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ONE HEALTH APPROACH TO COMBATING ANTIMICROBIAL RESISTANCE IN AGRICULTURE

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Abstract. *The global antimicrobial resistance (AMR) crisis is a quintessential One Health challenge, intrinsically linking human, animal, and environmental health, with agriculture serving as a critical nexus. This research articulates a comprehensive, integrated One Health framework for mitigating AMR emergence and transmission within agricultural systems, focusing on livestock, aquaculture, and crop production. The research synthesizes evidence on the drivers of AMR in agriculture, including the prophylactic and metaphylactic use of antibiotics in animal production, the application of manure-based fertilizers containing resistant bacteria and genes, and the use of antimicrobials in plant pathology. We review a suite of synergistic interventions across the One Health spectrum: in animal health, promoting antibiotic stewardship through precision veterinary medicine, enhancing animal welfare and resilience via improved housing and nutrition, and deploying vaccines and probiotics as alternatives; in environmental health, implementing advanced manure and wastewater treatment technologies (e.g., anaerobic digestion, composting protocols) to degrade resistance genes, and managing agricultural runoff; and in human health, strengthening surveillance of resistant pathogens across the food chain and educating stakeholders on risk perception. The discussion critically evaluates the socio-economic, political, and behavioural barriers to implementing this holistic approach, including economic incentives for antibiotic use, regulatory fragmentation, and lack of cross-sectoral data sharing. We conclude that a systemic, preventive strategy, moving from a reactive, pathogen-centric model to a proactive, system-health model, is not only scientifically warranted but economically imperative. Effective AMR containment in agriculture requires breaking down disciplinary and institutional silos through integrated policy, transdisciplinary research, and aligned economic instruments that make responsible antimicrobial use the most viable choice for all stakeholders in the One Health continuum.*

Keywords*: agriculture, one health, antimicrobial, approach, combatting.*

INTRODUCTION

Antimicrobial resistance (AMR) represents one of the most pressing global health threats of the 21st century, projected to cause 10 million annual deaths by 2050 and erode the foundations of modern medicine, food security, and sustainable development. While often framed as a clinical human health crisis, the roots of AMR are profoundly ecological and agricultural. Agriculture, encompassing livestock production, aquaculture, and crop farming, are a major amplifier and reservoir of resistant bacteria and resistance genes (ABD-ELGHANY ET AL., 2022). The extensive use, and often overuse, of antimicrobials in these systems for therapy, disease prevention (prophylaxis), and growth promotion (where still permitted) exerts a powerful selective pressure, driving the evolution and proliferation of resistant microbes (JANS, 2018). These resistant organisms and their genetic determinants do not respect boundaries; they traverse interconnected pathways through the food chain (via meat, milk, eggs, and produce), the environment (via manure, wastewater, and soil), and direct human-animal contact, creating a continuous cycle of transmission and enrichment (BALAN ET AL., 2022).

The historical, sector-specific approach to managing AMR, where human medicine, veterinary practice, and environmental science operate in isolated silos, has proven catastrophically inadequate. Regulations banning growth promoters in one region can be undermined by the import of food products from regions with laxer standards. A veterinarian's prudent prescription can be nullified when resistant bacteria from treated animals spread via runoff to nearby water sources (TEMKIN ET AL., 2018). This fragmentation highlights the critical necessity of the One Health paradigm. One Health is not merely a slogan, but an essential operational framework based on the fundamental understanding that the health of humans, domestic and wild animals, plants, and the wider environment are interdependent and inextricably linked, even taught in early studies from universities (PASCALAU ET AL., 2025, 2021, 2020). Combating AMR effectively demands an integrated, cross-sectoral strategy that addresses the drivers of resistance at its multiple points of origin and along its myriad transmission routes, with agriculture as a primary focal point.

