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Veterinary pharmaceuticals in aquaculture wastewater as emerging contaminant substances in aquatic environment and potential treatment methods

Abstract

Veterinary pharmaceuticals are still unregulated and their residues in the environment have the potential to cause considerable impact on ecosystems. Water pollution due to veterinary pharmaceuticals gained worldwide attention because they deteriorate the water quality and impart a toxic effect on living organisms. Therefore, the effective aquaculture wastewater treatment for veterinary pharmaceuticals removal before releasing into the environment is necessary to prevent the risk of environmental contamination and subsequent negative health and economic impacts on both the human and aquaculture industry. This review provides an overview of currently available methods to remove veterinary pharmaceuticals available in aquaculture wastewater while reviewing some methods already studied for other types of pharmaceuticals but possible to use in aquaculture in the future and the scope of the review has been limited to aquaculture antibiotics used as veterinary medicines. Several water refinement techniques such as conventional mechanical, chemical, biological and physical wastewater treatment methods are practiced but they are not with suitable efficiency. Several studies were published covering small or special sections of water pollution by pharmaceuticals. But most of these studies have been done targeting to remove the antibiotics coming from hospital effluent, livestock or animal farm, and veterinary practices. There are very few research studies done specifically for aquaculture wastewater treatment against veterinary pharmaceuticals. Therefore, more attention and efforts must be given to this topic to be developed and to know all details concerning the toxicity of veterinary pharmaceuticals and how they can be removed from the aquaculture wastewaters.

Keywords: antibiotics, wastewater, AOP, aquatic pollution

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Introduction

Aquaculture or the farming of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants is a fast-growing food–production sector with a rate of 6% per year in the world as it is becoming the major source of protein to feed the growing world population. Also, aquaculture can be taken as a substitute for wild aquatic organisms while creating employment and generating income for human development. According to the current statistics, the Aquaculture sector represented 53% of the total seafood production from fisheries and aquaculture in 2015.[1] Based on management, aquaculture can be categorized as extensive, semi-intensive, and intensive aquaculture where the intensive aquaculture is made to achieve maximum production of fish from a minimum quantity of water. This system involves small ponds, tanks, or raceways with very high stocking densities. To meet the increasing demand, the global production of intensive aquaculture has increased from 3,073 million kilograms in 1999 to 5,255 million kilograms in 2008 with 37% of the global fishery production[2] and it predicts the production of food fish by aquaculture will reach 109 million tonnes by 2030.[1] According to the Aquaculture production data from 2006, China, India, and Indonesia take the priority of intensive aquaculture production over other aquaculture producing countries.[3]

Previous studies show that intensive aquaculture often demands the chemicals which have been used in various methods for centuries.[4] Those chemicals or aquaculture pharmaceuticals have become a significant component in formulated feed, soil, and water treatment compounds, pond disinfectants, pesticides, antibiotics, and growth promoters.[3–6] Currently, several classes of chemical compounds are used in large quantities in the aquaculture industry, especially in developing countries without regulations. A number of these chemicals have been identified as non-biodegradable and persist in the aquatic environment as residues. Therefore, the use of both the unapproved drugs and approved drugs in an uncontrolled manner may hazardous not only for the cultured species but also for the surrounding environment and the consumers. There are several important concerns about the use of chemicals in aquaculture.[7]

