# GOVERNING ANTIMICROBIAL RESISTANCE: INTERNATIONAL AND DOMESTIC LEGAL RESPONSES TO A GLOBAL PUBLIC HEALTH CRISIS

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**ABSTRACT**

Antimicrobial resistance (AMR) has emerged as one of the most significant global public health and regulatory challenges of the twenty-first century, threatening healthcare systems, economic stability, and sustainable development. This article examines the evolving international and domestic legal architecture designed to address AMR through a multidisciplinary analysis of law, public health, economics, and scientific governance. The study evaluates the epidemiological and economic dimensions of AMR, highlighting the growing burden of mortality and the projected global financial consequences of unchecked resistance. It critically analyzes international initiatives, including the United Nations General Assembly Political Declaration on AMR, the Global Action Plan on AMR, and the One Health approach promoted by international organizations. The article further explores pharmaceutical regulatory reforms, focusing on market failures in antibiotic innovation and the emergence of subscription-based incentive models such as the United Kingdom's National Health Service model and the proposed United States PASTEUR Act. Special attention is given to veterinary pharmaceutical regulation, agricultural stewardship, and India's regulatory measures, including restrictions on antibiotic use in food-producing animals and reforms under the Drugs and Cosmetics Act and Food Safety standards. The paper argues that AMR requires coordinated legal intervention across human health, agriculture, environmental protection, and pharmaceutical innovation. It concludes that stronger international cooperation, enforceable regulatory mechanisms, and integrated One Health governance are essential to prevent AMR from becoming an irreversible global health catastrophe.]

**Keywords:** Antimicrobial Resistance, One Health, Public Health Law, Pharmaceutical Regulation, Global Health Governance, Antibiotic Stewardship.

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## *I. Introduction*

Antimicrobial resistance (AMR) has emerged as one of the most pressing global public health challenges of the twenty-first century. The discovery of antibiotics revolutionized modern medicine by transforming once-fatal infectious diseases into manageable conditions and enabling complex medical procedures such as organ transplantation, chemotherapy, neonatal care, and major surgeries. However, the effectiveness of these life-saving medicines is increasingly being undermined by the growing ability of microorganisms to develop resistance to antimicrobial agents. The widespread and often inappropriate use of antibiotics in human healthcare, veterinary medicine, agriculture, and aquaculture has accelerated this process, resulting in the emergence of multidrug-resistant pathogens that are difficult, and in some cases impossible, to treat. Unlike many traditional public health threats, antimicrobial resistance is not confined by national borders. Resistant microorganisms can spread rapidly through international travel, trade, food supply chains, animal migration, and environmental pathways, making AMR a truly global challenge that requires coordinated international action.[2] The consequences of unchecked resistance extend far beyond healthcare systems. AMR threatens economic productivity, food security, poverty reduction efforts, and sustainable development. As antimicrobial effectiveness declines, healthcare costs increase significantly due to prolonged hospitalizations, expensive alternative treatments, and higher mortality rates. Consequently, AMR has evolved from being viewed solely as a medical concern to being recognized as a complex governance issue involving law, regulation, economics, environmental management, and international cooperation.[3]

The regulatory challenges posed by antimicrobial resistance are particularly significant because the factors driving resistance operate across multiple sectors. Human misuse of antibiotics, excessive veterinary consumption, agricultural dependence on antimicrobial growth promoters, inadequate sanitation systems, pharmaceutical manufacturing pollution, and insufficient investment in antibiotic innovation collectively contribute to the emergence and spread of resistance.[4] These interconnected drivers demonstrate that AMR cannot be effectively addressed through isolated health policies alone. Instead, it requires a comprehensive legal and

[2] World Health Organization. (2023). *Global antimicrobial resistance and use surveillance system (GLASS) report 2023*. Geneva, Switzerland: World Health Organization.
[3] Davies, J., & Davies, D. (2010). Origins and evolution of antibiotic resistance. *Microbiology and Molecular Biology Reviews, 74*(3), 417–433. https://doi.org/10.1128/MMBR.00016-10
[4] Ventola, C. L. (2015). The antibiotic resistance crisis: Part 1: Causes and threats. *P&T, 40*(4), 277–283.

regulatory framework capable of coordinating action across human health, animal health, agriculture, environmental protection, and pharmaceutical development. Recognizing the multidimensional nature of the problem, international organizations and national governments have increasingly embraced the One Health approach, which views human, animal, and environmental health as interdependent components of a single ecosystem.[5] This approach has significantly influenced contemporary global health governance and has become a central feature of international efforts to combat antimicrobial resistance.[6] Institutions such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO)[7], the United Nations Environment Programme (UNEP), and the World Organisation for Animal Health (WOAH) have collaborated to develop strategies aimed at reducing antimicrobial misuse, strengthening surveillance systems, promoting responsible stewardship, and encouraging the development of new antimicrobial therapies.[8]

At the domestic level, countries have adopted varying regulatory approaches to address AMR. Some jurisdictions have focused on strengthening prescription controls and antimicrobial stewardship programmes, while others have introduced restrictions on veterinary antibiotic use, environmental regulations governing pharmaceutical waste, and economic incentives designed to stimulate antibiotic innovation. Nevertheless, considerable disparities remain in regulatory capacity, enforcement mechanisms, and access to essential medicines, particularly between developed and developing nations.[9] These differences create significant challenges for achieving a coordinated global response. This article examines the evolving international and domestic legal architecture governing antimicrobial resistance through a multidisciplinary analysis of public health law, pharmaceutical regulation, environmental governance, and international cooperation. It explores the epidemiological and economic dimensions of AMR, analyzes major international initiatives and legal frameworks, evaluates regulatory responses aimed at encouraging antibiotic innovation, and examines the role of veterinary and environmental regulation in reducing resistance pressures. Particular attention is given to

[5] O'Neill, J. (2016). *Tackling drug-resistant infections globally: Final report and recommendations*. London: Review on Antimicrobial Resistance.
[6] United Nations Environment Programme. (2023). *Bracing for superbugs: Strengthening environmental action in the One Health response to antimicrobial resistance*. Nairobi: UNEP.
[7] World Bank. (2017). *Drug-resistant infections: A threat to our economic future*. Washington, DC: World Bank Group.
[8] Gostin, L. O. (2014). *Global health law*. Cambridge, MA: Harvard University Press.
[9] Jasovský, D., Littmann, J., Zorzet, A., & Cars, O. (2016). Antimicrobial resistance—A threat to the world's sustainable development. *Upsala Journal of Medical Sciences, 121*(3), 159–164. https://doi.org/10.1080/03009734.2016.1195900

India's legal and regulatory framework, including recent reforms relating to antibiotic stewardship, agricultural use restrictions, and pharmaceutical regulation.[10] The article argues that addressing antimicrobial resistance requires stronger legal coordination across sectors and jurisdictions, supported by enforceable regulatory mechanisms and sustained international cooperation. Without such intervention, AMR risks undermining decades of medical progress and becoming one of the most severe public health crises of the modern era.

## *II. Epidemiological and Economic Dimensions of Antimicrobial Resistance*

The growing concern surrounding antimicrobial resistance is rooted not only in its impact on public health but also in its potential to disrupt economic stability and sustainable development across the world. The development of effective legal and regulatory responses requires a proper understanding of the epidemiological burden created by resistant pathogens and the economic consequences that follow. Over the last decade, scientific evidence has increasingly demonstrated that AMR is no longer a future threat but an ongoing global crisis responsible for millions of deaths and substantial financial losses.[11] These realities have compelled governments and international organizations to treat antimicrobial resistance as a priority issue within public health governance and regulatory policymaking. Recent epidemiological assessments reveal the alarming scale of the problem. Studies conducted under the Global Research on Antimicrobial Resistance (GRAM) project have shown that antimicrobial resistance has become one of the leading causes of death worldwide.[12] The burden of AMR now rivals, and in some instances exceeds, that of several major infectious diseases that have historically dominated global health agendas.[13] Available data indicates that more than one million direct deaths occur annually as a consequence of bacterial antimicrobial resistance. In 2019 alone, approximately 1.27 million deaths were directly attributable to resistant bacterial infections, while resistant pathogens contributed to nearly 4.95 million associated deaths worldwide. Although a slight decline was observed during the COVID-19 pandemic period, largely due to widespread public health interventions and reduced transmission of infectious

[10] World Health Organization, Food and Agriculture Organization of the United Nations, United Nations Environment Programme, & World Organisation for Animal Health. (2022). *One Health joint plan of action (2022–2026): Working together for the health of humans, animals, plants and the environment*. Geneva: WHO.
[11] World Health Organization. (2015). *Global action plan on antimicrobial resistance*. Geneva: World Health Organization.
[12] World Organisation for Animal Health. (2016). *The OIE strategy on antimicrobial resistance and the prudent use of antimicrobials*. Paris: WOAH.
[13] Food and Agriculture Organization. (2021). *FAO action plan on antimicrobial resistance 2021–2025*. Rome: FAO.

diseases, the overall trajectory remains deeply concerning. Current projections estimate that between 2025 and 2050, antimicrobial resistance could directly cause more than thirty-nine million deaths globally if existing trends continue without effective intervention.[14]

The demographic distribution of AMR-related mortality reveals significant shifts that have important implications for regulatory policy and healthcare planning. Progress in childhood healthcare, immunization programmes, improved sanitation systems, and access to clean drinking water has substantially reduced AMR-related mortality among children under five years of age. However, this positive development has been accompanied by a sharp increase in resistance-related deaths among elderly populations. The growing proportion of older individuals in many countries has created larger populations vulnerable to opportunistic and multidrug-resistant infections. As a result, individuals above the age of seventy are increasingly bearing the burden of resistant infections, and future projections suggest that mortality within this demographic group will continue to rise substantially over the coming decades.[15] These trends indicate that healthcare systems will face increasing pressure to provide specialized treatment for vulnerable populations while simultaneously managing the broader consequences of antimicrobial resistance. The public health burden created by AMR is closely linked to significant economic consequences. Resistant infections typically require longer hospital stays, more complex treatment regimens, additional diagnostic procedures, and the use of expensive reserve antibiotics. These factors substantially increase healthcare expenditures and place immense strain on already burdened public health systems.[16] The economic impact extends beyond direct healthcare costs. Patients suffering from prolonged illnesses experience reduced productivity, lost income opportunities, and increased dependency on social support systems. At a broader level, widespread resistance can affect labour markets, industrial productivity, food production systems, and overall economic growth.[17]

Economic assessments conducted by international institutions indicate that antimicrobial

