

Antibiotics and their environmental implications

Antibióticos y su implicancia ambiental

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ABSTRACT

Due to its extensive use in various livestock production activities and its use in human health care, antibiotics have become an environmental problem that draws the attention of the scientific community. Several research works report their presence in different ecosystems compartments, as well as their impact in organisms that inhabit these ecosystems which are being investigated by this community; until now, it has been reported problems of bacterial resistance and damages at DNA level in living beings, among others; in this perspective it is necessary to perform monitoring in various environmental matrixes, in order to detect and quantify their presence, to have a better understanding of their long-term effects on living beings. In this sense, it addresses aspects that determine their presence in the ecosystem, as well as shows results of works evaluating their removal of contaminated water, in order to ensure their safety from an environmental perspective and taking into consideration the health of living beings and human beings.

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RESUMEN

Debido a su amplio uso en diversas actividades de producción de ganado y su uso en el cuidado de la salud humana, los antibióticos, se han convertido en un problema ambiental que llama la atención de la comunidad científica. Diversos trabajos reportan su presencia en diversos compartimientos de los ecosistemas, así como su impacto a los organismos que habitan estos ecosistemas se encuentran siendo investigados por esta comunidad, hasta el momento se han reportado problemas de resistencia bacteriana y daños a nivel de ADN en seres vivos, entre otros, por lo que, se hace necesario realizar el monitoreo en diversas matrices ambientales, con el fin de detectar y cuantificar su presencia, para tener un mejor conocimiento de su efectos a largo plazo en seres vivos. En ese sentido, se abordan aspectos que determinan su presencia en el ecosistema, así como se muestra resultados de trabajos que evalúan su remoción de aguas contaminadas, con el fin de garantizar su seguridad desde una perspectiva ambiental y llevando en consideración la salud de seres vivos y del mismo ser humano.

1. INTRODUCTION

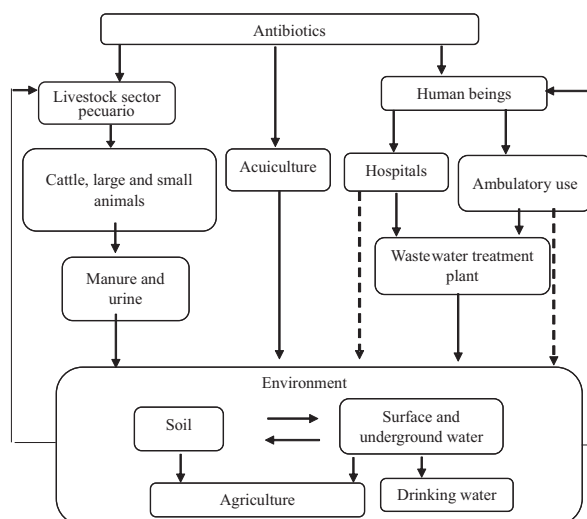
Population growth and increased urbanization, as well as industrialization (Zhang et al., 2017), have increased the demand for animal protein for human consumption (Boeckel et al., 2015), therefore, the livestock sector in South America has grown at an annual rate of 3.7 %, higher than the average global growth rate of 2.1 %, becoming the region with the largest export of beef and poultry (FAO, 2017), the intensive use of the productive systems of poultry, pigs and dairy cattle at large scale (Van et al., 2017). These activities are demanding the use of veterinary products for the treatment of diseases, such as lumpy skin (Molla, Frankea, Gari, & de Jong, 2017), protozoan, bacterial, viral, helminthiasis, nutritional and others (Byaruhanga et al., 2017); antibiotics are also used for the treatment and prevention of diseases in humans (Kim, Lee, & Oh, 2017).

On the other hand, 54 % of the deaths of people in 2015 were caused by diseases such as ischemic heart disease, lung cancer, diabetes, diarrhoeal diseases, tuberculosis, among others, which have been treated in hospital centers based of antibiotics (WHO, 2017), although, there are patients who self-medicated using antibiotics excessively because of their availability and low cost (OMS, 2016).

The consumption of antibiotics is causing serious impacts on the environment (Carvalho & Santos, 2016), because between 30 to 90 % of the antibiotics administered in the livestock system are not metabolized (Aminov, 2010); and 70 % of the dose of antibiotics applied in humans are eliminated (Butkovskiy, Hernandez, Rijnaarts, & Zeeman, 2015) to the natural ecosystems (Aminov, 2010); mainly the aquatic ecosystem, affecting its functions of mineralization and decomposition of organic matter, as well as the degradation of organic pollutants (Bergeron, Boopathy, Nathaniel, Corbin, & La Fleur, 2015; von et al., 2017,); on the other hand, these compounds cause impacts on soil microbiota (Zhang & Dick, 2014) and groundwater (Pan & Chu, 2017).

