

ANTIBIOTIC RESISTANCE AS AN EMERGING ENVIRONMENTAL HEALTH PROBLEM

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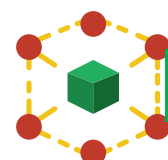
Abstract

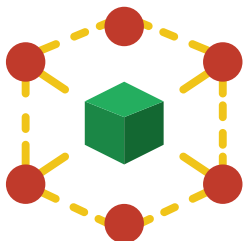
Antibiotic resistance is usually discussed as a clinical problem, but resistant bacteria and resistance genes also move through water, soil, food systems, wastewater, healthcare waste and industrial pollution. This environmental dimension is increasingly recognized as an important part of the One Health response to antimicrobial resistance (AMR). Antibiotic residues and resistant microorganisms can enter the environment through human excreta, animal production, pharmaceutical manufacturing, agricultural runoff and inadequately treated waste. Environmental settings can then provide opportunities for resistant organisms and resistance genes to persist, mix and spread. The United Nations Environment Programme describes pollution as an important driver and pathway of AMR, while the World Health Organization has emphasized the need to control antibiotic manufacturing waste and strengthen surveillance. This narrative review examines the relationship between antibiotic resistance and environmental health, focusing on wastewater, pharmaceutical pollution, agriculture, animal production, solid waste and environmental transmission. It also discusses surveillance, stewardship, sanitation and the One Health approach. The review argues that protecting antibiotics cannot be achieved by clinical prescribing policies alone. Environmental management must become part of routine AMR prevention, with stronger monitoring, safer waste systems, responsible antimicrobial use and cooperation among health, environmental, agricultural and industrial sectors.

Keywords: antibiotic resistance; antimicrobial resistance; environmental health; One Health; wastewater; pharmaceutical pollution; antibiotic residues; resistant bacteria; antimicrobial stewardship; environmental surveillance.

1. Introduction

Antibiotics transformed modern medicine. They made bacterial infections treatable, reduced complications from surgery and helped make cancer therapy, transplantation and other complex care





safer. Their effectiveness, however, is not permanent. Bacteria can acquire or select resistance mechanisms that reduce the ability of antibiotics to control them. The result is antimicrobial resistance, one of the major threats to public health recognized internationally.

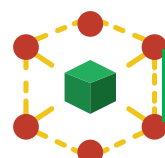
The environmental side of this problem is sometimes less visible. A resistant bacterium does not remain inside a hospital or a farm simply because that is where it first emerged. Bacteria, resistance genes and antibiotic residues can enter wastewater, rivers, soil and other environmental compartments. The 2023 UNEP assessment concluded that the environment plays a key role in the development, transmission and spread of AMR and emphasized that pollution prevention is part of the solution. [□cite□turn0search4□turn0search10□](#)

This perspective changes the question from 'How do we treat resistant infections?' to a broader public-health question: 'How do we reduce the environmental conditions that allow resistance to develop and circulate?' This narrative review explores that question and considers why environmental health should be treated as a central part of antibiotic-resistance prevention.

2. Why Antibiotic Resistance Is an Environmental Health Issue

Environmental health is concerned with how physical, chemical and biological conditions influence human wellbeing. Antibiotic resistance fits naturally within this field because environmental contamination can affect both the survival of resistant organisms and human exposure to them. Wastewater treatment plants, healthcare facilities, pharmaceutical manufacturing areas, livestock settings, agricultural soils and contaminated water bodies can all become points where antibiotic residues, bacteria and resistance genes meet.

