

Impact of Antibiotics on Aquatic Life

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1. Introduction

The use of antibiotics has increased over the years to enhance human and animal well-being since these infections are now easily controlled (Singer et al., 2003). However, their widespread use and improper disposal have led to a significant environmental crisis: Antibiotic resistance and the presence of antibiotics in water. This contamination is dangerous as it disrupts the natural distribution of life in water bodies beginning with microscopic organisms, fish, other water animals, and even man. Most of these antibiotics end up in water systems through agricultural drained water, treated sewage effluents, and discarded unused or expired medicines. Subsequently, these drugs remain and concentrate in water, thus causing a biochemical impact on every biological life stage of the aquatic life forms. The ecological importance of microorganisms in aquatic ecosystems makes them sensitive to antibiotics. They are involved in such important processes as nutrient cycling, decomposition of organic matter, and forming a source of food for organisms in higher trophic levels. Antibiotics affect microbial LM communities, decrease their diversity, and modify key biogeochemical processes (Grenni et al., 2018). Furthermore, utilization of water sources with antibiotics has been associated with the genesis of antibiotic-resistant bacteria, a notable concern in today's world. These resistant bacteria can spread resistance genes to human pathogens and hence directly affect the health of people. Antibiotics are not limited to humans and livestock only but also impact fish and other water animals. The use of these drugs can hurt height, fecundity, and character (Lee et al., 2007). In certain situations, antibiotics can be directly deadly to the fauna in the aquatic ecosystem, and lead to death. Interference with these species could result in detrimental effects on food chains and the general health of the water bodies. Antibiotics can potentially affect whole aquatic systems due to the contamination of water bodies. It was established that any imbalance in the water affects fish and other organisms; therefore, the use of antibiotics has ripple effects. This can bring about a reduction in the overall population of some species, an increase in the population density of other species, and an overall reduction in species diversity. It is established that human health is inextricably connected to the condition of the aquatic biome. Water can also affect the health of people directly if they drink the infected water and indirectly if they consume the fish and seafood obtained from such water (Iwamoto et al., 2010). Another great concern is the spread of antibiotic-resistant bacteria in the surrounding environment thereby increasing the risk of certain antibiotics being deficient in combating infections.

Due to the consequential impact of antibiotic contamination, the search for possible solutions and measures that could be taken is crucial. Some specific measures that need to be taken to combat this problem include better sanitation, higher regulatory standards, and the creation of environmentally friendly substitutes for antibiotics. Furthermore, public awareness and education on the proper utilization and disposal of antibiotics help minimize this environmental and epidemic health challenge (Manyi-Loh et al., 2018).

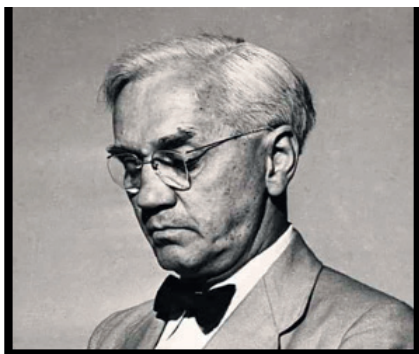
2. The Rising Tide of Antibiotic Pollution

Antibiotics, which many people consider to be one of the greatest discoveries of the past century, have contributed to the removal of bacterial diseases including millions of people's lives. However, the widespread and often indiscriminate use of these powerful drugs has led to an unforeseen and growing environmental crisis: the contamination of antibiotics. In preliminary to

this chapter, this chapter discusses the background, concern, and impact of antibiotic pollution on the aquatic environment (Penesyan et al., 2015).

2.1. Historical context and development

The general use of antibiotics started with the world's first antibiotic, penicillin, discovered by Alexander Fleming in 1928 (Kourkouta et al., 2018). Since then, antibiotics have found a wide application in the national health care system, livestock, and fish farming. Antibiotics became widely produced and used after World War II not only for human treatment but also to increase meat production in livestock and to avoid infections in fish farming.