[14] United Nations General Assembly. (2016). *Political declaration of the high-level meeting of the General Assembly on antimicrobial resistance* (A/RES/71/3). New York: United Nations.
[15] United Nations General Assembly. (2016). *Political declaration of the high-level meeting of the General Assembly on antimicrobial resistance* (A/RES/71/3). New York: United Nations.
[16] Murray, C. J. L., Ikuta, K. S., Sharara, F., Swetschinski, L., Robles Aguilar, G., Gray, A., Han, C., Bisignano, C., Rao, P., Wool, E., Johnson, S. C., Browne, A. J., Chipeta, M. G., Fell, F., Hackett, S., Haines-Woodhouse, G., Kumaran, E. A. P., McManigal, B., Agarwal, R., ... Naghavi, M. (2022). Global burden of bacterial antimicrobial resistance in 2019: A systematic analysis. *The Lancet, 399*(10325), 629–655. https://doi.org/10.1016/S0140-6736(21)02724-0
[17] Institute for Health Metrics and Evaluation. (2022). *Global research on antimicrobial resistance (GRAM) project findings*. Seattle: IHME

resistance poses a serious threat to global economic stability. Estimates suggest that under existing patterns of antibiotic consumption and resistance development, the world economy could experience annual losses ranging between one trillion and three trillion dollars within the coming decades. These losses arise from reduced workforce participation, increased healthcare spending, declining productivity, and disruptions to sectors that depend heavily on effective antimicrobial treatments. By 2050, healthcare systems alone may incur additional expenditures approaching one trillion dollars annually as a result of resistant infections and their associated complications. Such projections demonstrate that antimicrobial resistance should not be viewed merely as a clinical challenge but as a broader governance issue requiring comprehensive legal and regulatory intervention.[18] The epidemiological and economic realities of AMR highlight the interconnected nature of modern public health challenges. The emergence of resistance is influenced by human behaviour, pharmaceutical markets, agricultural practices, environmental conditions, and regulatory systems operating across multiple jurisdictions. Consequently, efforts to address antimicrobial resistance cannot rely solely on medical solutions or scientific innovation. Effective responses require legal frameworks capable of regulating antimicrobial use, promoting responsible stewardship, encouraging pharmaceutical research and development, strengthening surveillance mechanisms, and facilitating international cooperation. The growing recognition of these interconnected factors has contributed to the emergence of new approaches to global health governance, particularly the development of the One Health framework and various international initiatives aimed at coordinating action against antimicrobial resistance.[19]

## *III. International Law and Global Health Governance: The Emergence of the One Health Approach*

The transnational nature of antimicrobial resistance has transformed it from a domestic public health issue into a matter of global governance. Unlike many traditional health concerns that can be addressed through national legislation alone, AMR spreads across borders through human mobility, international trade, agricultural production networks, environmental contamination, and the global circulation of pharmaceutical products.[20] Consequently, the

[18] Naghavi, M., Murray, C. J. L., Ikuta, K. S., et al. (2024). Forecasting the global burden of antimicrobial resistance, 2025–2050. *The Lancet*. Advance online publication.
[19] World Health Organization. (2019). *Critically important antimicrobials for human medicine* (6th rev.). Geneva: World Health Organization.
[20] World Health Organization. (2023). *Global antimicrobial resistance and use surveillance system (GLASS) report 2023*. Geneva: World Health Organization.

effectiveness of any national regulatory strategy is heavily dependent upon the actions of other states. The interconnected nature of antimicrobial resistance has therefore necessitated the development of international legal frameworks designed to facilitate cooperation, harmonize regulatory standards, promote scientific information sharing, and strengthen national responses. In recent years, international organizations have increasingly recognized that combating AMR requires a coordinated global effort extending beyond healthcare systems to include agriculture, environmental protection, food safety, and pharmaceutical governance.[21] Historically, international health regulation focused primarily on the containment of infectious disease outbreaks and the prevention of cross-border transmission. While these traditional frameworks proved effective in addressing acute public health emergencies, they were not designed to tackle the complex and gradual development of antimicrobial resistance. Resistance emerges through cumulative practices occurring across multiple sectors and jurisdictions over extended periods of time.[22] Consequently, policymakers and international institutions gradually recognized the need for a more integrated governance model capable of addressing the diverse factors contributing to resistance. This recognition gave rise to the One Health approach, which has become the dominant conceptual framework guiding international responses to AMR.[23]

The One Health approach is based upon the principle that human health, animal health, plant health, and environmental health are interconnected and cannot be regulated in isolation. The misuse of antibiotics in livestock production can contribute to resistant infections in humans.[24] Environmental contamination from pharmaceutical manufacturing can accelerate resistance development among microorganisms. Similarly, inadequate healthcare stewardship can undermine progress achieved through agricultural regulation. By acknowledging these interdependencies, the One Health framework seeks to establish coordinated regulatory strategies across sectors that have traditionally operated independently. The adoption of this approach represents a significant evolution in international health governance, moving beyond

[21] United Nations Environment Programme. (2023). *Bracing for superbugs: Strengthening environmental action in the One Health response to antimicrobial resistance*. Nairobi: UNEP.
[22] World Health Organization, Food and Agriculture Organization of the United Nations, United Nations Environment Programme, & World Organisation for Animal Health. (2022). *One Health joint plan of action (2022–2026): Working together for the health of humans, animals, plants and the environment*. Geneva: WHO.
[23] Food and Agriculture Organization. (2021). *The FAO action plan on antimicrobial resistance 2021–2025*. Rome: FAO
[24] World Organisation for Animal Health. (2016). *The OIE strategy on antimicrobial resistance and the prudent use of antimicrobials*. Paris: WOAH.

conventional disease-control mechanisms toward a broader model of integrated risk management.[25]

A major milestone in the development of international AMR governance occurred during the High-Level Meeting on Antimicrobial Resistance convened by the United Nations General Assembly in September 2024. This meeting resulted in the adoption of a Political Declaration that reaffirmed antimicrobial resistance as one of the most serious threats to global health and sustainable development. Unlike earlier declarations that primarily emphasized general commitments, the 2024 declaration introduced measurable targets intended to guide national implementation efforts. Member states committed themselves to reducing bacterial AMR-related mortality, improving responsible antibiotic usage, increasing financial support for national action plans, and strengthening international cooperation.[26] The declaration also emphasized the need for improved surveillance systems, enhanced stewardship programmes, and greater investment in research and innovation. Although these commitments represent a significant advancement in global political consensus, their practical effectiveness remains dependent upon implementation at the national level.[27]

One of the most significant developments emerging from the 2024 Political Declaration was the decision to strengthen institutional coordination through the Quadripartite alliance consisting of the World Health Organization (WHO), the Food and Agriculture Organization (FAO), the United Nations Environment Programme (UNEP), and the World Organisation for Animal Health (WOAH). These organizations collectively play a central role in promoting the One Health framework and supporting member states in the development of national regulatory strategies.[28] The declaration further supported the establishment of an Independent Panel for Evidence for Action against AMR, intended to provide scientific assessments capable of informing policy development and regulatory decision-making. The increasing reliance upon expert-driven governance reflects the growing recognition that effective regulation of antimicrobial resistance requires continual engagement with rapidly evolving scientific

[25] World Health Organization. (2015). *Global action plan on antimicrobial resistance*. Geneva: World Health Organization.
[26] United Nations General Assembly. (2024). *Political declaration of the high-level meeting on antimicrobial resistance*. New York: United Nations.
[27] World Health Organization. (2024). *Antimicrobial resistance: High-level meeting commitments and implementation framework*. Geneva: WHO
[28] United Nations General Assembly. (2024). *Political declaration of the high-level meeting on antimicrobial resistance*, paras. 10–22.

evidence.[29] The evolution of international AMR governance was further reinforced through the adoption of the updated Global Action Plan on Antimicrobial Resistance for the period 2026–2036. The revised plan places greater emphasis on preventative interventions designed to reduce dependence upon antimicrobials before resistance develops. Rather than focusing exclusively on treatment and surveillance, the updated framework promotes vaccination programmes, biosecurity measures, infection prevention strategies, environmental protection initiatives, and agricultural reforms aimed at reducing antimicrobial consumption. This shift reflects a broader understanding that resistance cannot be effectively controlled solely through stewardship programmes but requires interventions targeting the underlying conditions that drive antimicrobial use.[30]

Despite these important developments, significant legal challenges continue to undermine the effectiveness of international AMR governance. A fundamental limitation of existing frameworks is their reliance on soft law mechanisms. Instruments such as political declarations, action plans, and international guidelines provide valuable policy direction but generally lack binding legal force.[31] States remain free to determine the extent and manner of implementation, and there are few effective mechanisms for ensuring compliance.[32] Unlike many international trade agreements or environmental treaties, existing AMR frameworks do not contain compulsory dispute settlement procedures, enforcement mechanisms, or meaningful sanctions for non-compliance. As a result, implementation often varies considerably depending upon domestic political priorities, institutional capacity, and available financial resources.[33]

Another major challenge concerns the relationship between global public health objectives and intellectual property protections governing pharmaceutical innovation. This issue has become particularly prominent during negotiations surrounding international health instruments and technology-sharing arrangements. Many developing countries argue that equitable access to antibiotics, diagnostics, and related technologies cannot be achieved without stronger

[29] Quadripartite Joint Secretariat for AMR. (2024). *Strengthening global governance for antimicrobial resistance through One Health cooperation*. Geneva: WHO.
[30] World Health Organization, Food and Agriculture Organization, United Nations Environment Programme, & World Organisation for Animal Health. (2024). *Quadripartite annual progress report on antimicrobial resistance*. Geneva: WHO.
[31] Independent Panel for Evidence for Action Against Antimicrobial Resistance. (2024). *Terms of reference and institutional framework*. Geneva: WHO.
[32] World Health Organization. (2025). *Updated global action plan on antimicrobial resistance 2026–2036: Draft framework*. Geneva: WHO.
[33] World Health Organization. (2025). *Prevention-focused approaches to antimicrobial resistance: Vaccination, sanitation and infection prevention strategies*. Geneva: WHO.