The environmental dimension does not mean that every resistant infection comes directly from a river or soil. Human-to-human transmission remains critically important. Instead, the environment should be viewed as one interconnected part of a larger system. The One Health approach recognizes that human, animal, plant and ecosystem health are linked, making AMR too complex for any single sector to manage alone. [□cite□turn0search0□turn0search6□](#)



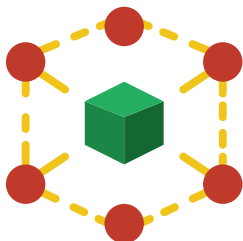


Figure 1. Environmental pathways that connect antibiotic use with resistance

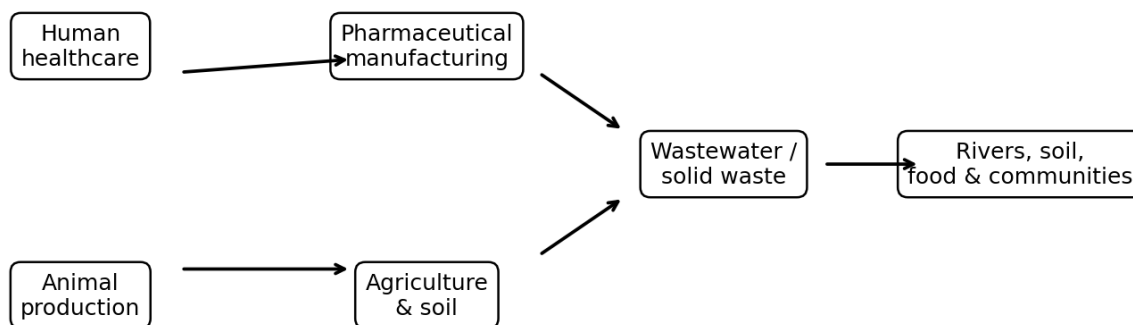
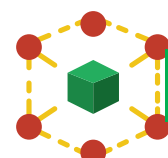


Figure 1. Conceptual pathways linking antibiotic use, waste and environmental dissemination of resistance. This is a synthesis diagram, not a quantitative transmission model.

3. The Scale of the Problem

The clinical consequences of antibiotic resistance provide the reason environmental prevention matters. A landmark global analysis estimated that bacterial AMR was directly attributable to about 1.27 million deaths in 2019 and was associated with approximately 4.95 million deaths. These estimates demonstrate that resistance is not a theoretical future problem; it already contributes substantially to mortality. [cite](#) [turn0search18](#)



