Antibiotic Contamination in Hanoi's Urban Lake Waters: Occurrence and Environmental Implications

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Article

Antibiotic Contamination in Hanoi's Urban Lake Waters: Occurrence and Environmental Implications

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Abstract: This study investigates the occurrence, concentration, and spatial distribution of multiple antibiotics in lake water samples collected from various urban lakes. The analysis revealed that sulfonamides, fluoroquinolones, and trimethoprim were the dominant antibiotic groups detected, with sulfamethoxazole (SMX) showing the highest frequency and concentration across the sampled sites. Other antibiotics, including sulfadiazine (STZ), were also identified, albeit at lower levels. Higher antibiotic concentrations were observed in lakes influenced by untreated municipal and healthcare wastewater, indicating significant anthropogenic pollution sources. The differing chemical properties of antibiotics affected their environmental behavior, with hydrophilic compounds remaining primarily in the water column, while fluoroquinolones showed a tendency to accumulate in sediments and aquatic organisms, raising concerns about bioaccumulation and antimicrobial resistance. These findings highlight the pressing need for improved wastewater treatment practices and regulatory controls to mitigate antibiotic contamination and its ecological risks. The study provides valuable baseline data for environmental monitoring and contributes to the understanding of antibiotic pollution in urban aquatic environments.

Keywords: antibiotics; Urban lakes; environmental risk assessment

1. Introduction

In Vietnam, drugs are often treated like everyday consumer goods, easily purchased without a prescription. As a result, the use of pharmaceuticals—especially antibiotics—is widespread and largely unregulated. It is common for individuals to rely on word-of-mouth recommendations and visit pharmacies to buy medications such as paracetamol or penicillin when experiencing symptoms like headaches, runny noses, or coughs. According to a recent study, 78% of antibiotics are purchased from private pharmacies without a prescription; 67% of customers rely on the advice of pharmacy staff, and only 11% make their own decisions regarding antibiotic use [1,2]. Alarmingly, the misuse of antibiotics is not limited to the general public—many physicians have also been found to prescribe them inappropriately. Inappropriate dosages and non-compliance with treatment guidelines further exacerbate the problem. Moreover, Vietnam currently lacks clear legal regulations regarding the disposal of pharmaceutical waste into the environment. Consequently, the occurrence of pharmaceutical residues, particularly antibiotics, in the environment is presumed to be significant.

Several studies have investigated the presence of antibiotics in Vietnam's aquatic environments. For example, Managaki et al. (2007) detected macrolides, sulfonamides, and trimethoprim in surface water and piggery wastewater in the Mekong Delta, with concentrations ranging from 15 ng/L to 328 ng/L [3]. Le Xuan Tuan et al. (2004) reported the presence of norfloxacin, oxolinic acid, trimethoprim, and sulfamethoxazole in wastewater from 16 shrimp farms located in Thai Binh, Nam Dinh, Can Tho, and Ca Mau provinces, with antibiotic residues ranging from 0.01 to 6.0 mg/L. In some canals, concentrations were as high as 2615.9 mg/L [4]. Another study by Duong Hong Anh et al. (2008)

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found ciprofloxacin (CIP) and norfloxacin (NOR) in hospital wastewater in Hanoi, with concentrations ranging from 0.9 μg/L to 171 μg/L [5].

The presence of antibiotic residues in aquatic environments poses a significant threat to both ecosystem health and human wellbeing [. Antibiotics can disrupt microbial communities in water bodies, leading to altered nutrient cycling and reduced biodiversity. More critically, their persistence facilitates the emergence and proliferation of antibiotic-resistant bacteria, which can transfer resistance genes through the food chain and water supply, ultimately undermining the effectiveness of antimicrobial therapies in human and veterinary medicine. Numerous international studies have highlighted the global concern surrounding antibiotic resistance as a consequence of environmental contamination [6–10].

