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Research Article

Occurrence and ecological risk assessment of antibiotics in water of Saigon River

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Abstract: The residual antibiotics in the environment have lately caused widespread concerns. However, little information is available on antibiotic pollution and its ecological risk to water resources of Saigon river. Therefore, an investigation of the occurrence and ecological risk of antibiotics in the Saigon river was necessary. Determination of antibiotics was analysed by liquid chromatography tandem mass (LC/MS/MS) and ecological risk assessment of antibiotics was used risk quotient (RQ) methods. Results revealed that the antibiotics concentrations total in water ranged from not determined (ND) to 697.3 ng/L in rainy season and to 869.3 ng/L in the dry season respectively. The ecological risk assessment via the risk quotient (RQ) of Quinolone class (Ciprofloxacin, Enrofloxacin, Norfloxacin and Ofloxacin) in areas affected by livestock, urban living and aquaculture activities were recorded to be higher than 1, indicating that Quinolone class has remained at high risk in the Saigon River. The RQ of Ciprofloxacin in the source area, in particular, has reflected a medium–risk level compared to other antibiotics in the Saigon River's low–risk category. The research findings have revealed the significance and necessity of protecting the Saigon River water from contamination by antibiotics for domestic water supplies and aquaculture.

Keyword: Antibiotics; Ecological Risk Assessment; Aquatic Environment; Saigon River.

1. Introduction

Antibiotics are one of the newest pollutants and are currently being researched for their prevalence and environmental impacts in recent years [1]. In the global study, it has indicated that the presence of antibiotics in surface water has a significant impact on water ecosystems such as antibiotic resistance [2], the inhibition of the pollutant–degrading activity of bacteria [3]. According to a globally representative study by the Water Research Foundation (WRF) [4], there are more than 30 different types of antibiotics present in surface water. Several has a high frequency of occurrence, such as Clindamycin (100%, 3 samples), Monensin (65%, 260 samples), Lincomycin (36%, 600 samples), Erythromycin (21%, 348 samples). Many antibiotics showed up more than 10% of the time (in hundreds of samples), including sulfamethoxazole (18%), trimethoprim (17%, 1087 samples), and sulfamethazine (16%, 715 samples). Antibiotic residues were additionally detected in surface water and wastewater with concentrations approximately 10–1000 ng/L [5]. The quinolones, chloramphenicols, sulfonamides and macrolides appear to be the primary antibiotics recognized in drinking water with the highest concentrations and frequencies of

detection, in which ciprofloxacin has identified values up to 679.7 ng/L [6]. In Guangzhou (China), the concentration of antibiotic residues in tap water is approximately 7.9–679.7 ng/L, which is greater than the level of antibiotics in tap water in 42 other Chinese cities. Synthesis of related studies [7] has revealed that Chinese tap water may contain more antibiotics than other countries' tap water does in terms of antibiotic residues. To assess the level of impact of antibiotics in water or sediment, an ecological risk assessment method is widely used and is expressed as a risk quotient (RQ) [8]. Based on this methodology, a number of studies on risk assessment for Qingshitan Reservoir [9] and the Subtropical River–Reservoir System [10] have been conducted.

The Saigon River takes the responsibility of supplying water to irrigate 58,350 hectares of agricultural land in the basin and providing water for all production and daily activities of Ho Chi Minh area [11]. Many livestock and aquaculture farms use antibiotics and wastewater from hospitals and pharmaceutical firms at the Saigon River's headwaters; domestic wastewater also contains many types of antibiotics that are discharged into water sources. Antibiotics account for 70% in livestock and aquaculture with 13 antibiotics [12] which are utilised in Ho Chi Minh City's hospitals [13]. A number of studies in the Saigon River basin have revealed high concentrations of antibiotic residues FQs, TCs and endocrine disruptors PEs with the occurrence frequency of fluoroquinolones (FQs) in water about 33%, in sludge about 62%; tetracyclines (TCs) in water about 33%, in mud about 57%; phthalate esters (PEs) in water about 25% and in sludge about 100% [14].