obligations requiring technology transfer and knowledge sharing. They contend that public health emergencies necessitate greater flexibility in the application of intellectual property protections, particularly where access to life-saving medicines is concerned.[34] Conversely, developed countries and pharmaceutical manufacturers maintain that strong intellectual property rights remain essential for encouraging investment in pharmaceutical research and innovation. According to this perspective, weakening patent protections could undermine incentives for the development of new antimicrobial products at a time when innovation is already declining. These competing perspectives became increasingly visible during negotiations concerning the WHO Pandemic Agreement and discussions relating to the Pathogen Access and Benefit-Sharing system. Developing countries advocated for legal arrangements that would guarantee equitable access to medical countermeasures in exchange for sharing pathogen information and scientific data. Developed countries expressed concerns regarding the potential impact of such obligations on pharmaceutical innovation and commercial competitiveness.[35] Similar disagreements emerged during discussions surrounding the updated Global Action Plan on AMR, where proposals for mandatory technology transfers and broader access to pharmaceutical knowledge encountered resistance from wealthier nations and industry stakeholders. The resulting compromises generally favored voluntary cooperation rather than legally enforceable obligations, illustrating the continuing tension between public health equity and intellectual property protection within global health governance.[36]

These challenges demonstrate that while considerable progress has been made in recognizing antimicrobial resistance as a global governance issue, the international legal architecture remains fragmented and largely dependent upon voluntary cooperation. The growing acceptance of the One Health approach has created an important conceptual foundation for coordinated action, but significant gaps remain in enforcement, financing, technology transfer, and accountability mechanisms. Strengthening international cooperation while respecting the diverse interests of states will therefore remain one of the central challenges in the ongoing effort to develop an effective global response to antimicrobial resistance.[37]

[34] Food and Agriculture Organization. (2024). *Reducing antimicrobial use in agriculture through biosecurity and sustainable farming practices*. Rome: FAO

[35] Abbott, F. M., & Reichman, J. H. (2007). The Doha Round's public health legacy: Strategies for the production and diffusion of patented medicines under the amended TRIPS provisions. *Journal of International Economic Law, 10*(4), 921–987.

[36] World Trade Organization. (1994). *Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement)*, Marrakesh Agreement Establishing the World Trade Organization, Annex 1C.

[37] Correa, C. M. (2015). *Trade related aspects of intellectual property rights: A commentary on the TRIPS*

## *IV. Domestic Pharmaceutical Regulatory Reform: Addressing Market Failure in Antibiotic Innovation*

One of the most complex challenges in combating antimicrobial resistance lies in the declining development of new antibiotics. While international organizations and national governments have devoted considerable attention to reducing antimicrobial misuse and strengthening stewardship mechanisms, comparatively less success has been achieved in stimulating pharmaceutical innovation. The growing prevalence of multidrug-resistant pathogens has created an urgent need for novel antimicrobial therapies capable of treating infections that no longer respond to existing medicines.[38] However, despite this need, the antibiotic development pipeline remains alarmingly weak. The shortage of innovative antibiotics is not primarily the result of scientific incapacity but rather reflects a fundamental market failure within the pharmaceutical industry.[39] This economic reality has compelled regulators across various jurisdictions to explore new legal and policy mechanisms designed to encourage antibiotic research while simultaneously preserving responsible stewardship practices. The development of pharmaceutical products requires substantial financial investment and carries significant scientific uncertainty. Drug manufacturers must invest considerable resources in research, clinical trials, regulatory approvals, and post-market surveillance before a product reaches consumers.[40] In most therapeutic areas, these costs are recovered through sustained sales over extended periods. Medications used to treat chronic illnesses, cardiovascular diseases, diabetes, and various forms of cancer generate predictable revenue streams because patients often require long-term treatment. Antibiotics operate under a fundamentally different economic model.[41] Public health authorities actively encourage limited use of newly developed antibiotics to preserve their effectiveness and reduce the likelihood of resistance development. Consequently, the most clinically valuable antibiotics are often the least commercially attractive because stewardship principles restrict their widespread prescription.

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*Agreement* (2nd ed.). Oxford University Press.

[38] World Health Organization. (2023). *Antibacterial agents in clinical and preclinical development: An overview and analysis*. Geneva: World Health Organization.

[39] O'Neill, J. (2016). *Tackling drug-resistant infections globally: Final report and recommendations*. London: Review on Antimicrobial Resistance.

[40] Renwick, M. J., Brogan, D. M., & Mossialos, E. (2016). A systematic review and critical assessment of incentive strategies for discovery and development of novel antibiotics. *The Journal of Antibiotics, 69*(2), 73–88. https://doi.org/10.1038/ja.2015.98

[41] Årdal, C., Findlay, D., Savic, M., Carmeli, Y., Gyssens, I., Laxminarayan, R., Outterson, K., Rex, J., & Piddock, L. J. V. (2020). Revitalizing the antibiotic pipeline: Stimulating innovation while driving sustainable use and global access. *Lancet Infectious Diseases, 20*(11), e300–e308. https://doi.org/10.1016/S1473-3099(20)30724-0

This contradiction creates a significant disincentive for pharmaceutical companies. From a public health perspective, new antibiotics should be preserved and used sparingly. From a commercial perspective, however, pharmaceutical manufacturers depend upon sales volume to recover development costs and generate profit.[42] As a result, many biotechnology firms specializing in antimicrobial research have struggled to achieve financial sustainability, and several have entered bankruptcy despite successfully bringing innovative antibiotics to market. The decline in antibiotic innovation over recent decades therefore illustrates a broader conflict between public health objectives and traditional pharmaceutical market structures.[43] Recognizing these challenges, governments have increasingly experimented with legal mechanisms designed to encourage antibiotic development. Early regulatory approaches relied primarily upon so-called "push incentives," which sought to reduce the cost of research and development through grants, subsidies, and public funding initiatives. Programmes such as the Combating Antibiotic-Resistant Bacteria Biopharmaceutical Accelerator (CARB-X)[44] and the Biomedical Advanced Research and Development Authority (BARDA) have played an important role in supporting early-stage research activities. These initiatives have contributed significantly to scientific advancement and have enabled smaller biotechnology firms to pursue promising antimicrobial projects. Nevertheless, push incentives address only part of the problem. While they reduce development costs, they do not solve the underlying challenge of generating sufficient revenue after a product receives regulatory approval. To address these limitations, policymakers began exploring regulatory models capable of providing financial rewards independent of sales volume. One of the earliest legislative efforts in this direction was the Generating Antibiotic Incentives Now (GAIN) Act enacted in the United States in 2012.[45] The legislation introduced the Qualified Infectious Disease Product (QIDP) designation, which granted eligible antibacterial and antifungal drugs several regulatory advantages. Products receiving QIDP status became eligible for priority review, fast-track regulatory pathways, and an additional five years of market exclusivity beyond existing statutory protections. The objective was to increase the commercial attractiveness of antimicrobial development by extending the period during which manufacturers could market products without generic

[42] Rex, J. H., & Outterson, K. (2016). Antibiotic reimbursement in a model delinked from sales. *Clinical Infectious Diseases, 63*(5), 690–695. https://doi.org/10.1093/cid/ciw378

[43] U.S. Department of Health and Human Services. (2023). *Biomedical Advanced Research and Development Authority (BARDA): Antimicrobial resistance program overview*. Washington, D.C.

[44] CARB-X. (2024). *Annual report: Accelerating antibacterial innovation.* Boston University School of Law.

[45] Generating Antibiotic Incentives Now Act, Pub. L. No. 112–144, 126 Stat. 993 (2012).

competition.[46]

Although the GAIN Act represented a significant attempt to stimulate antibiotic innovation, its practical effectiveness has been questioned. The primary economic value of the QIDP designation derives from extended market exclusivity. However, the financial benefits of exclusivity remain dependent upon future sales volumes. Since stewardship principles restrict the use of newly approved antibiotics, many products generate relatively modest revenues despite receiving additional exclusivity protections.[47] Consequently, the extension of exclusivity often fails to provide sufficient economic incentives for the development of highly innovative reserve antibiotics intended for limited clinical use. Critics have also observed that the legislation frequently rewarded modifications of existing antibiotic classes rather than encouraging the development of entirely new mechanisms of action. As a result, the regulatory framework sometimes promoted incremental innovation without adequately addressing the broader shortage of breakthrough antimicrobial therapies.[48] The limitations of exclusivity-based incentives have prompted a transition toward alternative regulatory approaches commonly referred to as "pull incentives." Unlike traditional market-based models, pull incentives seek to reward pharmaceutical innovation based upon public health value rather than prescription volume. The most prominent example of this approach is the subscription model pioneered by the United Kingdom through the National Health Service (NHS) and the National Institute for Health and Care Excellence (NICE). Under this system, pharmaceutical companies receive fixed annual payments in exchange for guaranteeing access to critical antimicrobial products. Revenue is therefore detached from the quantity of antibiotics prescribed, allowing stewardship objectives and commercial incentives to coexist more effectively.[49]

The United Kingdom's subscription model represents a significant departure from conventional pharmaceutical reimbursement practices. Instead of evaluating antibiotics solely through traditional cost-effectiveness analyses, regulators assess broader societal benefits, including the capacity of a drug to address resistant infections, preserve healthcare system resilience, and reduce future public health risks. By providing predictable long-term payments independent of

[46] U.S. Food and Drug Administration. (2022). *Qualified Infectious Disease Product (QIDP) designation guidance*. Silver Spring, MD: FDA.
[47] Outterson, K. (2014). New business models for sustainable antibiotics. *Chatham House Working Group on New Antibiotics Business Models*.
[48] Theuretzbacher, U., Outterson, K., Engel, A., & Karlén, A. (2020). The global preclinical antibacterial pipeline. *Nature Reviews Microbiology, 18*(5), 275–285. https://doi.org/10.1038/s41579-019-0288-0
[49] National Institute for Health and Care Excellence. (2022). *NICE health technology evaluation of antimicrobials under the NHS subscription model*. London: NICE.

sales volume, the model seeks to create a sustainable economic environment for antibiotic innovation while preserving responsible prescribing practices. The success of the initial pilot programme has encouraged broader adoption and has attracted international attention as a potential template for future reforms.[50]

A similar approach is reflected in the proposed Pioneering Antimicrobial Subscriptions to End Upsurging Resistance (PASTEUR) Act in the United States. The legislation seeks to establish federal subscription contracts for critically needed antimicrobial products, providing developers with substantial fixed payments over extended periods. In return, participating manufacturers would be required to maintain reliable domestic supply chains, support antimicrobial stewardship programmes, comply with reporting requirements, and adopt environmentally responsible manufacturing practices.[51] Unlike earlier incentive mechanisms, the PASTEUR model attempts to evaluate innovation using structured criteria that prioritize scientific novelty, clinical effectiveness against resistant pathogens, and broader public health benefits. This approach reflects a growing recognition that regulatory incentives should reward transformative innovation rather than incremental modifications of existing products. The emergence of subscription-based incentive models represents an important shift in pharmaceutical regulation. These frameworks acknowledge that antibiotics occupy a unique position within healthcare systems and therefore require specialized economic arrangements. Traditional market mechanisms have proven insufficient to encourage the development of urgently needed antimicrobial therapies while preserving stewardship objectives. By separating revenue generation from sales volume, subscription models attempt to reconcile commercial sustainability with public health priorities. Nevertheless, significant challenges remain regarding financing, eligibility criteria, global accessibility, and implementation across different healthcare systems.

