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The Current Status and Potential Technologies for Treating Antibiotic Pollution in the Aquatic Environment in Vietnam

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ABSTRACT: This study investigated the occurrence of antibiotic contamination in aquatic environments in Vietnam and proposed potential treatment technologies. Major sources of antibiotic release included urban domestic activities, livestock production, aquaculture, healthcare facilities, and pharmaceutical manufacturing. A wide range of antibiotics was detected at elevated concentrations in rivers, lakes, and canals, with the most frequently reported groups being sulfonamides, macrolides, quinolones, and tetracyclines, at levels ranging from several ng/l to thousands of ng/l. The paper critically reviewed existing treatment technologies, encompassing biological approaches such as activated sludge, biofilm reactors, and constructed wetlands; physical approaches including adsorption and membrane filtration; and chemical approaches such as Fenton oxidation, ozonation, and photocatalysis, with emphasis on their respective advantages and limitations. To address the specific conditions of Vietnam, a three-module integrated treatment model was proposed, consisting of activated sludge for organic matter degradation, activated carbon adsorption columns for antibiotic removal, and constructed wetlands for residual polishing. This integrated system was expected to provide high removal efficiency, low operational costs, and environmental sustainability. The findings offered a scientific basis for controlling antibiotic pollution, mitigating the risks of antimicrobial resistance, and protecting aquatic ecosystems.

KEYWORDS: Antibiotic pollution in Vietnam; aquatic environment; potential technologies; wastewater treatment.

1. Introduction

Since their discovery and widespread application in the early 20th century, antibiotics revolutionized modern medicine [1]. They were employed not only in medical treatment but also in agriculture, animal husbandry, and aquaculture to prevent diseases and promote growth [2–6]. However, their misuse and uncontrolled discharge resulted in antibiotic contamination of aquatic environments. According to the World Health Organization (WHO), antibiotics and antibiotic resistance genes have increasingly disseminated throughout aquatic ecosystems, posing threats to human health, biodiversity, and ecological balance. This issue has been recognized as one of the major global environmental challenges of the 21st century [7]. Each year, approximately 700,000 people die from infections caused by drug-resistant organisms, a figure projected to exceed 10 million by 2050 [8].

Vietnam is a developing country where awareness regarding the use and treatment of antibiotics has remained limited. As a result, the release of antibiotic residues into the environment from domestic wastewater, healthcare facilities, livestock production, aquaculture, and pharmaceutical manufacturing has been relatively common [9–12]. The commonly detected antibiotic groups include sulfonamides, macrolides, and lincomycin, with concentrations ranging from several hundred to over 4,000 ng/l in domestic and municipal wastewater. This contamination not only affected water sources, soil, and ecosystems but also exerted selective pressure, thereby accelerating the emergence and spread of antibiotic-resistant bacteria. Previous studies have examined antibiotic pollution in Vietnam [13]; however, few have connected the current contamination status with potential treatment solutions suitable for practical application. In many Vietnamese cities and rural areas, wastewater has been discharged without treatment in centralized wastewater treatment plants. Although numerous technologies have been applied to remove antibiotics from aquatic environments [14], each exhibited distinct advantages and limitations. Limited access to technological information has constrained the ability to evaluate and select appropriate treatment systems, often resulting in low removal efficiency, residual presence, or secondary pollution. Persisting antibiotics in aquatic environments have exerted adverse impacts on microbial communities, aquatic organisms, and human health [7, 15]. Against the backdrop of rapid urbanization and increasing antibiotic consumption, it has become imperative to review and assess antibiotic treatment technologies in aquatic environments in order to propose sustainable solutions for Vietnam.

This study pursued two main objectives: (i) to provide a detailed account of the current status of antibiotic contamination in aquatic environments in Vietnam and (ii) to propose potential treatment technologies based on the identified contamination patterns. The findings of this study are expected to provide both scientific and practical solutions for controlling and mitigating antibiotic pollution in Vietnam's aquatic environments.

