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Antimicrobial Resistance: A One Health Approach to Addressing Global Health and Food Security Challenges

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Abstract

Antimicrobial resistance (AMR) is a growing global health threat that jeopardizes both human and animal health, with significant economic implications. The overuse and misuse of antibiotics in human medicine, agriculture, and veterinary practices have driven the development of resistance, making infections harder to treat and increasing the risk of disease spread. In particular, the use of antibiotics in livestock and aquaculture has accelerated the emergence of resistant pathogens that can transfer to humans via the food chain. AMR is linked to an increase in morbidity and mortality rates, extended hospital stays, and higher healthcare costs. Projections suggest that AMR could lead to up to 10 million deaths annually by 2050, with devastating impacts on global economies, particularly in low- and middle-income countries. Addressing AMR requires a multi-faceted approach, including stricter antibiotic regulations, improved management practices in agriculture, and enhanced surveillance systems. This article reviews the mechanisms of AMR, its global and regional implications, and the strategies needed to mitigate its impact on public health and food security.

Keywords: ***Antimicrobial resistance; Antibiotics, Economic impact; Food security; Global health; Public health.***

1. Introduction

Antibiotics, naturally derived, synthetic, or semi-synthetic, inhibit or eliminate microorganism growth. Their extensive use in dairy, cattle, poultry, aquaculture, and beekeeping industries worldwide has contributed to their widespread availability and affordability. However, bacteria are increasingly acquiring resistance to diverse antibiotics, driven by horizontal gene transfer from resistant bacteria or through new genetic mutations, intensifying the global AMR challenge [1].

One of the biggest threats to global health is antimicrobial resistance (AMR), which presents significant public health and economic challenges. In 2019, AMR was associated with approximately 1.27 million deaths worldwide. The primary

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drivers of AMR are the overuse and misuse of antimicrobials across human, animal, and plant sectors [2]. AMR adversely affects both human and veterinary medicine, threatening public health and food security. As global livestock production expands, the reliance on antibiotics intensifies. However, improper or excessive antibiotic use contributes to the emergence of antibiotic-resistant bacteria, which can contaminate food and exacerbate the AMR crisis [3].

Over the past 40 years, research has identified key drivers of antimicrobial resistance (AMR) in East Africa, including excessive antibiotic use in small-scale production systems, close human-animal interactions, lack of withdrawal periods before consuming animal-derived products, and poor antibiotic use management (AMU). These practices have exacerbated AMR, rendering previously effective treatments for infectious diseases inadequate. In Ethiopia, high antibiotic use spans public health and veterinary sectors, with limited government oversight of the pharmaceutical industry and inadequate guidance on safe veterinary medication use. Additionally, food products can act as reservoirs and vectors for antibiotic-resistant bacteria, facilitating the efficient transfer of AMR factors to human digestive systems [4].

Antimicrobial resistance (AMR) in animal products arises when edible parts retain residues of veterinary medications, including parent compounds, metabolites, and contaminants. Consuming these products at levels exceeding standard residual limits can have serious health consequences. Veterinary medication residues, comprising pharmacologically active substances and their breakdown products, are frequently detected in animal-derived foods such as milk and meat [5].

Cattle and their products can serve as reservoirs for AMR bacteria, facilitating the transfer of resistant pathogens to humans through the food chain [6]. Notable antibiotic-resistant pathogens, including *Salmonella*, *Staphylococcus aureus*, and *Escherichia coli*, have emerged as significant challenges to global healthcare [7], [8]. In Ethiopia, studies in the veterinary and public health sectors have revealed a fragmented prevalence and susceptibility profile for these pathogens, highlighting gaps in AMR management [9]. Therefore, the objective of this article is to review the mechanisms of AMR, its global and regional implications, and the strategies needed to mitigate its impact on public health and food security.

2. Literature Review on AMR

2.1 Definition and History of Antimicrobial Resistance

Antimicrobial resistance (AMR) poses a severe global health threat, undermining the effectiveness of antibiotics, antivirals, antifungals, and antiparasitic. AMR occurs when microorganisms including bacteria, viruses, fungi, and parasites develop resistance to previously effective treatments, leading to increased morbidity, mortality, and healthcare costs [10]. The growing prevalence of AMR has escalated global concern, emphasizing the need for coordinated action across governments, healthcare providers, researchers, and the public [11]. Addressing AMR is now a critical health priority to safeguard the well-being of populations worldwide [12].