Alexander Fleming



Penicillin (world's

This exponential growth in antibiotic use has however come at the expense of the environment in the following ways:

2.2. Extent of Antibiotic Pollution

Antibiotic pollution may be described as the occurrence of these pharmaceuticals in ecosystems, specifically in water systems including rivers, lakes, and seas (Gothwal & Shashidhar, 2015). This pollution is on a very large scale. Research has established the presence of antibiotics in water systems worldwide, ranging from urban environments to rural wilderness.

Human Waste: Through urine excretion and fecal elimination, antibiotics taken by humans are not completely assimilated but instead are released into the sewerage system and water bodies.

Agricultural Runoff: From this kind of farming, antibiotics are washed downstream into rivers and streams.

Aquaculture: Aquaculture often treats fish with antibiotics to reduce the risk of disease, which is released directly into the aquatic environment.

Pharmaceutical Manufacturing: Manufacturers of antibiotics can emit large amounts of such compounds into the environment.

Improper Disposal: Flushing of unused medications into toilets is one common way through which high levels of antibiotics are found in water systems due to poor disposal methods.

3. Pathways of Antibiotic Entry into Aquatic Systems

Focusing on the major sources by which antibiotic contaminants are released into the environment including wastewater treatment plants, agricultural drainage, fish farming operations, medication disposal, industrial effluent, and dust. (Danner et al., 2019).

3.1. Wastewater Treatment Plants (WWTPs)

WWTPs are processing facilities that have been established to achieve the main goal of purifying sewage in a bid to discharge the water into water bodies (Qasim, 2017). However, most

WWTPs were reported to be lacking in the capacity to remove the pharmaceuticals, including antibiotics. These facilities can become major sources of antibiotic pollution due to inefficiency in the elimination of these compounds (conventional treatment processes remove only a small fraction of antibiotics and thus, effluent antibiotics are often released into the treated water) and concentration in sewage sludge (antibiotics have been observed to concentrate in the sludge, which is frequently applied as a fertilizer and may infiltrate water resources). Fluctuations in removal efficiencies the case of European WWTPs pointed out that antibiotics are discharged into rivers with concentrations measurable and have impacts on aquatic life in the lower reaches. In one way or the other, the mentioned deficiencies greatly affect the ability of the mentioned nations to contain and combat communicable diseases hence there is a need to improve on the treatment technologies and enhance the implementation of better regulation measures.

3.2. Agricultural Runoff

Antibiotics are used in animal production for therapeutic purposes, disease prevention and treatment, and growth promotion of these animals. They lead to the accumulation of antibiotics in manure, which is spread on farms as a type of manure. These residues can readily reach water bodies through surface runoff (the ability of rainwater to transport antibiotics from fields into streams, rivers, and lakes) and leaching (water solubility and carrying capacity to transport antibiotics through the soil depths and pollute water wells). For instance, over-prescribed antibiotics in feeding cattle in the United States have been reported to pollute the River Mississippi with high levels of water pollution through agricultural runoff (McEwen & Fedorka-Cray, 2002).

3.3 Aquaculture

Another related practice that leads to the release of antibiotics in the environment is the aquaculture or fish farming industry. To safeguard fish from more prevalent diseases, especially in crowded fish farming establishments, antibiotics are given through the feed or water dip. This results in a direct discharge in which many antibiotics not taken by the fish are expelled into the water and sedimentation because they are water soluble and may sink to the bottom affecting the benthic organisms and may sometimes be resuspended into the body of water (Hossain et al., 2022). It was established that intensive shrimp farming released high levels of antibiotics into coastal waters of Southeast Asia as well as posing a great danger to marine life and humans who consume such seafood products.