The debate surrounding antibiotic innovation ultimately illustrates a broader challenge within antimicrobial resistance governance. Effective stewardship requires reducing unnecessary antimicrobial consumption, yet sustainable innovation depends upon maintaining incentives for pharmaceutical research. Regulatory frameworks must therefore strike a careful balance

[50] National Health Service England. (2023). *Antimicrobial subscription model: Supporting innovation and stewardship*. London: NHS England.
[51] Towse, A., Hoyle, C. K., Goodall, J., Hirsch, M., Mestre-Ferrandiz, J., & Rex, J. H. (2017). Time for a new approach to reimbursement and reward for antibiotics. *European Journal of Health Economics, 18*(2), 231–234. https://doi.org/10.1007/s10198-016-0786-x

between conservation and innovation. As resistance continues to evolve and existing treatment options become less effective, the success of future legal and policy interventions will depend largely upon their ability to create a pharmaceutical marketplace that rewards innovation without encouraging excessive antimicrobial use.[52]

## *V. Veterinary Pharmaceutical Regulation and Agricultural Stewardship: Controlling Resistance Beyond Human Healthcare*

The global response to antimicrobial resistance cannot be confined solely to hospitals, healthcare institutions, and pharmaceutical markets. Scientific evidence increasingly demonstrates that the extensive use of antibiotics in agriculture, livestock production, aquaculture, and veterinary medicine constitutes one of the most significant drivers of antimicrobial resistance worldwide. For several decades, antibiotics have been routinely administered to food-producing animals not only for therapeutic purposes but also for disease prevention and growth promotion. Although these practices have contributed to increased agricultural productivity and commercial efficiency, they have simultaneously created ideal conditions for the emergence and dissemination of resistant microorganisms. Consequently, veterinary pharmaceutical regulation and agricultural stewardship have become integral components of contemporary antimicrobial resistance governance.[53]

The relationship between animal agriculture and antimicrobial resistance is scientifically well established. When antibiotics are administered continuously or in sub-therapeutic doses to livestock populations, susceptible bacteria are eliminated while resistant strains survive and proliferate. Over time, these resistant microorganisms become dominant within animal populations and may subsequently spread to humans through multiple pathways.[54] Direct contact between animals and humans, consumption of contaminated food products, environmental contamination resulting from animal waste, and the transfer of resistant genetic material between bacterial species all contribute to the transmission of resistance. As a result, regulatory efforts aimed at controlling antimicrobial resistance must address antibiotic

[52] Rex, J. H., Eisenstein, B. I., Alder, J., Goldberger, M., Meyer, R., Dane, A., & Friedland, I. (2013). A comprehensive regulatory framework to address the unmet need for new antibacterial treatments. *Lancet Infectious Diseases, 13*(3), 269–275. https://doi.org/10.1016/S1473-3099(12)70293-1

[53] Food and Agriculture Organization. (2021). *The FAO action plan on antimicrobial resistance 2021–2025*. Rome: FAO.

[54] World Organisation for Animal Health. (2023). *Annual report on antimicrobial agents intended for use in animals*. Paris: WOAH.

consumption patterns within agricultural systems alongside those occurring in human healthcare.[55]

Among major jurisdictions, the European Union has developed one of the most comprehensive legal frameworks governing veterinary antimicrobial use. Recognizing the long-term risks associated with agricultural overuse of antibiotics, the European Union progressively adopted stricter regulations designed to reduce unnecessary antimicrobial exposure within food-producing animals. These efforts culminated in the implementation of Regulation (EU) 2019/6 on Veterinary Medicinal Products and Regulation (EU) 2019/4 on Medicated Feed, both of which became fully operational across member states in 2022.[56] These regulations reflect a precautionary regulatory philosophy that prioritizes long-term public health protection over short-term agricultural productivity gains. A central feature of the European framework is the prohibition on the use of antibiotics as growth promoters. While growth promotion was historically a common practice in livestock production, European regulators concluded that the public health risks associated with resistance outweighed the economic benefits. The regulations therefore prohibit the routine administration of antimicrobials for the purpose of enhancing growth rates or increasing production yields. This prohibition is particularly significant because growth promotion typically involves prolonged exposure to low doses of antibiotics, precisely the conditions most conducive to the development of resistance.[57]

The European regulatory framework also imposes strict limitations on prophylactic and metaphylactic antibiotic use. Prophylaxis refers to the administration of antibiotics before any signs of disease appear, while metaphylaxis involves treating entire groups of animals when only some members exhibit symptoms. Although these practices were previously common within intensive farming systems, European law now permits them only under narrowly defined circumstances. Preventive treatment is generally restricted to exceptional situations involving high infection risks and serious potential consequences.[58] These restrictions reflect the principle that antibiotics should be used primarily for genuine therapeutic purposes rather

[55] World Health Organization. (2017). *Guidelines on use of medically important antimicrobials in food-producing animals*. Geneva: WHO.
[56] Marshall, B. M., & Levy, S. B. (2011). Food animals and antimicrobials: Impacts on human health. *Clinical Microbiology Reviews, 24*(4), 718–733. https://doi.org/10.1128/CMR.00002-11
[57] Van Boeckel, T. P., Brower, C., Gilbert, M., Grenfell, B. T., Levin, S. A., Robinson, T. P., Teillant, A., & Laxminarayan, R. (2015). Global trends in antimicrobial use in food animals. *Proceedings of the National Academy of Sciences, 112*(18), 5649–5654. https://doi.org/10.1073/pnas.1503141112
[58] Food and Agriculture Organization, United Nations Environment Programme, World Health Organization, & World Organisation for Animal Health. (2022). *One Health joint plan of action (2022–2026)*. Geneva: WHO.

than routine management practices. Another important innovation within the European model is the authority granted to regulators to reserve certain critically important antibiotics exclusively for human use. This mechanism recognizes that some antimicrobial classes represent essential last-resort treatments for serious human infections and should therefore be protected from agricultural consumption. By restricting veterinary access to these medicines, European regulators seek to preserve their effectiveness for human healthcare and reduce the likelihood of resistance developing within agricultural settings.[59] Perhaps the most influential aspect of the European framework is its extraterritorial dimension. European law requires imported food products and live animals originating from non-member states to comply with many of the same antimicrobial standards applicable within the European Union. Through these import requirements, the European Union effectively extends its regulatory influence beyond its territorial boundaries. Exporting nations seeking access to European markets must therefore modify agricultural practices to satisfy European standards. This approach illustrates how trade regulation can be utilized as a tool for advancing global antimicrobial stewardship and demonstrates the growing interaction between public health regulation and international commerce.

India has also undertaken significant reforms aimed at addressing antimicrobial misuse within agriculture and animal husbandry. Historically, antibiotics were widely available for veterinary and aquaculture purposes, including several antimicrobial agents regarded as critically important within human medicine. Growing international concern regarding resistance patterns and increasing domestic awareness of AMR prompted Indian authorities to adopt a series of regulatory interventions intended to reduce inappropriate agricultural use. One of the most significant reforms occurred in 2019 when the Government of India prohibited the manufacture, sale, distribution, and use of colistin for food-producing animals, poultry, aquaculture, and animal feed supplements.[60] Colistin occupies a particularly important position within antimicrobial therapy because it is often regarded as a last-resort treatment for severe multidrug-resistant infections in humans. The widespread agricultural use of colistin had generated serious concerns regarding the emergence of colistin-resistant pathogens capable of compromising one of the few remaining therapeutic options available for certain life-

[59] Regulation (EU) 2019/6 of the European Parliament and of the Council of 11 December 2018 on veterinary medicinal products, 2019 O.J. (L 4) 43.
[60] Regulation (EU) 2019/4 of the European Parliament and of the Council of 11 December 2018 on the manufacture, placing on the market and use of medicated feed, 2019 O.J. (L 4) 1.

threatening infections. The ban therefore represented a major step toward aligning agricultural practices with broader public health objectives.[61]

Further regulatory reforms followed in subsequent years. The government expanded restrictions by prohibiting the use of additional antibiotics, including chloramphenicol and nitrofuran compounds, within food-producing animal systems. Simultaneously, the Food Safety and Standards Authority of India (FSSAI) introduced amendments designed to strengthen food safety controls throughout the entire production process. These reforms extended regulatory oversight beyond final food products and sought to regulate antimicrobial use throughout the agricultural production cycle. By prohibiting several important antibiotic classes during the production of milk, meat, poultry, eggs, and aquaculture products, regulators attempted to address resistance risks at their source rather than relying solely upon post-production monitoring. The FSSAI reforms also introduced revised residue monitoring mechanisms and expanded the number of veterinary drugs subject to regulatory scrutiny. These measures reflected a growing recognition that antimicrobial stewardship requires continuous oversight from production through consumption. Nevertheless, significant implementation challenges remain. Regulatory enforcement in India is complicated by the country's vast agricultural sector, fragmented administrative structures, and substantial variations in institutional capacity across states. Although legal prohibitions exist at the national level, effective implementation often depends upon state authorities responsible for licensing, inspection, and enforcement activities.[62]

One of the most persistent challenges involves the continued availability of veterinary antibiotics through informal or inadequately regulated distribution channels. Over-the-counter sales of veterinary medicines without proper prescriptions continue to occur in various regions, undermining efforts to control antimicrobial use. Small-scale farmers frequently encounter limited veterinary supervision, and compliance monitoring remains inconsistent. In addition, enforcement of withdrawal periods designed to prevent antibiotic residues from entering food products often remains inadequate, particularly within decentralized agricultural systems.[63] These practical limitations illustrate the broader difficulty of translating legislative reforms into

[61] European Commission. (2022). *Veterinary medicinal products and medicated feed regulations: Guidance for implementation*. Brussels: European Commission.
[62] World Health Organization. (2019). *Critically important antimicrobials for human medicine* (6th rev.). Geneva: WHO.
[63] European Medicines Agency. (2022). *Antimicrobial resistance in the veterinary sector: Preserving critically important antibiotics*. Amsterdam: EMA.