2. Sources of Antibiotic Pollution

2.1. Domestic wastewater.

Research on antibiotic concentrations in domestic wastewater in Vietnam remained limited. However, insufficient awareness of antibiotic use and disposal practices contributed to widespread contamination. Furthermore, in many cities and rural areas, wastewater was discharged without any treatment in centralized wastewater treatment plants. In locations with poorly functioning treatment systems or operational failures, such as sludge overflow or pipeline leakage, antibiotics from untreated wastewater could directly infiltrate rivers, lakes, groundwater, and soils [16, 17]. Evidence of antibiotic presence in wastewater was documented through monitoring of urban drainage systems. Sulfonamides, particularly sulfamethoxazole, were detected at the highest concentrations in Hanoi (612–4,330 ng/l) and Can Tho (103–4,030 ng/l) [10, 11]. Macrolides (erythromycin, clarithromycin, roxithromycin) were also widely present in municipal wastewater, with concentrations in Hanoi reaching up to 2,246 ng/l [10]. Lincomycin exhibited particularly high concentrations (132–2,666 ng/l) with a 100% detection frequency across all five major cities in Vietnam [10, 18]. Collectively, these findings indicated that domestic wastewater constituted a major source of antibiotic pollution in Vietnam.

2.2. Livestock Production

In Vietnam, antibiotics in livestock farming were used for therapeutic purposes, disease prevention, and growth promotion. Certain high-risk antibiotics, such as chloramphenicol, furazolidone, and fluoroquinolones, were prohibited, while many others were permitted only under restricted use or at specific dosages [19]. Studies showed that 43.7% of commercial animal feed contained antibiotics, with bacitracin and chlortetracycline being the most common additives [20]. The use of antibiotics was generally higher in large-scale industrial farms compared to household-scale operations. Frequently administered antibiotics included tylosin, gentamycin, colistin, enramycin, ampicillin, salinomycin, and chlortetracycline [21, 22]. It was estimated that swine and poultry farming consumed up to 981.3 tons and 42.2 tons of antibiotics annually, respectively [20]. The antibiotic groups most commonly detected included sulfonamides, macrolides, lincosamides, and cyclines. Only a portion of these administered antibiotics was metabolized, while approximately 30–90% of the dose was excreted via feces and urine. As a result, livestock waste represented a significant source of antibiotic pollution, particularly when it was directly discharged into the environment or reused as fertilizer [23, 24]. Surveys reported sulfamethazine and sulfadimethoxine concentrations in swine farm effluents at 19,153 ng/l and 2,715 ng/l, respectively [9–11]. Among macrolides, erythromycin was the most prevalent (64 ng/L), whereas tylosin was detected at higher concentrations (381 ng/l) [22]. Lincomycin was present across all types of farms, with maximum concentrations reaching 503 ng/l [11]. Within the cycline group, oxytetracycline was the most frequently detected, with concentrations up to 900 ng/l in swine farms; tetracycline (275 ng/l) and doxycycline (1 ng/l) were also detected [11].

2.3. Aquaculture

In Vietnam, the use of antibiotics in aquaculture was widespread for disease prevention, treatment, and growth promotion, particularly in intensive farming systems. The Ministry of Agriculture and Rural Development (renamed the Ministry of Agriculture and Environment from March 1, 2025) permitted the use of more than 30 antibiotics belonging to various groups, including sulfonamides, β-lactams, quinolones, macrolides, and cyclines [25]. However, several broad-spectrum antibiotics, such as chloramphenicol, fluoroquinolones, and nitroimidazoles, were banned due to potential risks to human health. Antibiotic usage varied by species and farming stage, with fish farming, particularly pangasius (catfish), showing the highest levels of antibiotic application. Surveys indicated that 100% of pangasius farms used antibiotics [26]. Commonly applied groups included quinolones (such as enrofloxacin), amphenicols (such as florfenicol), sulfonamides (sulfamethoxazole and trimethoprim), and cyclines (such as doxycycline). The diverse and poorly controlled use of these substances increased the risk of misuse and environmental contamination. Multiple classes of antibiotics, including sulfonamides, quinolones, macrolides, and cyclines, were frequently detected in surface waters and sediments from aquaculture areas in Vietnam. In the Mekong Delta, 91.6% of water samples contained at least one antibiotic, with more than half containing three to four different types [27]. Fluoroquinolones, particularly enrofloxacin, were detected at high concentrations despite having been banned since 2009 [27]. Sulfonamides were found at concentrations as high as 1,966 ng/l in shrimp ponds and in integrated fish–livestock (swine/duck) farming systems [10, 11]. Erythromycin, oxytetracycline, and lincomycin were also reported, albeit at lower concentrations ranging from 0.4 to 63.9 ng/l [11].