3.4. Improper Disposal of Medications

Some individuals have the practice of flushing toilet facilities and disposing of unused or expired drugs by washing them down the drain, thereby contaminating the environment. High flushing of medications causes the antibiotics to get into the sewage system, and then without adequate treatment, the water gets into the water bodies. Drugs that are disposed of into the sewers through the sink find their way into the system through sewerage systems and treatment plant discharges. For example, surveys of occupant behavior in the UK reveal that many households throw medications in the trash, resulting in detectable levels of antibiotics entering rivers and lakes (Marwa et al., 2021). All pathways are shown in Fig 1.

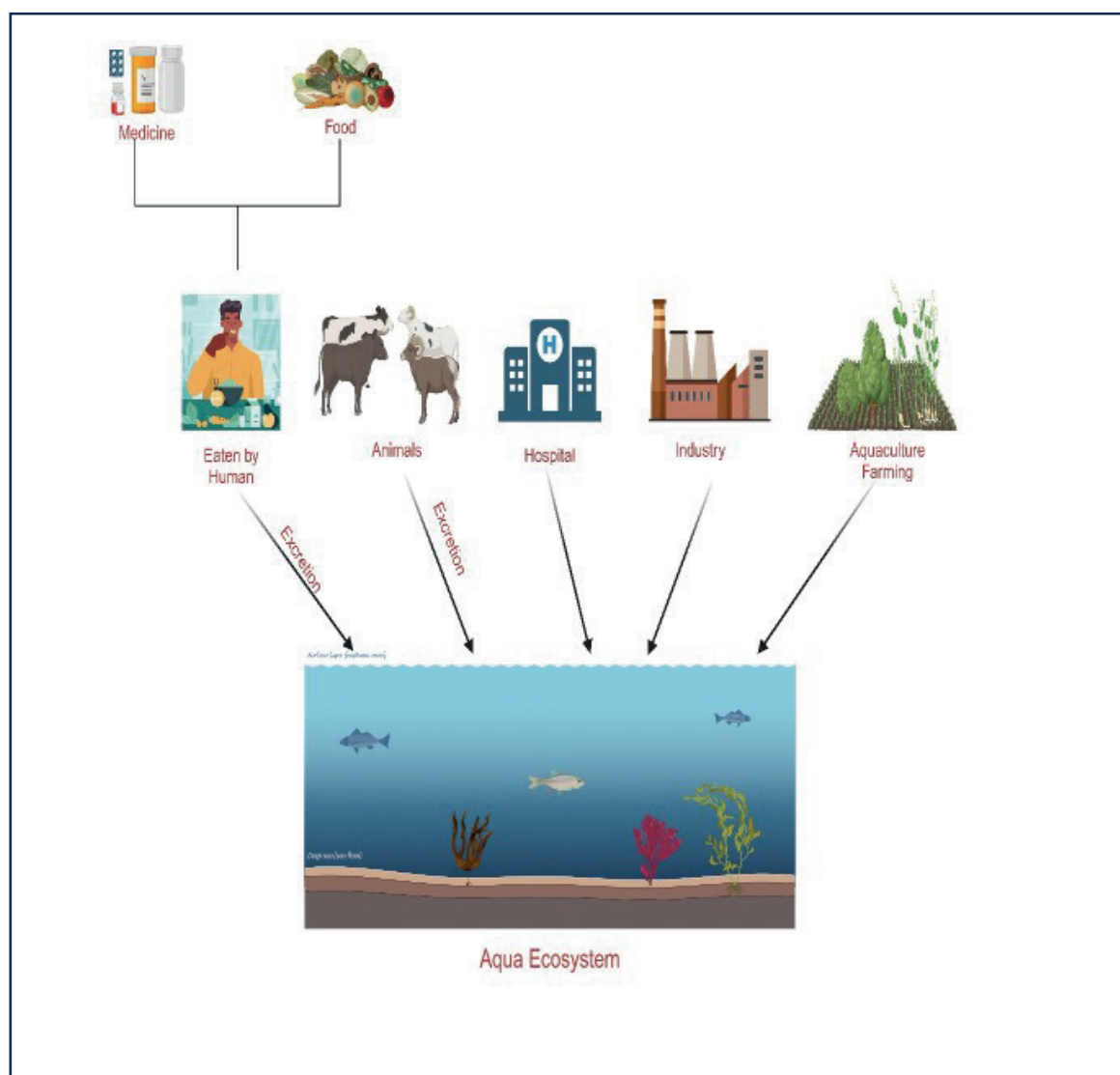


Figure 1:Pathways of Antibiotic Entry into Aquatic Systems

4. Effects of Aquatic Microorganisms

Bacteria, algae, fungi, and other microorganisms are the chief components of aquatic structures. They are important in cycling nutrients, breaking down organic matter throughout the water systems, and the health of water bodies (Sigee, 2005). Low concentrations of antibiotics, formulated to act against bacteria, are inevitably disruptive to these microbial ecosystems.

4.1. Impact on Bacterial Communities

Diversity and Abundance: Ampicillin significantly reduces species richness and density of bacteria in aquatic systems in a dose-dependent manner. In this case, sensitive bacterial species may be eradicated or substantially reduced in population thereby reducing the overall microbial diversity and leading to the emergence of resistant types.

Functional Impact: There are potential consequences for ecosystem functioning where bacterial communities undergo shifts. Some processes, such as nitrogen fixation and decomposition, are known to play crucial roles in bacteria. These functions are also negatively affected by disruptions caused by antibiotics, which in turn alter nutrient availability and rates of decomposition with potential ramifications for the structure of food webs and energy flows (Ambrosini et al., 2016).

4.2. Effects on Algal Populations

Growth and photosynthesis: Specifically, antibacterials can affect algal density, a key component in the primary producers of aquatic habitats (Sharma et al., 2021). It is important in oxygen-making and forms the basic component of the food chain. Some of the antibiotics can prevent algal growth, decrease primary production, and consequently decrease energy flow by preventing photosynthetic processes in aquatic habitats.

