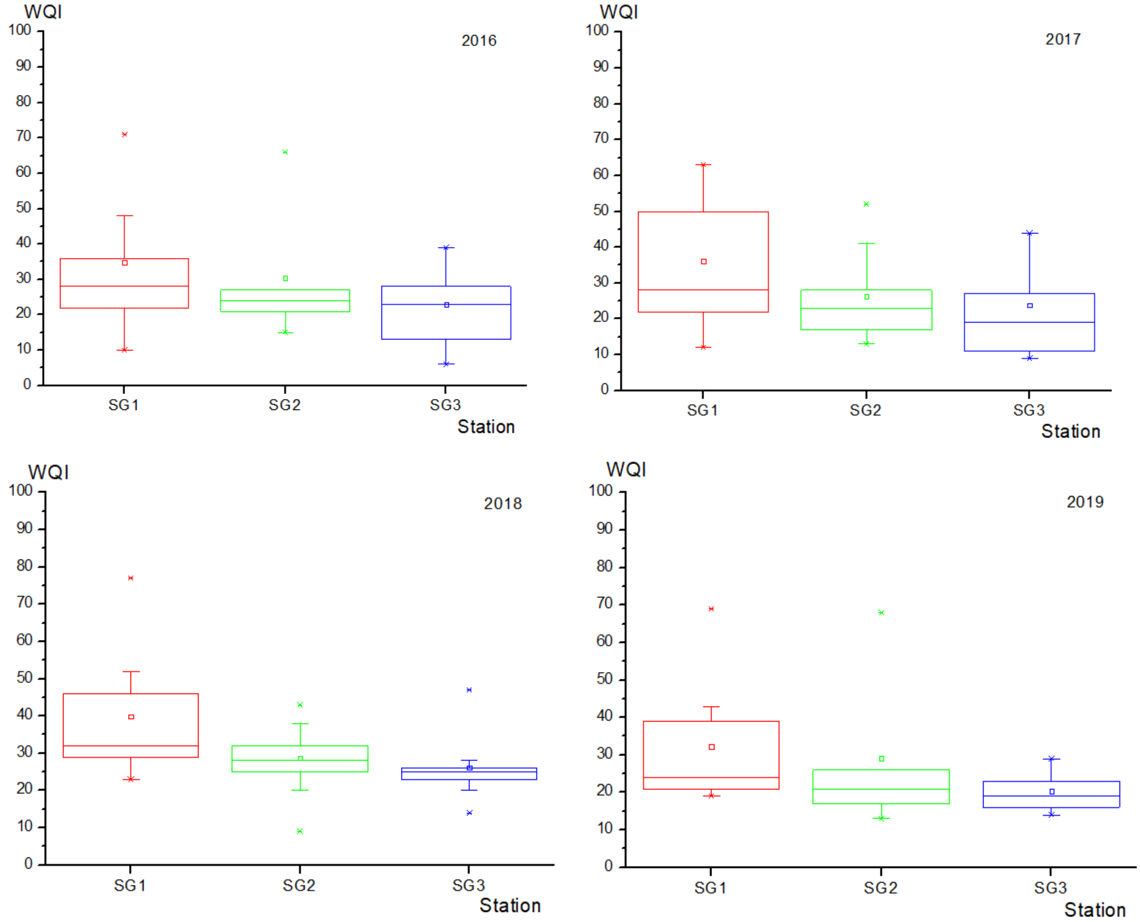

Figure 3. Variation of Saigon river WQIs in the period of 2016 - 2019.

Regarding the temporal variation of the river water quality, its WQIs varied in the range of 6 - 71 in 2016, 9 - 63 in 2017, 9 - 77 in 2018, and 13 - 69 in 2019. According to the above-noted water quality classification, the river water was rated poor quality (WQI ranges from 11 to 34), and medium quality (WQI ranges from 35 to 64) in most of the months. The good quality was recorded at SG1 station in March and April in 2016, July in 2018, and March in 2019; and SG2 in March in 2016 (WQI ranges from 65 to 89). The two-factor ANOVA demonstrated that the difference in water quality between months in 2016, 2018, and 2019 was statistically insignificant ($p > 0.05$). Whereas, a significant difference was observed in 2017 ($p < 0.05$) (Table 2).

Table 2. The results of two-way ANOVA.

Year	Source of variation	SS	df	MS	F	p	$F_{Critical}$	Significance
2016	Stations	873	2	437	2.61	0.10	3.44	No
	Months	3,994	11	363	2.17	0.06	2.26	No
	Residual	3,682	22	167				
	Total	8,549	35					
2017	Stations	1,020	2	510	4.76	0.02	3.44	Yes
	Months	4,315	11	392	3.66	0.005	2.26	Yes
	Residual	2,359	22	107				
	Total	7,694	35					
2018	Stations	1,254	2	627	5.70	0.01	3.44	Yes
	Months	1,619	11	147	1.34	0.27	2.26	No
	Residual	2,420	22	110				
	Total	5,293	35					
2019	Stations	918	2	459	3.07	0.07	3.44	No
	Months	2,817	11	256	1.71	0.14	2.26	No
	Residual	3,292	22	150				
	Total	7,027	35					

SS: sum of squares, df: degrees of freedom, MS: mean squares

In regard to spatial variation of the river water quality, its mean WQIs varied in the range of 21 - 35 in 2016, 24 - 36 in 2017, 26 - 40 in 2018, and 20 - 32 in 2019. The water quality decreased from the upstream (SG1: WQI ranges from 32 to 40) to the downstream (SG2: WQI ranges from 26 to 31, SG3: WQI ranges from 20 to 26). The difference in water quality between the sampling stations was significant ($p < 0.05$) in 2017 and 2018. However, it was insignificantly different in 2016 and 2019 ($p > 0.05$).