2.4. Hospitals

Vietnam has approximately 1,773 hospitals with around 320,000 patient beds. Eight groups of antibiotics were used in medical practice, among which β-lactams were the most prevalent (36 types), followed by sulfonamides, quinolones, macrolides, and aminoglycosides [13]. Surveys conducted in more than 60 hospitals revealed that antibiotics were prescribed to 67.4% of inpatients [28]. Another study reported that 10.2% of prescribed antibiotics were administered for inappropriate durations [29]. Notably, due to the easy availability of antibiotics in pharmacies, as many as 71% of patients self-medicated with antibiotics prior to hospitalization [13]. Children were also frequent users of antibiotics, with annual usage rates of 47.3% in Thai Nguyen and 34.7% in Ha Giang [30]. It was estimated that approximately 30–90% of antibiotic doses administered to patients were not fully metabolized and were excreted in urine and feces as biologically active compounds [31]. This resulted in the persistent presence of multiple antibiotics in hospital effluents. Given the limited capacity of hospital wastewater treatment plants (WWTPs), the risk of environmental dissemination increased in Vietnam. Surveys indicated that 18% of hospital WWTP effluent samples exceeded the permissible limits set by QCVN 28:2010, level B [12]. A study of 39 healthcare facilities in Ho Chi Minh City reported the presence of seven commonly used antibiotics in all wastewater samples, including sulfamethoxazole (2.5 ± 1.9 μg/l), norfloxacin (9.6 ± 9.8 μg/l), ciprofloxacin (5.3 ± 4.8 μg/l), ofloxacin (10.9 ± 8.1 μg/l), erythromycin (1.2 ± 1.2 μg/l), tetracycline (0.1 ± 0.0 μg/l), and trimethoprim (1.0 ± 0.9 μg/l) [12].

2.5. Pharmaceutical manufacturers

In Vietnam, very few studies investigated antibiotic contamination originating from pharmaceutical manufacturing. In 2014, a survey reported cefixime concentrations in pharmaceutical effluents ranging from 19.24 to 43.33 μg/l [32]. Another study detected ten antibiotics (ampicillin, cefuroxime, cefotaxime, clarithromycin, azithromycin, sulfamethoxazole, trimethoprim, ofloxacin, norfloxacin, and ciprofloxacin) at varying concentrations. Notably, sulfonamides and quinolones were occasionally found at extremely high levels, such as sulfamethoxazole (252 μg/l), trimethoprim (107 μg/l), ofloxacin (85 μg/l), and ciprofloxacin (41 μg/l) [33]. These findings indicated that wastewater from pharmaceutical factories could represent a significant source of antibiotic release into aquatic environments in Vietnam.

3. Antibiotic Contamination in Aquatic Environments

Antibiotic concentrations in aquatic environments varied widely depending on the compound and the type of water surveyed (Table 1). The β-lactam group, such as amoxicillin and ampicillin, reached concentrations of 425–3,710 ng/l in urban rivers of Hanoi, Da Nang, and Ho Chi Minh City, which were substantially higher than those reported in Japan [34]. Macrolides were frequently detected across all water sources, with clarithromycin concentrations up to 778 ng/l and erythromycin up to 2,246 ng/l in northern Vietnam. However, these values remained lower than those reported in South Korea (5,267 ng/l) [35].

