Antimicrobial Resistance through the One Health Lens

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Antimicrobial resistance (AMR) has silently evolved into one of humanity's most pressing health threats. This issue transcends conventional boundaries and extends beyond hospitals and clinics to farms, rivers, markets, and even residential kitchens [1,2]. The One Health approach, which recognizes an inseparable triad of humans, animals, and the environment, provides a holistic framework for confronting AMR [3]. It demands that specific fields, such as medicine, agriculture, environmental science, and policy-making, interact and coordinate, even though historically each has functioned individually [4].

At its essence, AMR — a biological inevitability — is bound to become a socio-behavioral and ecological crisis. Resistant genes do not respect borders; they traverse through trade, travel, and even the simple flow of water [4]. A study conducted by Velazquez-Meza and colleagues reminds us that the evolution of microbial communities is linked intimately to human action [5]. The misuse of antibiotics, inadequate infection control, and agricultural pollution together are promoting an invisible evolutionary race that the humans may not be able to win [6].

The escalating crisis of AMR demands a multifaceted, globally coordinated response. Recognizing that AMR is not limited to clinical settings but rather represents a complex, cross-sectoral threat to human, animal, and environmental health is essential for addressing the burden more holistically [5-7]. The One Health strategy requires integrated action across human medicine, veterinary practice, agricultural management, and environmental stewardship to curb both the emergence and transmission of resistant pathogens [8].

The Perfect Storm: Overuse, Misuse, and Cross-Contamination

From penicillin prescriptions in urban clinics to prophylactic tetracycline in poultry farming, the overreliance on antimicrobials creates sustained selective pressure, producing resilient microbial strains [9]. Antimicrobials that were once considered a triumphant achievement of the human beings have now become a means for the microbials to adapt and transform [10]. A study noted that 75%–90% of antimicrobials administered to animals are excreted unmetabolized into the environment, introducing resistance genes into the crops, water, and soil [5,11].

This contamination chain converts fields into bacterial laboratories and rivers into corridors of genetic exchange [12] [Figure 1]. Studies have found resistance plasmids in bacterial isolates from vegetables and aquaculture systems—suggesting that environmental pathways spread AMR far more widely than clinical misuse alone [13-15]. The agricultural-industrial complex, remarkably, remains a stubborn frontier for the mitigation of AMR. Therefore, both economic and behavioral change are essential [16].