3.2. Seasonal classification and map representation of the river water quality

The river water quality classification was indicated in Table 3. Based on the seasonal WQI values (wet season: from May to November; dry season: from December to April of the following year) at the sampling stations, the river water quality map was developed (Figure 4). The color in the map is corresponding to the WQI scale as shown in Table 1.

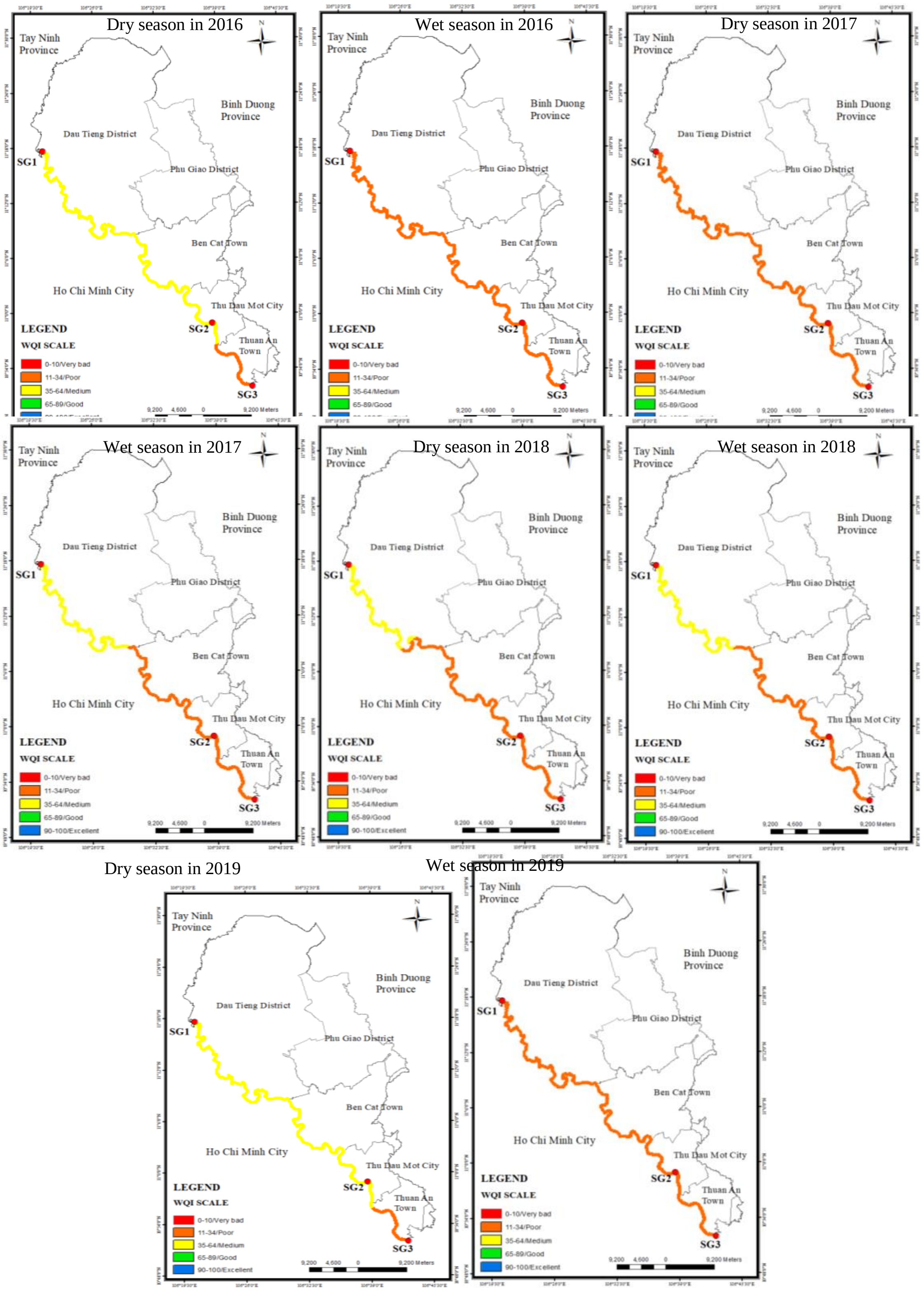

Figure 4. Map of Saigon river water quality for public water supply (2016 - 2019).

Table 3. Classification of Saigon river water quality for public water supply.

Station	Year							
	2016		2017		2018		2019	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
SG1	IV	III	III	IV	III	III	IV	III
SG2	IV	III	IV	IV	IV	IV	IV	III
SG3	IV	IV	IV	IV	IV	IV	IV	IV

Seasonally, Saigon river water quality could be rated at class III (medium water quality - WQI = 35 to 64) and class IV (poor water quality - WQI = 11 to 34), implying that the river water source did not meet public water supply's requirements. The high concentrations of ammonia, nitrite, and low dissolved oxygen in the river water (most F_i values = 0.01) were possibly the main causes of the river water quality degradation.

4. CONCLUSIONS

From 2016 to 2019, the WQI values of Saigon river water ranged from 6 to 77; in which, most of the water samples fell in medium water quality (class III, WQI ranges from 35 to 64), and poor water quality (class IV, WQI ranges from 11 to 34). Accordingly, the Saigon river water quality was not suitable for public water supply. It is, therefore, necessary to have solutions to improve river water quality.

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