4.3. Fungal Communities

Role in Decomposition: Aquatic fungi are essential in breaking down organic material and cycling the nutrients within the water body. Antibiotics can interact with fungi where the fungal growth is suppressed and this will lead to changes in the microbial community which in turn can impact nutrient cycling (Sharma et al., 2021).

The effects of ampicillin on aquatic microorganisms are described in Table 1.

Table 1: Effects of Ampicillin on Aquatic Microorganisms (Singh et al., 2019)

Microorganisms	Key Roles in Ecosystem	Observed Impact Due to Ampicillin Exposure	Potential Ecosystem Consequences
Bacteria	Nutrient cycling, decomposition, and maintaining water health	Reduced species diversity and abundance, potential emergence of resistant strains	Disrupted nitrogen fixation, altered decomposition rates, impacts on food webs and energy flow
Algae	Primary producers: oxygen generation, the base of the food chain	Decreased algal density, inhibited growth and photosynthesis	Reduced primary production, decreased oxygen availability, disrupted energy flow
Fungi	Decomposition and nutrient cycling	Suppressed fungal growth and altered microbial community composition	Disrupted nutrient cycle, potential accumulation of organic matter

4.4. Antibiotic Resistance Development

Mechanisms of Resistance: Thus, the investigated antibiotics are introduced into the aquatic environment, which leads to the development and proliferation of antibiotic resistance among microorganisms by a process referred to as horizontal gene transfer and selective pressure (Shao et al., 2018).

Ecological and Health Implications: It is estimated that a high number of antibiotic-resistant bacteria are present in water bodies which in turn; brings about ecological consequences as well as a direct threat to human health through water recreation and consumption.

Impact on Biofilms: Biofilms on the other hand can be described as structured microbial populations that are attached to the surfaces within the aquatic systems (Donlan, 2002). Some antibiotics can affect the formation and structure of a biofilm and also change its susceptibilities to other antibiotics.

