THE ROLE OF VETERINARY MEDICINE IN ANTIMICROBIAL RESISTANCE: CHALLENGES AND ONE HEALTH SOLUTIONS

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Abstract
Antimicrobial resistance (AMR) has emerged as a significant global health issue, compromising the efficacy of antimicrobial medicines essential for human and veterinary therapy. The veterinary sector, especially animal production systems, significantly contributes to the emergence and spread of resistant infections owing to the prevalent and frequently unregulated use of antibiotics. Resistant organisms and resistance genes can be transmitted to humans through foodborne exposure, direct contact with animals, or environmental routes, thereby exacerbating the public health burden. The One Health concept has emerged as a comprehensive framework for managing antimicrobial resistance (AMR) owing to its recognition of the multisectoral nature of the issue at the junction of human, animal, and environmental health. This review analyzes the epidemiology and primary factors contributing to antimicrobial resistance (AMR) in veterinary contexts, including antimicrobial overuse, insufficient stewardship, and environmental contamination. It further examines the ramifications of veterinary antimicrobial resistance on public health, emphasizing zoonotic transmission, occupational hazards, and environmental reservoirs. This review defines global and national One Health policies focused on surveillance, policy integration, and antimicrobial stewardship, while highlighting significant implementation gaps, especially in low- and middle-income nations. Challenges, including fragmented governance,

inadequate diagnostic capacity, inadequate regulatory enforcement, and insufficient awareness, persist and hinder advancement. The review asserts that effective mitigation of AMR necessitates continuous investment, coordinated intersectoral collaboration, and tailored strategies. Enhancing veterinary surveillance systems, advocating for appropriate antibiotic utilization, and driving research into alternatives are critical elements of an effective One Health response. In the absence of such coordinated initiatives, antimicrobial resistance will persist, jeopardizing animal productivity and public health safety.

INTRODUCTION

Antimicrobial resistance (AMR) is one of the largest global health threats that the world will face in this century, jeopardizing antimicrobial efficacy and decades of progress in human and animal health. While AMR was initially viewed as a clinical problem in human medicine, it has now become a multisectoral issue that affects human, animal, and environmental health (Horvat & Kovačević, 2025). The consumption of antimicrobials in veterinary practice has become widespread and indiscriminate, especially for food-producing animals, exposing microbiota to antimicrobials, thus hastening the process of selecting and spreading resistant microorganisms (Hosain et al., 2021). The network becomes even more complex when these resistant strains or their resistance genes can also be transferred from animals to humans via direct contact, food consumption, or environmental contamination (Otaigbe & Elikwu, 2023). With an understanding of these interconnections, the global health community has called for the implementation of the One Health approach, which highlights the need for integrated, interdisciplinary collaboration at the human-animal-environment interface to address AMR effectively (Bazzi et al., 2022).

Currently, the use of antimicrobials in the veterinary sphere encompasses treatment, prophylaxis, meta phylaxis, and, especially in extensive animal production systems, growth promotion. These practices are a major driver of drug-resistant zoonotic and commensal bacteria, especially when poorly regulated or monitored (Murungi et al., 2025). Pathogens such as Escherichia coli, Salmonella spp., Campylobacter spp., and Staphylococcus aureus have shown increasing levels of resistance in animal reservoirs, with subsequent spillovers to human populations through food or occupational exposure (Gruel et al., 2021). Moreover, waste from livestock production with antibiotic residues and resistant bacteria may contaminate the environment and impact the microbial ecosystem, with reservoirs of resistant genes in soil and water. This shows that the nature of the veterinary AMR problem is not purely a local issue but a transboundary problem with greater public health significance (Garcias et al., 2021).

