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Exposure of Brazilian soil and groundwater to pollution by coccidiostats and antimicrobial agents used as growth promoters

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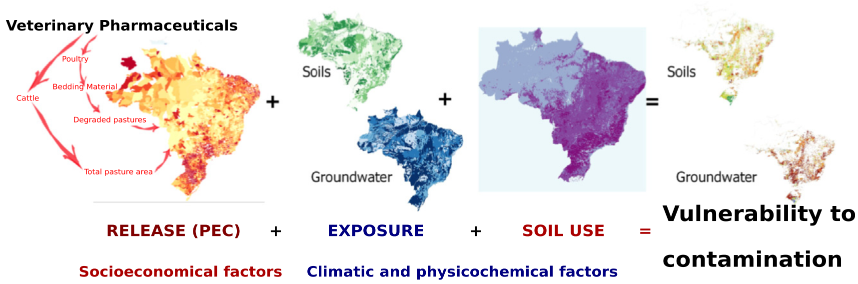
HIGHLIGHTS

- Data on release and fate of antimicrobials in the Brazilian environment are scarce.
- Socioeconomic, climate and soil parameters data are useful for transport modelling.
- Combination of layers in GIS allows the construction of vulnerability maps.
- Central-west, south and southeast regions are the most vulnerable to pollution.
- The presented data can be useful for monitoring and surveillance program.

GRAPHICAL ABSTRACT



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ABSTRACT

The World Health Organization has identified antimicrobial resistance as one of the most important threats to global health. Brazil is one of the world's leading meat producers and the Brazilian use of veterinary antimicrobials as therapeutic agents and prophylactic or growth promoters in animal production remains problematic. Many antimicrobials are not completely metabolized and their excretion represents a significant source of environmental exposure. The aim of this work was to estimate the exposure risk of soil and groundwater to pollution by growth promoters (GPs) and anticoccidial additives (AAs) in Brazil by using a method based on a geographical information system (GIS). The principle adopted is that the greater the amount of animals, the greater the quantity of antimicrobials present, and the greater the soil vulnerability to pollution. Our research showed that GPs and AAs are extensively used in the Brazilian animal production system. An analysis of market data showed that zinc bacitracin, monensin, salinomycin, colistin and tylosin are representative GPs and AAs. This study presents a qualitative approach for risk assessment based on worst-case scenarios. First, the probable environmental concentration was estimated using a correlation between the number of heads of the herds of poultry and cattle, and the amounts of drug released. The leaching risk potential was characterized for each compound, as proposed in ISO 15175. The potential of soil pollution was evaluated for each antimicrobial as a function of its binding and dissipation rates. These rates were calculated using georeferenced data of organic carbon, average temperature, water balance and hydro-geological parameters. The consequences were modeled based on Brazilian soil usage. Finally, the risk was calculated by combining the different maps generated using spatial multi-criteria decision analysis. Higher risk was found for the midwest, southeast and south regions of Brazil. Groundwater was found to be more vulnerable than soil.

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1. Introduction

Antimicrobials are largely used for the management of infectious diseases in humans and animals. Their production, consumption and consequent release in the environment on a large scale are causing significant concern because a growing body of evidence indicates that the selection of antimicrobial resistance bacteria in the environment could pose a serious risk to human health (Brandt et al., 2015; O'Neill, 2016; WHO, 2014, 2018).

In animal production, antimicrobials can be used as therapeutic or prophylactic agents, or growth promoters. In some parts of the world, such as in the USA, antimicrobial use for animals is far greater in animals than in humans. In the BRICS countries (Brazil, Russia, India, China and South Africa), it has been estimated that the consumption of antimicrobials by animals for meat production will double between 2010 and 2030 (O'Neill, 2015).

Livestock is considered as one of the driving forces of the Brazilian economy (FAO, 2017). The Brazilian cattle herd reached 212.3 million heads in 2013 and is presently the second in the world rankings, behind the USA (ABPA, 2017). Poultry (roosters, hens, chickens and chicks) constituted 1.3 billion heads in 2015, with an increasing rate of 6.6% when compared to 2013, which puts Brazil as the world's third largest producer (FAO, 2017; IBGE, 2015).

The relentless pursuit of increasing the feed efficiency and decreasing costs in livestock production has led to a growing interest in the use of additives, many of which are antimicrobials, in order to stimulate growth and improve metabolism and global animal health (Marcucci et al., 2014). Coccidostats are antibiotics that acts upon the protozoan parasites of the genus *Eimeria*, the cause of the coccidiosis, a significant disease for chickens and cattle (Chapman et al., 2010). For Brazil, Van Boeckel et al. (2015) estimated the consumption of antimicrobials in animal food at 5680 tons in 2010 with a projection to rise to 10,053 tons by 2030. Overall, antimicrobials constitute 17–18% of the Brazilian veterinary market, which is growing on average by 10% a year, reaching $R 4.9 billion BRL in 2015 (~$1.5 billion USD) (BNDES, 2013; SINDAN, 2016).