5. Antibiotic Resistance in Aquatic Environments

It was observed that antibiotic-resistant bacteria are on the rise within the clinical and environmental scenarios (Pepi & Focardi, 2021). As existing literature shows that antibiotic resistance in aquatic environments results from various origins, water bodies are sources of ARB and ARG.

5.1. Mechanisms of Antibiotic Resistance

Genetic Basis of Resistance: This occurs during a process known as mutational mechanisms which may include changes in genes or the structure of bacteria in antibiotic presence. These changes could include mutation which is heritable variation and is a genetic change that occurs without opportunity for modification; and horizontal gene transfer (HGT); the transmission of genetic material between organisms (Giedraitienė et al., 2011). HGT is the process of gene transmission through one or more bacteria through conjugation, transformation, or transduction.

Types of Resistance Mechanisms: It is, therefore, essential to understand the following strategies employed by bacteria as a response to the antagonizing effect of the antibiotics:

Efflux Pumps: Sometimes, bacteria can pump antibiotics out of their body through effluxed pumps, a mechanism that makes it hard for the antibiotic to function.

Target Modification: Another form of bacterial resistance is by altering the structure of the area in the bacterium that the antibiotic acts on, hence failing to bind to it properly.

Reduced Permeability: These can change the cell membrane permeability, and in this way, reduce the amounts of the antibiotics that can be incorporated.

WWTP Effluents: According to the research done by Barnett et al. (2017), this information reveals that when treated wastewater is discharged into natural water sources, both ARB and ARGs can be conveyed.

Agricultural Runoff: In farm areas, concentration enhances the distribution of ARB and ARGs through rivers and streams, and in industrial areas, the focus enhances the distribution of ARB and ARG in industrial waterways.

Aquaculture: Intensive fish farming practices have also been cited by studies that can result in the development of resistance.

Industrial Discharges: ARB and ARGs can be accumulated from entities that are in the business of manufacturing; for example, pharmaceutical manufacturers.

Water Flow: The movement of ARB and ARGs can also be attributed to water currents in the rivers and streams; such currents often create turbulence which may enhance the mobility of the bacterial species.

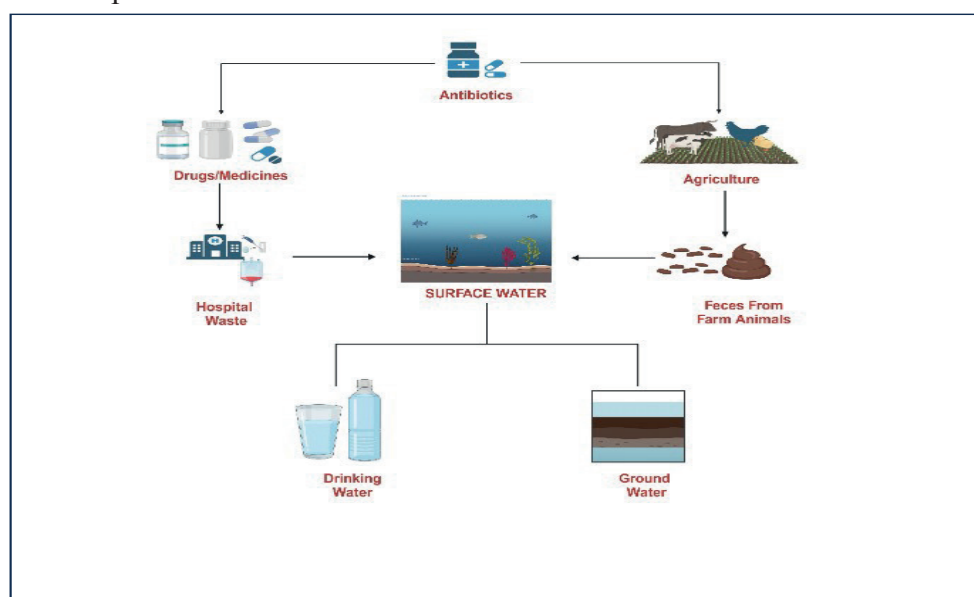


Figure 2: Antibiotic Resistance in Aquatic Environments

6. Impact on Fish and Other Aquatic Fauna

Pollution by antibiotics in the water bodies has numerous risks to the fish and many other water-dwelling creatures. These organisms are likely to come into direct contact with the antibiotics through the water they occupy, resulting in a range of physiological, behavioral, and ecological impacts (Amarasiri et al., 2020).