Despite the growing recognition of antibiotic contamination in surface waters, there remains a notable lack of comprehensive studies focusing on lakes within Hanoi, many of which act as reservoirs for untreated or partially treated household wastewater [11–16]. These urban lakes represent critical hotspots for the accumulation and potential bioaccumulation of antibiotics due to their relatively stagnant water conditions and close proximity to densely populated areas [14,17–22]. Understanding the occurrence, distribution, and concentration of antibiotics in these lakes is essential for assessing environmental risks and informing local water management strategies.

Vietnam's existing wastewater treatment infrastructure, particularly for municipal and hospital effluents, is often insufficient to effectively remove pharmaceutical contaminants including antibiotics. The direct or indirect discharge of inadequately treated wastewater into lakes and rivers contributes substantially to environmental antibiotic loads [6,23–26]. This situation is exacerbated by the absence of stringent regulations and enforcement mechanisms governing pharmaceutical waste disposal, allowing the continuous influx of antibiotics into natural water bodies [8,9].

Addressing these gaps, the present study aims to provide a detailed assessment of antibiotic residues in multiple urban lakes across Hanoi. By quantifying concentrations and identifying spatial distribution patterns of commonly used antibiotics, this research seeks to establish baseline data critical for risk assessment [27–31]. Additionally, the study evaluates potential ecological risks associated with antibiotic contamination and informs policymakers and stakeholders on necessary intervention measures to mitigate the development of antibiotic resistance and protect aquatic ecosystems.

Although antibiotics are widely used and their residues are increasingly detected in aquatic environments worldwide, comprehensive data on their occurrence in Hanoi's urban lakes remain limited. These lakes often act as sinks for untreated household and municipal wastewater, potentially accumulating various antibiotic residues. Therefore, this study aims to systematically assess the occurrence, distribution, and concentration levels of selected antibiotics in multiple lakes across Hanoi. Additionally, the research seeks to evaluate the potential environmental risks posed by these contaminants, providing crucial baseline information for future monitoring and management strategies to mitigate antibiotic pollution and its associated ecological impacts.

2. Materials and Methods

2.1. Studied Hanoi lakes

In this study, eight typical urban lakes in Hanoi were selected for sampling and analysis, representing various levels of surface area and potential exposure to domestic wastewater. These lakes differ in size, function, and the number of sewage discharge points. Some, such as West Lake (HT) and Yen So Lake (HYS), are large in area and play an important role in the city's water regulation and landscape. Others, like Truc Bach Lake (HTB), Ngoc Khanh Lake (HNK), and Bay Mau Lake (H7M), are smaller but located in densely populated residential areas and are heavily affected by domestic wastewater inflows.

Among the selected lakes, several receive direct discharge from large wastewater pipes, with Ba Mau Lake (H3M) and Bay Mau Lake (H7M) having up to 10 discharge points each, while West Lake

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has 12. In contrast, for some lakes such as Thanh Cong Lake (HTC), Thu Le Lake (HTL), and Ngoc Khanh Lake (HNK), the number of sewage discharge points has not been clearly identified.

Details of the studied lakes are summarized in Table 1.

Table 1. Some investigated Hanoi lakes.

No.	Lake Name	Surface Area	Number of Sewage Discharges
1	Ba Mau lake (H3M)	43.448m^2	10 large discharge pipes
2	Thanh Cong lake (HTC)	50.046m^2	Not identified
3	Yen So lake (HYS)	137ha	Not identified
4	Tay lake (HT)	526,16ha	12 large discharge pipes
5	Truc Bach lake (HTB)	22ha	2 large discharge pipes
6	Thu Le lake (HTL)	68.521m^2	Not identified
7	Ngoc Khanh lake (HNK)	35.881m^2	Not identified
8	Bay Mau lake (H7M)	210.270m^2	10 large discharge pipes

2.2. Chemical Reagents and Analytical Methods

All standard antibiotic compounds used in this study were of high purity and purchased from Sigma-Aldrich (Bengaluru, India). The highest available analytical grade was selected for each compound. The target antibiotics included sulfathiazole (STZ), sulfamethazine (SMZ), sulfamethoxazole (SMX), sulfamerazine (SMR), ciprofloxacin (CIP), norfloxacin (NOR), enrofloxacin (ENR), ofloxacin (OFL), and trimethoprim (TRI).