effective behavioural change. The comparison between European and Indian approaches highlights the diverse challenges confronting antimicrobial governance in the agricultural sector. While the European Union benefits from extensive regulatory harmonization, centralized enforcement mechanisms, and the leverage provided by international trade relationships, developing countries often face constraints relating to administrative capacity, financial resources, and monitoring infrastructure. Consequently, legal reforms alone cannot eliminate resistance risks unless supported by effective implementation mechanisms, professional oversight, farmer education programmes, and robust surveillance systems.[64]

Ultimately, veterinary pharmaceutical regulation represents a critical component of the broader effort to combat antimicrobial resistance. The emergence of resistant pathogens is not confined to hospitals or healthcare facilities but is deeply connected to the manner in which antibiotics are utilized throughout food production systems. Effective agricultural stewardship therefore requires comprehensive legal frameworks capable of balancing food security, economic productivity, animal welfare, and public health protection. As antimicrobial resistance continues to evolve, strengthening veterinary regulation and ensuring responsible agricultural practices will remain essential elements of any successful long-term strategy against this global public health threat.[65]

## *VI. Environmental Law and Pharmaceutical Pollution: The Overlooked Dimension of Antimicrobial Resistance*

While discussions concerning antimicrobial resistance frequently focus on clinical misuse and agricultural consumption of antibiotics, environmental contamination has increasingly emerged as a critical yet often overlooked driver of resistance. Scientific research has demonstrated that antibiotics released into rivers, lakes, groundwater systems, soils, and industrial effluents can create environmental conditions that promote the evolution and dissemination of resistant microorganisms. These contaminated environments function as reservoirs where bacteria are continuously exposed to antimicrobial substances, creating selective pressure that encourages the development of resistance mechanisms.[66] Consequently,

[64] McEwen, S. A., & Collignon, P. J. (2018). Antimicrobial resistance: A One Health perspective. *Microbiology Spectrum, 6*(2), 1–26. https://doi.org/10.1128/microbiolspec.ARBA-0009-2017
[65] Government of India, Ministry of Health and Family Welfare. (2019). Notification G.S.R. 28(E): Prohibition of manufacture, sale and distribution of colistin and its formulations for animal food industry.
[66] World Bank. (2017). *Drug-resistant infections: A threat to our economic future*. Washington, D.C.: World Bank Group.

environmental protection has become an increasingly important component of antimicrobial resistance governance, requiring legal frameworks capable of regulating pharmaceutical pollution, wastewater management, and industrial manufacturing practices.

The environmental dimension of AMR presents unique regulatory challenges because antibiotic contamination originates from multiple sources. Human consumption of medicines results in the excretion of active pharmaceutical compounds that enter sewage systems and wastewater treatment facilities. Veterinary antibiotic use contributes to contamination through animal waste, agricultural runoff, and aquaculture operations.[67] However, among all sources of environmental exposure, pharmaceutical manufacturing facilities have attracted particular attention due to their potential to discharge exceptionally high concentrations of active pharmaceutical ingredients into surrounding ecosystems. Unlike clinical or agricultural sources, which generally involve diluted antibiotic residues, manufacturing-related discharges can contain concentrations sufficient to create intense selection pressure favouring resistant microorganisms.[68] Recognizing these risks, regulators in several jurisdictions have attempted to incorporate environmental considerations into pharmaceutical governance. One of the most significant developments has occurred within the European Union through the revision of the European Medicines Agency's Environmental Risk Assessment (ERA) framework for medicinal products intended for human use. The revised guideline, which became operational in September 2024, introduced a more comprehensive and scientifically rigorous methodology for evaluating the environmental impacts of pharmaceutical products before regulatory approval.[69] The framework seeks to ensure that environmental risks are systematically assessed during the marketing authorization process and reflects the growing recognition that pharmaceutical regulation must extend beyond clinical safety and efficacy considerations. Under the revised ERA framework, pharmaceutical manufacturers are required to estimate the Predicted Environmental Concentration (PEC) of a medicinal product within surface water systems. This initial assessment determines whether environmental exposure is likely to reach levels capable of causing ecological harm. Where exposure remains below specified thresholds, the substance may be classified as presenting a relatively low environmental risk.[70] However,

[67] Department of Animal Husbandry and Dairying, Government of India. (2022). *National action plan on antimicrobial resistance: Veterinary sector implementation strategy*. New Delhi.
[68] World Health Organization. (2023). Antimicrobial resistance. Geneva: WHO.
[69] World Health Organization. (2024). *Global antimicrobial resistance and use surveillance system (GLASS) report 2024*. Geneva: WHO.
[70] United Nations Environment Programme. (2023). *Bracing for superbugs: Strengthening environmental action in the One Health response to antimicrobial resistance*. Nairobi: UNEP.

the revised framework adopts a more precautionary approach for certain categories of compounds, including antibacterial agents, endocrine-active substances, and antiparasitic products. These categories are automatically subjected to more extensive environmental evaluation regardless of their initial concentration estimates due to their heightened potential to affect ecological systems and contribute to resistance development. The second phase of the assessment requires detailed scientific studies examining the environmental fate, persistence, toxicity, and ecological effects of pharmaceutical compounds. Regulators utilize concepts such as the Predicted No-Effect Concentration (PNEC) to determine the concentration below which adverse environmental impacts are unlikely to occur.[71] Environmental risks are subsequently assessed through a risk quotient methodology comparing anticipated environmental exposure against scientifically established safety thresholds. Where unacceptable risks are identified, manufacturers may be required to implement mitigation measures designed to reduce environmental exposure and ecological harm.[72] The revised framework also incorporates assessment methodologies relating to persistent, bioaccumulative, and toxic substances, aligning pharmaceutical regulation more closely with broader European environmental protection standards.[73]

Despite these scientific advancements, important legal limitations remain within the European regulatory framework. Existing pharmaceutical legislation continues to prioritize clinical benefits over environmental concerns.[74] Consequently, environmental risks alone generally cannot serve as an independent basis for refusing marketing authorization where a medicinal product demonstrates significant therapeutic value. Furthermore, the current framework focuses primarily on environmental impacts arising from patient use and disposal of medicines, while largely excluding contamination generated during the manufacturing process itself. These limitations illustrate the continuing challenge of integrating environmental protection objectives into pharmaceutical regulation without compromising access to essential medicines.[75] The consequences of inadequate manufacturing-stage regulation are particularly evident in certain pharmaceutical production hubs. One of the most widely discussed examples

[71] Larsson, D. G. J., & Flach, C. F. (2022). Antibiotic resistance in the environment. *Nature Reviews Microbiology, 20*(5), 257–269.
[72] Bengtsson-Palme, J., Kristiansson, E., & Larsson, D. G. J. (2018). Environmental factors influencing the development and spread of antibiotic resistance. *FEMS Microbiology Reviews, 42*(1), 68–80.
[73] European Medicines Agency. (2024). *Guideline on environmental risk assessment of medicinal products for human use*. Amsterdam: EMA.
[74] European Commission. (2024). *Environmental risk assessment requirements for medicinal products*. Brussels: European Commission.
[75] Kümmerer, K. (2009). Antibiotics in the aquatic environment—A review. *Chemosphere, 75*(4), 417–434.

is the Patancheru-Bollaram industrial cluster located near Hyderabad, India, which has long served as a major centre for the production of active pharmaceutical ingredients. Scientific investigations conducted in the region revealed extraordinarily high concentrations of antibiotic residues in local water bodies, groundwater systems, and river sediments situated downstream of industrial treatment facilities. Studies identified concentrations of fluoroquinolone antibiotics, including ciprofloxacin, at levels substantially exceeding those typically observed in natural environments.[76] Researchers concluded that these concentrations were sufficiently high to create strong selective pressures favouring the emergence and persistence of resistant bacterial populations. The Patancheru experience has consequently become an important case study demonstrating the relationship between pharmaceutical manufacturing practices and environmental antimicrobial resistance.[77]

In response to growing concerns regarding pharmaceutical pollution, India's Ministry of Environment, Forest and Climate Change (MoEFCC) initiated efforts to strengthen environmental regulation of the pharmaceutical sector. In January 2020, the Ministry proposed the Environment (Protection) Amendment Rules through draft notification G.S.R. 44(E).[78] The proposed rules represented a significant regulatory innovation because they sought to establish specific concentration limits for residues of 121 antibiotic compounds discharged from pharmaceutical manufacturing facilities. These limits were based upon scientifically derived Predicted No-Effect Concentration values intended to prevent environmental concentrations from reaching levels capable of promoting resistance development. The draft framework also proposed mandatory high-temperature incineration of sludge containing antibiotic residues in order to reduce contamination risks associated with waste disposal.[79]

The proposed regulations were widely regarded as one of the first comprehensive national attempts to directly regulate antibiotic pollution from pharmaceutical manufacturing. Nevertheless, the initiative encountered substantial opposition from segments of the pharmaceutical industry. Industry representatives argued that monitoring individual antibiotic

[76] European Commission. (2024). *Environmental risk assessment requirements for medicinal products*. Brussels: European Commission.
[77] arsson, D. G. J. (2014). Pollution from drug manufacturing: Review and perspectives. *Philosophical Transactions of the Royal Society B, 369*(1656), 20130571.
[78] Fick, J., Söderström, H., Lindberg, R. H., Phan, C., Tysklind, M., & Larsson, D. G. J. (2009). Contamination of surface, ground and drinking water from pharmaceutical production. *Journal of Hazardous Materials, 172*(2–3), 1273–1281.
[79] Lübbert, C., Baars, C., Dayakar, A., et al. (2017). Environmental pollution with antimicrobial agents from bulk drug manufacturing industries in India. *Clinical Infectious Diseases, 65*(3), 499–501.

compounds within complex manufacturing environments would be technically challenging and economically burdensome. Concerns were also raised regarding the potential impact of stringent discharge standards on the international competitiveness of India's pharmaceutical sector. These objections generated significant debate concerning the appropriate balance between environmental protection and industrial development. When the government ultimately issued the Environment (Protection) Second Amendment Rules in 2021, many of the most ambitious provisions contained within the draft framework were omitted.[80] The final notification retained conventional wastewater parameters such as biological oxygen demand, chemical oxygen demand, pH levels, suspended solids, and certain chemical contaminants. However, the specific antibiotic residue limits proposed in the 2020 draft were removed entirely. Consequently, while general industrial pollution remained regulated, direct controls targeting antibiotic residues in pharmaceutical effluents were not incorporated into the final regulatory framework. This decision generated criticism from environmental groups and public health advocates who argued that the final rules failed to address one of the most important environmental drivers of antimicrobial resistance.[81]

