Influences of anthropogenic activities on water quality in the Saigon River, Ho Chi Minh City

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ABSTRACT

Water quality for the surface water along the Saigon River in Ho Chi Minh City was assessed for four groups of water samples collected at the agricultural, industrial, residential, and less impacted areas. A variety of parameters indicating water quality including physicochemical parameters, nutrients, heavy metals, and antibiotic residues were measured for both the rainy and dry seasons, two main tropical seasons in HCM City using the standard methods. The results showed that the river water in the rainy season was detected with significantly higher values of turbidity, BOD5, PO4-P, NH4-N, NO3-N; and lower values of pH, temperature, conductivity, DO, salinity, Cu, Zn, As, Ni, Hg compared to that in the dry season. Sulfamethoxazole and trimethoprim were highly detected in the industrial areas compared to the agricultural and residential areas. Multivariate analyses suggested that the industrial and residential activities were more important contributors to the pollution of the Saigon River than the agricultural activities in HCM City.

Key words: anthropogenic activities, antibiotics, heavy metal, Saigon River, surface water

HIGHLIGHTS

- The occurrences of nutrients, heavy metals, and selected antibiotics in the Saigon River were different between the dry and rainy seasons.
- Industrial and residential activities were found as more important contributors to the contamination in the Saigon River in comparison to the agricultural activities.
- The highly polluted sites in the Saigon River were impacted by both industrial and residential activities.
1. INTRODUCTION

Although rivers account for a tiny amount (0.49%) of total surface freshwater on the earth, they are not only a precious source of drinking water for people across the world, but also support growing crop, manufacturing, energy, transport, and natural habitats for many other organisms. However, more and more rivers are significantly polluted all around the world, while the global demand for freshwater is estimated to increase one-third by 2050 (Programme and Raymond 2018). Anthropogenic activities in industry, agriculture, and residence are considered as major reasons causing this environmental degradation, and putting substantial pressure on the aquatic ecosystem (Marques et al. 2008; Paerl et al. 2014). More than 350,000 registered chemicals and 70,000 unidentified chemicals have been produced and used in the global market (Wang et al. 2020). Industrial wastes may carry many types of compounds such as heavy metals, antimicrobial agents, inorganic, organic, biodegradable, hydrophilic, hydrophobic, non-volatile, volatile, non-toxic, and toxic compounds (Abdel-Satar et al. 2017; van Wezel et al. 2018; Bashar & Fung 2020). These dangerous pollutants can enter aquatic environments in some main ways such as gaseous emission, liquid wastes, and solid wastes. In developing countries, about 70% of industrial wastes are discharged into waters without any treatments, and endanger the existing water supplies (Programme 2009). Domestic waste from the residential areas is a major cause of river pollution. Domestic wastes are sewage from the kitchen, bathroom, laudry, and wastes from food preparation, garbage, toilet, shower, sink, etc. They contain mainly biodegradable organic and inorganic nutrients as well as a variety of bacteria and human pathogens. On average, less than 50% of domestic sewage in developing countries is treated properly before discharging into receiving rivers, which can pose a high risk on both aquatic life and public health. Agricultural activities use approximately 70% of total freshwater consumption around the world and are a major contributor of non-point source pollution to aquatic environments (UNEP 2016). The pollution can be caused by pesticides, and fertilizers used in agriculture, as well as antibiotics, and organic wastes in livestock and fisheries. Besides, although agricultural activities are the main causes of water pollution in surface water, agriculture is also a victim of
Physical parameters such as pH, temperature, dissolved oxygen, and conductivity were measured.