Consequently, the One Health paradigm has been established as a conceptual framework for planning, designing, and executing integrated AMR counter-attack measures (Raboisson et al., 2020). Well into the 21st century, preventive efforts to curb zoonotic diseases and foster healthy ecosystems require coordinated actions across the veterinary, medical, agricultural, and environmental sectors, while international bodies such as the World Health Organization (WHO), World Organization for Animal Health (WOAH, formerly OIE), Food and Agriculture Organization (FAO), and United Nations Environment Program (UNEP) increasingly promote the necessity of this approach (Alabi et al., 2025). However, the practical implementation of One Health still constitutes a major challenge, particularly within low- and middle-income countries (LMICs), where veterinary surveillance capacities are often poorly developed and effective antimicrobial stewardship is lacking (Espinosa-Gongora et al., 2021). This review examines the status of antimicrobial resistance (AMR) in veterinary public health from a One Health perspective, providing an overview of the drivers, transmission pathways, monitoring, and policy aspects of AMR. This highlights the importance of collaboration across sectors and policymaking guided by the best available evidence to prevent AMR and safeguard animal and human health (Chung et al., 2023).

2. Epidemiology and Drivers of Antimicrobial Resistance in Veterinary Settings

There are specific interactions between antimicrobial management and selection pressures resulting from veterinary practices, as well as the transmission of resistance elements from one compartment to another, indicating that veterinary AMR epidemiology is both complex and multifactorial as shown in **Figure 1 (Kimera, Frumence, et al., 2020)**. Antimicrobials are frequently administered to food-producing animals for the treatment of clinical infections, as well as for metaphylactic and prophylactic purposes, particularly in high-density animal production systems (Hosain et al., 2021). Lower doses of antimicrobials have been used to promote growth and feed efficiency in many countries, expanding the use of antimicrobials beyond therapeutic applications to include subtherapeutic levels in most intensive poultry, swine, and dairy operations. Such practices have applied selection pressure on microbial communities to induce resistance in bacteria and the acquisition of mobile genetic elements, including plasmids, integrons, and transposons, which promote horizontal gene transfer. Escalating multidrug resistance in these bacteria is supported by veterinary surveillance data: high levels of resistance in E. coli, Campylobacter, and Salmonella isolated from livestock have been frequently reported by the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) and comparable programs based in North America and Asia (Hassan et al., 2024).

Veterinary AMR is influenced by more than just the use of antimicrobials but is driven largely by systemic factors such as regulatory oversight (or lack thereof), absence of veterinary diagnostics, poor biosecurity at the farm level, and insufficient training of animal health professionals (Odoi et al., 2021). In many low- and middle-income countries (LMICs), antimicrobials are not sold on veterinary prescriptions and are freely available over the counter, resulting in misuse and overuse. Furthermore, the empirical treatment model in the absence of pathogen identification or sensitivity testing encourages inappropriate or excessive antimicrobial use (Magstadt et al., 2018). Environmental transmission is also of immense importance: resistant bacteria and residual antibiotics contained in animal manure used directly for fertilization or discharged into water systems spread, and this becomes an environmental reservoir for resistance to be amplified in environmental microbiota (Field et al., 2015). Close contact with companion animals also places humans at risk for transmission of resistant pathogens, such as extended spectrum β-lactamase (ESBL)-producing Enterobacteriaceae, which are present in pets. These elements, in aggregate, form a bank of resistance in animals and the environment, driving transmission to humans and undermining the control efforts across domains (Luo et al., 2019).

