AI-Powered Antimicrobial Resistance Surveillance and Management in a One Health context: A Scoping Review and Lessons for Vietnam.

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Summary

Background: Antimicrobial resistance (AMR) constitutes a foremost threat to global public health, primarily attributable to the inadequately regulated use of antimicrobial agents across human medicine, animal production, and environmental systems. The implementation of a "One Health" (OH) strategy is therefore essential to mitigate the adverse consequences of AMR.

Objective: This scoping review aims to systematically collate scientific evidence regarding the application of artificial intelligence (AI) in the surveillance, prediction, and management of AMR, with specific emphasis on the OH ecosystem.

Methods: The study adhered strictly to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines. A comprehensive search of the peer-reviewed literature was conducted across PubMed, Embase, Scopus, Web of Science, and Google Scholar, supplemented by forward and backward citation tracking.

Results: A total of 549 records were retrieved. Following duplication and preliminary screening, 27 studies fulfilled the inclusion criteria and were incorporated into the analysis. Evidence demonstrates that AI is being actively deployed to combat AMR within a OH framework, with applications spanning detection of resistance determinants, early prediction of resistance phenotypes, real-time surveillance, and clinical decision support. Nonetheless, considerable limitations persist, including heterogeneity in data quality, infrastructural and operational barriers, and unresolved regulatory constraints

Introduction

Antimicrobial resistance has emerged as one of the most critical public health challenges of the twenty-first century, substantially eroding the efficacy of therapeutic regimens and amplifying the global burden of healthcare. Vietnam has long been a hotspot for AMR shaped by the intersection of economic liberalization, weak pharmaceutical regulation, and high infectious disease burden. This has generated strong selective pressure on microorganisms, resulting in documented resistance to a broad range of antimicrobials - including penicillins, quinolones, cephalosporins, aminoglycosides, methicillin, and carbapenems - across multiple pathogens including M. tuberculosis, Streptococcus pneumoniae, gram-negative bacteria, and malaria parasites.

The misuse and overuse of antimicrobials across clinical, agricultural, and environmental settings have driven the rapid emergence and spread of resistant pathogens. Compounding this, resistant bacteria discharged from pharmaceutical facilities, hospitals, farms, and untreated wastewater accumulate in environmental reservoirs, where resistance genes persist and proliferate. These genes can subsequently transfer to human pathogens through contaminated water, soil, and food chains, further amplifying the AMR threat across human, animal, and environmental health - a phenomenon that underscores the urgency of a coordinated OH response. This framework acknowledges the profound interdependence among human, animal, and environmental health, and recognises that AMR cannot be effectively controlled by addressing any single domain in isolation. OH approach, however, necessitates the integration and analysis of highly diverse and heterogeneous data streams, presenting considerable difficulties for the development of coordinated AMR response strategies. The rapid expansion of AI has supplied superior automated analytical tools for understanding and combating AMR. Despite this potential, research on AI applications in AMR control remains fragmented and dispersed across numerous disciplines. This scoping review was therefore conducted to synthesise and critically evaluate the existing evidence on AI in AMR response, identify breakthrough directions, and delineate persistent knowledge gaps.

This review aims to address the following questions:
- What AI applications have been explored for AMR control across human, animal, and environmental health globally and in Vietnam?

- What challenges are currently faced in applying AI to AMR prevention within a OH framework?
- What measures can be proposed to promote the application of AI in OH-integrated AMR prevention in Vietnam?

Methods

This study was developed in strict accordance with the PRISMA-ScR (1) criteria, specifically designed for scoping reviews.

Search Strategy:
Studies were identified through a systematic and comprehensive search of established academic databases - PubMed, Embase, Scopus, Web of Science, and Google Scholar - supplemented by citation tracking. The following search terms were applied in various combinations: "artificial intelligence", "machine learning", "deep learning", "neural network", "global health", "antimicrobial resistance", "antibiotic resistance", "drug resistance", "OH", "animal health", "human health", "environmental health", "human-animal-environment interface", and "Vietnam". All retrieved citations were imported into EndNote for retrieving duplication. Two independent reviewers subsequently conducted study selection in two sequential stages: an initial screen based on titles and abstracts, followed by full-text evaluation of all records satisfying the first-stage criteria.