2.3. Analysis of physicochemical parameters and nutrients

All the river water samples were taken in the morning, started from 9:00 AM to 11:00 AM (local time, GMT +7), when the average temperature of the surface water fluctuated from 28.0 to 30.5 °C for the rainy season in August 2019, and from 28.0 to 31.5 °C for the dry season in April 2020. The water samples were directly collected and preserved according to the standard methods for the examination of water and wastewater (Baird & Bridgewater 2017). Briefly, all the surface water samples were collected at about 20–30 cm below the surface of the river to avoid any scum. For each sample site, three samples of 2 L were collected, two samples near to the sides of the river and one sample at the middle of the river, and then mixed well into a 10 L container before dividing into several 0.5 L sterilized glass bottles for later laboratory analysis. All water samples were kept on ice and transported to the Environmental Analytical Laboratory located at District 9, Ho Chi Minh City within 2 h, and processed properly for further analysis.

2.3. Analysis of physicochemical parameters and nutrients

Physical parameters such as pH, temperature, dissolved oxygen, and conductivity were measured in situ at the sampling sites using a portable multi-parameter water quality meter YSI Professional Plus (YSI, USA). Dissolved oxygen (DO) was measured using a portable multi-parameter water quality meter YSI Professional Plus (YSI, USA).
measured using before-mixed water samples to avoid any rise in oxygen concentration due to the mixing. For Chemical Oxygen Demand (COD) analysis, 0.5 L water samples were collected in a 0.5 L glass bottle and preserved with sulfuric acid to a pH<2 at the sampling sites. Then, COD was measured by the colorimetric method using a UV-Vis spectrophotometer UV-1800 (Shimadzu, Japan), following the standard methods of SMEWW 5220B (Baird & Bridgewater 2017). BOD was analyzed by the 5-day BOD method using a BOD instrument VELP-FOC 225E & F10220137 following the standard method of SMEWW 5210D (Baird & Bridgewater 2017).

For nutrient analysis, 0.5 L water samples were collected into a polyethylene terephthalate (PET) plastic bottle and analyzed immediately after samples were transported to the analytical chemistry laboratory. Total nitrogen, total phosphorus, nitrite nitrogen (NO₂-N)/nitrate nitrogen (NO₃-N), orthophosphate (PO₄-P), and ammonia nitrogen (NH₄-N) were measured by the colorimetric methods using the UV-1800 instrument (Shimadzu, Japan), following the standard methods of SMEWW 4500-N, SMEWW 4500-P B&E, SMEWW 4500-NO₂, B, SMEWW 4500-NO₃-E, SMEWW 4500-P E, and SMEWW 4500-NH₃ B&F, respectively (Baird & Bridgewater 2017). Briefly, persulfate method was used to determine total nitrogen by a 110 °C oxidation of organic and inorganic nitrogen to nitrate which was measured in the digestate. Nitrite nitrogen was quantified through the formation of a reddish-purple azo dye produced at pH 2.0–2.5 by coupling diazotized sulfanilamide with N-(1-naphthyl)-ethylenediamine dihydrochloride. The absorbance was detected at 543 nm by Spectrophotometer Shimadzu UV-1800 (Shimadzu, Japan). For total phosphorus, water samples were hydrolyzed by a persulfate digestion method to convert condensed phosphates and organic phosphate compounds to reactive phosphorus. Ammonium molybdate and antimony potassium tartrate reacted in an acidic medium with orthophosphate to form a complex of heteropoly acid-phosphomolybdc acid that was reduced to intensely colored molybdenum blue by ascorbic acid. For ammonium nitrogen, samples were distilled at pH 9.5 with a borate buffer to decrease hydrolysis of cyanates and organic nitrogen compounds. Alkaline phenol and hypochlorite reacted with ammonia to form indophenol blue that was proportional to ammonia concentrations. The formed blue color was intensified with sodium nitroprusside and its absorbance was detected at 640 nm by Spectrophotometer Shimadzu UV-1800.