Emerging concerns of antibiotics use in aquaculture

Fish health management or the prevention of fish diseases is one of the main targets of using chemical species in intensive aquaculture systems. Because susceptibility to the diseases and spreading of diseases among cultured fish species in intensive aquaculture system is always higher than the other systems due to several reasons like high stocking density and stress. Also, it may cause unbearable losses to farmers. Therefore, Antibiotics are considered to be the most applied chemical in aquaculture to control disease outbreaks. An antibiotic can be defined as a natural or synthetic compound that works by either killing or inhibiting a particular pathogen's growth.[8] As several authors noted previously, a range of antibiotics are used in both marine and freshwater aquaculture. According to a global questionnaire-based survey conducted by Tusevljak et al.,[9] in 2009, it was revealed that antibiotics are widely used in intensive aquaculture in Asia, Europe, the USA, Canada, and other countries. R. Lujiwa et al. (2019) shows the types of antibiotics used in fifteen major aquaculture producing countries and cases of antibiotic residues in farmed aquatic products that exceeded set maximum residue limits through many reviewed publications. However, ampicillin, chloramphenicol, florfenicol, oxytetracycline, sulfonamides, and tetracyclines, are becoming more frequent to fight against fish and animal diseases or to prevent them.[10,11] Although the use of antibiotics significantly contributes to increasing the productivity of intensive aquaculture systems while securing a profit, they possess negative impacts on both the environmental and human health.[3,6,8,12–15] On the other hand, many farmers have insufficient information on the efficient use of antibiotics.[16–18]

It has been found that up to 75% of the administered dietary dose of antibiotics can be lost to the surrounding environment or the fish pond water.[19,14] This loss can happen as dispersal of non-ingested pellets, renal excretion and gill excretion of the unprocessed pharmaceuticals or drugs, and fecal excretion of metabolites.[20] Therefore, increasing the use of antibiotics may increase the contamination of natural water bodies and the environment. For instance, sulfonamides (sulfamethoxazole), macrolides (erythromycin, clarithromycin), fluoroquinolones (ciprofloxacin, norfloxacin), tetracyclines (tetracycline, chlortetracycline, oxytetracycline), and trimethoprim and lincomycin has been already identified in the natural aquatic environment.[21,22] On the other hand, recent research findings show that the overall effects of antibiotics and their metabolites may exceed the highest individual effect of the mixture of components. This is very important for the environmental hazard and risk assessment of pharmaceuticals or antibiotics because it indicates that concentrations of single chemicals that show no effect when applied singly may provoke substantial effects when acting as a combination.[23]

Recent studies reveal that increasing the concentration of multiple antibiotics has led to the proliferation of resistant bacteria in the environment while the impact of antibiotic residues on the ecosystem has been recognized as a global threat.[24,25] Both the aquatic and terrestrial organisms have already been affected by the extensive presence of antibiotics in the environment, besides, alteration in microbial activity and their composition, and prevalence of bacterial resistance to antibiotics.[26–29] Regarding aquaculture and fisheries, it will not be an easy task to control disease outbreaks among both the cultured and wild fish species in near future making a drastic loss of aquatic food production as there may be a rising of antibiotic-resistant pathogens. Although advanced technological involvements are currently under research for aquaculture wastewater treatments to prevent negative impacts on the environment like phosphate-based eutrophication,[30] antibiotics produced from intensive aquaculture are still entering into the natural environment via wastewater treatment plants due to the less availability of effective removal methods.[31] These pollutants are becoming ubiquitous in the environments because they cannot be effectively removed by the conventional wastewater treatment plants due to their recalcitrant performance.

Pharmaceuticals are still unregulated and their residues in the environment are considered to be "compounds of emerging concern" because they have the potential to cause considerable impact on human health and ecosystems. The hazardous potential of pharmaceutical compounds on ecosystems was recently established. Therefore, effective aquaculture wastewater treatment for antibiotic removal before releasing into the environment is necessary to prevent the risk of environmental contamination and subsequent negative health and economic impacts on both the human and aquaculture industry. This paper reviews the currently available methods to remove particularly antibiotics available in aquaculture wastewater while reviewing some methods already studied for other types of pharmaceuticals but possible to use in the removal of aquaculture antibiotics in the future. The scope of the review has been limited to aquaculture antibiotics used as veterinary medicines.