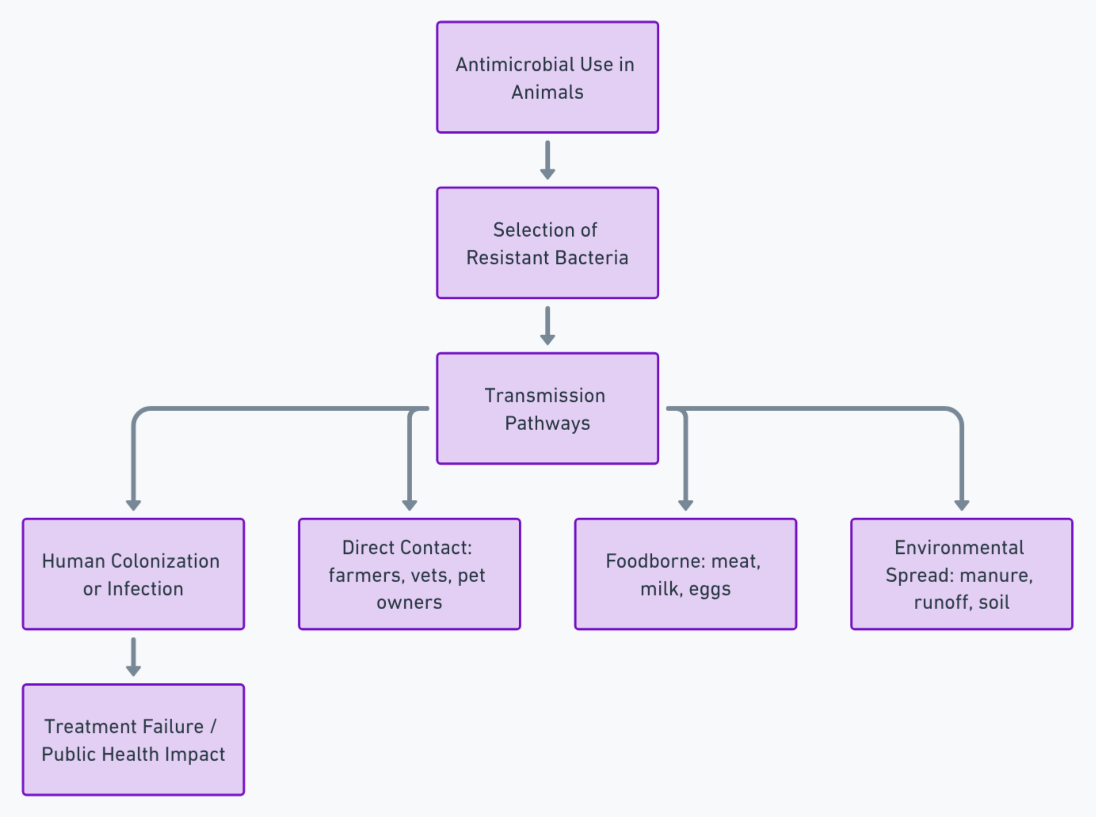

Figure 1: Flowchart illustrating how antimicrobial use in animals can lead to resistant bacteria, their transmission to humans, and the resulting public health impacts.

3. Veterinary Public Health Implications of Antimicrobial Resistance

AMR in animal populations is a major concern for veterinary public health, as it can allow the direct or indirect transmission of resistant pathogens from animals to humans. Human-associated pathogens of zoonotic origin, including Salmonella spp., Campylobacter jejuni, Escherichia coli, and Staphylococcus aureus, have been demonstrated in livestock and poultry with resistance profiles resembling those of human clinical isolates (Reddy et al., 2016). These pathogens can be transmitted from animals to humans through the intake of contaminated animal products, direct contact with infected animals, and environmental exposure through water and soil contaminated with animal feces (Muloi et al., 2018). Examples include a range of outbreaks of foodborne illness attributed to resistant strains, such as multi-drug-resistant Salmonella Typhimurium and fluoroquinolone-resistant Campylobacter, often associated with poultry or bovine sources. As a result, not only does the disease burden increase, but there are also more severe clinical consequences, including treatment failure, prolonged illness, and increased mortality (Daoud & Rolain, 2023).

In addition to food chain transmission, animal AMR has far-reaching implications for public health via occupational exposure and environmental contamination. Repeated exposure to animals and their waste increases the risk of colonization and infection with resistant organisms in veterinarians, farmworkers, slaughterhouse employees, and animal handlers (Chuchu et al., 2024). This is especially worrisome for pathogens such as methicillin-resistant Staphylococcus aureus (MRSA), which has been documented to span species barriers from companion animals and livestock to humans (Muloi et al., 2022). In addition, antimicrobial residues and resistant bacteria in manure can persist in the environment and may be washed off agricultural land, where they can contaminate surface water, groundwater, and crops (Taing et al., 2022). The environmental dissemination of AMR genes results in the development of resistance reservoirs in microbial communities outside clinical and agricultural settings, which have long-term ecological and epidemiological consequences. These public health risks warrant an integrated approach to AMR mitigation that connects human health surveillance, veterinary practices, and environmental management from a One Health perspective (Loayza et al., 2020).