2.4. Analysis of heavy metals

In this study, eight heavy metals including Hg, Pb, Cu, Zn, Cd, Cr, Ni, and As were examined in the surface water in the Saigon River. Briefly, 1 L samples were collected in a PET plastic bottle and preserved with nitric acid to a pH<2 at the sampling site before transporting them to the analysis laboratory. The samples were filtered through a 0.45 μm micropore membrane filter and kept at 4 °C until analysis. After nitric acid digestion, six metals including Pb, Cu, Zn, Cd, Cr, and Ni were analyzed directly by an inductively coupled plasma-optical emission spectrometer (ICP-OES) (Perkin Elmer, USA) following the standard method of SMEWW 5310B (Baird & Bridgewater 2017). Mercury (Hg) and Arsenic (As) were analyzed by cold vapor atomic absorption spectrometry and followed the method of SMEWW 5312B (Baird & Bridgewater 2017). The instrument was calibrated according to the manufacturer’s recommended procedure using calibration standards and blanks. The analytical calibration curve was set up based on calibration standard solutions (Merck, Germany) at an appropriate wavelength and concentration for each metal.

2.5. Analysis of antibiotic residues

The occurrences of target antibiotics including amikacin (Sigma-Aldrich, USA), cefixime (Sigma-Aldrich, USA), amoxicillin (Sigma-Aldrich, USA), ciprofloxacin (Sigma-Aldrich, USA), trimethoprim (Sigma-Aldrich, USA), and sulfamethoxazole (Sigma-Aldrich, USA) in the surface water samples were determined using solid-phase extraction (SPE) coupled with high-performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS). A 200 mL of raw water samples were added with 100 mg Ethylenediaminetetraacetic acid (EDTA). Next, the samples were passed through a tandem SPE cartridge (Oasis HLB 3 mL, 60 mg) system at a flow rate of 5 mL/min. Before water samples were loaded into the tandem SPE system, SPE cartridges were preconditioned with 3 mL of a mixture of acetonitrile (Merck, Germany) – methanol (Merck, Germany) (7:3, v/v), and followed by 3 mL Milli-Q water at a flow rate of 3.0 mL/min. Then, SPE cartridges were dried under vacuum for 2 min. Next, the target antibiotic residues retained in the SB cartridge were eluted with 2.5 mL of a mixture of acetonitrile: methanol:formic acid (Merck, Germany) (7:2:7:0.3, v/v/v/v), then with 1 mL Milli-Q water. The final eluates were dried with a nitrogen stream at 35 °C until the final volume of 1 mL. The HPLC-MS/MS analysis was performed in a 1290 series HPLC system (Agilent Technologies, USA) with A ZORBAX 1.8 μm RRHD (50×2.1 mm) column (Agilent Technologies, USA). The mobile phase was acetonitrile (B) mixed in a gradient mode with 0.1% formic acid (A) at a flow rate of 0.4 mL/min, with the
following conditions: 95% (A) for 1 min; from 95 to 50% (A) for 2 min; maintains at 50% (A) for 2.6 min; from 50 to 95% (A) for 2 min. A triple Quadruple 6400 mass spectrometer with ESI source from Agilent Technologies (USA) was used in positive mode. The most intense multiple reaction monitoring (MRM) transition was used for quantification and monitored along with a second transition for qualitative confirmation (Supplementary Table S3).

2.6. Data analyses and statistical methods
To evaluate the impacts of different anthropogenic activities on the water quality of the surface water samples, average measures of the three samples classified in the same anthropogenic activities were used to present in tables and graphs using the software Origin 2018. The statistical significance among the impact of different human activities on water quality parameters was examined using analysis of variance (ANOVA). Tukey’s honest significant difference test was performed to determine any significant differences among the four groups of anthropogenic activities. To evaluate the seasonal variations on the water quality parameters of the river water, t-tests were conducted for each pair of variables using Microsoft Excel 2016. Any differences were considered significant only if p-values were less than 0.05. Factor analysis (FA) and principal component analysis (PCA) were conducted for all the physicochemical parameters, nutrient and heavy metal concentration in all the sampling sites using Origin 2018. For all the data values below the quantification limits, 50% method detection limit (MDL) was used as input data for the multivariate analysis.