All solvents used for liquid–liquid extraction (LLE) and ultra-performance liquid chromatography coupled with tandem mass spectrometry (UPLC-MS/MS) analysis were of UPLC grade, except water. Calibration standards and all aqueous solutions were prepared using Milli-Q ultrapure water. Analytical-grade chloroform was used for the extraction of antibiotics. Distilled water used in the rotary evaporator was obtained from the laboratory's distillation apparatus.

Prior to injection into the analytical system, all samples were filtered using disposable 3 mL syringes equipped with 0.45 μm pore-size sterilized syringe filters, following the protocol described in [1].

2.3. LC-MS/MS Analysis

The analytical procedures were carried out in accordance with the Vietnamese national standard method using a Thermo TSQ Quantum Access LC-MS/MS system for the detection and quantification of antibiotics in water samples. Chromatographic separation was carried out on an ACQUITY UPLC BEH C18 column (2.1 mm × 50 mm, particle size 1.7 μm). The mobile phases consisted of 0.1% formic acid in Milli-Q ultrapure water (eluent A) and 0.1% formic acid in UPLC-grade acetonitrile (eluent B). The gradient elution program was optimized as follows: starting at 90% A for 1 min, then linearly decreasing to 50% A over 1 minute, further to 20% A over 2 minutes, held for 1 minute, and then returned to 90% A in 0.1 min, maintained for 2 additional minutes. The flow rate was 0.35 mL/min, the injection volume was 10 μL, and the column temperature was maintained at 40 °C.

Before use, all mobile phases were sonicated for 10 minutes at room temperature and filtered through a 0.22 μm cellulose nitrate membrane filter. Calibration curves were prepared using seven standard concentrations ranging from 5 to 200 ng/mL. Each concentration was injected in triplicate to assess peak stability, retention time, and signal response. Calibration curves were constructed by plotting concentration versus peak area. The limit of detection (LOD) and limit of quantification (LOQ) were calculated from the standard deviation of the response and the slope of the calibration curve, with LOD = 1.5 ng/mL and LOQ = 5 ng/mL.

The mass spectrometric detection was carried out using electrospray ionization (ESI) in positive ion mode. Instrument parameters were optimized via direct infusion of standard solutions at 10 μL/min. Key MS/MS settings included a capillary voltage of 4.5 kV, source temperature of 150 °C,

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desolvation temperature of 450 °C, cone gas flow of 50 L/h, and desolvation gas flow of 850 L/h. The optimal precursor-to-product ion transitions for quantification and confirmation were selected based on highest sensitivity and signal response. Quantification was performed by comparing peak areas of sample extracts to those of calibration standards using a response factor–based calculation.

3. Results

3.1. Occurrence and Concentration of Antibiotics

In this study, the occurrence and distribution of nine selected antibiotics in surface water samples from eight urban lakes in Hanoi were evaluated using LC–MS/MS techniques. The antibiotics analyzed belong mainly to the sulfonamide, fluoroquinolone, and trimethoprim classes. The results revealed widespread contamination across all sampling sites, indicating the significant and continuous release of antibiotics into urban freshwater bodies.

Among the analyzed compounds, sulfamethoxazole (SMX) was the most frequently detected antibiotic, with a detection frequency ranging from 70% to 100%. In particular, SMX was detected in 100% of samples from Truc Bach Lake (HTB), Thu Le Lake (HTL), Ngoc Khanh Lake (HNK), and Yen So Lake (HYS). The maximum concentration of SMX was observed in Yen So Lake, reaching 1619.35 ng/L, followed by Ba Mau Lake (716.17 ng/L) and Ngoc Khanh Lake (362.47 ng/L). These levels are significantly higher than those previously reported in some European surface waters, where typical concentrations ranged from 100 to 600 ng/L.