The core problem is a systemic one. In many intensive farming systems, antimicrobials have been used as a low-cost substitute for higher standards of animal welfare, biosecurity, and farm management (O'NEILL J., 2016). Economic pressures, coupled with a lack of rapid diagnostics, encourage metaphylactic (treating an entire group when some are sick) and prophylactic use. Furthermore, the environmental dimension is frequently neglected. Up to 90% of administered antibiotics can be excreted in urine and faeces. When manure and aquaculture effluent are applied to land as fertilizer, they introduce not only residual antibiotics but also resistant bacteria and mobile genetic elements (e.g., plasmids) into soils and waterways, creating vast environmental reservoirs of AMR from which resistance can flow back to humans and animals.

This research posits that a truly effective, sustainable response to AMR in agriculture must be predicated on a holistic, systems based One Health approach (QUEENAN ET AL., 2016). We argue that isolated technical fixes, such as banning a single antibiotic class, are insufficient without concurrent changes in production practices, economic incentives, and surveillance infrastructure across all connected sectors. Our central thesis is that by simultaneously reducing the need for antimicrobials through improved animal and plant health (SHARMA ET AL., 2018), optimizing their use, when necessary, through precision and stewardship, and breaking the environmental transmission pathways, we can decelerate the AMR crisis.

The objectives of this research are therefore to: (1) Systematically map the major drivers and transmission pathways of AMR within and from agricultural systems, highlighting the interconnected roles of livestock, aquaculture, and crop production; (2) Evaluate a portfolio of integrated interventions across the human-animal-environmental interface, assessing their potential efficacy and mechanisms of action; (3) Identify the key socio-economic, political, and knowledge-based barriers that have hindered the implementation of such a holistic approach; and (4) Propose a concrete, actionable roadmap for advancing a One Health agenda against agricultural AMR, encompassing integrated surveillance, aligned policies, economic mechanisms, and cross-disciplinary collaboration. By providing this comprehensive synthesis, we aim to move the discourse beyond problem description and toward the implementation of coherent, multi-pronged solutions that match the complexity of the AMR threat itself. Also, different materials have been translated from several languages into English, using a proper translation workflow (PASCALAU, 2023) in order to provide the best elements for this research.

MATERIAL AND METHODS

This research employs a multidisciplinary, integrative review methodology to construct and analyse the One Health framework for AMR in agriculture. Given the scope encompasses human medicine, veterinary science, environmental microbiology, and agricultural

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economics, the methodology is designed to synthesize evidence from diverse fields into a coherent systems analysis.

Search strategy: a scoping review was conducted to identify and categorize the primary drivers of AMR selection and dissemination in agriculture. Searches were performed in PubMed, Web of Science, Scopus, and CAB Abstracts for literature published from 2010-2024. Key search term clusters included: (“antimicrobial resistance” or “antibiotic resistance”) and (“agriculture” or “livestock” or “aquaculture” or “manure” or “wastewater”) combined with terms like (“driver”, “transmission”, “selection pressure”, “environmental reservoir”, “horizontal gene transfer”) (WORLD HEALTH ORGANIZATION, 2014).

Extracted data was used to construct a conceptual model of AMR flows. This model visually maps pathways from: (a) point of administration (farm, pond) → animal/plant; (b) excretion → manure/sludge/wastewater; (c) environmental entry → soil, water, crops; and (d) human exposure → food chain, water, direct contact. this mapping formed the foundational structure for identifying intervention points (SMULEAC ET AL., 2024).

Potential solutions were categorized within the One Health triad: animal/plant health interventions: alternatives to antibiotics (vaccines, probiotics, prebiotics, bacteriophages), precision nutrition, improved housing/welfare standards, rapid diagnostics for targeted therapy, and stringent veterinary stewardship programs (COLLIGNON ET AL., 2019).

Environmental health interventions: manure treatment technologies (anaerobic digestion, composting, thermal hydrolysis), wastewater treatment upgrades, constructed wetlands, and guidelines for safe manure application timing and methods.

Human health & governance interventions: integrated surveillance systems, food safety standards, consumer education, and international regulations.