3. RESULTS AND DISCUSSION
3.1. Physicochemical parameters
Physicochemical parameters including pH, temperature, conductivity, salinity, turbidity, BOD5, COD, coliform, and DO were measured for the 12 sampling sites along the Saigon River in both the rainy and dry seasons. The pH values were ranged from 6.46 to 6.75 for the rainy season and from 6.13 to 7.06 for the dry season (Figure 1). The mean pH values for all the sites were found at a neutral range and within the permissible limit of the Vietnam regulation on surface water class 2 (Bộ Tài nguyên và Môi trường 2015). The average of the three samples in the same class of the dominant anthropogenic activities such as Agriculture (A), Industry (I), Residence (R), and Less impacted areas (L) are presented in Figure 2. Although there were no significant differences in pH between the rainy and dry seasons (p-value>0.05), the surface water samples for the industrial and residential activities were found to have higher pH than those at the agricultural and less impacted sites (Figures 1 and 2). Water temperature in the dry season was found from 28.1 to 31.0 °C, a little higher than that in the rainy season from 28.0 to 30.1 °C (Figure 1). They were normal in a tropical region like Ho Chi Minh City, where the average atmospheric temperatures varied from 26 to 38 °C in the dry season and from 24 to 33 °C in the rainy season. However, the average water temperatures at the sites impacted by industrial and residential activities were detected higher than those at the agricultural and less impacted sites (Figure 2). Temperature in the rainy season was found from 28.0 to 30.1 °C (Figure 1). They were normal in a tropical region like Ho Chi Minh City, where the average atmospheric temperatures varied from 26 to 38 °C in the dry season and from 24 to 33 °C in the rainy season. However, the average water temperatures at the sites impacted by industrial and residential activities were detected higher than those at the agricultural and less impacted sites (Figure 2). 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human activities at the sampling sites were frequently flushed by stormwater runoff, and then ended up in the river. A high level of organic matter and nutrients can lower the dissolved oxygen in the river water that was consumed by microorganisms during its decomposition process (Duc et al. 2013; Stefan & Stefan 2016). Among sampling sites, the DO were found highest in the less impacted areas and lowest in the industrial areas (Figure 2).

Biological oxygen demand (BOD) and chemical oxygen demand (COD) are used to examine organic contamination in the water environment. The median values of 5-day BOD (BOD5) in the rainy season were detected at approximately 19.65 mg/L, which was higher than that in the dry season 16.25 mg/L (Figure 1); however, this difference was not statistically significant (p-value > 0.05). The median value of BOD5 in both seasons was observed at a higher level than the Vietnam regulation of BOD5 for the surface water (Bộ Tài nguyên và Môi trường 2015). Among all the sampling sites or surface water, the highest level of BOD5 was measured in the industrial areas. It suggested that industrial activities were the most impacted factor causing pollution of organic matter and nutrients in the Saigon River (Figure 2). This is consistent with the DO levels, which were measured at the lowest value for the surface water samples collected in the industrial areas. In this study, COD analysis was conducted for only the rainy season and showed a similar trend to the BOD5 parameter (Figure 2). The COD values in all water samples ranged from 18.0 to 48.2 mg/L, which were higher than the regulation level according to the Vietnam regulation for surface water (Bộ Tài nguyên và Môi trường 2015). The highest value of COD in the water samples was found in the industrial areas, which was about three times more than that in the less impacted areas (Figure 2). The mean values of total coliform in the river samples in the less impacted, agricultural, industrial, and residential areas were $3.80 \times 10^3$, $3.83 \times 10^3$, $1.73 \times 10^6$, and $1.00 \times 10^6$ MNP/100 ml, respectively. This indicated high contamination of human and animal waste in the sampling sites of the Saigon River in the industrial and residential areas over the agricultural and less impacted areas.