The controversy subsequently reached the National Green Tribunal (NGT), India's specialized environmental adjudicatory body. In April 2022, the Tribunal delivered a significant ruling addressing the environmental consequences of pharmaceutical pollution. The NGT concluded that existing regulatory measures were inadequate to address the risks posed by antibiotic contamination and directed regulatory authorities to enforce the standards originally proposed within the 2020 draft notification through licensing and consent mechanisms administered by State Pollution Control Boards.[82] The decision effectively sought to revive environmental safeguards that had been excluded from the final executive notification and represented an important example of judicial intervention within environmental governance. The Tribunal's decision has generated a complex legal dispute concerning the respective powers of regulatory agencies and judicial institutions. Pharmaceutical industry organizations challenged the ruling, arguing that the NGT exceeded its authority by enforcing provisions deliberately excluded during the administrative rulemaking process.[83] According to this view, regulatory standards

[80] Ministry of Environment, Forest and Climate Change. (2020). *Draft Environment (Protection) Amendment Rules, 2020* (G.S.R. 44(E)). Government of India.
[81] Ministry of Environment, Forest and Climate Change. (2021). *Environment (Protection) Second Amendment Rules, 2021*. Government of India.
[82] National Green Tribunal. (2022). *Paryavaran Suraksha Samiti & Anr. v. Union of India & Ors.*, Order dated 21 April 2022.
[83] Central Pollution Control Board. (2021). *Guidelines for pharmaceutical industry effluent management*. New

must derive from formally enacted rules rather than judicially revived draft proposals. Environmental advocates, by contrast, contend that judicial intervention was necessary to address regulatory deficiencies that threatened public health and environmental protection. The resulting litigation, including proceedings before the Supreme Court of India, highlights broader tensions between environmental precaution, industrial policy, administrative discretion, and judicial oversight.[84]

The Indian experience illustrates a broader challenge confronting global AMR governance. While scientific evidence increasingly demonstrates the importance of environmental contamination as a driver of resistance, legal frameworks regulating pharmaceutical pollution remain fragmented and inconsistent across jurisdictions. Significant disparities exist regarding permissible discharge levels, monitoring requirements, enforcement mechanisms, and liability standards. These regulatory differences create opportunities for "pollution havens," whereby pharmaceutical manufacturing may be concentrated in jurisdictions with comparatively weaker environmental controls. In the absence of harmonized international standards, environmental risks associated with pharmaceutical production are likely to remain unevenly regulated despite their global consequences. Environmental governance therefore represents an essential but frequently neglected component of antimicrobial resistance regulation. Effective AMR strategies must move beyond stewardship and healthcare interventions to address the environmental conditions that facilitate resistance development. Strengthening environmental monitoring systems, establishing science-based effluent standards, improving industrial waste management practices, and enhancing regulatory coordination between public health and environmental authorities will be critical to preventing ecosystems from becoming long-term reservoirs of antimicrobial resistance. The growing recognition of these challenges suggests that future legal responses to AMR must increasingly integrate environmental protection within broader public health governance frameworks.[85]

## *VII. India's Domestic Legal Framework for Antimicrobial Resistance: Regulatory Responses and Enforcement Challenges*

India occupies a unique position in the global antimicrobial resistance landscape. As one of the

Delhi: CPCB.

[84] World Health Organization, Food and Agriculture Organization, United Nations Environment Programme, & World Organisation for Animal Health. (2022). One Health Joint Plan of Action (2022–2026).

[85] World Health Organization, Food and Agriculture Organization, United Nations Environment Programme, & World Organisation for Animal Health. (2022). One Health Joint Plan of Action (2022–2026).

world's largest producers and consumers of antibiotics, the country plays a crucial role in both the emergence and containment of antimicrobial resistance. India's pharmaceutical industry supplies a substantial proportion of the global demand for generic medicines and active pharmaceutical ingredients, while its large population, extensive agricultural sector, and diverse healthcare infrastructure create complex regulatory challenges. Consequently, the development of an effective domestic legal framework for AMR has become an important public health priority. Over the past decade, Indian policymakers have introduced a range of legislative, regulatory, and administrative measures designed to strengthen antimicrobial stewardship, regulate antibiotic distribution, improve surveillance systems, and reduce misuse across human and animal health sectors. Despite these efforts, significant implementation challenges continue to hinder the effectiveness of these regulatory interventions.[86]

One of the earliest and most significant regulatory responses to antimicrobial misuse in India was the introduction of Schedule H1 under the Drugs and Cosmetics Rules. Prior to its implementation, antibiotics were frequently available without adequate medical supervision, contributing to widespread self-medication and irrational drug consumption. Recognizing the dangers posed by unrestricted access to antimicrobial medicines, the Government introduced Schedule H1 in 2014 to impose stricter controls on the sale and distribution of certain critical antibiotics. Under this framework, specified antimicrobial drugs can only be dispensed upon presentation of a valid prescription issued by a registered medical practitioner. Pharmacists are required to maintain detailed records of sales, including information relating to the prescribing physician and the patient receiving the medicine. These record-keeping requirements were intended to facilitate regulatory monitoring and discourage unauthorized antibiotic sales.[87]

The introduction of Schedule H1 represented an important advancement in pharmaceutical regulation because it acknowledged that antimicrobial resistance cannot be effectively addressed without controlling access to critical medicines. By creating a specialized category for antibiotics and certain other high-risk drugs, regulators sought to strengthen accountability within the pharmaceutical supply chain and encourage more responsible prescribing practices. However, despite its legal significance, the practical impact of Schedule H1 has been limited by inconsistent enforcement. Numerous studies and governmental assessments continue to

[86] Government of India. (2013). *Drugs and Cosmetics (Amendment) Rules, 2013* (Schedule H1). Ministry of Health and Family Welfare.
[87] Ministry of Health and Family Welfare. (2017). *National Action Plan on Antimicrobial Resistance 2017–2021*. Government of India.

report instances of over-the-counter antibiotic sales without prescriptions, particularly in rural and semi-urban areas where regulatory supervision remains inadequate.[88] The persistence of informal distribution networks and limited inspection capacity continues to undermine the objectives of the regulatory framework. In addition to statutory controls on antibiotic distribution, Indian regulatory authorities have issued a series of policy directives promoting rational antimicrobial use. The Central Drugs Standard Control Organisation (CDSCO) has repeatedly emphasized the importance of antibiotic stewardship and has issued advisories encouraging healthcare institutions to adopt evidence-based prescribing practices.[89] These initiatives seek to reduce unnecessary antibiotic consumption, promote adherence to clinical guidelines, and strengthen awareness regarding resistance risks among healthcare professionals. Such measures reflect an important shift from purely enforcement-oriented regulation toward a broader model incorporating education, professional responsibility, and institutional accountability.[90]

The growing recognition of AMR as a national public health concern also led to the formulation of India's National Action Plan on Antimicrobial Resistance. Inspired by the Global Action Plan developed by the World Health Organization, the National Action Plan adopts a comprehensive One Health approach that recognizes the interconnected nature of human health, animal health, and environmental protection. The Plan identifies several strategic priorities, including improving awareness and education, strengthening surveillance systems, reducing infection incidence, optimizing antimicrobial use, promoting sustainable investments, and encouraging research and innovation. By embracing the One Health framework, India formally acknowledged that antimicrobial resistance extends beyond clinical medicine and requires coordinated action across multiple sectors.[91] The National Action Plan has contributed significantly to institutional coordination by encouraging collaboration among ministries responsible for health, agriculture, animal husbandry, food safety, and environmental protection. Several states have subsequently developed their own State Action Plans on AMR, reflecting an effort to adapt national objectives to local circumstances. Nevertheless,

[88] Ministry of Health and Family Welfare. (2024). *National Action Plan on Antimicrobial Resistance 2.0 (2024–2029)*. Government of India.
[89] Indian Council of Medical Research. (2023). *Antimicrobial resistance surveillance and research network annual report*. New Delhi: ICMR.
[90] Indian Council of Medical Research. (2022). *Treatment guidelines for antimicrobial use in common syndromes*. New Delhi: ICMR.
[91] Central Drugs Standard Control Organisation. (2023). *Antimicrobial stewardship advisories and regulatory guidance*. New Delhi: CDSCO.

implementation remains uneven across different regions of the country. Variations in administrative capacity, financial resources, technical expertise, and surveillance infrastructure have produced substantial differences in regulatory effectiveness. Consequently, while the National Action Plan provides an important policy framework, translating its objectives into measurable outcomes remains an ongoing challenge.[92]

Surveillance constitutes another critical component of India's regulatory response. Effective AMR governance depends upon accurate data concerning antibiotic consumption patterns, resistance trends, and emerging threats. To strengthen evidence-based policymaking, India has expanded surveillance initiatives through networks coordinated by institutions such as the Indian Council of Medical Research (ICMR). These programmes seek to monitor resistance patterns across healthcare facilities and generate information capable of guiding treatment protocols and regulatory interventions. Although significant progress has been achieved, surveillance coverage remains incomplete, particularly in rural healthcare settings where diagnostic capacity and laboratory infrastructure are often limited. The absence of comprehensive nationwide data continues to impede effective regulatory planning and evaluation.[93]

India's legal response to antimicrobial resistance has also extended into the food safety and veterinary sectors. As discussed previously, restrictions on the use of critical antibiotics in food-producing animals, including the prohibition on colistin, represent important efforts to reduce agricultural contributions to resistance development. The Food Safety and Standards Authority of India has introduced measures designed to regulate antibiotic use throughout the food production chain and strengthen residue monitoring systems. These reforms demonstrate an increasing willingness to address antimicrobial resistance through integrated regulatory mechanisms rather than relying exclusively upon healthcare interventions. However, enforcement challenges similar to those observed within the pharmaceutical sector continue to affect agricultural regulation, particularly in relation to monitoring, inspection, and compliance verification.[94]

[92] Food Safety and Standards Authority of India. (2021). *Food Safety and Standards (Contaminants, Toxins and Residues) Regulations*. New Delhi: FSSAI.
[93] Government of India. (2019). *Prohibition of Colistin and its formulations for food producing animals*. Ministry of Health and Family Welfare Notification.
[94] Food and Agriculture Organization. (2023). *India's progress on antimicrobial resistance and One Health implementation*. Rome: FAO.