6.1. Physiological Effects on Fish

Health and Growth: Antibiotics have various physiological impacts on the life of fish their health and growth. If applied for a long period, antibiotics lower fish immunity and increase their vulnerability to diseases and infections. Apart from that, antibiotics affect the liver, kidneys, and gills and reduce their ability to perform their functions optimally and remain healthy. Conversely, low and environmentally safe doses of antibiotics can limit the rate of growth and the total biomass of fish (Yang et al., 2020).

6.2. Reproductive Impacts

Fertility and Development: Industrialized fish may be exposed to antibiotic substances that alter their reproductive mechanism and stunt the growth of their young ones (Manyi-Loh et al., 2018). Some types of antibiotics can cause hormonal dysfunction in the endocrine system hence affecting reproduction. Antibiotics have been found to decrease the rate of sperm production as well as the quality of the eggs, thus less chance of reproduction. Further, treating animals with antibiotics can also cause embryonic and larval malformation and mortality.

6.3. Behavioral Changes

Feeding and Predation: Chemicals such as antibiotics can interfere with fish by changing their feeding and predator/prey relationship patterns. Antibiotic agents can decrease the feed intake and feed conversion in animals, resulting in stunted growth and malnutrition. Both sensory and motor losses can negatively affect a fish's ability to evade predators hence increasing its chances of being preyed upon (Danner et al., 2019).

6.4. Effects on Other Water Biodiversity

Invertebrates: Antibiotics can affect the ability to grow, reproduce, and survive in water organisms of crustaceans, mollusks, and insects (Romero et al., 2012). Such organisms are involved in nutrient cycling and many of them are consumed by organisms at higher trophic levels.

Amphibians: Among these sensitive groups, frogs and salamanders are the most affected by antibiotic pollution because their skin is permeable. They lead to developmental malformations, immunosuppression, and higher risks of infections (Magalhães, 2016).

This pollution has dangerous implications for fish and other aquatic fauna in environments that are contaminated with antibiotics. Through the water they occupy, these organisms are directly subjected to antibiotics, which in turn, cause different physiological, behavioral, and ecological alterations.

6.5. Physiological Effects on Fish

Health and Growth: Physicochemical properties of antibiotics affect fish physiology and have a significant impact on fish health and growth. Long-term administration of antibiotics is dangerous for fish in that it compromises their immune systems, and they become more vulnerable to diseases and infections (Limbu et al., 2018). Antibiotics also affect the organs such as the liver, kidney, and gill in fish by damaging them and consequently reducing their health. Also, low levels of antibiotics can decrease the growth rates and the biomass of fish populations significantly.

6.6. Effects on Other Water Wildlife

Invertebrates: Chemicals like antibiotics can have undesirable effects on the growth, reproduction capacity, and mortality of water organisms such as crustacea, Mollusca, and insects (Gräslund & Bengtsson, 2001). These organisms are involved in the decomposition and recycling of nutrients and act as a base for higher trophic levels.

Amphibians: Frogs and salamanders are especially sensitive to antibiotic pollution because their skin is porous. Such developmental defects, as well as immune suppression and raised susceptibility to infections, are caused by antibiotics (Magalhães, 2016).