Nowadays, research on antibiotic residues and their ecological risks has not been performed. Therefore, the objectives of this study were: (1) to investigate the occurrence of antibiotics and (2) to assess the ecological risks of antibiotics to the water quality of the Saigon River. The research results may examine the status of antibiotic contamination in the river water and its ecological risk level and provide a scientific basis for antibiotic management in the Saigon river basin.

2. Materials and methods

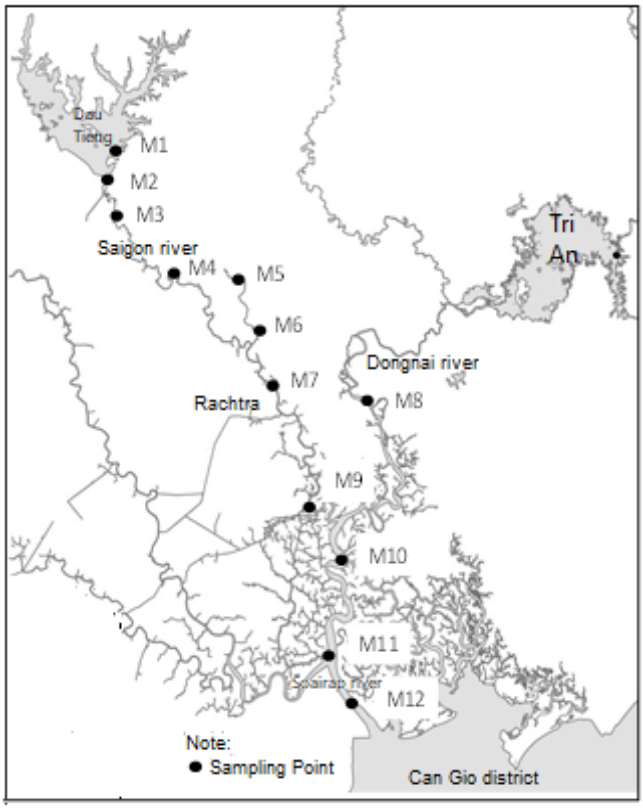
2.1. Sample sites and collection

Based on the environmental and hydrological characteristics of the Saigon river and its main entry tributaries, 12 sampling sites (M1–M12) were deployed in this study (Figure 1). According to Vietnamese Standards [15], from 0 to 50 cm depth, 2 L surface water samples were collected by barometer (Wilco company, US), then immediately loaded into a brown glass bottle and labeled. The water samples were stored in a 4^{o}C refrigerator and pre–treated within 48 h. Sampling Duration: dry season (September 2015) and rainy season (April 2016).

2.2. Sample preparation and detection

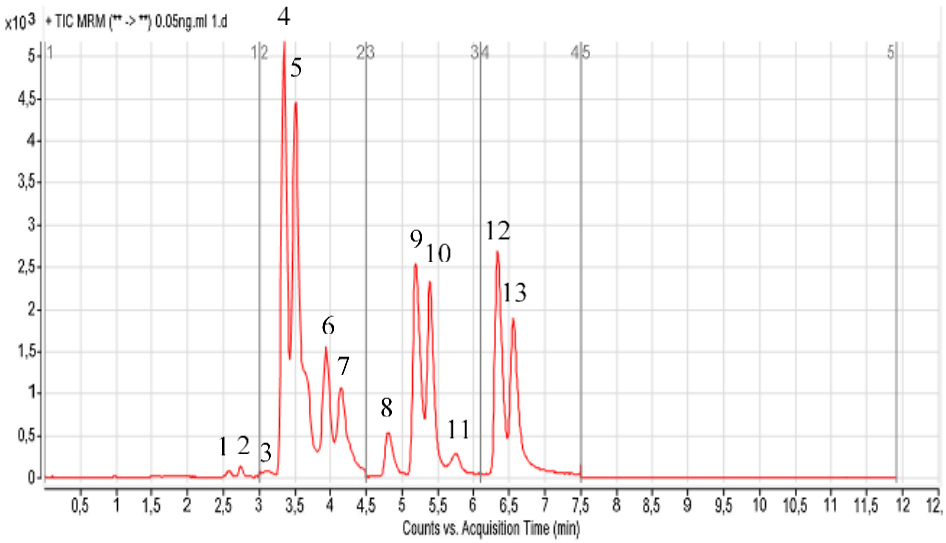
Sample extraction: Antibiotics in water were extracted according to the method reported in the literature [16–18], such as Water samples were purified by SPE, which is Oasis HLB (hydrophilic–lipophilic–balance) extraction column (60 mg, 3 mL, Waters). SPE vacuum manifold 12 pos (from Waters Corporation, U.S.A) were used (Figure 2).