4. One Health Approaches to Combat Antimicrobial Resistance

Owing to the interconnectedness of AMR among animals, humans, and the environment, the One Health approach serves as a holistic and integrated approach for addressing the complicated drivers of AMR as shown in **Figure 2**. To address this, global agencies, including the World Health Organization (WHO), World Organization for Animal Health (WOAH), Food and Agriculture Organization (FAO), and United Nations Environment Program (UNEP), have co-established the Tripartite and United Nations Environment Program (UNEP) Alliance on AMR, which highlights One Health in surveillance, policy development, and antimicrobial use (Kotwani et al., 2021). More than 140 countries have adopted national action plans in line with the Global Action Plan on AMR, with priorities for harmonized surveillance (e.g., integrated monitoring of AMR in humans, animals, and food), sensible use of antimicrobials, improved infection prevention, and research into alternatives such as vaccines and probiotics (Mader et al., 2021). This makes surveillance a key component of One Health approaches for tracking and assessing changes in the progression of AMR. Data on antibiotic usage can be collected and reported by the following important initiatives: the World Health Organization Global Antimicrobial Resistance Surveillance System (GLASS) (Anderson et al., 2019), the FAO's Assessment Tool for Laboratories and Antimicrobial Resistance Surveillance Systems (ATLASS) (Oberin et al., 2022), and the WOAH Annual Report on Antimicrobial Agents Intended for Use in Animals, which are necessary for cross-sectoral risk assessment and intervention planning (Kotwani et al., 2021). Furthermore, integrated national surveillance networks, such as DANMAP in Denmark and NARMS in the United States, have proven effective in linking data between the veterinary and human sectors to inform antimicrobial policies. For instance, One Health intervention involves the slaughtering of antimicrobials intended for growth promotion, the facilitation of veterinary prescriptions, and the awareness of animal health professionals over stewardship, in addition to bolstering laboratory capabilities towards the identification of resistant pathogens that can be shared between species (Mesa Varona et al., 2020). Additionally, this One Health approach reinforces community mobilization and public awareness to decrease over-the-counter sales and indiscriminate use of anti-infectives at the farm level. However, even with these advances, application is inconsistent among regions, indicating the need for continuous national-level dedication, interdisciplinary synergies, and global support to implement One Health as intended in both low- and high-resource environments (Haque et al., 2022).