The impact of Antibiotic Pollution on Aquatic Life is described in Table 2:

Table 2: Impacts of Antibiotic Pollution on Aquatic Life

	Specific Impact	Physiological Consequences	Behavioral Consequences	Reproductive Consequences	Ecological Consequences
Fish	Reduced immunity, organ damage (liver, kidney, gills)	Increased disease susceptibility, impaired detoxification, reduced respiratory function			
	Decreased growth rates	Reduced body size, lower energy reserves	Altered feeding patterns		Reduced population size, disrupted food webs
	Hormonal imbalances	Disrupted metabolism, impaired stress response		Reduced fertility, developmental abnormalities in offspring	
	Neurological effects	Impaired sensory perception, motor dysfunction	Altered predator avoidance, decreased foraging success		Increased predation risk
Invertebrates	Impaired growth and development	Reduced body size, delayed maturity		Reduced reproductive output	Disrupted nutrient cycling, decreased food availability for higher trophic levels
	Increased mortality				Reduced biodiversity, altered community composition
Amphibians	Developmental abnormalities	Malformed limbs, organ dysfunction		Reduced reproductive success	Increased mortality, population declines
	Immunosuppression	Increased susceptibility to infections			
	Disrupted metamorphosis	Delayed or incomplete transformation			Reduced recruitment, ecological imbalances

7. Disruption of Aquatic Ecosystems

This pollution leads to changes in the properties of water; impacts prokaryotes, macroinvertebrates, and fish; and alters the structure of an ecosystem.

7.1. Changes in Microbial Dynamics

Microbial Community Shifts: Antibiotics can shift the structure of microbial soil, where most of the susceptible species become non-competitive, while antibiotic-resistant strains can grow in the soil. It leads to a general reduction in microbial diversity and alters the architecture and dynamics of microbial communities (Topcu & Taşkan, 2021).

Functional Consequences: Such alterations may impact the fundamental activities of such ecosystems such as nutrient biogeochemical cycling, nitrogen and phosphorus, and decomposition of organic matter. Such occurs when nutrient cycling is inhibited, bacterial activity impacts primary production, or when reduced bacterial turnover rate impacts the sinking of organic matters which in turn affects the detrital food web and nutrient cycling (Bärlocher & Renneberg, 2014).

7.2. Impacts on Primary Producers

Algae and Phytoplankton: From this list, algae and phytoplankton may be considered as the first trophic level, or raw producers, in the water food chain. Because of the increased microbial load, antibiotics can suppress the growth and photosynthetic activity of these primary producers (Taşkan, 2016). Changes in microbial composition also affect other producers in a manner that will allow them to access nutrients in forms or with different microorganisms that they have not experienced before.

7.3. Disruption of Food Webs

Trophic Interactions: The effects of antibiotic pollution include the disruption of the traditional food chain by the conversion of various trophic levels. Changes in prey abundance and distribution ultimately impact predator structures and feeding habits. Alterations at one trophic level may cascade up and down the food chain altering the distribution of energy and redox state (Danner et al., 2019).

7.4. Habitat and Biodiversity Loss

Habitat Degradation: Antibiotic pollution can also lead to changes in physical and chemical properties at the depositional site of the environment. Water pollution affects the quality of water and also, and the level of antibiotics that are bound to sediments has implications on space use among species which has textbook implications on biological diversity (Lyautey et al., 2021).

Biodiversity Impacts: Endangered species are likely to reduce in population or even go extinct, thus reducing the additive level of species diversity. That is, with the decline in the number of species, the ecosystems become less able to tolerate the changes and loads that occur in the environment and receive.

7.5. Ecosystem Services

Provisioning Services: The major ecosystem services include the provision of fish and approval as the water quality controller. The discovery is that antibiotics contaminate the fish environment, which affects the condition of fisheries for maintaining fish supply. It can also hemo natural filtration and nutrient cycling processes that influence the water filtration rating.

Regulating Services: Another function that is sustained in aquatic environments is the regulation of temperature because they are carbon sinks. If the balance of these ecosystems is disrupted, then these functions can be affected. Disruption of one of these ecosystems automatically

leads to the disruption of these functions. Moreover, the presence of antibiotic compounds in the water body disrupts disease dynamics and distribution by transferring antibiotic-resistant bacteria into the aquatic food chain (Schulze, 2006).