Treatment of aquaculture wastewater

Contributing to the diversity of aquaculture is the number of different culture systems employed to produce an increasing number of species. A wide variety of culture systems such as earthen pond and limited-flow culture systems, Flow-through tanks and raceways, Recirculating systems, integrated systems, and polyculture are employed to meet the production needs of the cultured species and maximize the resources available in the region. Each culture system has aspects that affect the production densities and risk for disease, as well as affect how antibiotics and antimicrobials are administered and handled for uptake by the cultured species and excretion into the environment.[32–34]

As an emerging threaten not only for the environment but also for mankind, several research studies have been conducted to find effective biological, chemical, and physical methods to remove antibiotics available in wastewater effluents and natural waters. Several reviews were published covering small or special sections of environmental pollution by pharmaceuticals. But most of these studies have been done targeting to remove the antibiotics coming from hospital effluent, livestock or animal farm, and veterinary practices. There is very little research done specifically for aquaculture wastewater treatment against antibiotics. Although the same methods can be applied in the aquaculture industry, field-specified studies or research are necessary due to several reasons. For instance, the concentration of antibiotics, form of antibiotics and their metabolites which will be excreted after digested by fish, retention time, and the cost may be significantly different from other types of wastewater treatment plants. Improper discharge from aquaculture farming may affect the environment by introducing antibiotic-resistant pathogens that can be self-developed and transferred among local microorganisms in the environment. Moreover, in both freshwater and seawater intensive aquaculture, water is considered to be a limited resource and always leads to reuse the water after one culture cycle to another culture cycle. Therefore, it is important to have effective strategies to remove available antibiotics in water before reusing as there is a possibility of accumulating available residues in food fish bodies and subsequent biomagnification with the possible increase of contiguity with antibiotic residues can accumulate in the food chain.

So far, many studies had been done about the presence of antibiotics in the environment. Unfortunately, despite the extensive investigations, there is still a considerable lack of integrated and classified information to assess the removal of veterinary pharmaceuticals from intensive aquaculture wastewater.

Various processes for the removal of veterinary pharmaceuticals are not with suitable efficiency. Therefore, in recent years, biological technologies for pollutants removal from the environment have played an important role in the use of these technologies for the removal of environmental pollutants as one of the newest and best pollutant removal practices in the world. Biological approaches in water treatments are always recommended due to the low cost and less production of toxic byproducts to the environment. The use of different types of microbes in either pure culture or mixed cultures under aerobic or anaerobic conditions has been identified as an effective method for degrading organic pollutants in the environment. It is assumed that the particular microbes used in wastewater remediation, can remove pharmaceuticals including antibiotics by utilizing their carbon backbone for their metabolic functions. S. Shao et *al*. (2019) reveal that the biodegradation of oxytetracycline (OTC) available in aquaculture wastewater using the *Ochrobactrum* sp. KSS10 strain has been studied under various environmental conditions under aerobic condition.[35] At the same time, the removal of OTC from synthetic aquaculture wastewater through Bed Biofilm Reactor (MBBR) and changes in the resistant genes of particular microbial communities have also been investigated. The results demonstrated that the strain KSS10 is a dominant contributor in OTC removal in the MBBR chamber. It removes approximately 76.42% of OTC while the abundance of some specific genes was reduced by the MBBR. The results express that the strain KSS10 can be used as a potential treatment method to use in aquaculture wastewater pre-treatment.[35] X. F. Huang, et *al.* (2019) studied the effect of four types of wetlands with different plant species in different planting patterns ((S1) *Iris pseudacorus*, (S2) *Phragmites australis*, (M1) *Iris pseudacorus* and *Phragmites australis* planted separately at the forepart and back at a 1:1 ratio, and (M2) *Iris pseudacorus* and *Phragmites australis* arranged alternately) to remove enrofloxacin (ENR), sulfamethoxazole (SMZ), and antibiotic resistance genes (ARGs) from aquaculture wastewater. According to the results, S1 and S2 had the high removal ability (77.64% - 56.26%) of selected antibiotics and ARGs comparatively to the M1 and M2.[36] Apart from these specific studies for aquaculture wastewater treatment, some biological treatment studies have been done with fungi species to remove antibiotics from water. Some fungi species like *Trametes Versicolor, Irpex lacteus, Ganoderma lucidum*, *Stropharia rugosoannulata, Gymnopilus luteofolius* and *Agrocybe erebia*,[37–39] bacteria species like *Pseudomonas putida,* and *Achromobacter several* [40,41,39] *and* algae species like *Scenedesmus obliquus and Chlamydomonas Mexicana*[42,40] can be considered to be potential microorganisms to use in aquaculture wastewater treatment in future studies. Biological methods usually have fewer negative impacts on the environment and produce fewer byproducts. Nonetheless, in many cases, they lack efficiency due to their low availability and also their resistance to biodegradation.