The history of antimicrobial resistance (AMR) dates back to the discovery of penicillin by Fleming in 1929 and its widespread use in the 1940s [13]. Resistance emerged quickly, with penicillin-resistant *Staphylococcus aureus* reported in 1942 and tetracycline resistance by 1953 [14], [15]. The agricultural use of antibiotics in the 1950s–1960s further accelerated resistance, and methicillin-resistant *Staphylococcus aureus* (MRSA) was identified in 1961 [16]. By the 1980s, multidrug-resistant (MDR) tuberculosis had become a global epidemic, and in the 1990s, *Escherichia coli* and *Klebsiella pneumoniae* developed resistance to extended-spectrum beta-lactamases (ESBL) [17], [18].

The escalation of MDR bacteria has significantly reduced the efficacy of antibiotics, leading to a decline in antibiotic development by pharmaceutical companies. Today, healthcare systems face a "post-antibiotic era" where common infections and minor injuries risk becoming fatal. Without urgent solutions, AMR is projected to cause millions of deaths annually, posing a dire global health challenge.

2.2 Mechanisms of Antimicrobial Resistance

Antimicrobial resistance (AMR) arises when microorganisms develop the ability to survive exposure to antimicrobial agents designed to eliminate them or inhibit their growth [19]. Microorganisms achieve resistance through various mechanisms, including genetic mutations, horizontal gene transfer, and alteration of drug targets, drug inactivation, efflux pumps, and biofilm formation. Genetic mutations, and changes in the DNA sequence, play a pivotal role in AMR development. These mutations may occur spontaneously or be induced by the presence of antimicrobial agents, enabling microorganisms to evade drug effects [20].

Microorganisms develop AMR through genetic transfer mechanisms like horizontal gene transfer, which facilitates the sharing of resistance genes between organisms, often via plasmids or transposons [21], [22]. Resistance can also arise from alterations to drug targets, rendering antimicrobials less effective [21], [23]. Additionally, bacteria may produce enzymes that neutralize antimicrobial agents or use efflux pumps to expel drugs, preventing their accumulation to effective concentrations [24], [25].

Certain microorganisms can form biofilms, which are thin layers of microbial communities attached to surfaces and encased in an extracellular matrix. These biofilms provide a protective barrier against antimicrobial agents, making it significantly more challenging to eliminate the microorganisms within them [26].

2.3 Emergence of Antimicrobial Resistance

The history of antimicrobial resistance (AMR) reveals its deep-rooted origins. AMR was first described in *Escherichia coli* (then *Bacillus coli*) in 1940, shortly before penicillin was widely used in human medicine and after its discovery by Fleming in 1929 [27]. Since many medical antimicrobials are naturally derived from soil microorganisms, it has been known for over 40 years that these microorganisms harbor resistance genes that are now found in clinically significant bacteria [28]. Phylogenetic studies suggest that AMR genes existed long before antibiotic use, but retrospective analyses indicate that resistance was rare in clinical isolates before antibiotic introduction [29], [30].

2.4 Antimicrobial Use and Resistance Development

The primary driver of antimicrobial resistance (AMR) is the widespread use of antimicrobial medications across various sectors. These medications are used in veterinary clinics, farms, and feedlots, as well as in hospitals, outpatient facilities, and long-term care settings. In agriculture, antimicrobials are commonly administered to animals raised for food to treat or prevent disease, with some being added to nearly all animal feed at sub-therapeutic concentrations to promote growth and prevent illness. Food processing facilities also use antimicrobial agents to control bacterial growth and ensure the safety and quality of the final products [31].

Despite extensive research and scientific evidence supporting the link between antimicrobial use in agriculture and the development of antimicrobial resistance (AMR) in human diseases, some skeptics still question this connection. Globally, the amount of antibiotics used in food animals is believed to exceed that used in humans, with nearly every class of antibiotics utilized in both human medicine and food production. Overuse and misuse of antibiotics are recognized as major contributors to AMR, as these practices create selection pressure on both environmental bacteria and the microbiota of humans and animals [32].

Antibiotics can also activate gene expression, promoting mutations or the development of resistance genes in bacteria [33]. Through gene transfer, resistance genes can spread from agricultural bacteria to human pathogens. The potential for resistant pathogens to spread from one individual to others poses a significant global public health threat. Additionally, antibiotic residues in animal feed and waste can contaminate soil and water, impacting environmental and aquatic microbiomes [34]. Given that a large percentage (75–90%) of antibiotics administered to cattle are excreted unmetabolized, the persistence of these residues further elevates the risk of AMR development [31].

