

**HUMAN ACTIVITY AND ANTIMICROBIAL RESISTANCE IN THE CONTEXT OF
SDG 12: TARGET 12.4**

**A ATIVIDADE HUMANA E A RESISTÊNCIA MICROBIANA NO CONTEXTO DA
ODS 12: META 12.4**

**ACTIVIDAD HUMANA Y RESISTENCIA A LOS ANTIMICROBIANOS EN EL
CONTEXTO DEL ODS 12: META 12.4**

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ABSTRACT

The United Nations supports 17 Sustainable Development Goals (SDGs), self-described as ambitious and interconnected, aimed at addressing a range of development challenges facing countries worldwide. SDG 12 aims to "ensure sustainable consumption and production patterns" through 11 targets. In this context, this paper proposes a link between the antibiotic crisis and item 4 of SDG 12 and presents anthropogenic factors related to the goal not being achieved by 2020. Although regulated, the paper addresses the contexts of the agricultural and food industries, as well as arbitrary waste management, which allow the spread of resistant microorganisms in the environment. This paper was produced by students from two postgraduate programs as a final project for their course and proposes to discuss antimicrobial resistance as a public health problem in light of SDG 12, focusing on target 12.4 as the guiding principle.

Keywords: Antibiotic Crisis. Sustainable Development Goals. Environmental Contamination.

RESUMO

A Organização das Nações Unidas apoia os Objetivos de Desenvolvimento Sustentável (ODS) que totalizam 17, autodenominados como ambiciosos e interconectados, com o

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objetivo de enfrentar uma agenda de desafios de desenvolvimento enfrentado pelos países em todo o mundo. O ODS 12, visa “assegurar padrões de produção e de consumo sustentáveis” por meio de 11 metas. Neste contexto, o presente trabalho propõe uma relação da crise dos antibióticos com o item 4 do ODS 12, e apresenta fatores antropogênicos relacionados à meta não ter sido alcançada até o ano de 2020. Embora sob regulação, são abordados contextos da indústria agropecuária, alimentícia e do manejo de resíduos de forma arbitrária que permitem a disseminação de microrganismos resistentes no ambiente. Este trabalho foi produzido por discentes de duas Pós-Graduações, como trabalho final de Disciplina e propõe discutir a resistência microbiana como um problema de saúde pública à luz do ODS 12, com foco na meta 12.4 como eixo condutor.

Palavras-chave: Crise dos Antibióticos. Objetivos do Desenvolvimento Sustentável. Contaminação Ambiental.

RESUMEN

Las Naciones Unidas apoyan 17 Objetivos de Desarrollo Sostenible (ODS), que se describen como ambiciosos e interconectados, y que buscan abordar diversos desafíos de desarrollo que enfrentan los países de todo el mundo. El ODS 12 busca "garantizar modalidades de consumo y producción sostenibles" a través de 11 metas. En este contexto, este documento propone un vínculo entre la crisis de los antibióticos y el punto 4 del ODS 12, y presenta los factores antropogénicos relacionados con la imposibilidad de alcanzar el objetivo para 2020. Si bien está regulado, el documento aborda los contextos de las industrias agrícola y alimentaria, así como la gestión ineficaz de residuos, que permiten la propagación de microorganismos resistentes en el medio ambiente. Este documento, elaborado por estudiantes de dos programas de posgrado como proyecto final de su carrera, propone debatir la resistencia a los antimicrobianos como un problema de salud pública a la luz del ODS 12, centrándose en la meta 12.4 como principio rector.

Palabras clave: Crisis de Antibióticos. Objetivos de Desarrollo Sostenible. Contaminación Ambiental.

1 INTRODUCTION

Microbial resistance (MR) can be defined as the ability of bacteria, fungi, viruses, and parasites to resist the action of antimicrobial drugs, making conventional treatments complex clinical challenges (Silva; Nogueira, 2021). This problem addresses one of the greatest threats to global public health in the twenty-first century, becoming increasingly responsible for deaths throughout the year (Ho *et al.*, 2025). It is estimated that about 9% of all deaths are caused by microbial resistance. In 2019 alone, about 5 million deaths were reported worldwide (Murray *et al.*, 2022). According to these data, these deaths were associated with 33 microbial pathogens, with emphasis on *Staphylococcus aureus*, *Escherichia coli*, *Streptococcus pneumoniae*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa*, responsible for more than half of the deaths (GBD 2019 ARC, 2022).