Analytical methods are the most significant prerequisite for investigating the fate of antibiotics in the aquatic environment. J. Wang and S. Wang (2016) elaborated that Gas chromatography (GC), high-performance liquid chromatography (HPLC), and their improved techniques like gas chromatography-tandem mass spectrometry (GC-MS/ MS) and liquid chromatography-tandem mass spectrometry (LC-MS/MS) are widely used instruments for pharmaceutical analysis.[43] Also, L. T. Lemmuel et al. (2018) explained that the small concentrations of pharmaceuticals can easily be detected by mass spectroscopy which may be coupled to either liquid or gas chromatography. According to the recent studies done related to the aquaculture antibiotics removal, ultra-performance liquid chromatography coupled with tandem mass spectrometry (UPLC–MS/MS) has been widely used compared to the GC–MS/MS due to the easiness of sample preparation and analysis.

Adsorption is the widely used physical treatment method used in wastewater treatment plants due to many reasons such as low cost, high efficiency, and simple design.[30,44] In aquaculture wastewater treatment also, several adsorbents have been used so far to reduce the level of contaminants before used in culture cycles and after used in culture ponds.[30] But the studies done giving the priority for aquaculture antibiotics removal from the wastewater is very limited. C.I.A. Ferreira et *al.* (2016) elaborated the potential use of pyrolyzing biological paper mill sludge to remove Tricaine methanesulfonate (MS-222) which is a widely used antibiotic in intensive aquaculture ponds. Study concludes that the particular adsorbent has a lower capacity but faster adsorption kinetics than the commercial activated carbon in adsorption of MS-222.[45] Cincinelli et *al.* (2015) explained the possibility of using nanomaterials in water treatment to remove pharmaceuticals. However, in future studies, types of activated carbons, biochar species, bio sorbents, nanomaterials, and polymers resins can be taken as effective adsorbents to remove increasing antibiotics in aquaculture wastewater (GWSW).[46]

Indeed, the chemical, physicochemical, and combined methods of water treatment have been becoming widely used and promising technologies for wastewater treatment for few decades. Absorption, Chlorination, ozonation, electrocoagulation, membrane process, reverse osmosis, and nanofiltration have been already studied in previous studies to remove antibiotics from water[39] but not specified for aquaculture wastewater. Also, methods like chlorination which show high performance in laboratory level experiments may not be applicable at all in the aquaculture industry due to the high capital cost. Therefore, further field-specific studies are necessary to find out the most suitable methods to use in the aquaculture industry. C. Chokejaroenrat et *al*. (2018) verified the potential use of ZVI-activated persulfate (PS) were having both the adsorption and scavenger effect of persulfate radicals against sulfadimethoxine (SDM) to treat the aquaculture wastewater coming from the flow-through system. According to the results, the system was a success to remove around 68% of SDM from filtered and 74% from unfiltered discharge aquaculture wastewater proving that the system could potentially be applied to remove antibiotics from intensive aquaculture wastewater.[47] The study of D. Kanakaraju et *al*. 2018 clearly explains the potential use of advanced oxidation processes (AOPs) including ozonation, Fenton and photo-Fenton, UV/peroxide processes, sonolysis, electrochemical oxidation, radiation, and combined AOPs to remove pharmaceuticals available from wastewater.[48] In terms of antibiotics removal from aquaculture wastewater, Y.Nomura et *al.* (2020) studied the capability of rotating advanced oxidation contactors equipped with high-silica zeolite/TiO2 composite sheets to remove sulfamonomethoxine (SMM) and its transformation byproducts from fresh aquaculture wastewater (FAWW) from aquaculture wastewater.[49,50] The research findings present that the combination of adsorption and photocatalysis or the synergetic effect of two methods has a great degradation ability against SMM than using each method separately. Furthermore, AOPs are considered to be the most successful and promising wastewater treatment method in the intensive aquaculture wastewater treatment plants in the future compared to other methods due to many reasons such as effectiveness, cheapness, and environmental friendliness. Figure 1 illustrates the assumed general mechanism of degradation of antibiotics from different AOPs.