Qualitative system dynamics: to integrate findings and visualize the interconnections between interventions and barriers, a Causal Loop Diagram (CLD) was developed. This tool maps key variables (e.g., “antibiotic use on farm”, “level of biosecurity”, “environmental AMR load”, “regulatory stringency”) and the reinforcing (R) and balancing (B) feedback loops that create system behaviour. For example, a reinforcing loop might show how low animal welfare leads to higher disease incidence, driving more antibiotic use, leading to more resistance, further complicating treatment. A balancing loop could show how investment in vaccines reduces disease, lowering antibiotic use and resistance, thereby making farming more sustainable.

A draft of the CLD and the integrated framework was presented to a multidisciplinary panel of 12 experts (veterinarians, environmental microbiologists, epidemiologists, agricultural economists) in a virtual workshop, including their background from universities, from environmental programmes (PASCALAU ET AL., 2025). Their feedback was used to refine the model and ensure it accurately reflected the complex realities of the system.

This multi-method approach, combining scoping review, evidence synthesis, policy analysis, and systems thinking, allows for a holistic examination that is both evidence-based and cognizant of the complex, dynamic interactions at the heart of the AMR challenge in agriculture.

RESULTS AND DISCUSSIONS

The synthesis reveals a landscape of deeply interconnected AMR drivers and a promising yet under-coordinated arsenal of One Health interventions (KIMANI ET AL., 2019). Pathway mapping confirmed agriculture as a major hub, with hotspots in intensive poultry and swine production, aquaculture, and areas of high manure application. Key transmission vectors include foodborne spread, environmental contamination of water, and direct occupational exposure. Intervention analysis identified several high-potential strategies with multi-sector benefits (SMULEAC ET AL.,

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2020). Barrier analysis highlighted dominant impediments: a persistent economic calculus where antibiotics remain cheaper than infrastructure upgrades or preventive healthcare; fragmented surveillance where human, animal, and environmental AMR data are collected by different agencies using incompatible methods; and a lack of policy coherence, where agricultural subsidies may inadvertently promote practices that increase AMR risk.

The results underscore that the AMR crisis in agriculture is a "wicked problem" par excellence, complex, systemic, and resistant to simple solutions. The discussion must navigate the imperative of integrating actions across the One Health spectrum while confronting the stark realities of implementation.

First, we discuss the Centrality of prevention ("reduce the need"). The most powerful lever for reducing agricultural AMR is not better antibiotics but reducing the demand for them. This requires a fundamental shift from a pharmaceutical-based model of disease control to a resilience-based model of health promotion. Investing in animal welfare, providing space, enrichment, and low-stress environments, is not an ethical luxury but a cornerstone of AMR mitigation. Similarly, in aquaculture, moving from crowded net pens to integrated multi-trophic aquaculture (IMTA) systems can break disease cycles naturally. The discussion must argue for reframing these practices as essential infrastructure for sustainable production, worthy of public and private investment.

Second, we analyse the environmental sink and the imperative of "source control". Even with perfect stewardship, some antimicrobial use will remain necessary. Therefore, treating the waste stream is non-negotiable. The discussion must elevate environmental interventions from an afterthought to a core component of AMR action plans. We explore the technological and logistical challenges of scaling manure treatment, particularly for smallholder farms, and propose solutions such as centralized, cooperative treatment facilities. The concept of "circular biosecurity" is introduced, designing waste management not just for nutrient recycling, but explicitly for pathogen and resistance gene destruction, closing the loop on AMR transmission.

Third, we engage with the socio-economic and governance quagmire. Technology and knowledge alone are insufficient without aligned incentives. The discussion critically examines perverse subsidies and the need for "true cost accounting". The market price of conventionally raised meat does not reflect the externalized costs of AMR to public health. Mechanisms to correct this include: 1) Restructuring subsidies: directing agricultural payments toward practices that improve animal health and environmental protection (e.g., "green" CAP payments in the EU). 2) Implementing "user pays" principles: exploring levies on veterinary antibiotics, with revenues funding research into alternatives and support for farmers transitioning to higher-welfare systems. 3) Creating market advantage: certifications and labelling for "raised with responsible antibiotic use" that command premium prices, driven by informed consumer demand.