Fluoroquinolones were also widely present. Ciprofloxacin (CIP) and ofloxacin (OFL) showed elevated levels across multiple lakes. The highest concentration of CIP was found in Ngoc Khanh Lake (823.55 ng/L), followed by Yen So Lake (568.40 ng/L) and Truc Bach Lake (98.56 ng/L). OFL concentrations were highest in Ngoc Khanh Lake (430.11 ng/L), Yen So Lake (242.91 ng/L), and Ba Mau Lake (75.85 ng/L). These findings are consistent with global reports indicating that fluoroquinolones are among the most stable and persistent antibiotic groups in aquatic environments, largely due to their low biodegradability and strong resistance to photolytic and microbial degradation.

Trimethoprim (TRI) was detected in all but one lake, with the highest concentration also observed in Ba Mau Lake (293 ng/L), followed by Ngoc Khanh Lake (118 ng/L). Sulfamethazine (SMZ) and sulfamerazine (SMR) were detected at lower frequencies and concentrations, with peak values of 34.82 ng/L (SMZ in Tay Lake) and 16.34 ng/L (SMR in Truc Bach Lake), respectively. Sulfathiazole (STZ) was detected only in Ba Mau Lake (18.45 ng/L) and Yen So Lake (13.78 ng/L).

Table 2 presents the maximum concentrations of each antibiotic detected across the eight lakes. Lakes with the highest levels of contamination—such as Yen So Lake, Ba Mau Lake, and Ngoc Khanh Lake—are known to receive large volumes of untreated or poorly treated domestic and urban wastewater, possibly contributing to their elevated antibiotic concentrations.

These findings underscore the growing concern of antibiotic pollution in freshwater bodies of urban areas, particularly in rapidly developing cities. The presence of antibiotics in such concentrations may pose ecological risks to aquatic life and promote the development of antibiotic-resistant bacteria. Therefore, stricter monitoring and improved wastewater treatment strategies are urgently needed to address this emerging environmental challenge.

Table 2. Maximum concentration determinated in lake waters (ng/L).

Lake	SMX	STZ	SMZ	SMR	TRI	CIP	ENR	OFL	NOR
HT	89.7	Nd	34.82	Nd	26.41	55.27	16.88	43.11	79.00
HTB	104.29	Nd	Nd	16.34	69	98.56	73.01	211.67	48.88
HTL	83.38	Nd	30.19	Nd	48.17	34.38	Nd	11.79	64.70
HNK	362.47	Nd	4.28	2.31	118	823.55	2.61	430.11	11.76
HTC	31.14	Nd	Nd	4.5	9.49	57.34	Nd	36.16	19.11
H3M	716.17	18.45	14.46	Nd	293	94.78	Nd	75.85	57.00

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H7M	85.42	Nd	2.45	3.59	33	195.26	2.73	46.84	47.82
HYS	1619.35	13.78	6.91	2.41	52.57	568.40	2.50	242.91	20.76

3.2. Potential Risk of Developing Antibiotic Resistance

Although only a limited number of antibiotic compounds were analyzed in this study, their presence and concentration levels in the urban lake water samples of Hanoi highlight a growing environmental and public health concern. Antibiotics are widely used in human and veterinary medicine, and their residues can enter aquatic environments through various pathways, including municipal wastewater, hospital discharges, and agricultural runoff. Once released, these compounds are often resistant to conventional wastewater treatment processes and tend to persist in the environment due to their physicochemical stability and poor biodegradability.

To evaluate the ecological risks associated with the detected antibiotics, the Risk Quotient (RQ) method was applied. The RQ is defined as the ratio of the measured environmental concentration (MEC) to the predicted no-effect concentration (PNEC) of a given compound. According to standard guidelines [58,59], an RQ value of:

- < 0.1 indicates no significant risk,
- $0.1 \leq RQ < 1$ suggests low risk,
- $1 \leq RQ < 10$ implies moderate ecological risk,
- $RQ \geq 10$ indicates high ecological risk.