Sample analysis: All water samples were analyzed via high–performance liquid chromatography with mass spectrometer double quadrupole detection (HPLC/MS/MS, 6410 B, Agilent) and were referenced in the literature [17–18].



Symbol	Sampling sites	Coordinates
M1	Dautieng reservoir	11°20'16.8"N 106°21'05.0"E
M2	Moi bridge	11°18'29.3"N 106°20'23.9"E
M3	Ben Cui bridge	11°16'45.4"N 106°21'17.8"E
M4	Ben Suc bridge	11°09'22.3"N 106°27'05.6"E
M5	Do bridge	11°09'04.1"N 106°35'16.4"E
M6	Ong Co bridge	11°02'55.2"N 106°36'41.2"E
M7	Phu Cuong bridge	10°58'51.7"N 106°38'33.4"E
M8	Hoa An bridge	10°56'50.1"N 106°48'21.5"E
M9	Bach Dang boating	10°46'33.2"N 106°42'26.2"E
M10	Binh Khanh ferry station	10°40'46.9"N 106°46'09.5"E
M11	Vam Sat	10°31'48.6"N 106°45'18.9"E
M12	Ly Nhon, Can Gio dicstrict	10°26'32.7"N 106°46'52.8"E

Figure 1. The 12 sampling sites (M1–M12) of Saigon river.



1: atrazin; 2: vancomycin; 3: diuron; 4: trimethoprime, sulfamethazin; 5: ciprofloxacin, 6: ofloxacin; 7: tetracyclin; 8: sulfamethoxazol; 9: enrofloxacin; 10: erythromycin; 11: tylosin; 12: norfloxacine; 13: chlorotetracyclin.

Figure 2. 50 ng/L Standard Chromatogram of antibiotics.

2.3. Ecological risk assessment in water

The antibiotics in the environment are new organic pollutants, their concentration in the aquatic environment is very low, generally in order of magnitude from ng/L to µg/L. In this study, the risk quotient (RQs) method was selected to evaluate the potential risks of antibiotics to aquatic ecosystems. RQs values were calculated according to environmental concentrations (MEC) and predicted no–effect concentrations (PNEC), the formula used was as follows [8, 19]:

$$RQ_{water} = \frac{MEC}{PNEC_{water}} \quad (1)$$

where MEC is the actual measured concentration in the environment (ng/L); $PNEC_{water}$ is the predicted no–effect concentration in the water and it is the maximum drug concentration that will not have an adverse effect on the microorganisms or the ecosystem in the environment under the existing cognition (ng/L); $PNEC_{water}$ values were referenced in the literature [20–21].

Table 1. Predicted no–effect concentrations for antibiotics.

Antibiotic	Observed lowest MIC[1] (ng/L)	Size–adjusted lowest MIC[2] (ng/L)	PNEC (resistance selection)[3] (ng/L)	References
Chlortetracyclin	–	–	1000	as Tetarcyclin
Ciprofloxacin	2000	1000	64	[14–15]
Enrofloxacin	8000	500	64	[14–15]
Erythromycin	16000	8000	1000	[14–15]
Norfloxacin	16000	4000	500	[14, 15]
Ofloxacin	32000	16000	1000	[14–15]
Sulfamethazine	NA	NA	NA	[14–15]
Sulfamethoxazole	1000000	125000	16000	[14–15]
Tetracyclin	16000	16000	1000	[14–15]
Trimethoprim	16000	8000	500	[14–15]
Tylosin	2000	32000	4000	[14–15]
Vancomycin	125000	125000	8000	[14–15]