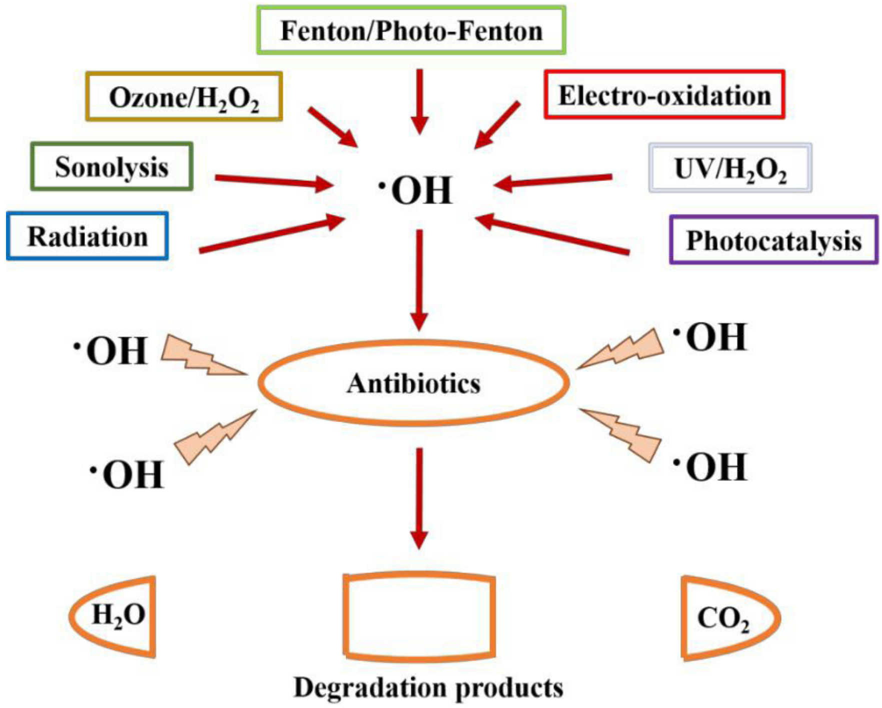

Figure 1 General mechanism of AOPs to degrade antibiotic.

Conclusion

Recent studies have shown that conventional mechanical, chemical, biological and physical wastewater treatment methods (or a combination of these) are incapable of removing or degrading the majority of these aquaculture antibiotics and a large amount of them and their metabolites are ultimately released to the aquatic environment via sewage effluents. No one can deny that aquaculture is the only way to fulfill the increasing demand for animal protein with the drastic increase in world population. Intensive aquaculture is the only way to produce this demand due to the less availability of natural resources to culture aquatic organisms in the natural environment or for fisheries. Antibiotics have been using for many years in intensive aquaculture practices to prevent the risk of disease outbreaks and sudden losses in the industry. But, antibiotic contamination to the natural environment has become a life-threatening issue in the world. Therefore, a number of studies have been done to reveal methods and technologies to remove these antibiotics from wastewater effluents. Although many studies have been done for industrial and hospital effluents, there is a very limited number of researches done to remove antibiotics in aquaculture wastewater. Therefore, more attention and efforts must be given to this topic to be developed and know all details concerning the toxicity of antibiotics and how can be removed from the aquaculture wastewaters.

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Conflicts of interest

There is no any conflict of interest.

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