Eligibility Criteria:
Studies were eligible for inclusion if they met all of the following criteria:
- Original research published in peer-reviewed journals, conference proceedings, or book chapters.
- Studies examining the application of AI tools and techniques to AMR within a OH scope.
- Published between 2020 and 2025.
- Written in English.

Results

Search Outcomes
The initial search yielded 549 potentially eligible records. Following deduplication and manual screening, 27 studies met the inclusion criteria and were retained for synthesis. Collectively, these studies addressed AMR prevention and control through a OH model, consistently emphasising the close linkages between human, animal, and environmental health.

Clinical Applications:
Rapid characterisation of bacterial antimicrobial susceptibility profiles is of paramount importance in clinical management. One study applied five machine learning (ML), a developing branch of AI algorithms - including XGBoost, LightGBM, Random Forest, AdaBoost, and Ridge Logistic Regression - to electronic medical records (EMRs) of intensive care unit (ICU) patients across two Vietnamese hospitals to predict AMR of key bacterial pathogens and antibiotic families. Using demographic, clinical, and laboratory data from 1,296 patients collected between 2020–2022, models were evaluated across multiple performance metrics, yielding promising results. The authors highlighted that ML-driven AMR prediction could support timely empiric antibiotic decision-making in resource-limited settings where culture results require 36–72 hours (2). Concurrently, natural language processing (NLP) algorithms have been applied to veterinary data platforms — such as VetCompass — to enable automated extraction of clinical information from medical records, elucidating antimicrobial prescribing patterns and practices among veterinary practitioners and supporting the optimisation of antimicrobial stewardship.

Genomic Analysis
Whole-genome sequencing (WGS) integrated with AI is advancing genotype-based prediction of resistance phenotypes. Studies applying ML to metagenomic analyses at poultry farms and abattoirs have identified antimicrobial resistance genes (ARGs) with potential for horizontal transfer between livestock and surrounding environments. The analysis identified a core set of 233 ARGs and 186 microbial species as strong predictors of E. coli resistance, including clinically relevant genera Arcobacter, Acinetobacter, and Sphingobacterium. Notably, 145 potentially mobile ARGs were shared between chickens and farm environments. Environmental temperature and humidity were further found to correlate with ARG presence, highlighting the role of ecological conditions in shaping resistome dynamics. This study exemplifies a OH approach by integrating the animal, environmental, and food production interfaces to uncover AMR transmission pathways in livestock systems, offering a scalable metagenomic surveillance framework applicable to low- and middle- income countries (LMICs) (3).

Next-Generation Antibiotic Discovery:

AMPlify, an attentive deep learning (DL) model combining Bidirectional Long Short-Term Memory (Bi-LSTM) with multi-head scaled dot-product attention and context attention layers, has been designed to predict and discover novel antimicrobial peptides (AMPs) from genomic sources. Applied to the North American bullfrog genome, AMPlify outperformed existing tools - including AMP Scanner Vr.2, iAMP-2L, and iAMPpred - achieving accuracy of 93.71%, F1-score of 93.66%, and AUROC of 98.37%. From 101 candidate sequences, 4 novel AMPs (RaCa-1, RaCa-2, RaCa-3, RaCa-7) demonstrated in vitro activity against WHO priority pathogens, including a multidrug-resistant carbapenemase-producing E. coli, with MIC values as low as 1–6 μM. This study illustrates how DL can accelerate AMP discovery from natural genomic resources as an alternative to conventional antibiotics (4). Multiple additional models have de novo generated AMPs from repositories comprising hundreds of millions of sequences. ProteoGPT, a protein large language model (LLM) pre-trained on 609,216 UniProtKB/Swiss-Prot sequences, further fine-tuned into three specialized submodels - AMPSorter (classification, AUC = 0.97), BioToxiPept (cytotoxicity screening), and AMPGenix (sequence generation) - enabling high-throughput screening of over 410 million peptide sequences. Both mined and generated AMPs demonstrated potent in vitro activity against ICU-derived carbapenem-resistant Acinetobacter baumannii (CRAB) methicillin-resistant Staphylococcus aureus (MRSA), with MIC values as low as 4 μg/ml, and showed comparable or superior therapeutic efficacy to clinical antibiotics in mouse thigh infection models, with bacterial elimination rates reaching 83–87%. Critically, these AMPs exhibited substantially reduced resistance development compared to polymyxin B and vancomycin over 20 passages. This generative AI framework represents a scalable approach for next-generation antimicrobial discovery.