A recurring challenge throughout India's AMR governance framework is the gap between legislative intent and practical implementation. While numerous regulatory measures have been introduced, their effectiveness frequently depends upon institutional capacity at the state and local levels. Regulatory authorities often face shortages of trained personnel, limited technological resources, and competing administrative priorities.[95] In addition, public awareness regarding antimicrobial resistance remains relatively low in many communities, contributing to continued demand for unnecessary antibiotics and self-medication practices.[96] These structural limitations highlight the reality that legal reform alone cannot resolve antimicrobial resistance unless supported by effective enforcement mechanisms and sustained behavioural change.[97]

Another important concern involves coordination among regulatory institutions. Responsibility for AMR governance is distributed across multiple ministries, agencies, and statutory bodies, each possessing distinct regulatory mandates. Although the One Health framework encourages intersectoral collaboration, institutional fragmentation can sometimes result in overlapping responsibilities, regulatory gaps, and inconsistent implementation. Strengthening coordination mechanisms, improving information sharing, and establishing clearer lines of accountability will therefore be essential for enhancing regulatory effectiveness.[98] India's experience illustrates both the opportunities and limitations of domestic legal responses to antimicrobial resistance. Significant progress has been achieved through pharmaceutical regulation, stewardship initiatives, veterinary reforms, food safety measures, and national policy planning. Nevertheless, the persistence of enforcement deficits, institutional constraints, and regulatory fragmentation continues to limit the overall effectiveness of these interventions. As antimicrobial resistance becomes an increasingly serious threat to public health and economic development, strengthening implementation capacity and improving regulatory coordination will be just as important as the adoption of new legal measures. The success of India's future response will depend not only upon the quality of its laws and policies but also upon its ability

[95] World Health Organization. (2023). *India country progress report on antimicrobial resistance*. Geneva: WHO.
[96] NITI Aayog. (2021). *Strengthening India's response to antimicrobial resistance*. New Delhi: Government of India.
[97] Laxminarayan, R., Chaudhury, R. R., et al. (2016). Antibiotic resistance in India: Drivers and opportunities for action. *PLoS Medicine, 13*(3), e1001974.
[98] Kotwani, A., Wattal, C., Joshi, P. C., & Holloway, K. (2012). Irrational use of antibiotics and role of the pharmacist. *Indian Journal of Medical Research, 136*(1), 11–18.

to ensure consistent and effective enforcement across all sectors contributing to antimicrobial resistance.[99]

### *VIII. Challenges and Regulatory Gaps in Global Antimicrobial Resistance Governance*

Despite growing international recognition of antimicrobial resistance as a major public health threat, significant regulatory gaps continue to undermine efforts to address the problem effectively. While numerous international declarations, national action plans, pharmaceutical regulations, veterinary controls, and environmental initiatives have been introduced over the past decade, antimicrobial resistance continues to increase across many regions of the world.[100] This persistent growth reflects not only the biological complexity of resistance but also the limitations of existing legal and institutional frameworks. A critical examination of contemporary AMR governance reveals several structural weaknesses relating to international cooperation, regulatory enforcement, pharmaceutical innovation, environmental protection, and institutional coordination.

One of the most fundamental challenges arises from the nature of international law governing antimicrobial resistance. Most international initiatives addressing AMR operate through soft law instruments such as political declarations, action plans, guidelines, and voluntary commitments. Although these mechanisms play an important role in promoting international cooperation and establishing common policy objectives, they generally lack legally binding obligations and effective enforcement mechanisms.[101] The United Nations Political Declaration on Antimicrobial Resistance, the Global Action Plan on AMR, and various One Health initiatives provide valuable guidance but depend largely upon voluntary implementation by member states. Unlike international trade agreements or certain environmental treaties, existing AMR frameworks do not impose binding sanctions for non-compliance. Consequently, implementation often varies significantly among countries, resulting in uneven regulatory standards and inconsistent progress toward global objectives.[102]

[99] Klein, E. Y., Van Boeckel, T. P., Martinez, E. M., et al. (2018). Global increase and geographic convergence in antibiotic consumption. *Proceedings of the National Academy of Sciences, 115*(15), E3463–E3470.
[100] United Nations. (2024). *Political Declaration of the High-Level Meeting on Antimicrobial Resistance.* New York: United Nations General Assembly.
[101] World Health Organization. (2025). *Global Action Plan on Antimicrobial Resistance 2026–2036.* Geneva: WHO.
[102] World Bank. (2017). *Drug-Resistant Infections: A Threat to Our Economic Future*. Washington, DC: World Bank

A related challenge concerns the financing of antimicrobial resistance programmes. Many countries have adopted National Action Plans in response to international recommendations, yet a substantial number continue to lack adequate financial resources for implementation. Surveillance systems, laboratory infrastructure, stewardship programmes, infection prevention initiatives, and public awareness campaigns require sustained investment over long periods. In many developing countries, competing public health priorities and budgetary constraints limit the availability of resources necessary to support comprehensive AMR strategies.[103] As a result, national action plans frequently remain policy documents with limited practical impact. The absence of legally enforceable funding commitments further weakens implementation efforts and contributes to significant disparities between countries.[104]

Another important regulatory gap involves the pharmaceutical innovation ecosystem. Although antimicrobial resistance continues to increase, the global pipeline for novel antibiotics remains insufficient to address emerging threats. Existing pharmaceutical markets generally reward high-volume consumption rather than long-term public health value. This creates a paradox in which the most important antibiotics are often the least commercially profitable because stewardship principles require their restricted use.[105] While initiatives such as the GAIN Act, Qualified Infectious Disease Product designation, and subscription-based incentive models have attempted to address this problem, no globally coordinated framework currently exists to ensure sustainable antibiotic innovation. The result is a fragmented landscape in which innovation incentives vary considerably across jurisdictions and remain heavily dependent upon national policy choices rather than international coordination.

Intellectual property and technology-transfer disputes further complicate global efforts to combat antimicrobial resistance. Developing countries frequently emphasize the need for greater access to pharmaceutical technologies, manufacturing knowledge, and research outputs in order to strengthen domestic healthcare systems and improve access to essential medicines.[106] Developed countries and pharmaceutical manufacturers, however, often stress the importance of maintaining robust intellectual property protections as a means of

[103] Organisation for Economic Co-operation and Development. (2023). *Stemming the Superbug Tide: Just a Few Dollars More*. Paris: OECD.
[104] O'Neill, J. (2016). *Tackling Drug-Resistant Infections Globally: Final Report and Recommendations*. Review on Antimicrobial Resistance.
[105] World Health Organization. (2024). *Antibacterial agents in clinical and preclinical development: An overview and analysis*. Geneva: WHO.
[106] Renwick, M. J., Brogan, D. M., & Mossialos, E. (2016). A systematic review and critical assessment of incentive strategies for discovery and development of novel antibiotics. *Journal of Antibiotics, 69*(2), 73–88.

encouraging innovation and attracting investment. These competing priorities have repeatedly generated disagreements during international health negotiations. The absence of consensus regarding technology transfer, equitable access, and intellectual property governance continues to impede efforts to establish a more comprehensive and equitable international AMR framework.[107]

Environmental regulation represents another area characterized by substantial legal fragmentation. Scientific evidence increasingly demonstrates that pharmaceutical pollution contributes to the development and dissemination of antimicrobial resistance. Nevertheless, environmental standards governing antibiotic residues vary significantly across jurisdictions. Many countries continue to regulate pharmaceutical effluents using conventional pollution indicators without establishing specific limits for antibiotic residues. Even where environmental standards exist, monitoring mechanisms and enforcement capacities frequently remain inadequate. The absence of harmonized international discharge standards creates opportunities for regulatory arbitrage, enabling pharmaceutical manufacturing activities to relocate to jurisdictions with weaker environmental protections. Such disparities undermine global efforts to control environmental sources of resistance and highlight the need for stronger international coordination.[108]

Veterinary and agricultural regulation also presents persistent governance challenges. Although many jurisdictions have introduced restrictions on antibiotic growth promoters and preventive antimicrobial use, enforcement remains inconsistent. In numerous countries, veterinary antibiotics continue to be sold without adequate regulatory oversight, and monitoring systems remain insufficient to detect non-compliance effectively. Small-scale farming operations often lack access to veterinary professionals and antimicrobial stewardship programmes, increasing the likelihood of inappropriate antibiotic use. Moreover, international differences in agricultural regulation create competitive pressures that may discourage the adoption of stricter standards. Without broader international harmonization, efforts undertaken by individual countries may be undermined by regulatory disparities elsewhere.

[107] World Trade Organization. (1994). *Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement)*.
[108] World Health Organization. (2023). *Global Framework for Development and Stewardship to Combat Antimicrobial Resistance*. Geneva: WHO.

Institutional fragmentation further complicates AMR governance at both international and domestic levels. The multidimensional nature of antimicrobial resistance requires cooperation among public health authorities, environmental regulators, agricultural agencies, pharmaceutical regulators, food safety authorities, and international organizations. However, these institutions frequently operate within separate administrative frameworks and pursue distinct policy objectives.[109] While the One Health approach seeks to promote integrated governance, practical coordination remains challenging. Overlapping responsibilities, inconsistent data-sharing mechanisms, and differing regulatory priorities can hinder effective implementation and reduce overall policy coherence.

Data collection and surveillance deficiencies constitute another major obstacle to effective regulation. Reliable information concerning antimicrobial consumption, resistance patterns, environmental contamination, and veterinary antibiotic use is essential for evidence-based policymaking. Although surveillance networks have expanded considerably in recent years, substantial gaps remain, particularly within low-income and middle-income countries. Limited laboratory capacity, inadequate reporting systems, and insufficient technical expertise often result in incomplete or unreliable data. These deficiencies hinder the ability of regulators to identify emerging threats, evaluate policy effectiveness, and allocate resources efficiently.[110]

The challenge of behavioural change must also be recognized. Legal rules and regulatory frameworks can establish standards of conduct, but their effectiveness ultimately depends upon compliance by healthcare professionals, pharmacists, veterinarians, farmers, pharmaceutical manufacturers, and consumers. In many regions, public awareness regarding antimicrobial resistance remains limited. Patients frequently demand antibiotics for viral infections, self-medication practices continue to occur, and economic pressures sometimes encourage inappropriate prescribing. Consequently, regulatory interventions must be supported by education, awareness campaigns, professional training, and institutional incentives capable of influencing behaviour across multiple sectors.[111]

[109] United Nations Environment Programme. (2023). *Bracing for Superbugs: Strengthening Environmental Action in the One Health Response to Antimicrobial Resistance*. Nairobi: UNEP.
[110] Larsson, D. G. J., & Flach, C. F. (2022). Antibiotic resistance in the environment. *Nature Reviews Microbiology, 20*(5), 257–269.
[111] Bengtsson-Palme, J., Kristiansson, E., & Larsson, D. G. J. (2018). Environmental factors influencing the development and spread of antibiotic resistance. *FEMS Microbiology Reviews, 42*(1), 68–80.