Notes: [1]The lowest MIC value observed for any species in the EUCAST database; [2]The size–adjusted lowest MIC (Minimal Inhibitory Concentrations) prediction, corresponding to the estimated upper boundary for the MSC (rounded down to the closest concentration on the EUCAST (European Committee on Antimicrobial Susceptibility Testing) testing scale; [3]The PNEC corresponds to the size–adjusted lowest MIC divided by an assessment factor of 10 (rounded down to the closest concentration on the EUCAST testing scale).

Ecological risk classification such as [22]: When RQ ranges from 0.01 to 0.1, the ecological risk assessment of antibiotics in water is low. The environment is in medium risk when RQ ranges from 0.1 to 1, while RQ is more than or equal to 1, the risk is at a high level.

3. Results and Discussion

3.1. Concentration of antibiotics in water

Determination results has revealed 12 antibiotics in water of Saigon River. The antibiotics concentration ranged between not determined (ND) and 697.3 ng/L (rainy season) and 869.3 ng/L (dry season). The highest concentration both was Sulfamethoxazole antibiotic.

The antibiotics concentration total of water (Fig. 3) is ranged from 12.9 to 3,048 ng/L (rainy season) and 3,227 ng/L (dry season). The rank of four antibiotics of highest antibiotics concentration in water of Saigon river was recorded as follows Sulfamethoxazole > Norfloxacin > Ciprofloxacin > Ofloxacin.

Table 2. Highest concentration of four antibiotics in water of Saigon river.

Antibiotics	**Dry season** (ng/L)	**Rainy season** (ng/L)
Sulfamethoxazole	364.2	313.5
Norfloxacin	230.0	207.8
Ciprofloxacin	226.2	188.2
Ofloxacin	220.0	192.6

The highest antibiotic concentration total was observed at sampling site M6 (3,048 – 3,227 ng/L) and the lowest at M1 (about 12.9 ng/L).

The total average concentration of 12 antibiotics varied greatly, ranging from not detected (ND) to 1293.5 ng/L (rainy season) and 1484.2 ng/L (dry season). In addition to natural factors, even in the aquatic environment, antibiotics are also adsorbed by substances suspended in water or by sediment [23].

In terms of antibiotics present in Saigon river water calculated at 12 sampling points, the total antibiotic concentration ranged from not detected (not detected, M1 site) to 3048 ng/L (rainy season), 3048 ng/L (rainy season) and 3227 ng/L (dry season) at Ong Co bridge sampling point (M6 site). The concentration of antibiotics was recored to be insignificantly low at Vam Sat sampling point (point M11) with total antibiotic concentration in the range of 2575 ng/L (rainy season) – 2587 ng/L (dry season) (Figure 3).

The results depicted on the graph (Figure 2) further demonstrate that each area has a distinct total concentration of antibiotics due to various applications and effect sources. Total antibiotic concentration was reported to be highest in livestock production areas, aquaculture areas and lowest in watershed areas, after Dau Tieng reservoir.