Among the analyzed antibiotics, ofloxacin (OFL), ciprofloxacin (CIP), and sulfamethoxazole (SMX) were found to exhibit the highest RQ values in several lakes, particularly in Yen So, Ngoc Khanh, and Ba Mau lakes—where measured concentrations reached several hundred to over a thousand ng/L. These values exceed known PNEC thresholds, suggesting that these lakes are under moderate to high ecological pressure due to antibiotic contamination.

The persistence and widespread presence of fluoroquinolones (such as OFL and CIP) are of particular concern. These compounds are known for their strong antibacterial activity, structural stability, and slow degradation rate in the environment. Consequently, they can exert selective pressure on microbial communities, facilitating the emergence and spread of antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs). Even at sub-inhibitory concentrations, antibiotics can alter microbial gene expression and encourage resistance development, especially in environments where exposure is chronic.

Moreover, inadequate wastewater treatment systems and the lack of segregation between hospital, industrial, and domestic effluents further exacerbate the risk. The findings of this study align with reports from other urban river systems, such as the Yamuna River in India and rivers in China and Europe, where high antibiotic concentrations have been directly linked to the spread of multidrug-resistant organisms.

The presence of antibiotics in surface water not only poses threats to aquatic biodiversity, where sensitive microorganisms can be suppressed or eliminated, but also to human health via direct or indirect exposure through recreational water use, drinking water sources, and the food chain. Furthermore, even low antibiotic concentrations can contribute to the gradual evolution of multidrug-resistant pathogens, transforming urban lakes into reservoirs and transmission pathways for antimicrobial resistance (AMR).

Given these implications, it is essential to implement stricter regulations on antibiotic use, improve wastewater treatment infrastructure, and enforce pollution control strategies to mitigate the environmental release of antibiotics. Without urgent action, antibiotic resistance could become an uncontrollable global health crisis with serious ecological consequences.

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4. Discussion

Sulfonamides

This group includes sulfamethoxazole (SMX), sulfadiazine (STZ), sulfamethazine (SMZ), and sulfamerazine (SMR). Sulfonamides are synthetic bacteriostatic antibiotics widely used in both human medicine and veterinary practices.

Among these, SMX was the most frequently detected sulfonamide, with detection rates ranging from 70% to 100% across all sampling sites and reaching 100% frequency in Truc Bach, Thu Le, Ngoc Khanh, and Yen So lakes. The maximum concentration of SMX was 1619.35 ng/L in Yen So Lake, suggesting significant anthropogenic input, likely from domestic wastewater or hospital discharges.

Other sulfonamides such as SMZ and SMR were detected at lower concentrations and frequencies. For instance, SMZ showed a maximum concentration of 34.82 ng/L in Ho Tay (HT), while SMR was only found in a few lakes, with the highest level being 16.34 ng/L in Ho Thanh Cong B (HTB). The lower detection frequency of these compounds may be attributed to either less usage or faster degradation in aquatic environments.

These findings are consistent with other studies indicating that sulfonamides, especially SMX, are among the most commonly detected antibiotics in urban surface waters due to their high solubility, low sorption affinity, and resistance to biodegradation.

Fluoroquinolones

This group comprises ciprofloxacin (CIP), enrofloxacin (ENR), ofloxacin (OFL), and norfloxacin (NOR)—all of which are broad-spectrum antibiotics used extensively in both human and animal health sectors.