According to the Ministry of Health, the situation in Brazil is similar to that observed in the rest of the world and has recorded serious infections caused by *E. coli*, *S. aureus* and *K. pneumoniae* in hospitals and large urban centers. Such infections make treatments difficult and increase costs by prolonging hospitalizations (Brasil, 2024). This problem is highly linked to the pattern of human behavior, such as indiscriminate use of antibiotics, improper disposal of medicines and disinfectants, contamination of soils and rivers, among others, contributing to the dissemination of resistance genes in the environmental microbiota (Carney *et al.*, 2019; Klein *et al.*, 2024).

Faced with this problem, it is essential to adopt an integrated approach, as proposed by the concept of "*One Health*". This perspective is key to understanding and addressing microbial resistance effectively and sustainably (Musicha *et al.*, 2024). In this sense, the UN Sustainable Development Goals (SDGs) offer an important framework for action. SDG 12, "Responsible Consumption and Production," highlights the need to reduce waste, improve waste management, and promote sustainable practices across sectors. Target 12.4, in particular, proposes to achieve environmentally sound management of chemicals and wastes, reducing their release into the air, water and soil (UN, 2025).

2 EXCESSIVE USE OF ANTIMICROBIALS IN AGRICULTURE AND ITS CONSEQUENCES

Modern agriculture, in the quest to maximize productivity and meet the growing demand for food security, has established itself as one of the main consumers of antimicrobials on a global scale (Van Boeckel *et al.*, 2015). This scenario is especially intensified in developing countries, where the increase in demand for animal protein

encourages intensive farming practices and the indiscriminate use of drugs that are often associated with the presence of antibiotic residues in animal products (Manyi-Loh *et al.*, 2018). It is estimated that more than 70% of the antibiotics consumed worldwide are destined for animal production, being used not only for therapeutic purposes, but predominantly as growth promoters and for infection prevention (Boeckel *et al.*, 2017). This widespread use has generated serious health and environmental implications, by favoring the selection and dissemination of resistant microorganisms in the environment (Tiseo *et al.*, 2020).

Different classes of antimicrobials widely used in agriculture, on a global scale, have aroused growing scientific concern due to their potential adverse effects and the complexity of risk management steps. Among these classes, tetracyclines, aminoglycosides, beta-lactams, lincosamides, macrolides, pleuromutilins and sulfonamides stand out (Baynes *et al.*, 2016; Finley *et al.*, 2013). These drugs share similar mechanisms of action or belong to the same therapeutic classes as antibiotics used in antibiotic therapy in humans, making their use, judicious in livestock, essential, given the possibility of transfer of resistant microorganisms between animals and humans (Gelband *et al.*, 2015).

The continuous use of antimicrobials in livestock, often in subtherapeutic doses, exerts constant selective pressure on the microbiota of these animals, favoring the selection and proliferation of resistant cells (Gelband *et al.*, 2015). These microorganisms can be transmitted to humans by different routes, either through the consumption of contaminated food or derivatives, or through direct contact with animals or by exposure to contaminated environments. In addition, antibiotic residues are commonly detected in animal waste, widely used as organic fertilizers, a practice that contributes to soil and water contamination (Manyi-Loh *et al.*, 2018).

From a broader perspective, the intensive and sometimes indiscriminate use of antimicrobials in animal production directly undermines the principles established by SDG 12, which seeks to promote sustainable production and consumption patterns. Item 12.4 proposed as a goal the significant reduction in the release of hazardous chemicals and waste into the environment by the year 2020. However, even after the deadline has passed, many countries still lack effective public policies to regulate the use of antimicrobials in livestock, as well as robust environmental surveillance systems aimed at monitoring microbial resistance (Van Boeckel *et al.*, 2015).