**Figure 1** | Physicochemical parameter values in the Saigon River for the rainy and dry seasons in Ho Chi Minh City. The horizontal lines (red dashes) present the guideline values for each physicochemical parameter according to the Vietnam regulation for surface water. Please refer to the online version of this paper to see this figure in colour: https://doi.org/10.2166/wh.2022.233.
In summary, our results showed that the water samples of the Saigon River in the dry season presented higher mean values of pH, temperature, conductivity, DO, salinity parameters, lower mean values of BOD5, and turbidity in comparison to those in the rainy season. This suggested a higher abundance of organic matter in the surface water in the rainy season than that in the dry season. It is likely that stormwater runoff from everyday rains during the rainy season in Ho Chi Minh City probably washes all the organic pollutants out to the water bodies. The industrial and residential activities showed stronger impacts on the pollution of the River water in Ho Chi Minh City compared to agricultural activities. This could be because Cu Chi District, where the surface water samples were collected for the agricultural activities, have recently been built as a high-tech agricultural park in Ho Chi Minh City. The majority of farming activities in this area are well organized and applied many environmentally benign technologies to control infectious diseases, and reduce wastes to the environment.

3.2. Nutrients

Nutrients in surface water are among important parameters for water quality management because an overabundance of nutrients can cause algae bloom, which depletes dissolve oxygen in the water and pollutes the aquatic ecosystem. In this study, four nutrient parameters including orthophosphate (PO4-P), ammonium nitrogen (NH4-N), nitrite nitrogen (NO2-N), and nitrate nitrogen (NO3-N) were measured and presented in Figures 3 and 4. Our result showed that these nutrient parameters shared a similar pattern that the mean level of nutrients in the rainy season was found higher than that in the dry season, although the only difference of NH4-N was statistically significant (p<0.05; Figure 3). The orthophosphate PO4-P presented in the Saigon River water from 0.04 to 1.168 mg/L in the rainy season and from 0 to 0.563 in the dry season. On average, orthophosphate abundance in the rainy season was found higher than the limit recommended by the Vietnam regulation for surface water (0.2 mg/L; Bộ Tài nguyên và Môi trường 2015), while that in the dry season was...
below the limit. The level of phosphate PO₄-P in the river water in the industrial and residential areas was significantly higher than that in the agricultural and less impacted areas (p-value<0.05; Figure 4). The ammonium nitrogen NH₄-N in the surface water samples of the Saigon River ranged from 0.003 to 13.92 mg/L in the rainy season, and from 0 to 4.482 mg/L in the dry season. The mean values of NH₄-N in both seasons were found higher than the limits set by the Vietnam regulation for surface water (0.3 mg/L; Figure 3; Bộ Tài nguyên và Môi trường 2015). Similar to the orthophosphate, the ammonium nitrogen concentrations in the river water mainly impacted by the industrial and residential activities were observed higher than those impacted by the agricultural activities, which showed similar levels to those in the less impacted areas (Figure 4). This was consistent with the physicochemical parameters reported above indicating that the industrial and residential activities were the main contributors to organic pollution in the surface water along the Saigon River in HCM City. Nitrite nitrogen NO₂-N varied from 0.0035 to 0.282 mg/L in the rainy season and from 0 to 0.156 mg/L in the dry season (Figure 3). The average value of nitrite nitrogen in the rainy season was found over the limits according to the Vietnam regulation for surface water (0.05 mg/L). The NO₂-N concentrations in the River water in the agricultural and residential areas were higher than those in the industrial and less impacted areas, although these differences were not statistically significant (p-value>0.05; Figure 4). Nitrate nitrogen NO₃-N ranged from 0.06 to 54.545 mg/L in the rainy season and from 0 to 2.64 mg/L in the dry season (Figure 3). The mean values of nitrate nitrogen were below the limit (5 mg/L) of the Vietnam regulation for surface water (Bộ Tài nguyên và Môi trường 2015; Figure 4).