Quinolones and fluoroquinolones were detected at relatively low levels, with ciprofloxacin, moxifloxacin, and ofloxacin in urban rivers of the Red River Delta measured at 87 ng/l, 11.56 ng/l, and 205 ng/l, respectively, whereas ciprofloxacin concentrations in Bangladesh reached up to 1,407 ng/l [36]. Tetracyclines in Vietnam ranged from 226 to 316 ng/l, higher than levels reported in Japan and Germany [34, 37]. Of particular note, sulfonamides exhibited the widest concentration range, with sulfamethazine detected up to 6,621 ng/l and sulfamethoxazole up to 4,330 ng/l, although these values were far lower than those recorded in the Philippines (764,910 ng/l) [38]. In addition, other compounds, such as lincomycin (667–1,375 ng/l) and oxfendazole (up to 2,500 ng/l), were also commonly detected in rivers, lakes, and canals of major urban areas. Comparative studies suggested a correlation between economic development and the concentrations of antibiotics detected in aquatic environments. In countries with lower or comparable economic status, antibiotic levels tended to be equal to or higher than those found in Vietnam. By contrast, developed countries typically reported much lower antibiotic concentrations in rivers and lakes. Limited financial resources and treatment technologies were identified as the primary reasons for this disparity. Furthermore, insufficient awareness and regulatory mechanisms regarding antibiotic use contributed significantly to the risk of environmental dissemination through human activities.

Table 1. Concentrations of antibiotics in aquatic environments in Vietnam.

Antibiotic	Water source	Concentration (ng/L)	Reference
Amoxicillin	Urban lake	17.4–51.8	[39]
	Urban river	2,390.0–3,710.0	[40]
Ampicillin	Urban lake	28.5–39.1	[39]
	Urban river	425.0–643.0	[18]
Azithromycin	Urban lake	0.0	[41]
	Urban lake	0.6–1.7	[39]
	Urban river	235.0–455.0	[40]
Cefaclor	Urban lake	48.6–51.7	[39]
Cefadroxil	Urban lake	0.1	[39]
Cefixime	Urban lake	33.1–87.4	[39]
Cefotaxime	Urban lake	8.9	[39]
Cefuroxime	Urban lake	0.2–2.0	[39]
Cephalexin	Farm pond	0.4–24.0	[42]
	City river	3.4–11.0	[42]
	Farm pond	14.0–127.2	[42]
	Aquaculture pond	1.0–40.0	[42]
Ciprofloxacin	Urban lake	87.1	[41]
	Urban lake	0.7–1.7	[39]
Clarithromycin	River	2.8–778.0	[10]
	Urban lake	1.8–45.8	[39]
	Urban river	29.0–169.0	[18]
	River	16.0	[18]
Erythromycin	River	154.0–2,246.0	[10]
	Canal	31.0–41.0	[9]
	River	1.0–12.0	[11]
	River	9.0–12.0	[9]
Enrofloxacin	Urban lake	73.0	[43]
Flumequine	Farm pond	1.7–245.0	[42]