The inefficiency in the management of livestock waste containing antimicrobials constitutes a direct violation of the principles of environmentally safe management, as

recommended in item 12.4 of SDG 12. When disposed of without proper treatment, these residues contribute to the transformation of agricultural soils and water bodies into reservoirs of resistance genes, forming the so-called environmental resistomes. These genes can be transferred horizontally between different microorganisms, including human pathogens, through mechanisms such as conjugation, transduction, and transformation, significantly exacerbating the global antimicrobial resistance crisis (Pal *et al.*, 2016).

In addition, the global scenario of antimicrobial resistance is aggravated by the absence of standardized and uniform regulations among countries. While European Union nations have adopted, since the early 2000s, strict restrictions on the use of antibiotics as growth promoters in livestock (Schmerold *et al.*, 2023). On the other hand, many developing regions still make indiscriminate use of antimicrobials, as classes considered critical by the World Health Organization (WHO) in human therapeutics (Adebowale *et al.*, 2016; Moyane *et al.*, 2013). Consumption in these contexts is often driven by abusive practices, such as the acquisition of antimicrobials without a medical prescription, facilitated by unregulated supply chains and over-the-counter sales in commercial establishments (Ayukekbong *et al.*, 2017). This normative disparity favors the emergence of critical points of microbial resistance, whose impacts go beyond geographical boundaries through international food trade, the movement of live animals, and the global flow of travelers (Maron *et al.*, 2013).

Global projections reinforce the seriousness of this scenario: Van Boeckel *et al.* (2015) estimated that the consumption of antibiotics in the BRICS countries should practically double in the coming years. This increase is associated with the intensification of large-scale animal production systems, which require the routine use of antimicrobials to ensure productivity and prevent diseases, in response to growing consumer demand for animal products. Antimicrobial resistance, therefore, constitutes an inevitable and cumulative side effect of the excessive and abusive use of these drugs (Williams-Nguyen *et al.*, 2016).

The critical analysis of this scenario shows a worrying mismatch between scientific advances in the understanding of microbial resistance mechanisms and the effective implementation of public policies aimed at mitigating them. While antimicrobial resistance is essentially a natural phenomenon, its acceleration by unsustainable human practices poses a growing threat to global public health (You; Silbergeld, 2014). Industrial agriculture, when devoid of regulations based on sustainability, acts as a silent but persistent vector in the spread of resistance genes (Schmerold *et al.*, 2023).

In this context, it is urgent that countries adopt stricter control measures on the use of antimicrobials in animal production, promote investment in sustainable alternatives, such as vaccines, probiotics, and good sanitary management practices. Additionally, it strengthens environmental surveillance systems (Salam *et al.*, 2023). Incorporating these strategies into the SDG 12.4 agenda is essential to curb the advance of microbial resistance and ensure that antimicrobial efficacy is preserved for future generations.

3 HOSPITAL AND PHARMACEUTICAL WASTE: FROM CURE TO ENVIRONMENTAL CONTAMINATION

Investments in health on a global scale have reached unprecedented levels and continue to grow annually. In 2017, health spending was estimated at approximately US\$ 7.8 trillion, corresponding to about 10% of the world's GDP (Kenny; Priyadarshini, 2021). Health care, a rapidly expanding industry driven by therapeutic advances and the growth in cases of chronic diseases, is responsible for generating a significant amount of waste. This scenario has intensified the demand for efficient waste management (Abosse *et al.*, 2024).

Hospitals, laboratories, medical centers, veterinary clinics, research institutions, morgues, blood banks, and nursing homes are among the main culprits for the generation of healthcare waste (Janik-Karpinska *et al.*, 2023). This waste from health services can be classified into two distinct categories. The first fraction is similar to household waste, composed of materials such as paper, cardboard packaging, glass, food scraps and inert substances. The second fraction, of a hazardous nature, is made up of toxic, harmful, potentially carcinogenic elements and agents at risk of infection (Assemu *et al.*, 2020).

The technologies currently used in the treatment and final disposal of health service waste (HSW) can be grouped, in general, into three major classes: thermal processes, chemical processes and irradiation-based methods. In addition to these approaches, complementary methods are also used, such as disposal in landfills, safe reuse after reprocessing procedures, and recycling of materials (Kenny; Priyadarshini, 2021).