Environmental AMR Surveillance:
Antimicrobial residues in environmental matrices represent an escalating concern. AI algorithms have been developed to applied an explainable artificial intelligence (XAI) framework - combining Random Forest and XGBoost regressors with SHAP (SHapley Additive exPlanations) values - to predict AMR-attributable mortality rates across 203 countries for five priority pathogens (Acinetobacter baumannii, Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, and Streptococcus pneumoniae), using 357 indicators spanning water quality, sanitation, food systems, socioeconomic conditions, and environmental pollution. Both ensemble models significantly outperformed linear regression across all pathogens, with R^2 values reaching 0.835 for K. pneumoniae and 0.742 for E. coli. SHAP analysis consistently identified water accessibility and sanitation indicators - including basic water access, improved sanitation, open defecation, and desalinated water - as the most influential predictors of AMR mortality, particularly in low-income countries. CO_2 emissions per capita and rainfed/irrigated crop ratios also emerged as significant environmental predictors. This study represents the first global-scale application of ML and XAI to predict and interpret AMR mortality, directly operationalizing the OH framework by linking human health outcomes to environmental and socioeconomic conditions, and offering a scalable decision-support tool for policymakers and health authorities.

Challenges and Barriers to AI Implementation
Data Quality, Fragmentation, and Standardisation: Training robust AI and ML models requires large, diverse, and well-curated datasets. In practice, microbiological and clinical data are highly fragmented and inconsistent. Within the OH network in particular, integrating human medical records with environmental and agricultural surveillance data faces significant obstacles stemming from divergences in governance frameworks, measurement standards, and data formats.

AI Transparency: Complex models such as deep neural networks - including convolutional neural networks (CNNs) and artificial neural networks (ANNs) - frequently function as "black boxes", generating high-accuracy predictions without interpretable reasoning. This opacity undermines trust among clinicians and regulatory authorities.

Ethical Considerations: Societal acceptance and professional ethics constitute substantial barriers. Evidence indicates a tension between individual and collective interests in AI-driven prescribing: individuals tend to prefer an "Individual-AI" paradigm - prioritising antibiotic prescription for rapid cure - over a "World-AI" paradigm aimed at restricting antimicrobial use to curb population-level AMR. Public resistance to AI-standardised diagnostics further underscores that technology alone cannot resolve AMR if psychological and sociological dimensions are overlooked. Additionally, health data sharing for AI development faces considerable obstacles related to patient privacy rights and the absence of clear regulatory oversight frameworks.

Infrastructural Inequities: Paradoxically, regions bearing the heaviest AMR burden - including parts of Africa and Asia - often lack the digital infrastructure, high-performance computing capacity, and specialised expertise required to develop and sustain AI-based solutions. Without equitable investment and international technology transfer, AI risks exacerbating existing global health inequities.

Discussion

The escalating AMR crisis represents one of the gravest threats to global public health and food security, demanding a systematic, cross-sectoral response - as embodied by the OH model - to address complex transmission dynamics at the human-animal-environment interface. Against this backdrop, AI has emerged as a set of transformative tools with substantial potential to reshape AMR surveillance, diagnostics, and stewardship. Among the most significant opportunities is AI's capacity to process massive, heterogeneous datasets from multiple sectors, enabling the establishment of biological surveillance systems with real-time early warning capabilities. AI is also revolutionising diagnostic pathways through the analysis of mass spectrometry data and genomic sequences to rapidly identify drug-resistant pathogens, supporting antimicrobial stewardship (AMS) programmes in formulating evidence-based treatment regimens and reducing the overuse of broad-spectrum antimicrobials. DL and generative AI further serve as powerful catalysts in novel drug discovery, particularly in the identification of next-generation antimicrobial peptides.