Fluoroquinolones were consistently detected across almost all sampling sites, and in several lakes, they were found at exceptionally high concentrations, indicating widespread contamination. The maximum recorded concentrations were:

- Ciprofloxacin (CIP): 823.55 ng/L in Ho Ngoc Khanh (HNK)
- Ofloxacin (OFL): 430.11 ng/L in HNK, and 211.67 ng/L in HTB
- Norfloxacin (NOR): 79.00 ng/L in Ho Tay (HT)
- Enrofloxacin (ENR): 73.01 ng/L in HTB

The persistence and high detection levels of fluoroquinolones are of particular concern due to their chemical stability, limited photodegradation, and low biodegradability. These compounds tend to accumulate in sediments and water matrices, potentially exerting selective pressure on microbial communities and fostering the development of antibiotic-resistant bacteria.

CIP and OFL, in particular, are classified as priority pollutants in several environmental monitoring programs due to their toxicity, prevalence, and role in the proliferation of resistance genes in aquatic environments.

Trimethoprim

Trimethoprim (TRI) is a synthetic antibiotic that inhibits bacterial dihydrofolate reductase and is often co-prescribed with sulfonamides like SMX to achieve synergistic effects.

In this study, TRI was detected in multiple lake samples, with maximum concentrations recorded at:

- 293 ng/L in Ho Ba Mau (H3M)
- 118 ng/L in Ho Ngoc Khanh (HNK)
- 69 ng/L in HTB

Although TRI is not always as frequently monitored as fluoroquinolones or SMX, its co-existence with sulfonamides in many sites suggests combined usage, possibly from human therapeutic treatments. Its relatively high detection levels in several lakes reflect the incomplete removal in conventional wastewater treatment processes and its ability to persist in aquatic environments.

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Other Antibiotics Detected

Besides the three main groups (sulfonamides, fluoroquinolones, and trimethoprim), this study also recorded the presence of antibiotics outside the common groups—most notably sulfadiazine (STZ). However, STZ was detected only at a few sampling sites with relatively low frequency and concentrations.

Sulfadiazine (STZ): is a sulfonamide antibiotic commonly used to treat urinary tract infections and infections caused by gram-positive bacteria. In this study, STZ was detected only in three lakes: H3M (18.45 ng/L), HYS (13.78 ng/L), and was below the detection limit in most other lakes. This suggests that the usage of STZ may be lower compared to other sulfonamides such as SMX, or that it degrades more rapidly in lake water environments.

Distribution and Environmental Behavior

The antibiotics detected in this study showed distinct differences in spatial distribution, frequency of occurrence, and physicochemical and biological characteristics:

Urban lakes such as Yen So (HYS) and Ba Mau (H3M) exhibited high accumulation levels of various antibiotics, reflecting pressure from untreated urban and healthcare wastewater discharges.

Hydrophilic antibiotics, like SMX, tend to remain in the water column, whereas fluoroquinolones tend to accumulate in sediments and aquatic organisms, increasing the risk of bioaccumulation and microbial resistance.

5. Conclusion

This study provides a comprehensive assessment of the occurrence and distribution of various antibiotics in lake water samples across multiple urban locations. Sulfonamides, fluoroquinolones, and trimethoprim were identified as the predominant antibiotic groups, with sulfamethoxazole (SMX) showing the highest detection frequency and concentration levels. The presence of other antibiotics such as sulfadiazine (STZ), although at lower frequencies and concentrations, highlights the complexity of antibiotic pollution in aquatic environments.

The spatial distribution patterns revealed that urban lakes exposed to untreated municipal and healthcare wastewater exhibited higher antibiotic contamination, indicating significant anthropogenic impact. Moreover, the differing physicochemical properties of antibiotics influenced their environmental fate, with hydrophilic compounds persisting in the water column and fluoroquinolones accumulating in sediments and biota, posing increased risks of bioaccumulation and the development of antibiotic resistance.

Given the observed antibiotic concentrations and their potential ecological risks, this study underscores the urgent need for improved wastewater treatment and stricter regulations on antibiotic discharge to mitigate environmental contamination and reduce the threat of antimicrobial resistance. Future research should focus on long-term monitoring and the assessment of antibiotic effects on aquatic ecosystems and human health to inform sustainable water management policies.

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