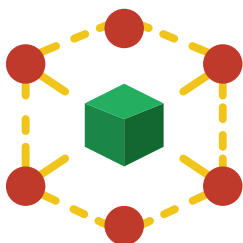


Figure 2. Global burden context for bacterial antimicrobial resistance

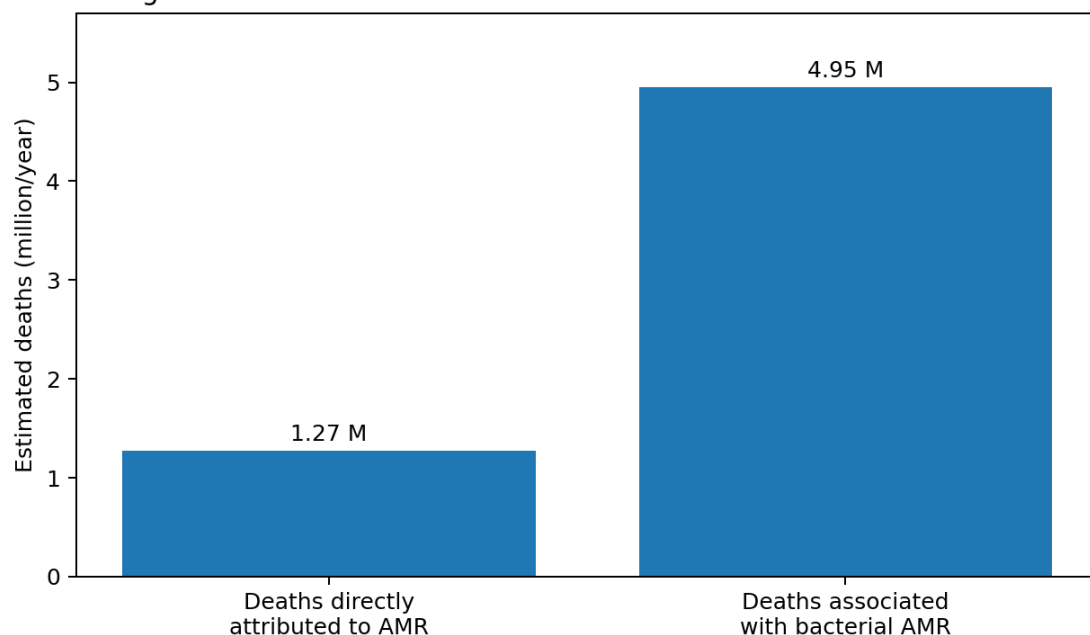


Figure 2. Global burden context based on the 2019 global bacterial AMR analysis. The values are published estimates and are shown for context rather than as annual current surveillance figures.

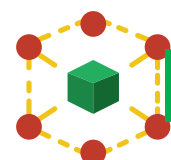
More recent WHO surveillance confirms the continuing scale of resistance. The 2025 Global antibiotic resistance surveillance report analyzed more than 23 million bacteriologically confirmed cases reported by countries and tracks resistance trends across multiple pathogen–antibiotic combinations. The report reinforces the importance of surveillance, while also showing that global data remain uneven across settings. [cite](#) [turn0search1](#)

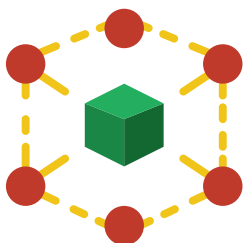
4. Wastewater: A Meeting Place for Antibiotics and Resistance

Wastewater is one of the clearest connections between human activity and environmental AMR. After antibiotics are used, a proportion of many medicines or their metabolites can leave the body and enter sewage. Wastewater can also contain bacteria from humans, hospitals and other sources. If treatment is incomplete, antibiotic residues, resistant organisms and resistance genes may reach receiving waters.

The concern is not simply that a river becomes contaminated. Wastewater contains a mixture of biological and chemical materials, and microbial communities in these settings can create opportunities for resistance genes to move between bacteria. The environmental risk therefore depends on concentration, persistence, microbial ecology, wastewater treatment and local conditions.

WHO has specifically issued guidance on wastewater and solid-waste management for antibiotic manufacturing, noting that high levels of antibiotics downstream of manufacturing sites have been





documented and that pollution from manufacturing can contribute to resistance.
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5. Pharmaceutical Manufacturing and Antibiotic Pollution

Antibiotic production can create environmental risks when manufacturing wastewater is not adequately controlled. This issue is especially important because very high concentrations of active antibiotic compounds may occur near production sites. Such concentrations can create strong selective pressure in environmental microbial communities, potentially favouring resistant organisms.

The problem is partly regulatory. Environmental standards for pharmaceutical manufacturing have not historically been as comprehensive as the standards used for product quality or worker safety. WHO's 2024 guidance therefore calls for better wastewater and solid-waste management, risk-based controls, auditing and transparency across the antibiotic manufacturing chain.

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This is an important reminder that antibiotic stewardship is not limited to doctors and patients. Manufacturers, regulators, procurement systems and waste-management services also influence whether antibiotic pollution enters the environment.

6. Agriculture, Livestock and Food Systems

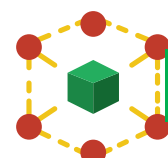
Antibiotics are also used in animal health and, in some settings, agriculture. Manure and animal waste can contain antibiotic residues and resistant bacteria. When waste is applied to land, resistance-related material may enter soil and potentially move through runoff into surface water. Food systems can therefore connect antibiotic use in animals with environmental exposure and, under some circumstances, human exposure.

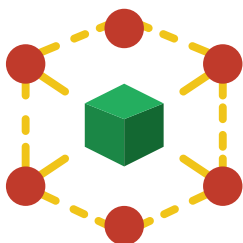
The goal is not to treat all agricultural antimicrobial use as inappropriate. Antibiotics remain important medicines for animals as they are for people. The public-health challenge is ensuring that treatment is justified, appropriately targeted and accompanied by good infection prevention, animal husbandry, vaccination and waste management. UNEP emphasizes responsible antimicrobial use in agriculture and stronger environmental controls as part of a One Health response.