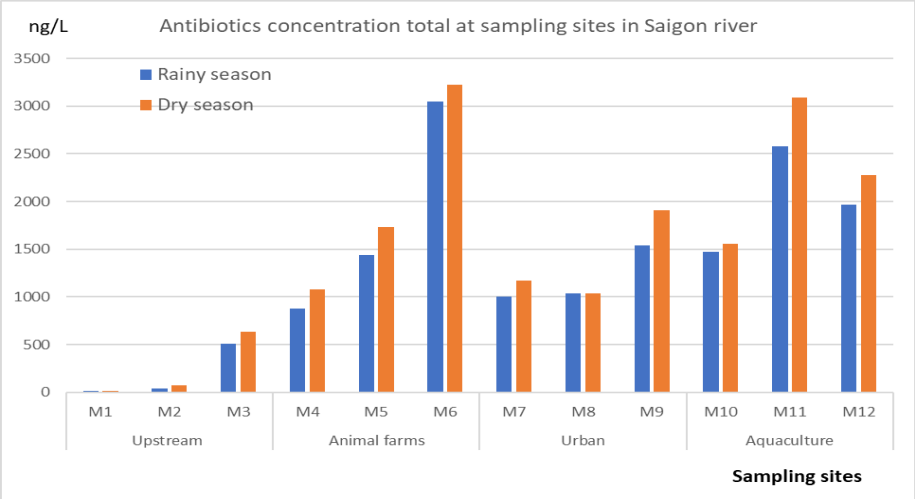


Figure 3. Antibiotic concentration total of water samples in ng/L at each sampling point of Saigon river.

The detection frequency of antibiotics in surface water of Saigon river basin gradually reduced, in the order sulfamethoxazole > norfloxacin > ofloxacin > ciprofloxacin > trimethoprim > enrofloxacin > tylosin > vancomycin > erythromycin > tetracyclin > sulfamethazine > chlotetracycline. Within the majority of the water samples analysis, sulfamethoxazole, trimethoprime, ciprofloxacin, norfloxacin, and ofloxacin frequency and high concentrations were recognised (frequency above 80%) (Table 3).

The frequency and concentration of detected antibiotics is variable depending on the sampling season. Calculating the standard deviation and variance of the antibiotic concentration analysis data also reveals that they are relatively similar and that there is little significant difference between the dry and rainy seasons.

Table 3. Occurrence frequency and antibiotics concentration in water of Saigon river.

Antibiotics	**Rainy season**			**Dry season**		
	Occurrence frequency (%)	Max concentration (ng/L)	Average concentration (ng/L)	Occurrence frequency (%)	Max Concentration (ng/L)	Average Concentration (ng/L)
Ciprofloxacin	83.3	469.3	188.2	83.3	598.3	226.2
Norfloxacin	83.3	540.9	207.8	83.3	604.3	230.0
Ofloxacin	83.3	358	192.6	83.3	386.2	220.0
Enrofloxacin	75.0	192.4	56.8	50.0	86.4	61.4

Antibiotics	Rainy season			Dry season		
	Occurrence frequency (%)	Max concentration (ng/L)	Average concentration (ng/L)	Occurrence frequency (%)	Max Concentration (ng/L)	Average Concentration (ng/L)
Tetracyclin	75.0	104.0	34.4	75.0	142.8	50.2
Chlotetracyclin	75.0	78.83	20.3	75.0	136.4	24.4
Sulfamethoxazole	91.7	697.3	313.5	91.7	869.3	364.2
Sulfamethazine	58.3	85.61	21.3	50.0	67.2	14.5
Trimethoprim	91.7	270.4	104.4	91.7	316.4	130.5
Vancomycin	50.0	311.6	50.2	50.0	214.6	42.6
Erythromycin	75.0	111.6	47.1	75.0	148.4	61.5
Tylosin	75.0	156.0	56.7	75.0	179.2	58.8

3.2. Residual characteristics of antibiotics in water

Antibiotics in to the aquatic environment mainly come from pharmaceutical, medical, animals farm, aquaculture and domestic wastewater [14, 18, 24]. Antibiotics are considered to be ideal antibacterial drugs for humans and animals, they have been widely used in livestock and poultry breeding, aquaculture [12].

Research has quite extensively studied the presence of antibiotics in the aquatic environment on other areas (Table 4).

Table 4. Compared of concentrations of antibiotics in different the aquatic environment with results of study.