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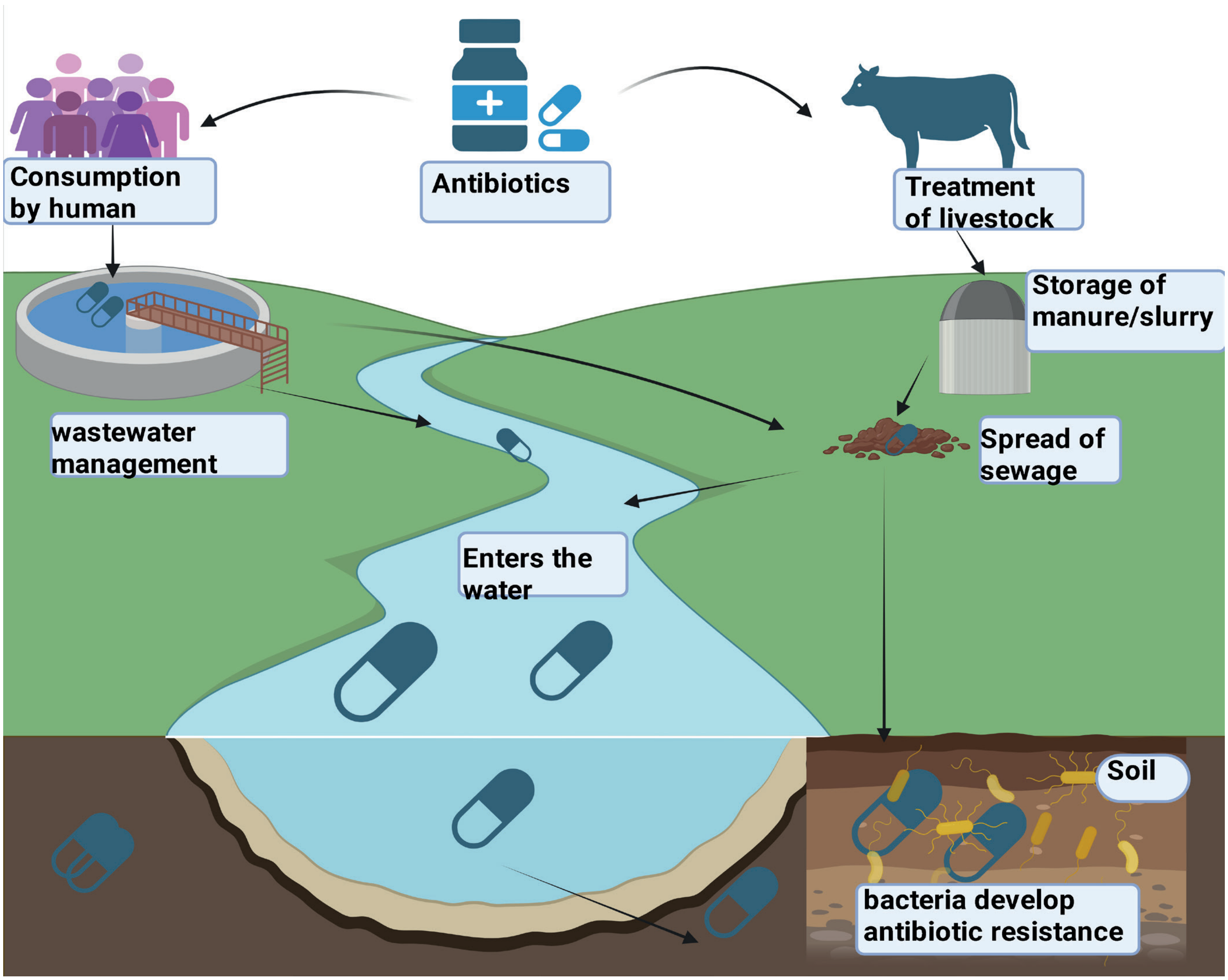

Figure 1: Display of the pathways of spread of antibiotic resistance in the environment by human consumption and animal treatment with antibiotics. This figure was drawn via the premium version of BioRender (https://biorender.com/), accessed on October 31st, 2025, with license number GM28XUBU04 [17]

Illustration Credit: Rahnuma Ahmad.

A Historical Continuum: From Virchow to the Present Crisis

The roots of One Health trace back to Rudolf Virchow's 19th-century concept of zoonosis and Calvin Schwabe's later advocacy for "one medicine" [18]. Therefore, it can be noted that the One Health model is not new; however, it has been overlooked during the antibiotic century [5,18,19].Modern globalization has only magnified this interconnection. Resistant pathogens can now cross continents in days, turning local epidemics into global challenges [5,20]. Even though the Manhattan Principles marked a turning point in recognizing disease transmission within ecosystems, nearly two decades later, AMR rates continue to rise [5,20]. Thus, it can be noted that recognition alone is insufficient without radical, sustained intervention.

Global Action and the Surveillance Imperative

The World Health Organization's Global Action Plan and the creation of the Global Antimicrobial Resistance Surveillance System (GLASS) are examples of large-scale institutional commitments for tracking microbial evolution [21]. These frameworks aim to standardize data across countries. This is an enormous challenge, particularly for regions where the health infrastructure is weak. To introduce effective interventions, surveillance is essential. Data obtained reveal where and how resistance proliferates, alerting to the rational use of antimicrobials and clarifying cross-sectoral transmission routes [21,22]. The cross-institutional collaboration among the United Nations Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the World Organization for Animal Health (WOAH—formerly OIE) forms a tripartite mechanism to coordinate AMR responses across sectors. These alliances symbolize the necessary interdependence between animal and human health agencies [19,20,23].