3.3. Heavy metals

Heavy metals are toxic and can cause cancer in the skin, lung, urinary tract, cardiovascular diseases, neurotoxicity, and diabetes, even at a low metal ion concentration (Vardhan et al. 2019). The concentrations of heavy metals in the Saigon River...
were found up to 75.03 μg/L (Cu), 15 μg/L (Pb), 47.41 μg/L (Zn), 2.6 μg/L (Cd), 2.4 μg/L (As), 7.06 μg/L (Cr), 29.31 μg/L (Ni), and 0.9 μg/L (Hg); following the decreasing order: Cu > Zn, Ni > Pb > Cd > As > Hg (Table 1). In general, the presence of tested heavy metals in the surface water of the sampling sites in the Saigon River was found at lower levels than the limits according to the Vietnam regulation for surface water (Bộ Tài nguyên và Môi trường 2015). In comparison to the rainy season, the mean concentrations of heavy metals such as Cu, Zn, As, Ni, and Hg in the river water was detected at a slightly higher in the dry season, while those of Pb, Cd, and Cr in the river water were lower in the dry season (Table 1). Although these differences were not statistically significant, this pattern of heavy metal concentration is similar to a recent study on the occurrences of heavy metals in a confluence of an urban canal and a mainstream of the Saigon River (Nguyen et al. 2020). Also, our results showed that the majority of the tested heavy metals such as Cu, Pb, Zn, As, Cr, and Ni were found slightly higher in the water samples collected at the industrial and residential areas compared to the agricultural and less impacted areas.

3.4. Antibiotic residues

The concentrations of six selected antibiotics in the surface water of 12 sampling sites along the Saigon River were detected using the LC-MSMS method as shown in Table 2. In general, the abundance of almost selected antibiotics (amoxicillin, amikacin, cefixime, and ciprofloxacin) were lower than the method detection limit for all the sampling sites, except for sulfamethoxazole and trimethoprim (Table 2). The abundance of sulfamethoxazole and trimethoprim were also found very low in almost the sampling sites, except for the industrial sites I2 (0.5 mg/L sulfamethoxazole, 0.01 mg/L trimethoprim) and I3 (0.11 mg/L sulfamethoxazole, 0.013 mg/L for trimethoprim). Among the six selected antibiotics, sulfamethoxazole

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**Figure 4** Nutrient parameters in the Saigon River impacted by main anthropogenic activities including Less impacted areas (L), Agricultural areas (A), Industrial areas (I), and Residential areas (R). The horizontal lines (red dashes) present the guideline value for each physicochemical parameter according to the Vietnam regulation for surface water. Please refer to the online version of this paper to see this figure in colour: https://doi.org/10.2166/wh.2022.233.
and trimethoprim were widely detected in the aquatic environments (Patrolecco et al. 2018; Delaney et al. 2020). In comparison to some other Rivers in the North of Vietnam, the level of sulfamethoxazole in the Saigon River was observed lower than those in the To Lich River (0.585 mg/L), the Lu River (1.09 mg/L), and the Kim Nguu River (0.535 ml/L), but higher than that in the Set River (0.2 mg/L) (Da Le et al. 2021). In a recent study in 2015, sulfamethoxazole and trimethoprim were detected in the aquatic environments on the Mekong Delta, about 20 km from the Saigon River, with an average level of 0.021 and 0.01 mg/L, respectively (Nguyen Dang Giang et al. 2015). The persistence of these antibiotic residues in the surface water may serve as selective pressures for the growth and spread of antibiotic resistant bacteria in the aquatic environments.