No.	Antibiotics	Max conc. of Ho Tay Lake [11]	Max conc. of Truc Bach lake [11]	Max conc. of Yen So Lake [19]	Mean conc. of Dongjiang River [20]	Mean conc. in water of another river [21]	Mean conc. of Saigon river (in rainy season)
1	Chlotetracyclin	NA	NA	NA	NA	690	20.3
2	Ciprofloxacin	55.27	98.56	568.4	169.2	39	188.2
3	Enrofloxacin	16.88	73.01	2.5	NA	40	57.2
4	Erythromycin	NA	NA	NA	0.7	280	47.1
5	Norfloxacin	79	48.88	20.76	62.3	120	207.8
6	Ofloxacin	43.11	211.67	242.91	7.1	270	192.6
7	Sulfamethazine	34.82	LOD	6.91	NA	472	21.3
8	Sulfamethoxazole	89.7	104.29	1619.35	NA	1900	313.5
9	Tetracyclin	NA	NA	NA	44.9	300	34.4
10	Trimethoprim	26.41	69	52.57	NA	710	104.4
11	Tylosin	NA	NA	NA	0.6	280	56.7
12	Vancomycin	NA	NA	NA	NA	NA	20.3

Compared with the concentration of antibiotics in rivers and lakes worldwide, the concentration of the antibiotic in water of the Saigon river was similar or at a moderately low level (Table 2). Of the twelve antibiotics, the highest concentration of antibiotics in water was Sulfamethoxazole and there were significant differences among the values for the other antibiotic at the sampling sites.

This result was similar to some other researches [4, 18, 25]. The highest water Sulfamethoxazole was observed at M6 site (about 697.3–786.2 ng/L) which is located near the high animal farms density. Sulfamethoxazole is a widely used antibiotic in medicine, in the field of livestock and aquaculture, so their presence in the environment with high concentrations is the result of a combination of all waste sources in the basin.

3.3. Ecological risk assessment in water

The ecological risk assessment of antibiotics in water is shown in Table 5 and Figure 3.

Some key characteristics of ecological risk levels through the risk quotient are as follows:

- RQ of Quinolone class (Ciprofloxacin, Enrofloxacin, Norfloxacin and Ofloxacin) in areas affected by livestock, urban living and aquaculture activities were recorded to be higher than 1, indicating that Quinolone class is remained at high risk in the Saigon River.

- In the headwaters of the Saigon River (area 1), the RQs of the Quinolones are reported to be less than 0.1 (except for Ciprofloxacin (RQ: 0.234–0.295), indicating that these CKS substances belonging to the low–risk group in the Saigon River. Particularly for the RQ of Ciprofloxacin in zone 1, the level of risk is moderate.

- The RQ risk quotient for the remaining antibiotics is low (0.0–0.382), indicating a low level of ecological threat.

- Although antimicrobial substances concentrations were discovered at low levels, ecological risk assessment still indicated a higher risk, suggesting that these antibiotics are still toxic to aquatic organisms at low concentrations and thus demand attention.

Table 5. Calculation results of Risk Quotient (RQs) in water of the Saigon river.

Antibiotics	Average		Upstream		Animal farm		Urban		Aquaculture	
	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
Chlotetracyclin	0.020	0.024	0.001	0.001	0.019	0.028	0.009	0.009	0.052	0.054
Ciprofloxacin	2.940	3.534	0.234	0.295	3.804	4.269	1.926	1.926	5.797	7.277
Enrofloxacin	0.894	0.959	0.034	0.186	1.663	1.479	0.162	0.162	1.719	1.130
Erythromycin	0.047	0.061	0.005	0.012	0.069	0.095	0.058	0.058	0.056	0.073
Norfloxacin	0.416	0.460	0.062	0.058	0.575	0.680	0.386	0.386	0.640	0.705
Ofloxacin	0.193	0.220	0.034	0.042	0.268	0.288	0.232	0.232	0.237	0.262
Sulfamethazine	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulfamethoxazole	0.020	0.023	0.004	0.005	0.023	0.027	0.018	0.018	0.033	0.040
Tetracyclin	0.034	0.050	0.001	0.001	0.053	0.083	0.036	0.036	0.046	0.075
Trimethoprim	0.209	0.261	0.038	0.063	0.298	0.371	0.187	0.187	0.313	0.382
Tylosin	0.014	0.015	0.003	0.002	0.028	0.031	0.016	0.016	0.010	0.011
Vancomycin	0.006	0.005	0.000	0.000	0.013	0.009	0.008	0.008	0.004	0.003