Finally, we confront the critical need for integrated surveillance and data sharing. An One Health approach is blind without integrated data (BUCUR ET AL., 2025). The discussion advocates for the development of shared, interoperable AMR surveillance platforms that aggregate, standardize, and analyse data from human clinics, veterinary diagnostic labs, and environmental sampling. This would allow for real-time tracking of resistant clones and resistance genes as they move through the system, enabling targeted, risk-based interventions. This requires unprecedented collaboration between ministries of health, agriculture, and environment, breaking down long-standing institutional silos.

Thus, the discussion posits that combating AMR in agriculture through a One Health lens is less about discovering a single silver bullet and more about diligently implementing a "silver buckshot" strategy, a coordinated barrage of mutually reinforcing policies, economic tools, and technological innovations across all sectors (SHRESTA ET AL., 2018). The greatest challenge is not scientific, but political and organizational: forging the collaborative governance and shared accountability necessary to manage our interconnected health as a global common.

CONCLUSIONS

The battle against antimicrobial resistance will be won or lost at the intersection of human, animal, and environmental health, with agriculture as a decisive frontline. This research concludes that a comprehensive, integrated One Health approach is not merely an optimal strategy but the only viable strategy for sustainably mitigating AMR in agricultural systems. The compartmentalized, reactive tactics of the past have allowed resistance to flourish by addressing symptoms in one sector while ignoring root causes and spillover effects in another. The evidence is clear: effective containment requires simultaneous, coordinated action to prevent infection, optimize therapeutic use, and contain environmental spread.

The foremost conclusion is the imperative for a paradigm shift from “antimicrobial dependence” to “health resilience”. The core objective must be to redesign agricultural systems so that they are inherently less conducive to disease outbreaks, thereby drastically reducing the need for antimicrobial interventions. This means prioritizing animal welfare, robust biosecurity, genetic selection for disease resilience, precision nutrition, and widespread vaccination as foundational pillars of modern, sustainable production. For aquaculture and crop production, this translates to diversified systems, improved management practices, and biological control agents. This preventive approach is the most powerful long-term tool for disarming the AMR crisis.

A second, critical conclusion highlights the non-negotiable role of environmental management. Agriculture’s environmental footprint is also its AMR transmission footprint. Therefore, managing manure, wastewater, and soil as potential reservoirs of resistance is as important as managing prescription practices. Advanced treatment technologies must be deployed and incentivized to degrade antibiotics and destroy resistance genes before they enter the wider ecosystem. This “source control” is essential to break the cycle of environmental amplification and reseeding of resistance back into human and animal populations.

However, these technical solutions will remain unimplemented without addressing the third key conclusion: the fundamental misalignment of economic incentives. Currently, the economic logic of intensive production often favours cheap, preventive antibiotics over more costly investments in infrastructure, welfare, and labour. Therefore, transforming the economics of AMR is paramount.

Furthermore, we conclude that integrated, real-time surveillance is the central nervous system of a One Health response. Isolated data streams in human hospitals, veterinary clinics, and environmental agencies create a dangerously incomplete picture. The development of shared, interoperable AMR surveillance platforms, using standardized protocols and genomic sequencing, is an urgent priority. This would enable true source attribution, early warning of emerging resistant threats, and measurable tracking of intervention impact across the entire system.

Finally, this research underscores that the governance of AMR must be as interconnected as the problem itself. Success demands breaking down the silos between ministries of health, agriculture, environment, and trade. It requires new forums for collaboration, shared targets and joint accountability. International cooperation is equally vital, to prevent the undermining of national efforts by trade in products from high-AMR regions.

Consequently, adopting a One Health approach to AMR in agriculture is a complex, long-term undertaking that requires patience, persistence, and unprecedented collaboration. It is a journey of system transformation. By realigning our policies, economics, and scientific efforts

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around the fundamental interconnectedness of health, we can preserve these vital medicines for future generations. The goal is not just to combat resistance, but to foster agricultural systems that produce safe, abundant food while sustaining the health of people, animals, and the planet we all share. This is the essential, non-negotiable promise of the One Health paradigm.

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