2.5 Mechanisms of Spread of Antimicrobial Resistance between Animals and Humans

Humans can be exposed to antimicrobial-resistant bacteria through direct contact with animals or their waste, as well as through the consumption of food contaminated with resistant bacteria (Fig. 1) [31]. Additionally, fomites, or inanimate objects, can play a significant role in the local and global transmission of these resistant bacteria. Genetic exchange between different strains or species can occur, enabling the spread of resistance genes. This genetic transfer can take place in environments where susceptible bacteria come into contact with resistant ones, such as the human or animal gut, agricultural soil treated with slurry, or aquatic ecosystems [35].

Resistance genes can travel from humans to poultry farms, raising concerns about contamination in water, food crops, and animal feed due to environmental bacteria acquiring resistance. This contamination can promote the exchange of resistance traits with commensal or pathogenic species in the gut microbiota of both animals and humans, posing substantial health risks [36]. However, there is limited information on the role of this transmission route in the spread of AMR. The environmental fate of different antimicrobials can vary, and it is crucial to consider that residues from pharmaceutical production or human antimicrobial treatments may also contribute to the selection of resistant bacteria in the environment [29].

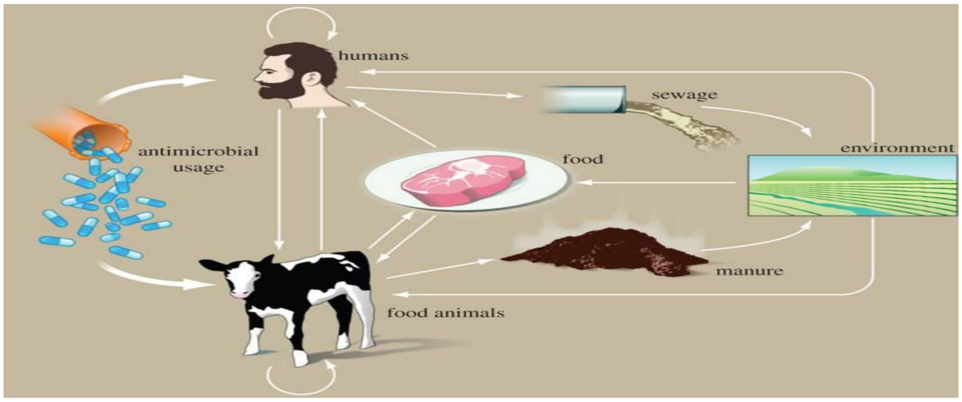

Fig. 1. Spread of antimicrobial resistance between animals and humans [37].

2.6 The impact of AMR on Human and Animal Populations

Antimicrobial resistance (AMR) has become one of the most critical health challenges of the 21st century. Infections once easily treatable are increasingly difficult to manage, leading to significant clinical and public health concerns. The loss of effective first-line antimicrobials has necessitated the use of second and third-line therapies, which are often costlier and more toxic and require longer treatment durations. Prolonged illnesses increase the burden on healthcare systems through extended hospital stays, additional outpatient visits, laboratory testing, and the need for isolation measures. They also strain individual and societal resources, reducing economic productivity due to longer recovery times and missed work [38].

Over a million people die every year from AMR infections [39]. Without effective antibiotics, routine medical procedures like surgeries, organ transplants, chemotherapy, and neonatal care could become much more dangerous because of infections that aren't under control [40]. Bacteria like *Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species are some of the most dangerous AMR threats in healthcare settings [41].

AMR threatens human health and food production by enabling animal-to-human transfer of resistant zoonotic pathogens [42]. Overuse of antibiotics in livestock to treat illness and promote livestock growth has precipitated reservoirs of resistance. This facilitates enhanced transmission risks of MDR bacteria like Salmonella and Campylobacter via the food chain or animal handlers [43]. Resistant bacterial strains spread readily between species. Wildlife similarly develops AMR from indirect environmental exposures driving additional pathogen transmission. Resistant microbes extend into the broader environment through fertilizers made from manure, contaminating waterways and produce that reaches consumer tables. They additionally exchange AMR genes with normal environmental and human commensal microflora. Restricted treatment options for animal infections resulting from resistance promote outbreak escalation among cattle, poultry, and sheep, necessitating culling and generating significant economic losses while threatening food supplies. Approximations indicate AMR could impose a $3–4 billion financial burden through livestock alone in the coming decades [44].