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7. Healthcare Waste and Community Sources

Hospitals generate wastewater and solid waste containing microorganisms, pharmaceutical residues and other biological materials. Healthcare facilities therefore require effective infection prevention, pharmaceutical-waste management and wastewater control. At the community level, unnecessary antibiotic use, inappropriate disposal of medicines and poorly managed sanitation can also contribute to environmental loading.



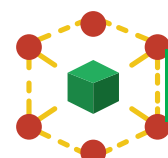


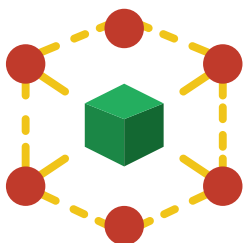
These pathways illustrate why public awareness and infrastructure matter. A person may think of antibiotic resistance as something that happens inside a patient after repeated antibiotic exposure, but resistance is also shaped by what happens to antibiotics and bacteria after they leave the body. Safe sanitation and waste management are therefore part of antimicrobial stewardship.

8. Environmental Factors and Their Potential Role

Environmental source	What may enter the environment	Potential AMR concern	Priority response
Municipal wastewater	Antibiotic residues, bacteria, resistance genes	Environmental mixing and downstream exposure	Improve sanitation and wastewater treatment; monitor hotspots.
Hospitals	Resistant organisms, pharmaceuticals, clinical waste	Release of clinically important organisms and residues	Strengthen infection control and healthcare waste management.
Pharmaceutical manufacturing	High concentrations of active antibiotics	Strong selective pressure near discharge points	Set discharge controls, auditing and transparent monitoring.
Livestock and manure	Antibiotic residues, resistant bacteria, genes	Soil and water contamination	Responsible veterinary use and safer manure management.
Agricultural runoff	Microorganisms, residues and genes	Transport to surface waters	Reduce contamination at source and manage runoff.
Solid waste / medicine disposal	Unused medicines and contaminated material	Persistent residues and microbial exposure	Safe collection and disposal systems.

9. How Resistance Can Persist and Spread in the Environment





Resistance can arise through natural bacterial evolution and selection, but environmental contamination can increase the opportunity for resistant organisms and resistance genes to persist and interact. Antibiotic residues can exert selective pressure, while dense microbial communities create opportunities for genetic exchange. Mobile genetic elements such as plasmids can carry resistance genes between bacteria, although the importance of individual pathways varies by organism and environment.

Environmental conditions are also dynamic. Rainfall can move contaminants from land to water, wastewater discharge can alter microbial communities, and sediments may act as reservoirs where bacteria and resistance genes persist. Climate-related changes in temperature, flooding and water availability may further alter exposure pathways. UNEP therefore describes environmental AMR as a multifaceted problem involving pollution, climate change, biodiversity and ecosystem health.

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10. One Health: Bringing the Pieces Together

The strongest response to environmental AMR is not a separate 'environmental programme' operating alongside healthcare. It is an integrated One Health strategy. Doctors, pharmacists, veterinarians, farmers, microbiologists, environmental scientists, engineers, wastewater professionals, regulators and communities all influence different parts of the resistance cycle.

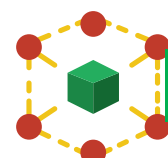
WHO's GLASS system provides a standardized framework for AMR surveillance and increasingly supports broader surveillance approaches, including antimicrobial use and the potential incorporation of food-chain and environmental information. As of December 2024, 141 countries, territories and areas had committed to contribute data to GLASS on AMR and/or antimicrobial use.

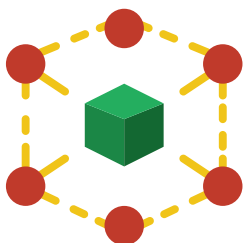
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Environmental surveillance can add information that clinical surveillance cannot provide on its own. Monitoring wastewater and environmental sites may help identify resistance trends, pollution sources and emerging threats earlier, particularly when surveillance is linked to laboratory capacity and public-health decision-making.