These challenges collectively demonstrate that antimicrobial resistance is not merely a scientific or medical problem but a complex governance issue involving law, economics, public policy, environmental protection, and international relations. Although important progress has been achieved through recent regulatory reforms, existing frameworks remain fragmented, unevenly enforced, and frequently underfunded. Addressing these shortcomings will require stronger international cooperation, more effective domestic implementation mechanisms, sustainable financing arrangements, harmonized environmental and veterinary standards, and improved institutional coordination. Without such reforms, the legal architecture governing antimicrobial resistance may prove insufficient to confront one of the most serious public health challenges of the modern era.[112]

## *IX. Recommendations for Legal and Regulatory Reform*

The growing threat of antimicrobial resistance demands a regulatory response that is comprehensive, coordinated, and capable of addressing the multifaceted drivers of resistance. Existing legal frameworks have undoubtedly contributed to greater awareness, improved stewardship practices, and enhanced international cooperation. Nevertheless, significant gaps continue to exist in implementation, financing, environmental regulation, pharmaceutical innovation, and agricultural governance. Addressing these deficiencies requires reforms that extend beyond isolated policy interventions and instead establish a coherent legal architecture capable of integrating public health, environmental protection, pharmaceutical regulation, and international cooperation. The following recommendations provide a framework for strengthening global and domestic responses to antimicrobial resistance.

A primary priority should be the establishment of legally enforceable funding mechanisms for National Action Plans on Antimicrobial Resistance. While many countries have formally adopted National Action Plans in response to international commitments, implementation frequently remains constrained by inadequate financial support. The effectiveness of surveillance systems, stewardship programmes, laboratory networks, public awareness initiatives, and infection prevention measures depends upon sustained funding over extended periods. Governments should therefore enact legislation requiring dedicated annual budgetary allocations for AMR-related programmes and establish independent oversight mechanisms

[112] European Commission. (2023). *EU One Health Action Plan against Antimicrobial Resistance: Progress Report*. Brussels: European Commission.

responsible for monitoring expenditure and evaluating outcomes. Such measures would transform National Action Plans from aspirational policy documents into operational governance instruments supported by enforceable financial commitments.

At the international level, greater efforts should be directed toward strengthening the legal status of global AMR commitments. Existing frameworks such as the United Nations Political Declaration and the Global Action Plan have played a significant role in generating political consensus; however, their largely voluntary nature limits their effectiveness. Future international negotiations should explore mechanisms capable of enhancing accountability and monitoring compliance. Although the adoption of a comprehensive international treaty on antimicrobial resistance may present political challenges, states should work toward developing more robust reporting obligations, peer-review mechanisms, and performance assessment systems. Increased transparency regarding national implementation efforts would improve accountability and encourage more consistent regulatory progress across jurisdictions.

Reforming pharmaceutical innovation incentives should constitute another central component of future AMR governance. The current pharmaceutical market structure remains poorly suited to the development of antibiotics because commercial success is traditionally linked to sales volume, whereas public health objectives require responsible stewardship and limited use. Governments should therefore expand subscription-based pull incentive models that reward innovation according to public health value rather than prescription volume. Regulatory frameworks similar to the United Kingdom's National Health Service subscription model and the proposed United States PASTEUR Act provide promising examples of how this objective can be achieved. Such initiatives should prioritize truly novel antimicrobial agents targeting critical resistant pathogens while simultaneously requiring compliance with stewardship principles, supply chain obligations, and environmental manufacturing standards.

In addition to supporting innovation, policymakers must address issues relating to equitable access to antimicrobial therapies. Many low-income and middle-income countries continue to face difficulties in obtaining access to essential antibiotics, diagnostic technologies, and surveillance infrastructure. International organizations and developed countries should strengthen financial and technical assistance programmes designed to improve access while supporting responsible antimicrobial use. Technology transfer partnerships, collaborative research initiatives, and capacity-building programmes should be expanded to reduce

disparities in healthcare capabilities and strengthen global preparedness against resistant infections.

Environmental regulation requires substantial reform if the environmental drivers of antimicrobial resistance are to be addressed effectively. Existing regulatory frameworks often focus on traditional pollution indicators while neglecting antibiotic residues capable of promoting resistance development. National governments should establish science-based discharge standards for pharmaceutical manufacturing facilities using Predicted No-Effect Concentration methodologies and other evidence-based risk assessment tools. Environmental monitoring systems should be strengthened to ensure compliance, and pharmaceutical manufacturers should be required to disclose information regarding antibiotic emissions and waste management practices. Regulatory authorities must also be equipped with adequate inspection and enforcement powers capable of addressing violations effectively.

Given the global nature of pharmaceutical supply chains, environmental regulation cannot be addressed solely through domestic legislation. International organizations such as the World Health Organization, the United Nations Environment Programme, and the International Council for Harmonisation should collaborate in developing harmonized global standards governing antibiotic discharges from manufacturing facilities. Such standards would reduce opportunities for regulatory arbitrage and help ensure that environmental protection does not become dependent upon the jurisdiction in which production occurs. Importing countries may also consider incorporating environmental compliance requirements into procurement policies and market access regulations to encourage cleaner manufacturing practices throughout global supply chains.

Veterinary pharmaceutical regulation should be further strengthened through the adoption of stricter controls on agricultural antimicrobial use. Governments should prohibit the use of medically important antibiotics for growth promotion purposes and impose stringent restrictions on routine preventive administration. Regulatory authorities should establish comprehensive prescription-based systems governing veterinary antibiotic distribution and strengthen oversight of retail sales channels. Digital prescription monitoring systems can play an important role in improving transparency and reducing unauthorized access to antimicrobial products. At the same time, governments should support farmers through education

programmes, veterinary services, vaccination initiatives, and biosecurity measures that reduce dependence upon antibiotics while maintaining agricultural productivity.

Food safety regulation should also be enhanced to ensure effective monitoring of antimicrobial residues throughout production and distribution chains. Regular testing, improved traceability systems, and stronger inspection mechanisms can help identify non-compliance and reduce the risk of resistant microorganisms entering the food supply. International trade agreements should encourage adherence to responsible antimicrobial use standards while respecting legitimate public health objectives. Harmonized residue standards and surveillance protocols would contribute significantly to reducing resistance risks associated with global food production systems.

Within healthcare systems, antimicrobial stewardship programmes should become mandatory components of institutional governance. Hospitals, clinics, and healthcare facilities should be required to establish stewardship committees responsible for monitoring antibiotic prescribing practices, promoting clinical guidelines, and evaluating antimicrobial consumption patterns. Professional education relating to antimicrobial resistance should be integrated into medical, pharmaceutical, nursing, and veterinary curricula to ensure that future practitioners possess the knowledge necessary to support responsible prescribing and stewardship practices. Public awareness campaigns should similarly be expanded to address misconceptions regarding antibiotic use and encourage behavioural changes among consumers.

Surveillance and data collection systems must also be strengthened significantly. Reliable information is essential for effective policymaking and regulatory evaluation. Governments should invest in laboratory infrastructure, diagnostic technologies, and integrated surveillance networks capable of monitoring antimicrobial consumption, resistance trends, veterinary antibiotic use, and environmental contamination. Data-sharing arrangements should be improved both nationally and internationally to facilitate early detection of emerging resistance threats and support evidence-based decision-making. The development of interoperable surveillance systems operating within the One Health framework would represent a major advancement in global AMR governance.

Finally, institutional coordination should be improved through the creation of integrated governance structures capable of implementing the One Health approach effectively. Antimicrobial resistance spans multiple regulatory sectors, including healthcare, agriculture,

food safety, environmental protection, and pharmaceutical regulation. Fragmented governance arrangements often result in duplication of effort, inconsistent implementation, and regulatory gaps. Governments should therefore establish formal intersectoral coordination mechanisms bringing together relevant ministries, regulatory agencies, scientific institutions, and stakeholders. Such structures would promote information sharing, improve policy coherence, and strengthen accountability across all sectors contributing to antimicrobial resistance.

The success of future legal responses to antimicrobial resistance will ultimately depend upon the ability of governments and international institutions to recognize the interconnected nature of the problem and develop regulatory frameworks that address its multiple causes simultaneously. Effective governance requires not only stronger laws but also adequate resources, institutional capacity, scientific expertise, and sustained political commitment. Without comprehensive reforms of this nature, antimicrobial resistance may continue to expand despite existing efforts, threatening public health, economic development, and the long-term effectiveness of modern medicine.

## *X. Conclusion*

Antimicrobial resistance has emerged as one of the most significant public health challenges of the modern era, threatening the effectiveness of medicines that have formed the foundation of contemporary healthcare for decades. As resistant pathogens continue to spread across human, animal, and environmental settings, AMR has evolved beyond a purely medical concern into a complex governance issue requiring coordinated legal, regulatory, and institutional responses at both national and international levels.

This study has demonstrated that the drivers of antimicrobial resistance are multifaceted, encompassing inappropriate antibiotic use in healthcare, extensive agricultural consumption, pharmaceutical market failures, environmental contamination, and weaknesses in global governance structures. In response, international organizations, national governments, and regulatory authorities have increasingly adopted the One Health approach, recognizing the interconnected relationship between human health, animal health, and the environment. Significant progress has been made through initiatives such as the Global Action Plan on AMR, the United Nations Political Declaration, pharmaceutical stewardship measures, veterinary regulations, and environmental risk assessment frameworks.

However, substantial challenges continue to impede effective implementation. The predominance of non-binding international commitments, inadequate funding for national action plans, fragmented regulatory frameworks, weak enforcement mechanisms, and insufficient incentives for antibiotic innovation remain major obstacles. The experiences of both developed and developing countries illustrate that legal reform alone is insufficient unless accompanied by effective institutional capacity, scientific surveillance, and sustained political commitment.

The study concludes that antimicrobial resistance can only be effectively addressed through integrated and coordinated governance that combines public health regulation, environmental protection, agricultural stewardship, and pharmaceutical innovation. Strengthening international cooperation, adopting enforceable regulatory standards, improving surveillance systems, and supporting sustainable antibiotic development are essential for preserving the effectiveness of antimicrobial therapies for future generations. Without such comprehensive action, antimicrobial resistance risks undermining decades of medical progress and becoming one of the most serious global health crises of the twenty-first century.