Detrimental resistance impacts across agriculture and economic systems also spur disruptive ripple effects for national security and trade. Hence, a proper One Health approach encompassing human, animal, and environmental health surveillance and interventions remains necessary to fully address AMR's substantial existing and prospective adverse impacts on animals that, in turn, heighten human exposure risks further [45].

2.7 Impact on the Global Economy

Antimicrobial resistance (AMR) disproportionately impacts certain populations and regions, with low- and middle-income countries and vulnerable groups enduring the greatest burden. According to the World Health Organization (WHO), over 75% of the global population is affected by AMR, particularly individuals living with HIV, those with chronic illnesses, and patients in healthcare settings where infection risks are elevated [46]. Currently, antibiotic-resistant infections cause over 700,000 deaths annually, and this figure could rise to 10 million deaths per year by 2050 if current trends persist. These alarming projections highlight the critical need for coordinated global action to address AMR effectively [47].

AMR poses a considerable challenge in effectively combating numerous infectious diseases, rendering their treatment increasingly arduous [48]. Certain significant global phenomena in AMR encompass the rise of antibiotic-resistant bacteria, exemplified by methicillin-resistant *Staphylococcus aureus* (MRSA) and carbapenem-resistant Enterobacteriaceae (CRE). The dissemination of multidrug-resistant tuberculosis (MDR-TB) represents another prevailing occurrence. AMR instills mounting apprehension within the context of sexually transmitted infections, notably gonorrhea. Additionally, it progressively compromises the efficacy of novel antimicrobial agents, including antivirals and antifungals [49]. Countries must collaborate on a global scale to combat this predicament effectively, as AMR transcends geographical boundaries and exhibits the potential for seamless cross-border propagation [50].

2.8 Impact of Antibiotic Resistance

Antibiotic resistance (ABR) poses significant threats to public health, global economies, and food security. Treatable infections become harder to manage, resulting in prolonged illnesses, complications, and over 700,000 deaths annually. This figure is projected to rise to 10 million deaths per year by 2050 if current trends continue [47]. Resistance necessitates the use of expensive and often toxic second- or third-line treatments, leading to prolonged hospital stays and increased healthcare costs [38]. Antibiotic resistance affects workforce productivity and incurs significant costs related to healthcare and food production, with an estimated burden of $3–4 billion in livestock sectors alone in the coming decades [44]. Routine medical procedures like surgeries, organ transplants, and cancer therapies become riskier due to the limited efficacy of antibiotics to prevent and treat infections [40]. Resistance in agricultural settings leads to animal disease outbreaks, reduced production, and compromised food safety due to contaminated produce and water sources [43].

3. Conclusion and Recommendations

Antimicrobial resistance (AMR) represents one of the most pressing global health crises of the 21st century. The overuse and misuse of antibiotics in human medicine, agriculture, and veterinary practices have accelerated the development and spread of AMR, undermining the efficacy of life-saving drugs. Genetic mutations, horizontal gene transfer, and

biofilm formation enable microorganisms to evade treatment, increasing morbidity, mortality, and economic burdens. AMR poses significant threats to public health, food security, and global economies, especially in low- and middle-income countries. Without immediate and coordinated action, the spread of AMR could result in catastrophic outcomes, including millions of preventable deaths annually, escalating healthcare costs, and reduced agricultural productivity.
Based on the above conclusion, the following recommendations were forwarded:

- Strengthened cross-sectoral collaboration can improve surveillance, prevention, and management of AMR.
- Agriculture should restrict antibiotics to therapeutic use, prohibiting sub-therapeutic and growth-promoting use.
- Robust national and international surveillance systems should monitor antibiotic usage and resistance patterns in humans, animals, and the environment.
- Education of healthcare providers and farmers, and the public on the risks of antibiotic misuse and AMR is crucial.
- Investment in new antimicrobials and alternatives therapies (e.g., phage therapy), and vaccines is critical.
- Strengthening infection prevention and control measures in healthcare facilities, farms, and food production systems can reduce the spread of resistant pathogens.

4. Contribution of Authors

Both authors contributed equally during the preparation of the manuscript.

5. Conflict of Authors

The authors declare no conflict of interest.

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