Antibiotic Use Across Sectors: The Shared Burden

Among the antibiotic classes used across species and ecosystems, the examples of colistin, cephalosporins, and fluoroquinolones are particularly illuminating [24-27]. Colistin, once a reserve antibiotic for life-threatening infections, has led to the development of the plasmid-mediated mcr-1 gene. This gene has been detected across continents within months of its first identification in China [28]. A similar pattern has occurred in the case of third-generation cephalosporins—ceftiofur in poultry, ceftriaxone in hospitals—producing cross-resistance that bridges farms and hospitals [29]. Fluoroquinolones, too, follow this pattern: their use in poultry promotes resistance in *Campylobacter jejuni*, an agent of foodborne disease that directly impacts human health [30]. Resistance flows bi-directionally between animals and humans, mediated by market forces, inadequate regulation, and environmental leakage [31].

The Socioeconomic Dimension

AMR is not only a microbiological problem but also a socioeconomic crisis. The economic burden of resistance includes prolonged hospital stays, lost productivity, and increased mortality. These costs are disproportionately borne by low- and middle-income countries, where antimicrobials are often available over the counter and infection control systems remain fragile [32]. This imbalance is ethically troubling. Bacteria do not discriminate, but economic inequities shape who bears the brunt of their resistance. There is a need to strengthen governance, ensure legislative uniformity, and ensure equitable access to clean water and sanitation [33].

Human Costs and the Veterinary Paradox

From a clinical viewpoint, AMR reverses decades of medical progress. Common infections become untreatable [34]. Complex surgeries face renewed risk. Neonatal sepsis, urinary tract infections, and wound infections that were once treatable now threaten mortality in resource-constrained facilities. At the same time, it is becoming increasingly challenging to create a balance between the needs of the food productivity system and the dangers to public health. The practice of using antimicrobials as growth promoters exemplifies this tension. Such practices need to be banned, as they are a scientific necessity [5,35].

Within agriculture and veterinary medicine, there is the need for continued restraint and judiciousness in antimicrobial use. Curtailing the use of antibiotics as growth promoters in livestock and aquaculture is fundamental to reducing selection pressures that drive resistance [36]. The challenge, however, lies in deploying alternative strategies such as enhanced biosecurity, vaccination programs, and improved husbandry practices to maintain animal health and productivity without exacerbating AMR risks [37,38]. Coordinated efforts by international organizations such as the WOAH, the FAO, and the WHO are pivotal in driving policy harmonization and capacity building at the animal-human-environment interface [19,23].

Education, Awareness, and Behavioral Change

Technological interventions, while vital, cannot be a substitute for behavioral transformation. Awareness campaigns—such as the World Antimicrobial Awareness Week—seek to empower both consumers and professionals to act responsibly [39]. Education must modify the patient's insistence on antibiotics, the farmer's reliance on prophylactic feeds, and the policymaker's short-term economic calculations. AMR is sustained not only by ignorance but also by ingrained practices and incentives that outpace regulation [40,41].

The Innovation Gap: Where Are the New Drugs?

While the microbial evolution gains pace, human innovation in antibiotic development has slowed dramatically. Of the 32 new antimicrobials under development in hospitals in 2019, only six were truly innovative. Pharmaceutical economics discourages investment in drugs that may quickly become obsolete [42]. Thus, global mechanisms such as the Global Innovation Fund and public–private partnerships (e.g., the Global Alliance for Antibiotic Research and Development) aim to reignite the discovery pipeline [43]. However, new antibiotics alone will not be able to handle the current AMR trend. Without stewardship, even novel agents like ceftazidime-avibactam or meropenem-vaborbactam will soon lose their edge. The challenge lies not only in creation but in conservation [44].