2. ANTIBIOTIC SOURCES IN THE ENVIRONMENT

The presence and persistence of antibiotics in the aquatic environment is a worldwide concern (Fram & Belitz, 2011; von Schiller et al., 2017), because they are widely used in animal production (Tasho & Cho, 2016), aquaculture and agriculture (Jiang, Zhou, Yang, Chen, & Cheng, 2017). Antibiotics are disseminated mainly through direct and indirect emissions such as excrement, sewage irrigation and sludge compost, getting into the environment negatively impacting soil ecosystems (Li et al., 2015; Shi, Yue, Du, Wang, & Li, 2016) and Agua (Vo et al., 2016), as it is shown in graph 1, the interaction of antibiotics and the environment.



Graph 1. Antibiotic sources

2.1. Humans

Gothwal & Shashidhar (2015) suggest that antibiotics used for the treatment of diseases in human health are classified according to their mechanism of action such as β -lactams, sulfonamides, monobactams, carbapenem, aminoglycosides, glycopeptide, lincomycin, macrolides, polypeptides, polyenes, rifamycin, tetracyclines, chloramphenicol, quinolones and fluoroquinolones.

Unfortunately, the misuse of these products brings bacterial resistance problems (Villalobos, Barrero,

Rivera, Ovalle, and Valera, 2013), that is the case of the enteric bacteria and the fecal coliform bacteria (Mudryk et al., 2013), causing public health problems such as infections (Magdaleno et al., 2012; Peña-Álvarez & Castillo-Alanise, 2015).

2.1.1. Wastewater treatment plants

70 % of the dose of antibiotics applied in humans are eliminated through urine and feces (Ikehata, Jodeiri, & Gamal El-Din, 2006; Butkovskyi et al., 2015), which may contain different active compounds and metabolites (Klatte, Schaefer, & Hempel, 2017) that are discharged into wastewater (Özcan, Özcan, & Demirci, 2016) causing ecological damage (Baquero, Martínez, & Canton, 2008; Liu et al., 2013; Padilla-Robles et al., 2015).

Domestic wastewater is arranged in treatment plants (WWTP) (Nnadozie, Kumari, & Bux, 2017), where they undergo three stages: preliminary, primary (physical-chemical) and secondary (biological) (Verlicchi, Al Aukidy, & Zambello, 2012); However, these treatments are not effective in the removal of organic contaminants that are present in these waters (Batt, Bruce, & Aga, 2006); Because WWTPs are not designed to remove these substances (Marx et al., 2015). Some studies show the presence of up to seven groups of antibiotics in the tributaries and effluents of the WWTPs, sulfamethoxazole ($2.5 \pm 1.9 \mu\text{g L}^{-1}$), norfloxacin ($9.6 \pm 9.8 \mu\text{g L}^{-1}$), ciprofloxacin ($5.3 \pm 4.8 \mu\text{g L}^{-1}$), ofloxacin ($10.9 \pm 8.1 \mu\text{g L}^{-1}$), erythromycin ($1.2 \pm 1.2 \mu\text{g L}^{-1}$), tetracycline ($0.1 \pm 0.0 \mu\text{g L}^{-1}$), and trimethoprim ($1.0 \pm 0.9 \mu\text{g L}^{-1}$) (Vo et al., 2016) (Li, Jianman, Cheng, Weixiao, Xu, Like, Jiao, Yanan, Ali Baig, Shams, 2015) (singer et al., 2014).

The main factors that are influencing the final concentration of antibiotics in the environment are: prolonged sludge retention time (SRT), hydraulic retention time (HRT) (Nnadozie et al., 2017); operating temperature (Le-Minh, Khan, Drewes, & Stuetz, 2010); oxygen concentration, amount of

substrate (sludge) (Rizzo et al., 2013); coexistence of microbial pathogens in WWTPs; as well as seasonality and common infectious diseases, forming a complex cycle of transformation and bioaccumulation, causing toxicity to human health (Carvalho & Santos, 2016) (Pan & Chu, 2017a) and aquatic ecotoxicity (Ternes et al., 2017).

2.2. Livestock

It has been estimated that between 30 to 90 % of antibiotics administered to animals are excreted through manure and urine (Aminov, 2010), reaching concentrations of up to $66.5 \mu\text{g kg}^{-1}$ in swine manure, $15.7 \mu\text{g kg}^{-1}$ in chicken manure and $1.6 \mu\text{g kg}^{-1}$ in cattle manure (Martínez-Carballo et al., 2007). The waste is released directly to the environment by runoff processes, whilst leaching reach the water bodies causing eutrophication and bacterial resistance (Drogui, 2013).