Antibiotic	Water source	Concentration (ng/L)	Reference
Lincomycin	Urban lake	72.7	[41]
	Urban river	1,030.0–1,300.0	[40]
	Urban river	667.0–1,375.0	[18]
	Canal	111.0–1,301.0	[18]
	Canal	9.0–188.0	[11]
	River	1.0–15.0	[11]
	River	120.0	[18]
Moxifloxacin	Urban lake	11.6	[39]
N-acetylsulfamethazine	Farm pond	0.3–3,005.0	[42]
	City river	1.2–2.7	[42]
	River	1.3–23.0	[42]
	Aquaculture pond	1.3–5.3	[42]
Nalidixic acid	Farm pond	4.3–17.4	[42]
	City river	5.4–18.0	[42]
Norfloxacin	Urban lake	0.1–0.2	[39]
Ofloxacin	Farm pond	0.2–9.9	[42]
	Urban lake	129.0	[41]
	Urban lake	33.2–73.6	[39]
	Urban river	205.0	[40]
Oleandomycin	River	369.0–530.0	[18]
Oxytetracycline	Urban lake	316.0	[11]
	Canal	226.0	[11]
	River	7.0	[11]
Oxfendazole	Urban river	2,030.0–2,500.0	[40]
	Canal	7.0–87.0	[11]
	Urban river	22.0–48.0	[18]
Sulfacetamide	Urban river	163.0–670.0	[40]
Spiramycin	River	134.0–621.0	[18]
Sulfadiazine	Farm pond	0.9–474.0	[42]
	City river	0.9–50.0	[42]
	Farm pond	6.6–113.0	[42]
	Canal	26.0–63.0	[27]
Sulfadoxine	Canal	≤593.0	[18]
Sulfamethazine	Farm pond	1.8–6,621.0	[42]
	City river	3.1–34.0	[42]
	Aquaculture pond	0.2–14.3	[42]
	River	0.5–6,662.0	[10]
	Urban lake	≤34.8	[43]
	Surface water	15.0–328.0	[9]
Sulfamethoxazole	Farm pond	1.5–2,017.0	[42]
	City river	0.3–781.0	[42]
	River	0.2–47.0	[42]
	Aquaculture pond	0.9–642.0	[42]
	River	612.0–4,330.0	[10]
	Urban lake	41.5	[41]
	Urban lake	7.5–178.9	[39]
	Urban river	623.0–2,159.0	[18]
	Urban lake	104.3	[43]
	Canal	185.0–239.0	[27]
	Urban river	200.0–1,090.0	[40]
Sulfamethoxypyridazine	Urban lake	16.3	[43]
Tetracycline	Urban lake	258.0	[11]
Trimethoprim	Farm pond	0.8–78.0	[42]
	City river	4.8–70.0	[42]
	River	0.4–19.0	[42]
	Urban lake	≤69.0	[43]
	Urban river	28.0–176.0	[18]
	Aquaculture pond	1.5–3.3	[42]
	Surface water	7.0–44.0	[9]
	Urban lake	1.1–13.3	[39]

4. Antibiotic Treatment Technologies

4.1. Biological processes.

Biological treatment technologies were characterized by low cost, environmental friendliness, operational simplicity, and the ability to simultaneously remove multiple organic pollutants while generating fewer toxic by-products compared with chemical methods. Several biological approaches were investigated for antibiotic removal, including activated sludge, biofilm reactors, and constructed wetlands. Previous studies demonstrated the effectiveness of activated sludge systems in removing various antibiotic classes, such as tetracyclines, sulfonamides, and fluoroquinolones [44–46]. Biofilm reactors showed particularly high removal efficiencies for tetracyclines (>90%) [47, 48]. Constructed wetlands, as low-cost ecological systems, were well suited to the tropical monsoon climate of Vietnam [49–51]. For example, sulfamethazine (a sulfonamide) was removed with efficiencies of 67–95% [52, 53], while tetracycline removal rates reached 98–99% [53].

Despite these advantages, biological processes had limitations. Antibiotic removal efficiencies were often inconsistent, as they strongly depended on environmental conditions such as pH, temperature, and nutrient concentrations. Certain antibiotics possessed highly stable chemical structures, making them resistant to microbial degradation and leading to their accumulation in water or sludge. Furthermore, intermediate by-products formed during degradation sometimes remained toxic, necessitating additional treatment steps. High antibiotic concentrations could also inhibit microbial activity, reducing overall treatment efficiency and prolonging system operation.

4.2. Physical processes.

Physical treatment methods, such as adsorption, ion-exchange resins, and membrane filtration, were relatively simple, easy to operate and control, and capable of rapidly removing various antibiotics without requiring additional chemicals. Compared with chemical methods, they generated fewer toxic by-products and often achieved high removal efficiencies, particularly at low antibiotic concentrations in water. Adsorbents and membranes could also be regenerated, contributing to cost reduction and environmental sustainability. For instance, adsorption technologies removed up to 98.6% of amoxicillin and 98.5% of doxycycline [54]. Membrane-based processes showed very high efficiencies, generally above 90%, for antibiotics such as levofloxacin, enrofloxacin, sulfadiazine, sulfamethoxazole, trimethoprim, cefixime, and rifampicin [55–58].