Incineration is widely adopted as the preferred technique for the disposal of waste from health services, since it enables a rapid and significant reduction in the residual volume, which can reach up to 90%. However, in the absence of appropriate technologies, this method can pose environmental and human health risks, especially due to the release of air pollutants and the formation of toxic byproducts (Chistholm *et al.*, 2021). Only modern incinerators, with emission control and operating at high temperatures (850-1100 °C), meet international

standards for dioxins and furans. Alternative methods, such as autoclaves, microwaves, and steam treatment with internal mixing, should be considered in places with adequate resources, as they reduce the release of pollutants (WHO, 2024).

The disposal of waste from health services in landfills is also widely used, and can cause relevant environmental impacts, especially the contamination of water resources as a result of leaching (Lee; Lee, 2022). Prior decontamination of chemical and pharmaceutical waste is essential before its final destination in landfills (Chi *et al.*, 2020).

The inadequate management of pharmaceutical waste represents a challenge, especially due to the lack of adequate guidance to the population on the correct ways of disposal. As a consequence, it is common for expired or unused medicines to be discarded in household garbage or flushed down toilets, which contributes to the presence of these compounds in landfills, water systems, and sewage networks, promoting environmental contamination (Endale; Mathewos; Abdeta, 2023). Residues in subinhibitory concentrations, from expired or degraded drugs, favor the adaptation of environmental microorganisms, stimulating the development of antimicrobial resistance mechanisms (Stanton *et al.*, 2020).

In this context, the continuous application of manure and organic waste as fertilizers can lead to the absorption of antibiotics by plants. This is due to soil contamination, the use of polluted water in irrigation, or the use of untreated manure. This practice represents a potential pathway of human exposure to subtherapeutic amounts of antimicrobials through the food chain (Zalewska *et al.*, 2021). This cycle, which results in environmental contamination, leads to an increase in microbial resistance, posing a serious risk to human health, in an era where antibiotics are less developed and infections become increasingly serious and pose a real threat.

According to WHO (1997), engineered landfills are the safest and most environmentally appropriate alternative, as long as the waste is previously subjected to immobilization processes, such as encapsulation or inerting, ensuring the containment of contaminants. Controlled landfills, in turn, are considered acceptable only on a transitional basis, and should also receive only immobilized waste. Uncontrolled landfills, on the other hand, because they pose significant risks to public health and the environment, are strongly discouraged. Its use is exceptional and restricted to emergency contexts, as long as the waste is properly encapsulated and there is a record of the site for future remediation.

Therefore, the reduction in the generation of waste from health services should be treated as a priority, as it considerably reduces the demand for treatment and final disposal.

Effective strategies include sustainable procurement of inputs, preference for products with eco-friendly packaging, use of reusable items whenever possible, rationalization of the purchase of medicines according to actual demand, and the adoption of recycling practices (WHO, 1997).

In summary, the management of waste from health services represents a growing challenge, especially in view of the increase in production and the complexity of discarded materials. The adoption of appropriate technologies, combined with the education of the population and the implementation of effective public policies, is essential to mitigate environmental impacts and protect public health. Sustainability in the health sector depends, therefore, on integrated actions based on scientific evidence.

4 INDUSTRIES AND ENVIRONMENTAL POLLUTION: WHEN PRODUCTION FUELS THE PROBLEM

One of the most notable threats to global public health is characterized by microbial resistance, causing a series of repercussions that are not limited to medicine, but include socio-environmental and economic aspects. Although there is recognition of the indiscriminate use of antibiotics as a determining factor, the responsibility of the industry in this process cannot be disregarded. Specifically considering the role of the agricultural and pharmaceutical industry in the dumping of antimicrobial residues into the environment, its role as an expressive vehicle in the dispersion of resistance can be seen (Larsson, 2014; Silva *et al.*, 2020). In light of target 12.4 of SDG 12, it is necessary to debate how the industry feeds this problem.

Manufacturing effluents, especially from pharmaceutical plants, have high concentrations of active ingredients that are not completely removed by conventional sewage treatment methods (Larsson, 2014; Rizzo *et al.*, 2013). This results in environmental contamination and may benefit the selection and dissemination of antimicrobial-resistant bacteria, which in turn can transfer their genes to other species through transformation and conjugation mechanisms (Rizzo *et al.*, 2013). Some antibiotics, such as ciprofloxacin, have been detected in high concentrations in industrial wastewater (Larsson, 2014). In addition, the improper disposal of industrial solid waste acts as reservoirs for microorganisms, which increases the risks of contamination of soils and groundwater (Souza *et al.*, 2018).