2.3. Aquaculture

The use of antibiotics in aquaculture is intended for the prevention of infectious diseases in fish (Santos & Ramos, 2016). The most widely used antibiotics in this sector are: oxytetracycline, oxolinic acid, chloramphenicol and tetracycline which comprises about 40 % of the consumption (Sapkota et al., 2008; Donate, Venkatesan, & Halden, 2015). Therefore, aquaculture is a potential consumer of antibiotics due to intensive fish production (he et al., 2017). For example, in Chile during 2003, it was used 0.005 kg of antibiotic for each kg of salmon produced, whilst Norway as the second leading exporter of aquaculture products, used 0.002 kg of antibiotic per kg of salmon (Done et al., 2015).

3. ENVIRONMENTAL IMPACT OF ANTIBIOTICS

3.1. Impact on water

Sui et al., (2015) determined concentrations of 2.1 and

124.5 ng L⁻¹ of sulfonamide, as well as Boxall et al., (2003), Sulfadiazine and oxytetracycline with concentrations of 0.001 and 145 µg L⁻¹ respectively in water bodies. The constant presence of these pollutants generates bacterial resistance (Pan-American Health Organization, 2015). In addition, alterations in plant growth (Zhang, Ying, Pan, Liu, & Zhao, 2015), and modification of the structure in bacterial communities and inhibit the process of nitrate reduction, due to elevated levels of sulfamethoxazole (SMX) Underwood et al., (2011). Therefore, studies are underway to quantify acute toxicity and its effect on reproduction (Bundschuh et al., 2016) and antibacterial resistance affecting the population of macro-invertebrates (beard-Alvarez, Lance-Hawthorn, Contreras-Ramos, & González-Mora, 2013), likewise, to determine which antibiotics and to which concentrations cause toxicity in macro-invertebrates of aquatic ecosystems (Grenni, Ancona, and Barra Caracciolo, 2017).

Considerable interest has been developed on the importance of the presence of pharmaceutical products in potable water (Cui et al., 2016) and its possible long-term alterations which may cause adverse health effects in humans and animals (Archer, Petrie, Kasprzyk-Hordern, & Wolfaardt, 2017) or public health conditions (Cunha & Fernandes, 2010), as allergic reactions (Kümmerer, 2009), as well as toxic effects that reach aquatic life (Nieto, Borrull, Marce, & Pocurull, 2007).

3.2 Impact on soil

It is estimated that between 75 and 90 % of these unmetabolized products in the organisms of animals are excreted through manure (FAO, 2017). This manure is applied to the soil as fertilizer; however, the active constituents of antibiotics are not biodegraded (Li et al., 2015; Shi et al., 2016) since they are persistent in the environment (Koba et al., 2017), this generates negative impacts on the micro biota of the soil, which meet important processes (Jechalke et al.,

2014), such as the breakdown of organic matter, availability of nutrients and fertility (Duchene, Vian, & Celette, 2017). In addition, the pollution of soils by antibiotics has favored the increase of resistant genes in the environment (Chen et al., 2017); likewise, the bodies of groundwater are at contamination risk because these compounds have the property of leaching during rain processes (Pan & Chu, 2017).

4. IMPORTANCE OF ANTIBIOTIC MONITORING

Due to the impact that antibiotics are causing in different ecosystems, it is necessary to determine the levels of pollution of the environment to improve the current state of knowledge about its origin, transport, destiny and effects (Ternes, Joss, & Oehlmann, 2015). On the other hand, risk assessment is an essential tool that becomes an important global concern in the field of public health and the problem of food safety (Reynaud & Deschaux, 2006). Therefore, water and soil monitoring must be applied, as part of the biological-based transition (Werbeloff, Brown, & Loorbach, 2016), applying a variety of interactions patterns (Poel, 2003) making the execution of surveillance actions, and control of resources through monitoring could allow the assessment of the quality, determining the contaminants contained in the water body (ANA, 2016), identified with priority the relevant aspects in the water field through each monitoring strategy (Murphy, Post, Buckley, Lippincott, & Robson, 2012).

5. CONCLUSION

There is a real and concerning presence of antibiotic residues in the environment, and the impact is affecting the functions of the soil and water ecosystems and moreover the organisms that inhabit them.

Short-term negative impacts such as the disappearance of bacteria populations and long-term bacterial resistance problems have been reported; on

the other hand, wastewater treatment plants do not have the capacity to remove these compounds, becoming a major source of pollution for water bodies.

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