Despite this widespread consumption, studies on the presence, release, fate and toxicity of antimicrobials in the Brazilian environment are still very limited to a low number of compounds, most of which were detected in aquatic environments (Pereira et al., 2012). Antimicrobials used in animals enter the environment mainly by direct deposition of urine and feces on soil, or when manure is applied to soils as fertilizer. Thereafter, their interaction with soil plays a major role in determining their distribution between the different compartments (*i.e.*, soil/groundwater/surface water). For Environmental Risk Assessment (ERA), the persistence and potential of sorption are currently used to estimate the fate and behavior of antimicrobials and other veterinary products in the environment (de la Torre et al., 2012). The factors affecting the persistence and sorption of antimicrobials depend on both the characteristics of the antimicrobial and the soil, and also on the biomass and the microbial activity in the soil and climatic factors, such as rainfall and temperature (Singer et al., 2016).

When considering the size of a country such as Brazil and its geographical diversity (soil, climate and farming activity), tools are necessary that can estimate the areas where antimicrobials are more likely to be present in the environment. A geographical information system (GIS) is useful for this purpose because it allows for the analysis of the geographic variation of the use of antimicrobials and can provide information on the pollution risk. The basic principle is that the greater the amount of animals, the greater the quantity of antimicrobials present, and the greater the soil vulnerability to pollution (de la Torre et al., 2012).

The purpose of this work was to identify the areas that are most vulnerable to pollution by coccidiostats and growth promoters. For this, a qualitative additive model of GIS layers is proposed related to release, exposure and consequences, which was already used for soil resources in the European Union (de la Torre et al., 2012). This model presents a worst-case scenario that can illustrate, for different stakeholders, the geographical magnitude of eventual problems of pollution by pharmaceuticals. The generated maps may help to define areas of future research with the aim of quantifying the effective pollution.

2. Material and methods

2.1. Framework and principal approximations

As in most countries, detailed data on the distribution of intensive livestock production units and the use of veterinary products (VPs) are not readily available for Brazil. Therefore, modeled estimates are required (Robinson et al., 2011). For this purpose, it can be assumed that the amount of VPs released is proportional to the number of animals, because there is a correlation between the number of heads and the amount of consumed drugs (EMA, 2008; Thiele-Bruhn, 2003). Alternatively, the spatial distribution of the vulnerability to pollution of soil-groundwater can be modeled using socioeconomic factors, such as the animal density, veterinary-livestock production practices and soil usage (de la Torre et al., 2012). Environmental Risk Assessment (ERA) uses persistence and adsorption data to estimate the potential of transformation of VPs in soil and their mobility potential to reach deeper layers of soil and groundwater (leaching) (EMA, 2008). Persistence is commonly expressed by the average lifetime of the product and adsorption is described as the attraction between the molecule and soil surfaces. These qualitative approaches can be utilized to classify larger areas with respect to their potential exposure to pollution of groundwater or soil. They can also be utilized as an introductory step in the identification/assessment of actual polluted sites. The proposed exposure analysis was, therefore, built in five steps, as detailed below.

2.1.1. Selection of veterinary products under study

For products intended for animal feed, the Brazilian Normative Instruction defines an additive as "a substance, micro-organism or formulated product, intentionally added to products, not normally used as an ingredient, whether or not it has a nutritional value and which improves the characteristics of products intended for animal feed, improve the performance of healthy animals, or meet nutritional requirements or have an anticoccidial effect" (MAPA, 2004). A list of antimicrobial additives, anticoccidials and agonists with authorized use in animal feed is provided by the Brazilian Ministry of Agriculture, Livestock and Supply (MAPA, 2015). Due to the lack of data on the amount of commercialized products, it was considered that the number of registered products and the number of companies that produce them can be used to estimate the importance of an antimicrobial in the market and its consumption.

2.1.2. Estimation of the amount released and the predicted environmental concentration (PEC)

In this work, only cattle and the poultry herd were considered because they account for the principal livestock in Brazil (FAO, 2017; IBGE, 2017). The PEC equations can vary for different regions, because the use, discharge and fate of the pollutants depend on regional factors. For this work, an intensive production system was considered for poultry, in which all the produced manure is discharged in a bedding material. It was then considered that after a number of production cycles, this material is deposited in soil as a form of organic amendment source for the recovery process of degraded pastures (Adeli et al., 2017; Ranatunga et al., 2013). As bovine production in Brazil is mainly extensive, it was considered that the cattle and the produced manure are homogeneously distributed in pasture areas.

The PEC_{soil} for poultry (p) and cattle (c) was calculated by Eqs. (1)–(4):

$$PEC_{soil \cdot poultry} = \frac{Q_p}{A_d} \tag{1}$$