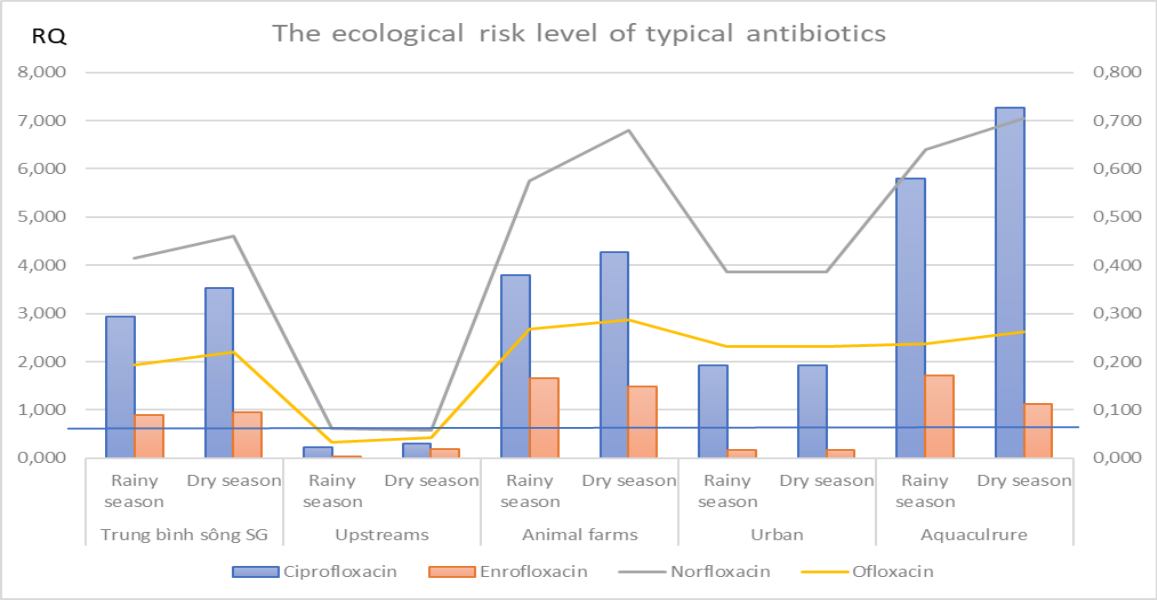


Figure 3. The ecological risk level of typical antibiotics in water of Saigon river.

The most significant degree of ecological risk in the Saigon River is the antibiotics Ciprofloxacin, Enrofloxacin, Norfloxacin, and Ofloxacin with a high RQ risk quotient. Other antibiotics are belonging to the low ecological risk category. The study's main weakness is that it is unable to demonstrate a continuous association between risks on the

Saigon River due to the dispersed nature and diverse sampling locations. The RQ method's results for risk assessment are unrelated, lack homogeneity between the examined positions, and do not accurately reflect the amount of risks.

4. Conclusion

The detection frequency of antibiotics in water was higher 75.0%. Sulfamethoxazole antibiotic was observed to be the highest concentration in water of Saigon river. In terms of spatial distribution, concentrations of antibiotics are distributed variably from upstream to downstream depending on the region. Two areas with total antibiotic concentrations greater than 3,000 ng/L are due to the influence of livestock and aquaculture.

The degree of ecological risk is reported to be low with the majority of RQs less than 1, and only two antibiotics, Ciprofloxacin and Enrofloxacin, have high–risk quotients in livestock, urban living, and aquaculture areas. There are signs of antibiotic pollution in the Saigon river and long–term monitoring of antibiotics' residues is required. In near by future, antibiotic pollution control policy and technology need to be used to protect the water quality of Saigon river.

Author contribution statement: Author contribution statement: Set up the input data of model; Analyzed and interpreted the data; Materials, analysis tools and data; Calculation, analyzed and interpreted the results; Wrote the draft manuscript: N.P.B., D.Q.T.; Analyzed and interpreted the data; Analyzed and interpreted the results; Materials, manuscript editing: P.H.N., N.T.M.H.

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