Emerging Alternatives and Future Directions

Central to this approach is the acknowledgment that successful AMR mitigation cannot rely solely on the development of new antibiotics. The diminishing pipeline of novel antimicrobials, reducing the overall demand for these drugs, emerges as a critical pillar of intervention. Woolhouse identified effective means to achieve this goal, including expanding Universal Health Coverage (UHC), promoting the widespread adoption of water, sanitation, and hygiene (WASH) protocols, and strengthening infection control measures within healthcare settings [45]. For example, improved WASH infrastructure lowers infection rates among communities, which in turn diminishes the necessity for antibiotic administration. This domino effect not only preserves the efficacy of current antimicrobials but also contributes to global health equity and sustainability [46].

Critically, the environmental dimension of AMR is gaining recognition. Woolhouse has emphasized in his study how environmental reservoirs—through wastewater, manure, and run-off—facilitate the dissemination of resistant determinants across sectors [45]. Implementing robust surveillance, waste stream management, and environmental monitoring is essential not only for curbing the spread of AMR genes but also for preserving ecological integrity [47]. Recent global action plans, such as the One Health Joint Plan of Action (OH JPA), stress the need for policy alignment, cross-sector research, and interdisciplinary collaboration to tackle these intertwined challenges [47,48] [Figure 2].