Nevertheless, the main limitation of physical processes was that they primarily transferred antibiotics from the liquid phase to the solid phase without complete degradation. This posed a risk of secondary pollution if adsorbent materials or sludge were not handled safely. Removal efficiency also strongly depended on the type of material used, the physicochemical properties of the antibiotics, and environmental conditions, making stable performance difficult to maintain in practice. In addition, the costs of high-quality adsorbents and advanced membranes were considerable. Membranes were prone to fouling and required periodic regeneration or replacement, further increasing operational costs.

4.3. Chemical processes.

Chemical treatment methods had the capacity to completely degrade antibiotics by breaking down their chemical structures into low-molecular-weight compounds that were less toxic or harmless. These processes were typically rapid and effective, and they could be applied to a wide range of persistent antibiotics that were difficult to remove using biological technologies. In addition, chemical processes (such as chlorination, ozonation, ferrate oxidation, Fenton processes, and advanced oxidation processes) could simultaneously provide disinfection, reduce antibiotic-resistant bacteria, and limit the dissemination of resistance genes in the environment.

Chlorination demonstrated high removal efficiency, with several studies reporting complete removal of ciprofloxacin and norfloxacin, along with up to 75% removal of levofloxacin [59]. However, chlorination by-products were often highly toxic, restricting practical applications. Ferrate demonstrated rapid and efficient degradation of many antibiotics, with tetracycline removal exceeding 98% within 60 seconds and ciprofloxacin removal above 90% under neutral pH conditions [60, 61]. Fenton and Fenton-like oxidation processes effectively degraded metacycline (38.4–92.5%), lincomycin (93.9–100%), and metronidazole (41.0–84.3%) [62–64]. Feng et al. reported complete degradation of flumequine by ozonation [65]. Photocatalytic oxidation was also effectively applied to remove ciprofloxacin, levofloxacin, oxytetracycline, tetracycline, and sulfaquinoxaline [66, 67]. More advanced electrochemical oxidation technologies efficiently eliminated a wide variety of antibiotics, including ciprofloxacin, chlortetracycline, and sulfamethazine [68, 69].

Overall, chemical treatment technologies were often prioritized due to their high efficiency and rapid reaction rates. However, their major limitations included high capital and operational costs, particularly regarding the selection and use of suitable electrodes. In addition, certain metal anodes were prone to dissolution, which could result in secondary pollutants. Moreover, mineralization was not always complete, necessitating the combination of chemical methods with additional treatment stages to ensure long-term effectiveness.

5. Potential Technological Solutions for Vietnam

Given limited financial resources allocated to environmental protection and constraints in technological capacity, antibiotic treatment technologies in Vietnam needed to satisfy key requirements related to treatment efficiency, cost-effectiveness, and operational simplicity. As discussed above, biological, physical, and chemical methods each presented specific advantages and limitations. Integrating these approaches could create synergistic effects, enhancing overall treatment performance by compensating for the weaknesses of individual methods.

Li et al. (2021) proposed a hybrid system combining photocatalysis and biodegradation using natural loofah fibers as microbial carriers [70]. Karaolia et al. (2017) investigated a system integrating biofilm reactors with solar-driven Fenton processes, demonstrating high removal efficiencies for antibiotics such as sulfamethoxazole, erythromycin, and clarithromycin [71]. Similarly, combining biofilm reactors with activated carbon adsorption achieved removal rates exceeding 90% for sulfamethoxazole and triclosan [72]. In Vietnam, antibiotic treatment technologies remained limited; however, studies using adsorbent materials and photocatalysts showed promising results [73]. Additionally, the Vietnamese Government established a National Action Plan on antimicrobial resistance and issued legal documents to regulate antibiotic use [13].

To optimize both cost and treatment efficiency, we proposed a three-module system consisting of: (i) an activated sludge process, (ii) an activated carbon adsorption column, and (iii) a constructed wetland. Wastewater was first treated by the activated sludge process to reduce antibiotics, organic matter, and nutrients. Subsequently, an activated carbon adsorption column removed the majority of residual antibiotics. Finally, constructed wetlands served as a polishing stage to completely eliminate remaining pollutants.