Therefore, resolutions to combat microbial resistance must consider its multifactoriality, considering the relationship of several stages of the production system,

application, and commercialization of antimicrobials, with consequences for the different industrial and economic sectors (Silva *et al.*, 2020). From production, distribution, and final consumption, each link in this web can cooperate to select and disperse resistant microorganisms. In this context, it is of paramount importance to use approaches encompassing competent public policies, thorough regulation, instruction of health professionals and other sectors such as agriculture. In addition, the need to encourage research, update therapeutic alternatives and sustainable conducts is highlighted (Anvisa, 2017).

The impacts generated by the industries are not limited to the production and disposal of drugs. With regard to the food industry, there are several ways to ensure greater safety and quality of products, despite this, outbreaks of foodborne diseases continue to affect populations worldwide, resulting in high health costs (Damião *et al.*, 2023). In this context, bacterial resistance to disinfectants used in the food industries stands out. Since the intensive and often inappropriate use of these compounds can select resistant microorganisms, able to resist hygiene processes (Langsrud *et al.*, 2003). Among the substances authorized to compose sanitizing products with antimicrobial functions, some belong to the class of phenolics, aldehydes, inorganic chlorine-releasing agents and quaternary ammonium. Subinhibitory concentrations of these biocides, in addition to contributing to the development of resistance, can also lead to cross-resistance to antibiotics (Santos; Goals, 2021).

In addition, cross-contamination stands out as a critical factor in food industries, since it is constantly related to the formation of biofilms by pathogenic microorganisms such as *Salmonella enteritidis*. These biofilms, which form easily on porous or hard-to-clean surfaces, such as wood and certain plastics, give high resistance to disinfectants commonly used in industrial routines. These microbial structures can resist, functioning as a reservoir of pathogens and favoring the transfer to ready-to-eat products (Carrascosa *et al.*, 2021).

From this perspective, resistance to disinfectants in the food industry is related to environmental pollution, since, if not properly treated before disposal, the waste generated during sanitization processes can reach soils, rivers, and sewage systems, affecting the natural microbiota of aquatic and terrestrial ecosystems, promoting the environmental dissemination of resistance genes. This context highlights the need for effective hygiene strategies, combined with the correct selection of materials in contact with food and the continuous training of handlers, as part of good manufacturing practices.

The agricultural industry also contributes significantly to this scenario. The use of antimicrobials as animal growth promoters generates waste that, when released into the environment without adequate treatment, exerts selective pressure on natural microbial communities (Silva *et al.*, 2020; Silva *et al.*, 2025). This aspect plays a relevant role in the emerging public health crisis, especially in antibiotic resistance. Although most of the use of antibiotics is carried out in agricultural systems, it is noteworthy that their use in livestock deserves significant attention as it contributes to the general issue of antibiotic resistance (Landers *et al.*, 2012).

Given this scenario, it is understandable that the absence of strict regulations in developing countries makes the situation even more aggravating. Many industries are installed in regions with poor environmental inspection, taking advantage of gaps in local legislation to operate with disposal standards below the recommended (Laxminarayan *et al.*, 2013; Silva *et al.*, 2020).

Therefore, it is of paramount importance to rethink industrial production models. It is necessary to search for alternative ways that minimize the impacts generated during these processes. In this context, clean technologies, such as bioremediation and advanced effluent treatment systems, should be encouraged through public policies and subsidies (Bengtsson-palme; Kristiansson; Larsson, 2018; Larsson, 2014). In addition, it is necessary to strengthen environmental surveillance and demand transparency from industries regarding the composition of their waste. International cooperation is also crucial, especially in the sharing of technologies and the agreement of regulatory standards (Larsson, 2014; Laxminarayan *et al.*, 2013).