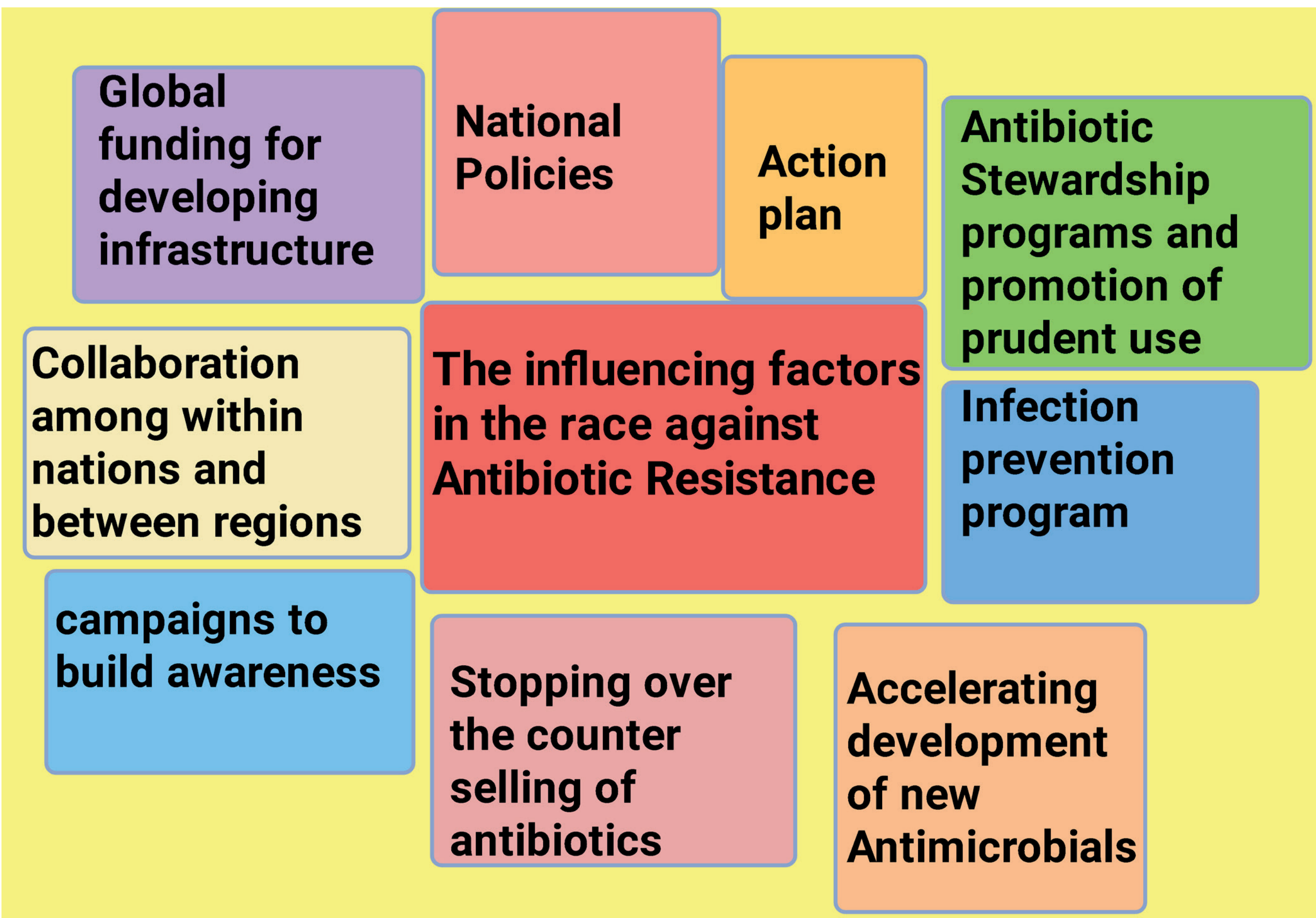

Figure 2: Display of the factors that influence the race against Antibiotic Resistance. This figure was drawn via the premium version of BioRender (https://biorender.com/), accessed on November 1st, 2025, with license number VV28Y1VLY7 [17]. (Illustration Credit: Rahnuma Ahmad).

Expanding vaccine development, bacteriophage therapy, and immunotherapeutic strategies as complements to antimicrobial drugs needs to be considered. These alternatives aim to bypass the resistance hurdle altogether by preventing infections or exploring natural microbial antagonism. Additionally, the integration of rapid diagnostics could curb overprescribing. Machine learning-based diagnostic tools and genomic sequencing for resistance profiling promise to improve clinical decision-making, tailoring antibiotic use with precision [49,50].

A Call for Global Solidarity

Ultimately, the AMR crisis is not a distant scientific problem but an existential one. For the One Health Approach to succeed, it is necessary to recognize that humanity cannot separate itself from the ecological networks that it disrupts [51]. Collaboration must be transnational and transdisciplinary. Governments must see antimicrobial stewardship as a security policy and not just medical ethics [52]. The COVID-19 pandemic provided both a warning and an opportunity. It revealed how interconnected global health is, and how resource prioritization can shift rapidly under existential threat [53]. Now, this vigilance must be redirected toward AMR, which kills silently but persistently.

Towards a Common Future

One Health is not an abstraction—it is a survival strategy. Mitigating AMR requires humility, collaboration, and sustained action across all domains of life. Human well-being, animal welfare, and environmental integrity are not competing interests but interdependent pillars of existence [54]. Advances in surveillance and data-sharing frameworks are now enabling real-time tracking of resistant strains, antimicrobial consumption patterns, and intervention outcomes. Such systems foster greater accountability, inform targeted stewardship programs, and facilitate evidence-based policy-making that is adaptable to regional contexts and evolving threats [55]. The time for incremental reforms has passed. What remains is the collective determination to redefine what responsible medicine means in a globalized world. The cure for AMR is a mindset.

Consent for Publication

The author has reviewed and approved the final version and agrees to be accountable for all aspects of the work, including any accuracy or integrity issues.

DISCLOSURE

The authors declare that they do not have any financial involvement or affiliations with any organization, association, or entity directly or indirectly related to the subject matter or materials presented in this review paper.

Data Availability

Information for this review paper is taken from freely available sources.

Authorship Contribution

All authors contributed significantly to the work, whether in the conception, design, utilization, collection, analysis, or interpretation of data, or all these areas. They also participated in the paper's drafting, revision, or critical review, gave their final approval for the version that would be published, decided on the journal to which the article would be submitted, and made the responsible decision to be held accountable for all aspects of the work.

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