The advantages of this model included low cost and operational simplicity. The system could remove multiple types of contaminants to meet Vietnam's discharge standards. Furthermore, as it relied primarily on biological and physical processes, the risk of secondary pollution was minimized. Properly optimized design calculations were essential for maximizing treatment performance. In particular, the adsorption column required careful consideration regarding material reuse or replacement intervals, which should be determined based on system requirements. System performance could also be enhanced by reducing the load on preceding stages through optimization of the constructed wetland, for example, by modifying filter media, selecting appropriate aquatic plants, or expanding the treatment area [74–76].

Notably, constructed wetlands not only served as a treatment step but also improved landscape aesthetics, enhanced biodiversity, and offered potential opportunities for water reuse. The disadvantages of biological processes and materials included long treatment times and large land requirements. However, they were low-cost and suitable for rural areas in Vietnam, where land was abundant. Overall, this integrated model represented a promising solution for low-cost, high-efficiency, and environmentally friendly wastewater treatment. It could be scaled up or flexibly adjusted according to the characteristics of local wastewater sources and management requirements in different regions of Vietnam.

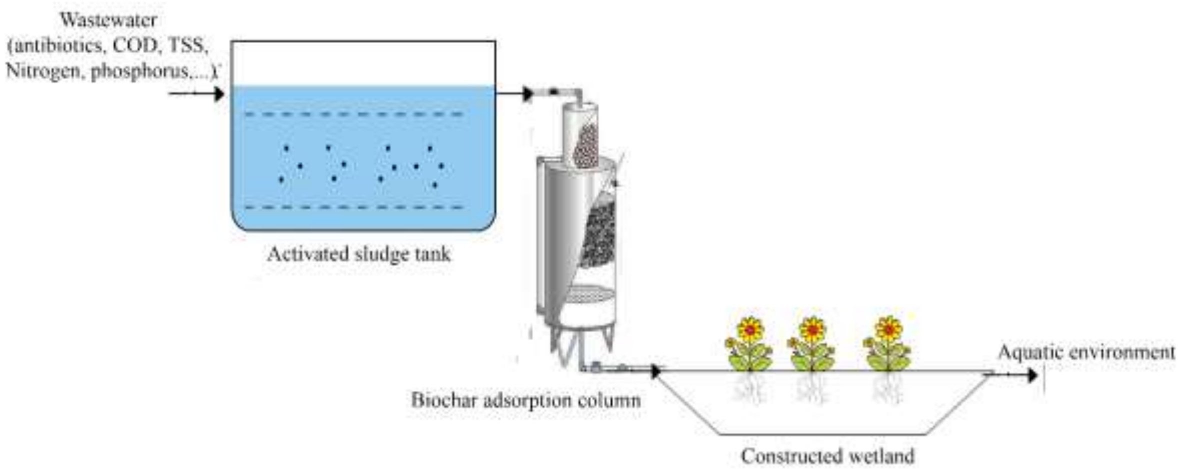

Figure 1. Proposed technological model for the treatment of antibiotic-containing wastewater in Vietnam.

6. Conclusions

Antibiotic contamination in aquatic environments in Vietnam has emerged as a critical issue, with elevated concentrations from diverse sources posing significant risks to human health, biodiversity, and ecological balance. Studies have consistently reported the widespread presence of antibiotic groups such as sulfonamides, macrolides, and tetracyclines, particularly in urban rivers and lakes where concentrations remain high. This situation underscores the urgent need for effective control and mitigation strategies. Biological, physical, and chemical treatment technologies each offer potential, but their integration provides the most robust solution. The proposed model comprising activated sludge, activated carbon adsorption, and constructed wetlands, represents a sustainable approach adapted to Vietnam's economic and climatic conditions. This integrated system can efficiently remove antibiotics while minimizing secondary pollution. Implementing such solutions will not only reduce environmental risks but also support sustainable development goals, safeguard water resources, and protect public health amid rapid urbanization and increasing antibiotic consumption..

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Author Contribution

Tran Van An: Conceptualization, literature search, writing, review, and editing.

Competing Interest

The author declares that there are no competing interests, financial or otherwise, that could influenceor bias the content of this review article.

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