11. Prevention and Control Priorities

Priority	Why it matters	Examples of action
Reduce unnecessary antibiotic use	Less antibiotic pressure means fewer opportunities for selection and pollution	Antimicrobial stewardship; appropriate prescribing; veterinary stewardship.





Control pharmaceutical pollution	High environmental antibiotic concentrations can favour resistance	Manufacturing discharge standards, monitoring and auditing.
Improve wastewater and sanitation	Reduces release and movement of bacteria, genes and residues	Treatment upgrades, sanitation coverage, hotspot surveillance.
Strengthen healthcare waste management	Limits release of resistant organisms and medicines	Segregation, safe disposal, infection prevention.
Improve agricultural practices	Reduces contamination from animal waste and runoff	Vaccination, hygiene, responsible treatment and manure management.
Build integrated surveillance	Connects clinical, use and environmental information	One Health data platforms and laboratory networks.
Support public awareness	People influence antibiotic demand and disposal	Education on appropriate use and safe medicine disposal.

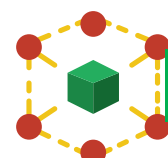
12. Challenges and Research Gaps

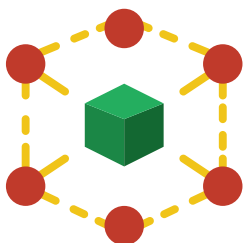
Several gaps make environmental AMR difficult to manage. First, the presence of a resistance gene in an environmental sample does not automatically mean that it will cause human disease. Risk depends on the organism, gene, mobility, concentration, exposure route and ability to reach susceptible people. Second, methods for environmental AMR surveillance are not yet as standardized globally as clinical surveillance. Third, low-resource settings may face simultaneous challenges in sanitation, laboratory capacity, regulation and access to antibiotics.

Research should therefore move toward harmonized environmental monitoring, better risk assessment and studies that connect environmental measurements with human and animal outcomes. More evidence is also needed to determine which wastewater interventions provide the greatest AMR benefit and how environmental controls can be implemented without compromising equitable access to essential antibiotics.

13. A Humanized Public-Health Perspective

Antibiotic resistance can feel like a problem belonging to laboratories and hospitals, but the environmental perspective makes it much more relatable. The medicines used in clinics, the





antibiotics used to protect animal health, the wastewater leaving a community and the water flowing downstream are parts of the same system. What happens in one place can influence another.

A humanized response does not mean placing blame on individual patients, farmers or healthcare workers. Antibiotic use is shaped by access to healthcare, diagnostic uncertainty, prescribing practices, animal-health needs, pharmaceutical supply chains and environmental infrastructure. Effective prevention therefore requires supportive systems that make the responsible choice easier.

The goal is not to create fear around antibiotics. It is to protect their value. Antibiotics remain essential medicines, and the environmental health approach asks society to preserve them while reducing the pollution and transmission pathways that make resistance more likely.

14. Conclusion

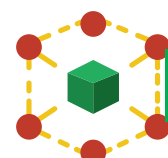
Antibiotic resistance is an emerging environmental health problem as well as a clinical one. Resistant bacteria, resistance genes and antibiotic residues can move through wastewater, healthcare waste, pharmaceutical manufacturing, livestock systems, agricultural soils and surface waters. These pathways connect human, animal and ecosystem health and demonstrate why a One Health response is necessary.

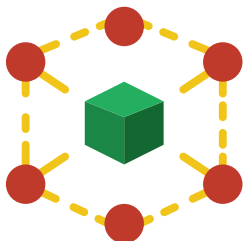
The environmental component of AMR should be addressed through prevention at the source, responsible antimicrobial use, stronger sanitation and wastewater management, control of pharmaceutical pollution, safer agricultural practices and integrated surveillance. WHO and UNEP both emphasize that environmental action is an important part of protecting the effectiveness of antibiotics. □cite□turn0search10□turn0search16□

Ultimately, the fight against antibiotic resistance is not only about developing new medicines. It is also about managing the environments in which bacteria live, move and exchange genetic information. Protecting water, soil and ecosystems is therefore also a way of protecting future patients.

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