Despite this substantial promise, practical integration of AI into OH-based AMR management continues to face considerable challenges. Data quality and standardisation constitute the most critical barrier, followed by the opacity of complex DL algorithms, which impedes the interpretability of machine-generated decisions. A persistent concern is the pronounced disparity in digital infrastructure, financial resources, and technical expertise between nations. Data collection for AI model development is also accompanied by unresolved ethical dilemmas concerning patient privacy and the absence of comprehensive legal frameworks. To fully realise the potential of AI in AMR prevention and control, future efforts must emphasize developing open, explainable AI models (XAI) and fostering robust interdisciplinary collaboration among data scientists, microbiologists, veterinarians, and policymakers to establish transparent regulatory frameworks that ensure effective AI deployment within a global OH vision.

In recent years, the Vietnamese government has adopted a series of policies to accelerate digital transformation, with the strategic aim of positioning AI as a priority technology sector. In January 2021, the gorvernment issued the National Strategy for Research, Development, and Application of Artificial Intelligence to 2030, targeting Vietnam's emergence as an AI innovation hub within ASEAN by 2030. Subsequently, the Law on Artificial Intelligence entered into force on 1 March 2026 - the first standalone AI legislation enacted by a Southeast Asian country. Comprising 35 articles and designed around a "govern to enable development" principle, the law seeks to balance risk management with the promotion of innovation, in alignment with international norms. Additionally, Vietnam has also recognized the threat posed by AMR. Vietnam's Ministry of Health developed the National Action Plan on Combating Antimicrobial Resistance 2013–2020 (NAPCA), structured around six strategic pillars: policy and management, public education and communication, technical capacity strengthening, healthcare workforce training, financing, and international research cooperation.

Notwithstanding these advances, the development of AI infrastructure specifically for AMR control - and more broadly for managing shared health risks at the human-animal-environment interface in Vietnam - remains insufficiently prioritised. At the time of this review's preparation, only a single study conducted in Vietnam and meeting the defined inclusion criteria was identifiable on Google Scholar (2). This critical research gap underscores the urgent need for decisive, coordinated strategies that leverage digital technologies for OH-based AMR control. Priority measures should include the establishment of a national, multisectoral AMR surveillance database integrating data from health, agricultural, and environmental sectors. Guided by the AI Law, the government should issue standards for secure data sharing and create dedicated scientific funding mechanisms for interdisciplinary AI and OH research. Relevant authorities should also promote the deployment of AI-assisted clinical decision support systems across both human and veterinary medicine to optimise prescribing, limit prophylactic antibiotic overuse, and leverage smart digital platforms to enhance public awareness of biosafety risks and the hazards of unsupervised antimicrobial use.

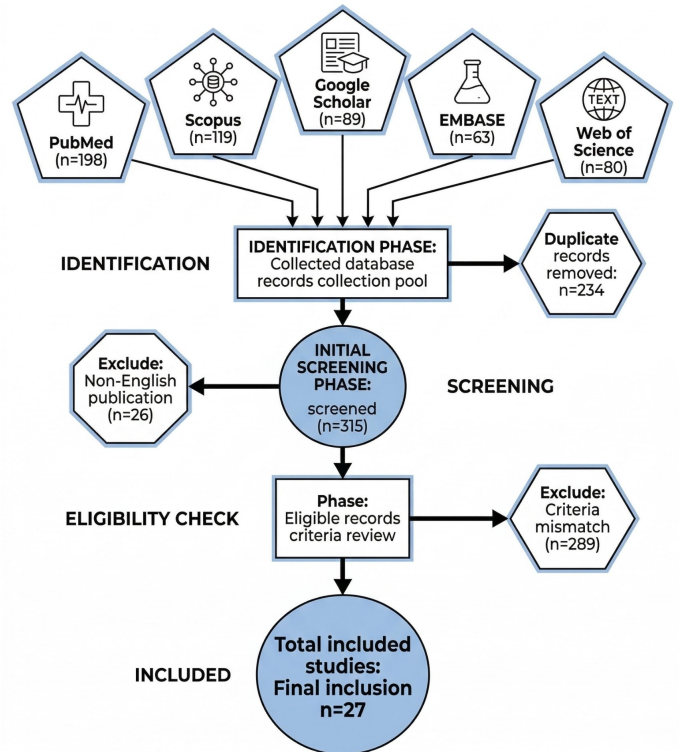


Figure 1. Flow diagram of the literature search process.

Keywords: Artificial Intelligence, Antimicrobial Resistance, One Health, Surveillance.

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