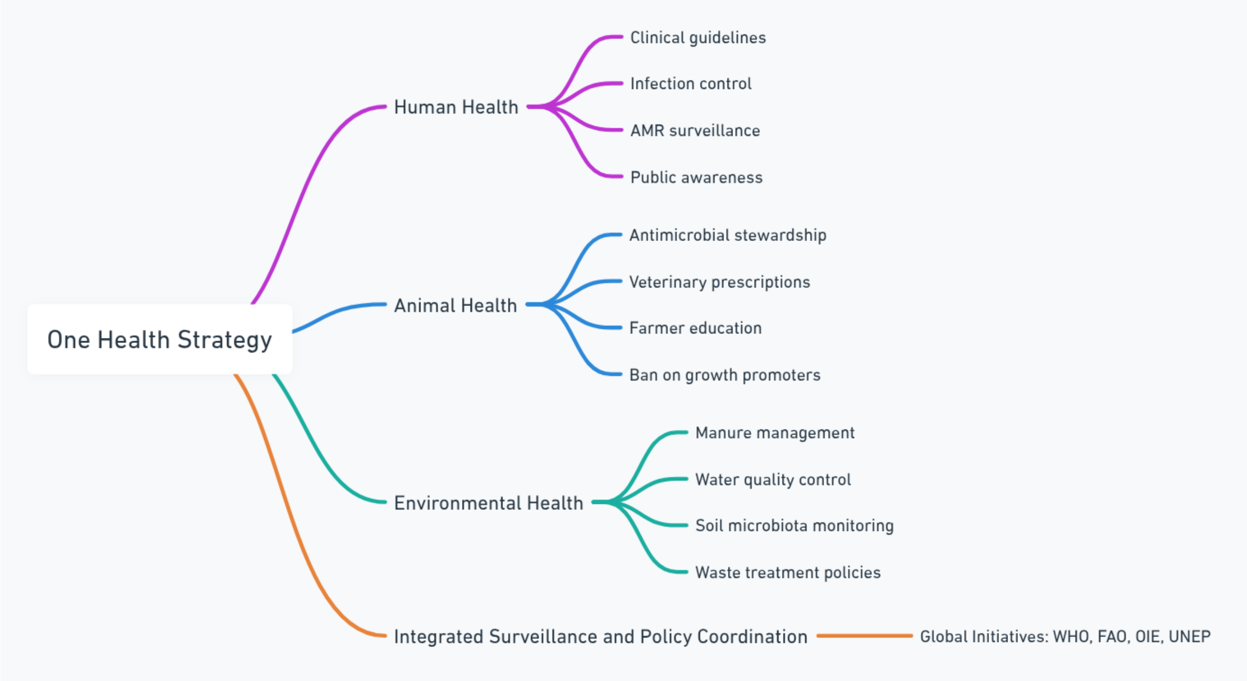

Figure 2: Mind map outlining the One Health Strategy, emphasizing the interconnected roles of human, animal, and environmental health, with coordinated global efforts to address antimicrobial resistance.

5. Current Gaps and Challenges in Implementation

Despite a broader consensus on the utility of the One Health approach in addressing AMR worldwide, persistent and troubling implementation gaps exist in the full articulation and sustained application of this strategy, particularly in LMICs like India (Bordier et al., 2021). The second major issue is the lack of effective veterinary AMS programs. The situation with veterinary antimicrobial use is quite diverse, and poor regulation of the sale and use of antimicrobials in animal species persists in many regions, where critically important antimicrobials can be obtained without veterinary oversight (Kimera, Mshana, et al., 2020). Although it is essential to provide a basis for the correct use of antimicrobials, veterinary diagnostics are often unavailable or underutilized because of high costs, infrastructural limitations, and insufficient training. This contributes to continued empirical treatment based on non-specific symptoms, leading to unnecessary or inappropriate antimicrobial therapy. However, even if national AMR action plans are in place, their implementation is often fragmented due to cross–sectoral responsibilities spread out among different ministries (e.g., agriculture, health, and environment) and a lack of financing and technical capacity (Hayami et al., 2019).

The available collected surveillance and surveillance data, especially for multisectoral problems, are fragmented and lack integration. Many countries have AMR surveillance in humans or animals, but few have streamlined systems to connect these datasets in real time. Environmental surveillance, which involves monitoring antimicrobial residues and resistance genes in soil and water, is another poorly supported element of most national plans. This weakens early warning systems and slows the response to new threats from resistance (Hart et al., 2023). Additionally, there is often a lack of awareness and education about AMR among farmers, veterinarians, and policymakers, especially in rural or resource-limited settings. The problem of noncompliance with guidelines and regulations is compounded by cultural norms, economic pressures, and weak enforcement mechanisms (Lee et al., 2018). Finally, alternatives to antibiotics (such as vaccines, bacteriophages, and feed additives) are constrained by prohibitive costs, regulatory hurdles, and limited market access. These gaps highlight the urgent need to transition from policy to practice, with greater investment in One Health infrastructure, elevated political commitment, and multisectoral capacity building adapted to local epidemiological and economic contexts (Kariuki et al., 2018).

6. Conclusion

Antimicrobial resistance (AMR) poses a serious and increasing risk to veterinary public and animal health across species and ecosystems. These properties suggest that AMR in animals is not an isolated issue but an integral element within a larger connected system involving human health and the environment. Antimicrobials used in animal agriculture under insufficiently regulated conditions generate reservoirs of resistance that threaten food safety, therapeutic effectiveness, and ecological stability. The One Health approach provides a scientifically robust and operational integrative framework for reducing AMR by bringing together communities from human, animal, and environmental health. Despite worldwide advancements in surveillance and policy formulation, there are still inconsistencies in implementation linked to lagging diagnosis, veterinary stewardship, intersectoral collaboration, and infrastructure, most notably in low- and middle-income countries. Substantial political commitment is required to maintain existing progress in protecting public health by protecting the efficacy of current antimicrobials, investing in laboratory and surveillance systems, and educating veterinary professionals and livestock producers. Additionally, developing novel substitutes for antibiotics and integrating AMR mitigation into sustainable development goals will be crucial. A One Health strategy that is sociable and adequately financed is not a choice; it is a necessity to address the multivariate nature of AMR and to uphold the future stability of human and animal health systems.

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