5 SOCIAL AND ECONOMIC IMPACTS OF MICROBIAL RESISTANCE ASSOCIATED WITH HUMAN ACTIVITY

The accelerated urban growth has evidenced the absence of planning and infrastructure capable of keeping up with population expansion. Among the consequences, the increase in the generation of Urban Solid Waste (MSW) stands out, whose management is often neglected or treated as of minor importance. Despite representing a growing public health problem on a global scale, these difficulties are particularly pronounced in low- and middle-income countries, such as Latin America (Corrêa *et al.*, 2022).

In Brazil, the management of MSW is now regulated by Law No. 12,305/2010, which establishes the National Solid Waste Policy (PNRS), covering the political, economic,

environmental, cultural and social spheres. However, its effectiveness is still far from being achieved. (Brazil, 2010)

Capitalism, as the dominant economic model, encourages unbridled consumerism, generating mountains of MSW and impacting the ecosystem. The *International Solid Waste Association* (ISWA, 2022) estimates that waste generation will increase worldwide, reaching 3.4 billion tons in 2050. This expansion will be especially seen in low-income countries, where generation is expected to triple. The management of USW in small cities is also insufficient, since municipal leaders point out difficulties in keeping waste away from the urban area, which contributes to the emergence of environmental and public health problems (Silva; Zanchi; Lopes, 2023).

The negative impacts of MSW extend to many aspects in terms of environmental impact. Among the consequences are the advance of AMR, aggravated by the excessive or inappropriate use of antibiotics, as well as climate change and problems related to hygiene and basic sanitation (Brasil, 2025). In addition, AMR is one of the greatest public health challenges today, being considered one of the ten leading causes of death in the world. It is estimated that by 2030, global GDP could lose US\$ 3.4 trillion per year due to AMR, and 24 million people could be pushed into extreme poverty by 2050. With the growing increase in resistance, treatments become more expensive, with longer duration and less availability (Brasil, 2025).

With the increase in environmental imbalance caused by garbage, it becomes an environment conducive to the development of pathogenic microorganisms. Mphasa *et al.* (2024) evidenced the presence of pathogenic microorganisms in organic materials, fabrics, and plastics recovered from waste piles, increasing the risk of human exposure.

The systems for the treatment and disposal of MSW considered less harmful to the environment demonstrate positive results, both in the recovery of secondary matter for reuse and in the generation of economic return. In addition, they contribute to reducing the volume of garbage discarded in nature. Among the technologies used in the treatment and final disposal of MSW, landfills, systems for collecting and using or burning biogas, as well as drainage and leachate treatment, in addition to continuous environmental monitoring (Abrema, 2023), stand out.

Despite these advances, it is still common to use inappropriate places, such as dumps, controlled landfills, ditches, dumps and similar areas, unsuitable for the ecosystem and its resources. According to ISWA (2022), the precariousness in the proper disposal of waste is

largely due to the low coverage of collection, as well as the absence of appropriate disposal for all waste, pollution caused by irregular disposal, open fires, formation of dumps, and the presence of hazardous substances. In addition, the lack of funding and resources for the theme, as well as the low demand for secondary raw materials, also contribute significantly to the obstacles faced.

6 FINAL CONSIDERATIONS

Microbial resistance is a silent crisis that grows every year, driven by the inappropriate use of antimicrobials in medicine, agriculture, and industry. Incorrect waste disposal, environmental contamination, and lack of enforcement contribute to the spread of resistance genes in different ecosystems. This scenario compromises the effectiveness of treatments and threatens global health, requiring urgent and coordinated responses across sectors. The "One Health" approach is essential to understanding the connections between human, animal and environmental health. In addition, sustainable consumption and production must be prioritized as a way to contain this advance. Microbial resistance is not just a technical problem, but an ethical and structural challenge.

In this context, target 12.4 of SDG 12 highlights the fundamental axis to promote the environmentally safe management of chemicals and waste. For this to happen, it is necessary to strengthen health and environmental surveillance, regulate the use of antimicrobials, invest in clean technologies, and encourage sustainable practices in all sectors involved. Reducing microbial resistance depends on education, research, political commitment, and long-term integrated actions. Without these measures, there is a risk of significant setbacks in modern medicine. Therefore, preserving the efficacy of antimicrobials is a collective responsibility that must be addressed as a global priority.

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