8. Human Health Implications

Antibiotic pollution in water bodies is said to pose various risks of exposure to man and animals through the sequences (Gothwal & Shashidhar, 2015). More specifically, specific environmental, contagion, and direct exposure to contaminated water.

Recreational Water Use: Food consumed from seeds that are washed with polluted water or even prepared with water from sources containing antibiotics also exposes the consumer to direct antibiotics and antibiotic-resistant bacteria responsible for skin infections, gastrointestinal diseases, and other related diseases.

Drinking Water Contamination: A large number of antibiotic compounds can enter water, primarily through raw and inadequately treated water and effluence, as well as livestock farming. This directly exposes the consumers to the possible risks of infection, allergic reactions, and health complications due to the consumption of toxic substances in the form of antibiotic residues and antibiotic-resistant bacteria through drinking water containing antibiotics (Khan et al., 2020).

Food Chain Transmission The virus can also spread through contact with foods that have been in contact with an infected individual.

Contaminated Seafood: These fish and prawns contain antibiotics in their meat that when consumed enter the body making the body adapt to the new antibiotics thus making it resistant to them.

Agricultural Products: Consumption of food crops produced using water that has been contaminated with antibiotics is also a threat to human beings.

Environmental Reservoirs: Antibiotic-contaminated effluent could increase the release and dissemination of ARB and horizontal transfer of antibiotic-resistance genes in microbes.

Health Implications: This is due to the ease of infections with highly resistant characteristics which are a threat to public health since ARB-associated infections are more difficult to treat, cause more severe and longer illness, involve considerably higher costs of medicines, and produce more deaths.

8.1. Broader Public Health Implications

Increased Healthcare Costs: The social cost can also be incurred through healthcare costs since antibiotic-resistant infections are treated using expensive and more complex procedures.

Global Health Threat: Environmental pollution is another well-known factor that leads to the development of antibiotic resistance, which is one of the biggest challenges facing the healthcare system. The spread of antibiotic-resistant bacteria is through water, trade, and human movements meaning more effort has to be made to address this issue.

Improving Water Treatment: By incorporating new technologies in the treatment of water and establishing strict bureaucratic standards, the consumption of antibiotics in water can be prevented.

Promoting Responsible Antibiotic Use: The cases of polluting the environment with antibiotics only require a change in the daily rate of using antibiotics in healthcare, livestock, and farm fish production.

Public Awareness and Education: For instance, in the case of antibiotic pollution, educating the people on the consequences of polluting the environment with antibiotics and the right process

of discarding any unused antibiotics is very useful for the mitigation measures.

9. Conclusion

The quest to always strive to reduce antibiotic pollution in water bodies and the impacts it has on wildlife and human beings is always a challenging task. It will involve enhancing the laws for the usage of water resources, the issue and dissemination of effective water treatment techniques, bringing in effective techniques in farming, and coming up with the best techniques for communicating ideas to the people. Hence, by promoting a better code of antibiotic disposal and use both at the domestic and cross-national level, it is possible to reduce, if not eradicate, environmental pollution. The number of interventions laid for the removal of antibiotics from water strings at wastewater treatment plants has been augmented with technologies such as membrane filtration and advanced oxidation processes. In addition, enhancing quality nutrition by increasing the production of quality crops and animals, and advice on the right practices such as integrated pest management instead of resorting to antibiotic circulation in the first place would also be an avenue to minimize the use of antibiotics. Public awareness of the potential consequences of antibiotic pollution to the environment and human health should be observed. Members of the public should also ensure that they dispose of their waste adequately and even take a section on the usage of antibiotics as this can decrease the contamination of pollinators. This challenge can be partly addressed within the context of international cooperation and therefore ensuring and encouraging research and innovation activities. This paper has highlighted that, despite most of the aquatic habitats being on the brink of destruction, the protection of the few remaining ones, the health of the nation/province, and the sustainability of water resources can only be achieved through cooperation among the stakeholders.

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