### 3.5. Relationship between water quality parameters and anthropogenic activities in the Saigon River

The correlation analyses (e.g., Pearson and Spearman analysis) and Principal component analysis (PCA) was conducted on the data set for all surface water samples along the Saigon River in both the rainy and dry seasons to uncover any relationship among the physicochemical parameters, nutrients, heavy metals, and human activities (Supplementary Tables S2, S4, and...
S5). In the PCA analysis, factor analysis of the data set suggested seven significant components (eigenvalues > 1), with 86.67% of the total variance explained (Supplementary Figure S2). Five principal components were extracted and cumulative explained 75.1% of the total variance of all water quality parameters (Supplementary Table S2). The first principal component (PC1) explained for 28.16% of the total variance was correlated with pH, temperature, BOD5, Cu, Ni, and Zn, which have positive loading values greater than 0.3. The positive correlation between the PC1 with many samples collected at the industrial (samples I1, I2, I3) and residential areas (samples R1, R2, R3) indicated that domestic and industrial wastes in HCM City could be the main contributors to the contamination of organic matter, and heavy metals (e.g., Cu, Ni, and Zn) in the Saigon River (Figure 5). The negative correlation between PC1 with many samples collected from the agricultural (samples A1, A2, A3) and less impacted areas (samples L1, L2, L3) suggested that the agricultural activities in the Cu Chi District did not cause significant contaminations of organic matter, and heavy metals to the Saigon River. For the industrial activities, the site I2 in the Tan Binh Industrial Park, and the site I3 in the Sai Gon High-Tech Park were among the most contaminated sites. It could be because these industrial areas were located in the central of the HCM City, where the water samples from these sites were impacted not only by industrial activities but also domestic wastewaters from the residential activities. The second principal component (PC2) described 16.95% of the total variance was correlated with conductivity, salinity, and DO with their positive loading values ranging from 0.39 to 0.48 (Supplementary Table S2). Samples collected at the residential (R1, and R2) and less impacted (L1) sites have positive correlations with the PC2, which indicated that the surface water samples at these sampling sites were likely contaminated with inorganic compounds (Figure 5). The PC3 explained for 12.26% of the total variance of all water quality parameters and had negative loading values of PO4-P (−0.41) and NH4-N (−0.38), but positive loading values of NO3-N (0.48); thus, these components attributed to the areas less contaminated by the organic waste. PC4 and PC5 components described approximately 10 and 7% of the total variance of all water quality parameters, respectively (Supplementary Table S2). Both PC4 and PC5 components showed a similar pattern that was significantly related to the heavy metal and organic matter, which could be influenced by residential and industrial wastewaters (Supplementary Table S2).

4. CONCLUSION

Surface water in the river, which is an important source of drinking water supply for humans as well as provides natural habitats for many aquatic organisms, has been influenced by seasonal changes and a variety of anthropogenic activities, especially...
in the megacity of Ho Chi Minh City. Our results indicated that many water quality parameters including physicochemical, nutrients, heavy metals, and some selected antibiotics in the Saigon River were significantly affected by tropical seasons and human activities. The river water samples in the rainy season were likely contaminated with higher concentrations of organic matter and nutrients, but lower concentrations of many tested heavy metals such as Cu, Pb, Zn, As, Cr, and Ni than those in the dry season. Among the selected antibiotics, sulfamethoxazole and trimethoprim were observed high in the industrial sites (I2 and I3), while the other antibiotics were found lower than the method detection limit in the Saigon River. Multivariate analysis suggested that industrial and residential activities are the main contributors to the contamination of organic matters, some heavy metals (e.g., Cu, Ni, and Zn) and deteriorating the water quality of the Saigon River compared to the agricultural activities in Ho Chi Minh City. Further research is necessary to examine whether there are any synergistic effects by both industrial and residential wastewaters at the industrial sites on the persistence of major contaminants such as organic matters, heavy metals, and antimicrobial compounds in the surface water.

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**CONFLICTS OF INTEREST**
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Not applicable.

**ETHICS APPROVAL**
Not applicable.

**CONSENT TO PARTICIPATE**
Not applicable.

**CONSENT FOR PUBLICATION**
Not applicable.

**DATA AVAILABILITY STATEMENT**
All relevant data are included in the paper or its Supplementary Information.

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